

# Prediction Model of in-Hospital Venous Thromboembolism in Chinese Adult Patients after Hernia Surgery: The CHAT Score

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## Abstract

**Background:** Venous thromboembolism (VTE) events after hernia surgery influence prognosis and life quality and may be preventable. This study aimed to develop a useful model for predicting in-hospital VTE in Chinese patients after hernia surgery.

**Methods:** Patients after hernia surgery were retrospectively recruited from 58 institutions (n = 14 322). Totally, 36 potential predictors were involved in the regression analysis. Weighted points were assigned to the predictors of in-hospital VTE identified in the multivariate logistic regression analysis and a prediction model was established. Decision curve analysis was performed to evaluate the net clinical benefit between the established and Caprini models.

**Results:** A total of 11 707 patients were included and five variables were explored as predictors related to in-hospital VTE: varicose veins of lower extremity, history of VTE, family history of thrombosis, interruption of antithrombotic agents, and reducible hernia. The prediction model (the CHAT score) revealed a good performance metrics (c-statistic, 0.81 [95% CI, 0.80 to 0.81]; Nagelkerke R<sup>2</sup>, 0.27 [95% CI, 0.26 to 0.30]; Brier score, 0.16 [95% CI, 0.13 to 0.23]). The rate of in-hospital VTE after hernia surgery at low-risk (−4 points), intermediate-risk (0-1 points), high-risk (4 points) and very high-risk (≥5 points) were 0.05%, 0.39%, 0.73% and 8.62%, respectively. The CHAT score identified a considerable variability (from 0.05% to 8.62%) for in-hospital VTE among the overall population after hernia surgery. Decision curve analysis found a superior net benefit of the established model than the Caprini score.

**Conclusions:** The CHAT score is likely to be a practical 5-item supporting tool to identify patients at high risk of in-hospital VTE after hernia surgery that might assist in decision making and VTE prevention. Further validated study will strengthen this finding.

## Keywords

venous thromboembolism, inguinal hernia, prediction model, risk classification, Caprini score

## Introduction

Inguinal hernia repair is one of the most commonly performed surgeries, with approximately 20 million hernioplasties worldwide each year.<sup>1,2</sup> Recent advances in hernia repair technology have contributed to improve the outcomes of patients with hernia.<sup>3,4</sup> However, in these postoperative patients, venous thromboembolism (VTE) events during the hospitalization are the potentially serious complication, adversely influencing the prognosis and life quality. The rate of VTE complications is reported to be 0.18% to 0.45% within the 30 to 90 days after hernia surgery, with most episodes occurring in-hospital.<sup>5,6</sup> Notably, such events may be preventable beforehand by identifying the potentially VTE-related risk factors. The most extensively used assessment tool in predicting postoperative VTE is the Caprini risk score. Nevertheless, a multitude of factors as

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well as a box for additional risk factors make it complicated for surgeons to use in their clinical practice.<sup>7</sup> Furthermore, as the Caprini score is a universal scale for VTE risk prediction in general surgery, it is necessary to develop a prediction model specialized for VTE risk following hernia surgery. In this study, we aimed to derive a clinically useful prediction model for predicting in-hospital VTE after hernia surgery based on a multicenter study in China and make a comparison of the model performance with the Caprini models.

## Methods

This study was conducted in accordance with the Helsinki Declaration and was approved by the Ethics Committee of Beijing Chaoyang Hospital, Capital Medical University (2018-kd-315). Written informed consent for hernia surgery was obtained from all patients before the procedure. The need for informed consent was waived because this study was a retrospective design and the patient's data were anonymized.

### Study Design and Patient Population

This study followed the Transparent Reporting of a Multivariable Prediction Model for Individual Prognosis or Diagnosis (TRIPOD) reporting guidelines.<sup>8</sup> To develop a reliable prediction model for in-hospital VTE after hernia surgery, we conducted this retrospective study with the following three steps: (I) identification of clinically significant predictors of in-hospital VTE after hernia surgery based on a multicenter, retrospective cohort (CHAT-1 trial, registration number: ChiCTR1900020853); (II) development of a prediction model for predicting in-hospital VTE, and (III) comparison of the model performance between established and Caprini models.

The study population was recruited from 58 major institutions in 6 different regions of China (east China, north China, northwest China, southwest China, northeast China, and central and south China) between January first, 2017 and December 31st, 2017. All participating institutions had more than 500 beds and were able to perform hernia surgery. The study included patients who met the following criteria: (I) adult patients undergoing emergency or selective hernia surgery; (II) involved potential risk predictors associated with in-hospital VTE, consisting of demographics, diseases history, comorbidities, procedure, and drug therapy; (III) reported in-hospital VTE event or not during the hospitalization. The patients were excluded if (I) they were outpatients and underwent an ambulatory operation, (II) included missing data or illogical data, (III) they suffered a recent VTE and received an anticoagulant before admission.

### Candidates for Predictors of in-Hospital VTE After Hernia Surgery

On the basis of the Caprini score,<sup>7</sup> Padua score<sup>9</sup> and clinical relevance, we identified the following variables potentially associated with in-hospital VTE after hernia surgery: demographics

(sex, age, smoking, body mass index), diseases history (sepsis, stroke or transient ischemic attack, serious lung disease, congestive heart failure, varicose veins of lower extremity, cancer, heart valve implantation, percutaneous coronary intervention, inflammatory bowel disease, thrombosis, family history of thrombosis, congenital or acquired thrombophilia), comorbidities (hypertension, atrial fibrillation, coronary heart disease, diabetes, systemic lupus erythematosus, nephrotic syndrome, chronic bronchitis), hernia type (reducible hernia, irreducible hernia, incarcerated hernia, strangulated hernia), procedure information (operation type, anesthesia type, operative time, intraoperative blood loss, postoperative compression, postoperative bleeding, postoperative hematoma). We also selected drug-related characteristics that may influence the occurrence of VTE, including the interruption of antithrombotic agents and oral contraceptives or hormone replacement. In those with the intake of antithrombotic agents (warfarin, dabigatran, rivaroxaban, apixaban, aspirin, clopidogrel, ticagrelor, prasugrel), the decision on continuing or interrupting the agents before the operation were mainly based on the selection of the doctors in charge.

### Data Collection and Outcome Definition

In each participating institution, variables above were collected from the medical records and surgical anesthesia reports. The primary outcome of this study was to develop a prediction model for in-hospital VTE after hernia surgery in China. VTE events included DVT and PE: (I) DVT is diagnosed by combining the clinical symptoms of swelling and pain of the lower limbs, tenderness behind the lower leg and/or medial thigh and auxiliary examination of color ultrasound of the veins of both lower limbs, and lower extremity venography is the gold standard for the diagnosis of DVT<sup>10</sup>; (II) PE should be initially diagnosed in combination with related clinical manifestations such as dyspnea and shortness of breath and laboratory tests such as plasma D-dimer. CT pulmonary arteriography (CTPA) is the preferred examination method for the diagnosis of PE.<sup>11</sup> Interruption of antithrombotic agents was defined as stopping antithrombotic agents including temporary replacement by heparin or not.

### Statistical Analysis

Categorical variables are expressed as numbers and percentages and were compared using the Chi-square test. Continuous variables are reported as mean  $\pm$  standard deviation and were compared using the Wilcoxon rank-sum test. Univariate and multivariate logistic regression analyses were used to determine the associations of candidate variables with in-hospital VTE after hernia surgery. Multicollinearity among the variables was screened according to the variance inflation factor (VIF) ( $VIF > 5$  was considered strong collinearity).<sup>12</sup> Two criteria were considered necessary for a variable to be included in the final prediction model: (I) a univariate  $p$  value indicative of  $VTE \leq 0.05$  and (II) a plausible association with VTE based on the Caprini and Padua scores. We assigned weighted points proportional to  $\beta$  coefficients multiplied by 2 to the

**Table 1.** Demographics and Characteristics of Patients in this Study.

Variables	Overall (n = 11 707)	Absence of VTE (n = 11 691)	Presence of VTE (n = 16)	P value
<b>Demographics, n (%)</b>				
Male	10 523 (89.90%)	10 508 (89.90%)	15 (93.80%)	1.00
Age (years)				.52
≤60	4914 (42.00%)	4908 (42.00%)	6 (37.50%)	
61 to 74	4394 (37.50%)	4389 (37.50%)	5 (31.20%)	
≥75	2399 (20.50%)	2394 (20.50%)	5 (31.20%)	
Smoking	2295 (19.60%)	2290 (19.60%)	5 (31.20%)	.22
Body mass index (>25 kg/m <sup>2</sup> )	2753 (27.40%)	2748 (27.40%)	5 (31.20%)	.78
<b>Disease history, n (%)</b>				
Sepsis (<1 month)	3 (0.03%)	3 (0.03%)	0 (0.00%)	1.00
Stroke or TIA (<1 month)	20 (0.17%)	20 (0.17%)	0 (0.00%)	1.00
Serious lung disease (<1 month)	24 (0.21%)	23 (0.20%)	1 (6.25%)	<b>.03</b>
Congestive heart failure (<1 month)	5 (0.04%)	5 (0.04%)	0 (0.00%)	1.00
Varicose veins of lower extremity	116 (0.99%)	114 (0.98%)	2 (12.50%)	<b>.01</b>
History of cancer	489 (4.18%)	489 (4.18%)	0 (0.00%)	1.00
History of heart valve implantation	56 (0.48%)	56 (0.48%)	0 (0.00%)	1.00
History of percutaneous coronary intervention	187 (1.60%)	185 (1.58%)	2 (12.50%)	<b>.03</b>
History of inflammatory bowel disease	161 (1.38%)	160 (1.37%)	1 (6.25%)	<b>.20</b>
History of VTE	204 (1.74%)	200 (1.71%)	4 (25.00%)	<b>&lt;.01</b>
Family history of thrombosis	30 (0.26%)	26 (0.22%)	4 (25.00%)	<b>&lt;.01</b>
Congenital or acquired thrombophilia	63 (0.54%)	61 (0.52%)	2 (12.50%)	<b>&lt;.01</b>
<b>Comorbidities, n (%)</b>				
Hypertension	2915 (24.90%)	2909 (24.90%)	6 (37.50%)	.25
Atrial fibrillation	303 (2.59%)	302 (2.58%)	1 (6.25%)	.34
Coronary heart disease	822 (7.02%)	817 (6.99%)	5 (31.20%)	<b>&lt;.01</b>
Diabetes	848 (7.24%)	847 (7.24%)	1 (6.25%)	1.00
Systemic lupus erythematosus	6 (0.05%)	6 (0.05%)	0 (0.00%)	1.00
Nephrotic syndrome	29 (0.25%)	29 (0.25%)	0 (0.00%)	1.00
Chronic bronchitis	171 (1.46%)	170 (1.45%)	1 (6.25%)	.21
<b>Hernia type, n (%)</b>				
Reducible hernia	10 959 (93.60%)	10 948 (93.60%)	11 (68.80%)	<b>&lt;.01</b>
Recurrent hernia	534 (4.56%)	531 (4.54%)	3 (18.80%)	<b>.03</b>
<b>Procedure, n (%) or mean ± SD</b>				
Open operation	5519 (47.10%)	5512 (47.10%)	7 (43.80%)	.98
General anesthesia	7704 (65.80%)	7691 (65.80%)	13 (81.20%)	.30
Operative time >45 min	9189 (80.50%)	9173 (80.40%)	16 (100%)	<b>.05</b>
Intraoperative blood loss >10 mL	5460 (46.60%)	5455 (46.70%)	5 (31.20%)	.33
Postoperative compression	9101 (77.70%)	9086 (77.70%)	15 (93.80%)	.22
Compression time >24 h	5497 (60.60%)	5492 (60.60%)	5 (33.30%)	.06
Postoperative bleeding	258 (2.20%)	258 (2.21%)	0 (0.00%)	1.00
Postoperative hematoma	224 (1.91%)	223 (1.91%)	1 (6.25%)	.27
White blood cell count (post operation)	6.20 (1.97)	6.20 (1.97)	5.23 (2.54)	.16
C-reactive protein (post operation)	6.08 (21.0)	6.09 (21.0)	3.42 (3.48)	.12
<b>Agent therapy, n (%)</b>				
Interruption of antithrombotic agents	602 (5.14%)	595 (5.09%)	7 (43.80%)	<b>&lt;.01</b>
Oral contraceptives or hormone replacement	35 (0.30%)	33 (0.28%)	2 (12.50%)	<b>&lt;.01</b>

Abbreviations: SD, standard deviation; TIA, transient ischemic attack; VTE, venous thromboembolism. The bold indicates statistically significant between presence of VTE or not ( $P < .05$ ).

nearest integer for the predictors determined in the multivariate analysis. Using this scoring system, we derived four risk categories: low risk, intermediate risk, high risk and very high risk. A similar risk classification was also derived according to the Caprini scoring system. The trend in the risk for in-hospital VTE among risk categories was evaluated by the Cochran-Armitage trend test. The overall performance of

model was assessed by the Brier score and Nagelkerke  $R^2$ , and its discrimination was examined by the c-statistic. Decision curve analysis was performed to evaluate the net clinical benefit of the models for predicting in-hospital VTE after hernia surgery, with zero indicating no benefit and values  $>0$  indicating increased benefit.<sup>13</sup> Net benefit was defined as the difference between true-positive and false-positive rates

across a range of possible individual high-risk thresholds. For any given threshold, the model with the higher net benefit is preferred.<sup>13</sup> All statistical analyses were performed by an independent statistician (Y. Y.) who used R software version 4.0.3., and  $P < .05$  was considered statistically significant. All authors had access to the study data and had reviewed and approved the final version of manuscript.

## Results

### Patient Enrollment Process and Patient Characteristics

As shown in Supplementary Table 1, 14 322 patients who were enrolled in the CHAT-1 study between January first, 2017 and December 31st, 2017 were selected in this study. After excluding 166 patients aged <18 years and 2449 patients consisting of missing data or illogical data, 11 707 patients were eligible for further analysis. The demographics and characteristics of patients are presented in Table 1. Almost 90% of patients were male and 20% of patients were aged  $\geq 75$  years. About one-third of patients had one or multiple comorbidities, including hypertension (24.9%), diabetes (7.2%), coronary heart disease (7.0%). More than 90% of patients were reducible hernia and 4.6% were recurrent hernia. Open surgery accounted for 47.1% of patients. A total of 602 patients (5.1%) interrupted the antithrombotic agents before surgery. The in-hospital VTE rate after hernia surgery in this study was 0.14% (16 events).

### Predictors of in-Hospital VTE After Hernia Surgery

As shown in Supplementary Table 2, 36 potential predictors were initially included in the univariate regression analysis and 11 of them were identified as statistically associated with the risk of in-hospital VTE after hernia surgery: serious lung disease, varicose veins of lower extremity, history of PCI, history of VTE, family history of thrombosis, congenital or acquired thrombophilia, coronary heart disease, reducible hernia, recurrent hernia, interruption of antithrombotic agents, oral contraceptives or hormone replacement ( $P < .05$  for each variable). Except for 9 categorical variables and 2 continuous variables, other 14 variables ( $P > .05$  for each variable) related to VTE based on the Caprini and Padua scores were also included in the multivariate regression analysis. Therefore, we finally involved 25 candidate predictors for prediction model development and identified 5 variables as predictors of in-hospital VTE after hernia surgery (Table 2).

### Prediction Model Development

The VIF ranged from 1.05 to 3.77 ( $< 5$ ), indicating that the multicollinearity among the variables was not a concern. Weighted points of 5 predictors were assigned proportionally to  $\beta$  regression coefficient values by multiplying 2 to obtain the nearest integer: 5 points for varicose veins of lower extremity; 4 points for history of VTE; 8 points for family history of

thrombosis; 4 points for interruption of antithrombotic agents, and -4 points for reducible hernia (Table 2).

The established prediction model (the CHAT score: Chinese Hernia Adult Thromboembolism) is presented in Table 3. This model had good overall performance, with a Nagelkerke  $R^2$  of 0.27 and a Brier score of 0.16, and showed good discrimination, with a c-statistic of 0.81 (95% CI, 0.80 to 0.81; Table 4). According to the risk classification, the CHAT score was categorized as low-risk (-4 points), intermediate-risk (0 to 1 point), high-risk (4 points) or very high-risk ( $\geq 5$  points) for in-hospital VTE after hernia surgery. As a result, the rates of VTE for each risk category were 0.05%, 0.39%, 0.73% and 8.62% (Table 5), and a significantly increasing trend of risk from low-risk to very high-risk groups was observed ( $P < .01$  for Cochran-Armitage trend test). The score identified a considerable variability (from 0.05% to 8.62%) in VTE risk among the overall population after hernia surgery.

### Example for the use of CHAT Score

As shown in Tables 2 and 3, a male patient who was a reducible hernia, had a history of VTE, and interrupted antithrombotic agents before operation. Total score = 4 points (for history of thrombosis) + 4 points (for interruption of antithrombotic agents) - 4 points (for reducible hernia) = 4 points. This patient therefore fits the high-risk category, with the in-hospital VTE risk of 0.73%.

### Comparison of the Model Performance Between the CHAT and Caprini Scores

As shown in Table 4, the Caprini score also had a good model performance, with a Nagelkerke  $R^2$  of 0.15 and a c-statistic of 0.79, which was relatively lower than the CHAT score (Nagelkerke  $R^2$ : 0.27; c-statistic: 0.81). A decision curve analysis was conducted to ascertain the applicability of the CHAT score to clinical practice. This analysis indicated a threshold to define in-hospital VTE risk  $> 0.05\%$  using the CHAT score (Figure 1). In summary, compared with the Caprini score, the CHAT score showed superior net benefit and improved predictive performance for in-hospital VTE after hernia surgery.

### Characteristics and Management After in-Hospital VTE

Sixteen patients (16/11,707, 0.14%) experienced in-hospital DVT after inguinal hernia surgery. The patient age ranged from 49 to 90 years and most (14/16, 87.50%) were male. Five patients fell in the very high-risk category ( $\geq 5$  points using the CHAT score). Notably, only 5 patients (31.30%) had received mechanical or pharmacological prophylaxis of VTE during the hospitalization. After diagnosed with DVT, all patients received guideline-recommended anticoagulation, with details described in Supplementary Table 3.

**Table 2.** Multivariate Logistic Regression Analysis of 25 Predictors for VTE after Inguinal Hernia Surgery and the Scoring System.

Potential Predictors	Levels	Adjusted OR	95% CI	P value	$\beta$ coefficients	Points <sup>a</sup>	VIF
Sex	Female	0.28	0.03 to 2.88	.28	-1.28	-	1.23
Age	61 to 74 years	1.59	0.36 to 6.89	0.54	0.46	-	1.67
	$\geq 75$ years	2.83	0.64 to 12.54	0.17	1.04	-	1.74
Smoking	Yes	1.34	0.39 to 4.62	0.64	0.29	-	1.13
Body mass index	$>25$ kg/m <sup>2</sup>	0.88	0.25 to 3.08	0.84	-0.13	-	1.15
Serious lung disease (<1 month)	Yes	2.39	0.03 to 202.53	0.70	0.87	-	1.70
<b>Varicose veins of lower extremity</b>	Yes	11.56	1.59 to 83.94	0.02	2.45	5	1.19
History of PCI	Yes	0.18	0.01 to 5.31	0.32	-1.71	-	2.70
History of inflammatory bowel disease	Yes	0.38	0.02 to 7.67	0.53	-0.97	-	1.94
<b>History of VTE</b>	Yes	7.92	1.50 to 41.65	0.02	2.07	4	1.68
<b>Family history of thrombosis</b>	Yes	47.31	5.41 to 413.31	<0.01	3.86	8	2.16
Congenital or acquired thrombophilia	Yes	9.42	0.32 to 279.31	0.20	2.24	-	2.70
Hypertension	Yes	1.23	0.37 to 4.04	0.74	0.21	-	1.22
Atrial fibrillation	Yes	0.24	0.01 to 5.00	0.36	-1.43	-	1.99
Coronary heart disease	Yes	0.49	0.08 to 2.94	0.43	-0.72	-	2.01
Diabetes	Yes	0.65	0.08 to 5.44	0.69	-0.43	-	1.07
Chronic bronchitis	Yes	4.60	0.48 to 43.95	0.19	1.53	-	1.18
<b>Reducible hernia</b>	Yes	0.14	0.03 to 0.56	0.01	-1.99	-4	1.55
Recurrent hernia	Yes	0.40	0.02 to 8.14	0.55	-0.91	-	3.77
Operation type	Open	0.73	0.18 to 2.96	0.66	-0.31	-	1.74
Anesthesia type	Others <sup>b</sup>	0.31	0.06 to 1.70	0.18	-1.16	-	1.43
Intraoperative blood loss	$>10$ mL	1.02	0.31 to 3.40	0.97	0.02	-	1.27
Postoperative compression	Yes	3.52	0.44 to 28.30	0.24	1.26	-	1.05
Postoperative hematoma	Yes	5.08	0.59 to 43.81	0.14	1.63	-	1.11
<b>Interruption of antithrombotic agents</b>	Yes	6.76	1.50 to 30.50	0.01	1.91	4	1.88
Oral contraceptives or hormone replacement	Yes	3.90	0.11 to 135.30	0.45	1.36	-	2.92

Abbreviations: CI, confidence interval; OR, odds ratio; PCI, percutaneous coronary intervention; VIF, variance inflation factor (VIF < 5 indicates low multicollinearity); VTE, venous thromboembolism. The bold indicates the 5 variables as predictors of in-hospital VTE after hernia surgery.

<sup>a</sup>Weighted points were assigned proportional to  $\beta$  coefficients multiplied by 2 to the nearest integer in the significant predictors.

<sup>b</sup>Include lumbar or epidural anesthesia.

## Discussion

### Major Findings

In this study, we developed a prediction model for in-hospital VTE after hernia surgery, based on the data of 11 707 patients in a retrospective multicenter study. The major findings were as follows: (I) 36 candidate predictors were explored and 5 of them

**Table 3.** Distribution of Prediction Model for in-Hospital VTE after Hernia Surgery.

Total points	No. of patients	No. of VTE	Rate of VTE, % (95% CI)
-4	10 225	5	0.05 (0.02 to 0.11)
0	1 193	5	0.42 (0.18 to 0.98)
1	94	0	-
4	137	1	0.73 (0.13 to 4.02)
5	19	0	-
8	25	0	-
9	2	1	50 (9.45 to 90.55)
12	9	3	33.33 (12.06 to 64.58)
13	1	1	100 (20.65 to 100)
16	2	0	-

Abbreviations: CI, confidence interval; No., number; VTE, venous thromboembolism.

were finally identified as predictors associated with in-hospital VTE: varicose veins of lower extremity, history of VTE, family history of thrombosis, interruption of antithrombotic agents, and reducible hernia; (II) the established prediction model, namely the CHAT score, achieved good model performance (c-statistic, 0.81; Nagelkerke  $R^2$ , 0.27; Brier score, 0.16); (III) compared with the Caprini score, the CHAT score showed superior net benefit and improved predictive performance in predicting risk for in-hospital VTE after hernia surgery.

### Pivotal Predictors of in-Hospital VTE After Hernia Surgery

VTE episodes are still a clinically significant complication resulting in prolonged hospitalization and reduced life quality.

**Table 4.** Performance of the Prediction Model and Caprini Score

Prediction indexes	CHAT score	Caprini score
Nagelkerke $R^2$	0.27 (0.26 to 0.30)	0.15 (0.13 to 0.16)
Brier score (95%CI)	0.16 (0.13 to 0.23)	0.02 (0 to 0.06)
c-statistic (95%CI)	0.81 (0.80 to 0.81)	0.79 (0.78 to 0.79)

Abbreviation: CI, confidence interval.

**Table 5.** Risk Classification for in-Hospital VTE after Hernia Surgery in CHAT and Caprini Scores

Risk category	Total points	No. of Patients	No. of VTE	Rate of VTE*, % (95% CI)
<b>CHAT score</b>				
Low risk	−4	10 225	5	0.05 (0.02 to 0.11)
Intermediate risk	0 to 1	1287	5	0.39 (0.17 to 0.91)
High risk	4	137	1	0.73 (0.13 to 4.02)
Very high risk	≥5	58	5	8.62 (3.74 to 18.64)
<b>Caprini score</b>				
Low to intermediate risk	0 to 2	1036	0	–
High risk	3 to 4	4689	1	0.02 (0 to 0.12)
Very high risk	≥5	5952	15	0.25 (0.15 to 0.42)

Abbreviations: CI, confidence interval; No., number; VTE, venous thromboembolism.

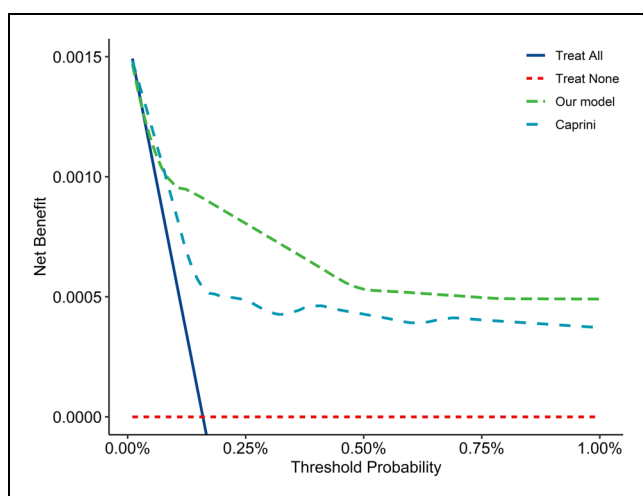
\**P* value of Cochran-Armitage test for trend <.001 in both CHAT and Caprini scores.

In this study, varicose veins of lower extremity ( $\beta$  coefficient, 2.45), history of VTE ( $\beta$  coefficient, 2.07), and family history of thrombosis ( $\beta$  coefficient, 3.86) were detected as extremely pivotal predictors for predicting in-hospital VTE after hernia surgery, which are also vital risk factors in the Caprini score.<sup>14</sup> In addition, we identified that reducible hernia procedure decreased the risk of in-hospital VTE. More complicated types such as irreducible hernia, incarcerated hernia, and strangulated hernia were assumed to have an abdominal wall plication during abdominoplasty or transverse rectus abdominus myocutaneous flap breast reconstruction, which could

significantly increase the intra-abdominal pressure and result in venous stasis in the lower extremities and dilation of the common femoral vein.<sup>15,16</sup> These are known to create vein wall microtears and activate the local clotting cascade and initiate thrombus formation.<sup>17</sup> Furthermore, the interruption of antithrombotic agents was considered a predictor of in-hospital VTE, with the  $\beta$  coefficient of 1.91. Patients with in-hospital VTE were much more common to interrupt the antithrombotic agents (43.80%) than those without (5.09%), which may be informative in the management of patients with hernia surgery.

### Comparison with the Current Models

Considering the relatively low incidence of VTE after hernia surgery, the development of a prediction score with high predictability is of great importance. Scarce studies focused on the prediction model for VTE after hernia surgery. Pannucci et al.<sup>18</sup> reported a weighted VTE risk assessment model for hernia surgery based on the database of the American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP) involving 113 873 patients. This study explored 14 variables using multivariate analysis and yielded a moderate model performance (c-statistic,  $0.79 \pm 0.01$ ). Although this was a standard modeling study specific to the population undergoing hernia procedure, it still had several limitations: (I) variables selected were based on the ACS-NSQIP database instead of the classic VTE prediction models such as the Caprini score, Padua score, inevitably leaving out certain pivotal predictors such as history of VTE and family history of thrombosis; (II) the vast sample size could explore minor differences of the association between the variables and VTE risk, with a significant *p* value; however this association reflected not necessarily the clinical importance; (III) the said issues of study finally derived a relatively complicated prediction model that incorporated 14 predictors and only achieved a moderate model performance. In comparison, the CHAT-1 study<sup>19</sup> investigating the current prevalence of early VTE in Chinese hernia patients could provide a suitable sample size and a tailored variables pool. In this study, we selected the potential predictors on the basis of the recognized scores, hernia type, and drug-related characteristics. Finally, we developed a practical 5-item model (the CHAT score) for in-hospital VTE after hernia surgery, with good performance discrimination (c-statistic, 0.81; 95% CI, 0.80 to 0.81). It should be noted that the c-statistic reached its satisfactory value, since the lower limit of 95%CI was 0.80. Compared with a gold standard for VTE risk assessment (the Caprini score), the CHAT score had superior net benefit (threshold value: 0.05%) and improved predictive performance (c-statistic: 0.81 vs 0.79). Accordingly, we believe that the CHAT score could be applied as a simpler and more effective tool to clinical decision-making for identifying patients at risk of in-hospital VTE after hernia surgery.



**Figure 1.** Decision curve analysis of the CHAT score and Caprini score for in-hospital VTE after hernia surgery. The result showed a threshold to define in-hospital VTE risk >0.05% using the CHAT score. The horizontal red line represents the assumption that no patient will suffer the event, and the solid blue line represents the assumption that all patients will suffer the event.

### Management Considerations

Only 23.40% of patients underwent VTE risk assessment using the Caprini score in our previous study.<sup>19</sup> Therefore, a simple

prediction model specifically aiming at the population after hernia surgery might be desirable to triage patients. First, surgeons should conduct a comprehensive assessment of patient conditions for the risk factors before procedure. Patients with a history of varicose veins of lower extremity, history of VTE, or family history of thrombosis might be at a very high-risk for in-hospital VTE (the CHAT score  $\geq 5$  points). These patients often take antithrombotic agents routinely, and the interruption could definitely increase the risk of VTE, whereas continual antithrombotic therapy could increase the risk of bleeding. Therefore, heparin bridging might be an option to balance the risk of thrombosis and bleeding. As for complicated hernia types, specific techniques such as laparoscopic or robotic hernia repair could minimize surgical trauma and shorten the time of abdominal wall tight closure,<sup>4</sup> leading to reduced VTE risk. Second, patients at very high risk for in-hospital VTE should receive guideline-recommended pharmacological prophylaxis for 10 to 14 days after hernia surgery. Third, with pharmacological prophylaxis such as low-molecular-weight heparin, potential thrombosis and bleeding events should be closely monitored via D-dimer detection and ultrasonic evaluation. Taken together, the matter of prime importance is to identify patients at the highest risk, then the preventive measures to improve prognosis and accelerate hospital discharge could be conducted.

### Strengths and Limitations

Several strengths of this study warrant mention. First, according to the TRIPOD guidelines,<sup>8</sup> the design of the present study is robust. The method also satisfied recent developments for improved prediction model assessment, including decision curve analysis.<sup>13</sup> Second, the data for creating a prediction model were derived from a big multicenter cohort. Third, a simple 5-item prediction model is easy to understand and convenient for clinical practice. Certainly, this study has several inherent limitations. First, this study is retrospective design and the prediction model was developed in China. Therefore, it is unclear that whether this model can be extrapolated to other geographical areas, such as U.S.A or Europe. Second, certain intra-operative variables such as surgery techniques were not considered in this model. Third, this study only assessed the VTE incidence during hospitalization and inevitably underestimated the overall VTE burden in patients during the perioperative period. Lastly, given the low incidence of VTE after hernia surgery, we did not conduct an external validation in this study. For further study, our ongoing study involving 1008 patients with hernia (the CHAT-3 trial, registration number: ChiCTR2000033769) will confirm this prediction model.

### Conclusions

In summary, we derived a practical 5-item prediction model (the CHAT score) to identify patients at the highest risk of in-hospital VTE following hernia surgery. This model can be applied in routine practice to optimize the management of

patients after hernia surgery based on individual VTE risk. However, further external validation is required.

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### Author Contributions

Zhang is guarantor of the entire manuscript. Gu, Wang, and Li contributed to the study conception and design, critical revision of the manuscript for important intellectual content. Zhang and Yang contributed to the data acquisition, analysis, and interpretation. All the authors have read and approved the final version of this manuscript.

### Declaration of Conflicting Interests

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### Ethical Approval

This study was conducted in accordance with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards, and was approved by the Ethics Committee of Beijing Chaoyang Hospital, Capital Medical University (2018-kd-315).

### Data Availability

The data that support the findings of this study are available on reasonable request from the corresponding authors.

### Informed Consent on Studies with Human Subjects

Written informed consent for hernia surgery was obtained from all patients before the procedure. The need for informed consent was waived because this study was a retrospective design and the patient's data were anonymized.

### Supplemental Material

Supplemental material for this article is available online.

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