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Development, validation and visualization of risk prediction model for postoperative shivering in patients undergoing video-assisted thoracoscopic lobectomy: a real-world retrospective study

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To develop, validate, and visualize a risk prediction model for postoperative shivering in patients undergoing video-assisted thoracoscopic (VATS) lobectomy, addressing the lack of individualized tools for this high-risk population. This retrospective study analyzed 530 patients undergoing VATS lobectomy from a tertiary hospital in Wuhan (January 2022–December 2023). The data were randomly divided into training set and validation set at a ratio of 7∶3. Patients were stratified into postoperative shivering ($n = 198$) and non-postoperative shivering ($n = 332$) groups based on Bedside Shivering Assessment Scale (BSAS) criteria. Logistic regression identified independent risk factors, and a nomograph was developed. Model performance was evaluated using the area under the receiver operating characteristic curve (AUC), calibration curves, Hosmer-Lemeshow test, and decision curve analysis (DCA). An online visualization tool was created for clinical implementation. Postoperative shivering occurred in 198 of 530 patients undergoing VATS lobectomy (37.36%). The logistic regression analysis identified age < 60 years, intraoperative hypothermia, delayed anesthesia recovery, absence of postoperative analgesia, operation duration > 180 min and lower preoperative temperature as significant risk factors for postoperative shivering ($P < 0.05$). The resulting nomograph demonstrated strong discrimination with AUCs of 0.847 (95%*CI*: 0.809–0.885) in the training cohort ($n = 424$) and 0.836 (95%*CI*: 0.747–0.925) in validation ($n = 106$), while calibration curves and the Hosmer-Lemeshow test ($\chi^2 = 13.123$, $P = 0.108$) confirmed model reliability. DCA demonstrated clinical utility across threshold probabilities of 0.20–0.98. In order to promote clinical implementation, deployment of the visualization tools online (https://shivering.shinyapps.io/dynnomapp/), which supports dynamic risk assessment. This study established the first risk prediction model for postoperative shivering in patients undergoing VATS lobectomy, integrating six perioperative variables into a clinically applicable nomograph and online tool. The model facilitates identification of high-risk patients, enabling targeted interventions to mitigate shivering-related complications.

Keywords Postoperative shivering, Video-assisted thoracoscopic lobectomy, Prediction model, Risk factors, Visualization tool

Abbreviations

VATS Video-assisted thoracoscopic

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PACU	Post-anesthesia care unit
ASA	American society of anesthesiologists
LASSO	Least absolute shrinkage and selection operator
ROC	Receiver operating characteristic
DCA	Decision curve analysis
BSAS	Bedside shivering assessment scale
FAW	Forced-air warming

Postoperative shivering refers to involuntary muscle tremor, which is characterized by systemic or local rhythmic shivering, during the postoperative recovery period (especially the recovery from anesthesia) after general or regional anesthesia[1]. It is a common complication after anesthesia, with an incidence between 20% and 70%[2]. A meta-analysis study showed that the incidence of postoperative shivering in adults was as high as 53%-55%[3]. The occurrence of shivering will bring a series of adverse pathological and physiological changes to patients during the recovery period after general anesthesia. It can cause a sharp increase in oxygen consumption, a significant increase in carbon dioxide production, and can induce myocardial ischemia and increase cardiac output[4]. These changes, particularly in patients with preexisting inadequate cardiopulmonary reserve, lead to marked oxygen-demand imbalance and the risk of hypercapnia, which could trigger metabolic (tissue hypoxia) or respiratory (hypoventilation) acidosis. Severe acidosis and/or excessive work of breathing burden may eventually lead to respiratory depression[5]. In pathophysiological terms, postoperative shivering can increase oxygen consumption by up to 400%, the production of carbon dioxide and lactic acid, and increase metabolic rate to more than 400%, increasing risks to patients suffering from pulmonary and cardiac conditions considerably[6].

During video-assisted thoracoscopic (VATS) lobectomy, patients often face a higher risk of postoperative shivering due to factors such as body heat loss (such as hypothermia environment and body cavity exposure), inhibition of the thermoregulatory center by anesthetic drugs, and relatively long operation time[7]. It is worth noting that with the development of minimally invasive techniques, the indications for this surgery have expanded to include elderly and advanced lung cancer patients[8]. This group of patients often have decreased physiological functions (especially thermoregulatory functions) and multiple complications, further increasing the susceptibility to postoperative shivering. It has been reported that the occurrence of postoperative shivering is affected by multiple factors, mainly including the type and dose of anesthetic drugs, the age of patients, the time of fasting before surgery, the method of anesthesia, the duration of operation, the amount of intraoperative blood loss and infusion[2,4]. Among them, intraoperative hypothermia is generally considered to be the most important risk factor for inducing shivering[9]. However, it must be emphasized that shivering is not solely caused by hypothermia; factors such as painful stimuli, stress responses, residual effects of anesthetic agents may also trigger the shivering response in patients with normal core body temperature[10].

At present, the existing research focuses mostly on the effect evaluation of postoperative shivering prevention measures[3,11,12]. However, tools for dynamically predicting the postoperative shivering risk of individual patients based on multi-dimensional clinical parameters are relatively scarce. Existing evidence indicates that the occurrence of postoperative shivering is influenced by multiple factors and shows individual differences. The key risk factors include: (1) Changes in core body temperature during the operation (It is reported that for every 1 °C drop in room temperature, the risk of shivering increases significantly)[13]; (2) Types of anesthesia and drugs (for example, intraspinal anesthesia may be more likely to induce shivering than general anesthesia due to its vasodilation effect)[3]; (3) Surgical characteristics (such as an increased incidence of shivering in surgeries lasting more than 3 h and with high complexity)[4]. In recent years, process-oriented risk management tools such as failure mode and effects analysis (FMEA) have been applied to the improvement of hypothermia prevention and control processes, showing the potential to reduce the incidence of shivering[14]. However, their essence is the optimization of the system process and cannot use patient-specific data for individualized risk prediction. Focusing on patients undergoing VATS lobectomy, no research has been reported on the risk prediction model for postoperative shivering. The few existing risk prediction models for other populations generally have limitations such as insufficient study sample, lack of dynamic and key variables, and insufficient generalization. Li[15] developed a predictive model for postoperative shivering under epidural anesthesia in cesarean section patients, but the study sample was too small. Ma et al.[16] developed predictive models for postoperative shivering in adults, but excluded body temperature as a key variable. Therefore, there is an urgent need to develop a predictive model that can integrate perioperative multi-dimensional clinical parameters to dynamically predict the risk of postoperative shivering in patients undergoing VATS lobectomy.

In summary, in order to cope with the risk of postoperative shivering as an important complication of anesthesia in patients undergoing VATS lobectomy, the present study integrated multi-dimensional perioperative clinical parameters based on the data and methodological basis accumulated in the previous research team's development of prediction models for intraoperative hypothermia[8] and delayed recovery from anesthesia[17]. To develop, validate and visualize a risk prediction model for postoperative shivering. The model aims to develop a predictive tool for patients undergoing VATS lobectomy and to help medical staff to more accurately identify patients at high risk of postoperative shivering for timely intervention.

Methods

Study design

According to the TRIPOD statement, 530 patients who underwent VATS lobectomy in The Central Hospital of Wuhan, Tongji Medical College, Huazhong University of Science and Technology from January 2022 to December 2023 were retrospectively enrolled. The inclusion criteria for this study were as follows: (1) Meeting indications for VATS lobectomy[8]; (2) Adult patients (aged ≥ 18 years); (3) Elective surgical cases; (4) General anesthesia regimen implemented; (5) Complete and verifiable medical records. The exclusion criteria for this study were as follows: (1) Thermoregulatory dysfunction; (2) History of nasal surgery or anatomical abnormalities precluding nasopharyngeal temperature monitoring; (3) Intraoperative conversion to open thoracotomy; (4) Preoperative fever (axillary temperature ≥ 37 °C within 24 h); (5) Postoperative failure to transfer to the post-anesthesia care unit (PACU). Figure 1 shows the flowchart of the study.

Sample size

The data of 550 patients undergoing VATS lobectomy were retrospectively collected from the information system of The Central Hospital of Wuhan, Tongji Medical College, Huazhong University of Science and Technology. Through the inclusion and exclusion criteria, the complete data of 530 patients were finally obtained. Based on existing literature and clinical expertise, this study incorporated 16 risk factors. Based on the sample size calculation of the events-per-variable (EPV) principle[18], 198 shivering events and 16 predictors met the requirement of EPV ≥ 10 (198/16 = 12.4), which was in line with the TRIPOD statement's specification for the sample size of the prediction model.

Ethical consideration

This study was approved by the Ethics Committee of the Central Hospital of Wuhan (number WHZXKYL2024-011-01) and followed the principles of Declaration of Helsinki. Due to the retrospective nature of the study, the Ethics Committee of the Central Hospital of Wuhan waived the need of obtaining informed consent. This retrospective study utilized anonymized historical data collected prior to hypothesis formulation, which exempts it from preregistration per International Committee of Medical Journal Editors (ICMJE) guidelines.

Measures

This study designed a data collection table, including the following three parts. Demographic characteristics: including gender, age, body mass index, body surface area, diagnosed with diabetes, past surgical history, surgical spot, type of operation. Intraoperative data: including intraoperative hypothermia, operation duration, preoperative temperature, indoor temperature. Anesthesia data: including American society of anesthesiologists

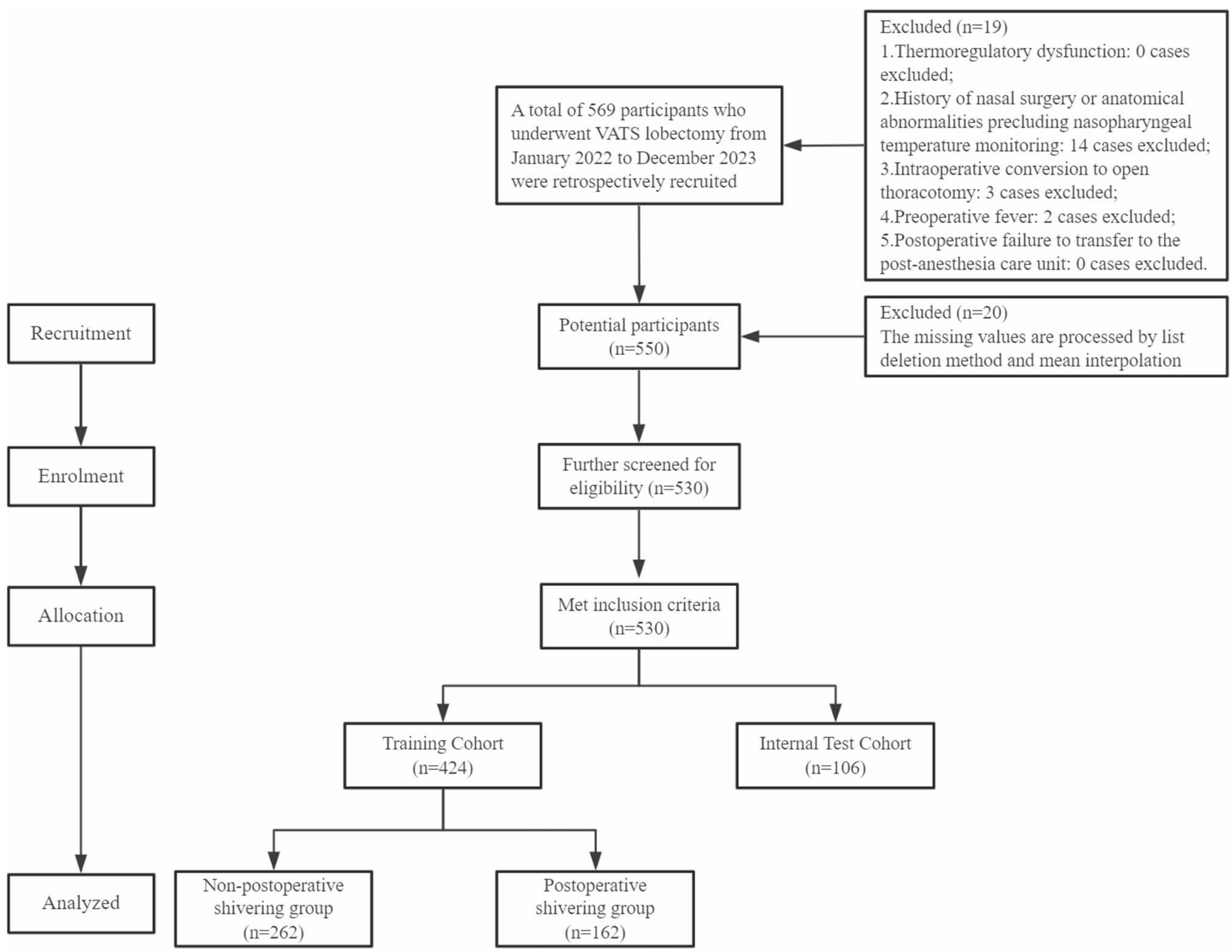

Fig. 1. Flowchart of the study.

(ASA), delayed recovery from anesthesia, postoperative analgesia, anesthesia duration. The body surface area = 0.0061 * Height (cm) + 0.0124 * Body weight (kg) – 0.0099. The preoperative body temperature was axillary temperature. The intraoperative temperature was nasopharyngeal temperature. The delayed recovery from anesthesia is defined as failure to regain consciousness more than 90 min after general anaesthesia is stopped and failure to respond correctly to external stimuli and verbal commands[17]. Postoperative analgesia is defined as receiving at least one of the following intervention measures before or after surgery: (1) patient-controlled intravenous analgesia pump (including opioid or non-opioid drugs); (2) continuous thoracic paravertebral or intercostal nerve block.

Data collection
All real-world data were collected retrospectively from the hospital information system. Postoperative shivering was evaluated using the Bedside Shivering Assessment Scale (BSAS)[19], which required the assessor to observe the patient for 2 min, including visual examination and palpation of the neck, chest, arms and legs. The final classification was based on BSAS[20]: Grade III was characterized by severe tremors in the lower limb muscles and abdomen of the patient, grade II was characterized by obvious tremors in the upper limb muscles and chest, grade I was characterized by slight tremors in the neck muscles and face, and grade 0 was classified as no shivering. Among them, patients with grade I, II, and III shivering after surgery were all recorded as postoperative shivering[6,16]. The assessment of postoperative shivering was jointly completed by two researchers in the PACU. The observation period started from the moment the patient entered the PACU and ended when the patient returned to the ward fully conscious. Intraoperative hypothermia is determined by real-time monitoring of the patient's body temperature through the nasopharyngeal probe of the electrocardiogram monitor. Intraoperative hypothermia is defined as the core body temperature of the patient below 36℃ caused by any reason during surgery[8]. All the data are entered by two people to ensure accuracy.

Data processing
After handling missing data via list deletion ($n = 20$ excluded) and mean interpolation, a cohort of 530 cases was retained. This dataset was partitioned into a training set (70%) and an independent validation set (30%) through random assignment. Cases in the training set were grouped according to postoperative shivering status. Model predictors were identified and the nomograph was developed utilizing the training data. The validation set evaluated the nomograph's predictive performance for postoperative shivering after VATS lobectomy.

Data analysis
Statistical analysis was performed using SPSS 26.0 and R 4.3.2 software. The dataset was randomly partitioned into training and validation cohorts in a 7:3 ratio. Baseline variable comparisons were performed. Categorical variables were assessed using chi-square or Fisher's exact tests, while continuous variables were analyzed via t-tests or the Wilcoxon rank-sum test as appropriate. Based on existing literature and clinical expertise, this study incorporated 16 risk factors. Subsequently, within the training cohort, multivariable analysis was conducted using least absolute shrinkage and selection operator (LASSO) logistic regression to identify independent risk factors for postoperative shivering and to construct a predictive nomograph. Model performance was evaluated employing receiver operating characteristic (ROC) curves, with discriminatory capacity quantified by the area under the ROC curve. Internal validation involved 1000 bootstrap resampling iterations. Calibration accuracy was appraised using calibration curves in conjunction with the Hosmer-Lemeshow goodness-of-fit test. A decision curve analysis (DCA) was implemented to determine the net benefit threshold across different probability thresholds. To facilitate their incorporation into the clinical practice, an interactive online visualization tool was developed using the R Studio Shiny package 1.7.4. Statistical significance was defined as a p-value < 0.05.

Results
Clinical characteristics
Among 530 patients undergoing VATS lobectomy, 332 cases (62.64%) were aged over 60 years. The incidence of intraoperative hypothermia was 65.28% (346/530). The incidence of delayed recovery from anesthesia was 10.38% (55/530). The incidence of postoperative shivering was 37.36% (198/530). The incidence of postoperative shivering in the two comparative groups were 38.21% (162/424) and 33.96% (36/106), respectively. No statistically significant differences were observed in epidemiological characteristics or the incidence of postoperative shivering between the two groups, with all P values exceeding 0.05. Detailed demographic and baseline characteristics are presented in Table 1.

Baseline data were compared between the two groups in the training set
Univariate analysis showed that eight variables including age, intraoperative hypothermia, delayed recovery from anesthesia, type of operation, postoperative analgesia, anesthesia duration, operation duration and preoperative temperature were significantly different between the postoperative shivering group and the non- postoperative shivering group, and the difference was statistically significant ($P < 0.05$). More information is shown in Table 2.

LASSO regression achieves variable screening
From 8 univariate-significant variables, LASSO regression (10-fold cross-validation) identified 6 meaningful predictors: age, intraoperative hypothermia, delayed recovery from anesthesia, postoperative analgesia, operation duration and preoperative temperature (Fig. 2A-C).

Characteristic	Cohort		p-value[b]
	Training cohort (n = 424)[a]	Internal test cohort (n = 106)[a]	
Gender			> 0.999
Male	232 (54.7%)	58 (54.7%)	
Female	192 (45.3%)	48 (45.3%)	
Age			0.445
< 60 years	155 (36.6%)	43 (40.6%)	
≥ 60 years	269 (63.4%)	63 (59.4%)	
Body mass index			0.343
<18.5 kg/m^2	40 (9.4%)	14 (13.2%)	
18.5–23.9 kg/m^2	222 (52.4%)	59 (55.7%)	
24.0–28.0 kg/m^2	130 (30.7%)	24 (22.6%)	
> 28.0 kg/m^2	32 (7.5%)	9 (8.5%)	
Body surface area			0.687
< 1.5 m^2	181 (42.7%)	47 (44.3%)	
1.5-2.0 m^2	158 (37.3%)	35 (33.0%)	
> 2.0 m^2	85 (20.0%)	24 (22.6%)	
Diagnosed with diabetes			0.329
No	364 (85.8%)	87 (82.1%)	
Yes	60 (14.2%)	19 (17.9%)	
Past surgical history			0.090
No	201 (47.4%)	60 (56.6%)	
Yes	223 (52.6%)	46 (43.4%)	
ASA			0.483
I	12 (2.8%)	5 (4.7%)	
II	286 (67.5%)	73 (68.9%)	
III	126 (29.7%)	28 (26.4%)	
Surgical spot			0.729
Superior lobe of left lung	110 (25.9%)	32 (30.2%)	
Inferior lobe of left lung	85 (20.0%)	20 (18.9%)	
Superior lobe of right lung	129 (30.4%)	35 (33.0%)	
Middle lobe of right lung	18 (4.2%)	4 (3.8%)	
Inferior lobe of right lung	82 (19.3%)	15 (14.2%)	
Intraoperative hypothermia			0.931
No	194 (45.8%)	48 (45.3%)	
Yes	230 (54.2%)	58 (54.7%)	
Delayed recovery from anesthesia			0.075
No	375 (88.4%)	100 (94.3%)	
Yes	49 (11.6%)	6 (5.7%)	
Type of operation			0.728
Non-multidisciplinary treatment	216 (50.9%)	56 (52.8%)	
Multi-disciplinary treatment	208 (49.1%)	50 (47.2%)	
Postoperative analgesia			0.339
No	210 (49.5%)	47 (44.3%)	
Yes	214 (50.5%)	59 (55.7%)	
Anesthesia duration			0.510
≤ 180 min	80 (18.9%)	23 (21.7%)	
>180 min	344 (81.1%)	83 (78.3%)	
Operation duration			0.709
≤ 180 min	288 (67.9%)	74 (69.8%)	
>180 min	136 (32.1%)	32 (30.2%)	
Preoperative temperature			0.587
Continued			

Characteristic	Cohort		*p*-value[b]
	Training cohort (*n* = 424)[a]	Internal test cohort (*n* = 106)[a]	
Mean ± SD	36.48 ± 0.15	36.47 ± 0.14	
Indoor temperature			0.589
Mean ± SD	23.09 ± 0.68	23.13 ± 0.71	

Table 1. Patient demographics and baseline characteristics. Note: [a]n (%); [b]Pearson's Chi-squared test; Fisher's exact test; Welch Two Sample t-test.

Development of risk prediction model and nomograph

The occurrence of postoperative shivering was used as the dependent variable (non- postoperative shivering group = 0, postoperative shivering group = 1), we incorporated 6 variables selected by LASSO regression into the logistic regression analysis. Table 3 presents the assignment of independent variables. The logistic regression analysis identified age, intraoperative hypothermia, delayed recovery from anesthesia, postoperative analgesia, operation duration and preoperative temperature as significant risk factors for postoperative shivering in patients undergoing VATS lobectomy ($P < 0.05$). Supplementary outcomes are detailed in Table 4, with the derived nomograph in Fig. 3.

Validation of risk prediction model for postoperative shivering

1. Discrimination of the risk prediction model.

For internal validation of the nomograph, we employed the bootstrap resampling technique with 1,000 iterations. The model's discriminatory capacity was assessed via ROC analysis, yielding an AUC of 0.847 (95% CI: 0.809–0.885) for the training set and 0.836 (95% CI: 0.747–0.925) for the validation set (Fig. 4). These results confirm robust discriminative performance. Furthermore, Fig. 5 illustrates the predictive efficacy of a single indicator for postoperative shivering risk in patients undergoing VATS lobectomy.

2. Calibration of the risk prediction model.

Model calibration was assessed through calibration curves and the Hosmer-Lemeshow goodness-of-fit test. The calibration curve demonstrated close alignment between predicted probabilities and observed outcomes across risk strata (Fig. 6), indicating robust reliability of the risk estimates. This finding was further substantiated by the Hosmer-Lemeshow test (χ^2=13.123, $P = 0.108$), which confirmed no significant deviation from perfect calibration.

3. Clinical utility of the risk prediction model.

The clinical utility of the risk prediction model was evaluated by DCA curve. DCA curve evaluates the clinical utility of predictive models by calculating the net benefit for patients when the risk threshold for postoperative shivering is reached. As illustrated in Fig. 7 (training set) and Fig. 8 (internal validation set), the DCA curves plot net benefit (y-axis) against threshold probabilities (x-axis). The model demonstrated sustained clinical value across threshold probabilities of 0.20–0.98 in the training set, where net benefit consistently exceeded zero. This indicates robust clinical utility for guiding intervention decisions within this risk spectrum.

Development of a visualization tool

To enhance clinical translation of the prediction model, we deployed an interactive web application that generates individualized postoperative shivering risk stratification upon input of six variables. Parameters of a representative patient (e.g., age: 65 years, intraoperative hypothermia: yes, delayed recovery from anesthesia: yes, postoperative analgesia: yes, operation duration: 200 min, preoperative temperature: 36.5 ℃) were input into the model. The model predicts an 77.50% risk of postoperative shivering for this patient, indicating high-risk stratification (Fig. 9A). For another patient with preoperative parameters (age: 48 years, intraoperative hypothermia: no, delayed recovery from anesthesia: no, postoperative analgesia: yes, operation duration: 120 min, preoperative temperature: 36.0 ℃), the model predicts a low-risk probability of 16.42% (Fig. 9B). The online visualization tool is accessible at: https://shivering.shinyapps.io/dynnomapp/.

Discussion

This study constructs the first prediction model and visualization tool for postoperative shivering in patients undergoing VATS lobectomy, which fills the gap of individualized prediction tools and helps to identify high-risk patients for precise intervention.

This study found that the incidence of postoperative shivering in 530 patients undergoing VATS lobectomy was 37.36%, which was consistent with the incidence range of general anesthesia patients reported previously (20%-70%)[2], but lower than the incidence of 55% after cesarean section under intraspinal anesthesia[21]. This difference may be related to the anesthesia method, patient characteristics and postoperative analgesia. First, the patients in this study all received general anesthesia, and the degree of inhibition of the thermoregulatory center by general anesthesia drugs and the influence of different anesthesia maintenance drugs on the occurrence of

Characteristics	Training Cohort		
	Non-postoperative shivering (*n* = 262)[a]	Postoperative shivering (*n* = 162)[a]	*p*-value[b]
Gender			0.381
Male	139 (53%)	93 (57%)	
Female	123 (47%)	69 (43%)	
Age			< 0.001
< 60 years	80 (31%)	75 (46%)	
≥ 60 years	182 (69%)	87 (54%)	
Body mass index			0.366
< 18.5 kg/m^2	29 (11%)	11 (7%)	
18.5–23.9 kg/m^2	132 (50%)	90 (56%)	
24.0–28.0 kg/m^2	79 (30%)	51 (31%)	
> 28.0 kg/m^2	22 (8%)	10 (6%)	
Body surface area			0.454
<1.5 m^2	118 (45%)	63 (39%)	
1.5-2.0 m^2	93 (35%)	65 (40%)	
>2.0 m^2	51 (19%)	34 (21%)	
Diagnosed with diabetes			0.581
No	223 (85%)	141 (87%)	
Yes	39 (15%)	21 (13%)	
Past surgical history			0.119
No	132 (50%)	69 (43%)	
Yes	130 (50%)	93 (57%)	
ASA			0.124
I	9 (3%)	3 (2%)	
II	184 (70%)	102 (63%)	
III	69 (26%)	57 (35%)	
Surgical spot			0.753
Superior lobe of left lung	74 (28%)	36 (22%)	
Inferior lobe of left lung	51 (19%)	34 (21%)	
Superior lobe of right lung	77 (29%)	52 (32%)	
Middle lobe of right lung	11 (4%)	7 (4%)	
Inferior lobe of right lung	49 (19%)	33 (20%)	
Intraoperative hypothermia			< 0.001
No	139 (53%)	55 (34%)	
Yes	123 (47%)	107 (66%)	
Delayed recovery from anesthesia			< 0.001
No	250 (95%)	125 (77%)	
Yes	12 (5%)	37 (23%)	
Type of operation			< 0.001
Non-multidisciplinary treatment	150 (57%)	66 (41%)	
Multi-disciplinary treatment	112 (43%)	96 (59%)	
Postoperative analgesia			< 0.001
No	82 (31%)	128 (79%)	
Yes	180 (69%)	34 (21%)	
Anesthesia duration			0.003
≤ 180 min	61 (23%)	19 (12%)	
>180 min	201 (77%)	143 (88%)	
Operation duration			< 0.001
≤ 180 min	206 (79%)	82 (51%)	
Continued			

Characteristics	Training Cohort		
	Non-postoperative shivering ($n=262$)[a]	Postoperative shivering ($n=162$)[a]	p-value[b]
>180 min	56 (21%)	80 (49%)	
Preoperative temperature			0.027
Mean ± SD	36.49 ± 0.15	36.46 ± 0.16	
Indoor temperature			0.361
Mean ± SD	23.11 ± 0.68	23.05 ± 0.68	

Table 2. Comparison of two groups of baseline data in the training set. Note: [a]n (%); [b]Pearson's Chi-squared test; Fisher's exact test; Welch Two Sample t-test.

shivering may be different from that of intraspinal anesthesia[22]. Second, most patients undergoing cesarean section are young women, and the operation itself involves abdominal organs and sympathetic nerve stimulation, which may be more likely to trigger strong stress response and shivering. However, the subjects of this study were mainly middle-aged and elderly patients (median age 63.00 years), and the surgery was a chest operation. These differences may affect the incidence of shivering[4]. In addition, differences in postoperative analgesia regimens may also have an effect. In this study, 51.51% of patients took postoperative analgesia, and adequate postoperative analgesia can effectively reduce pain, an important trigger of non-temperature shivering[23].

The results of this study showed a relatively low incidence of postoperative shivering in patients aged 60 years or older undergoing VATS lobectomy, consistent with most studies[3,5,24]. One possible reason is that the decrease of basal metabolic rate in elderly patients slows body temperature reduction. The decline of central sensitivity in thermoregulation increases the physiological response threshold to hypothermia[3]. Reduction in muscle function and decline in nerve-conduction efficiency further limit high-intensity shivering responses. However, some studies suggest elderly patients have higher shivering risk[25], possibly due to confounding factors: because of fragile cardiopulmonary function, they often receive stricter temperature protection measures, which may artificially reduce shivering incidence.

The usability of maintaining core temperature during surgery for preventing postoperative shivering has been widely known[10]. The results of this study indicate that postoperative shivering occurrence is primarily influenced by both intraoperative hypothermia and preoperative temperature. Intraoperative hypothermia can lead to postoperative shivering, while preoperative warming measures to maintain normal preoperative temperature can prevent the occurrence of shivering. A possible explanation is that shivering represents a physiological response to maintain warmth through peripheral vasoconstriction induced by hypothermia, explaining the close temperature-shivering relationship[10]. During surgery, core temperature passively decreases due to anesthesia and environmental exposure. Upon recovery of hypothalamic thermoregulatory function postoperatively, the center still detects hypothermia, thus activating shivering as an innate compensatory mechanism to elevate body temperature. Higher preoperative temperature enhances hypothalamic regulatory sensitivity and raises the shivering trigger threshold. When combined with pre-insulation measures, this approach increases peripheral heat retention, counteracts redistributive hypothermia, and significantly reduces shivering risk[26].

The results of this study showed that extended operation duration correlated with higher postoperative shivering incidence in patients undergoing VATS lobectomy, consistent with prior research[27]. Evidence confirms significantly increased hypothermia risk in procedures exceeding 180 min; furthermore, shivering-related complications (e.g., elevated oxygen consumption and myocardial ischemia risk) rise progressively with each additional operative hour[27]. Consequently, optimizing surgical efficiency, implementing pre-warming measures, and shortening anesthesia duration constitute essential strategies for reducing postoperative shivering and hypothermia.

This study revealed that delayed recovery from anesthesia in patients undergoing VATS lobectomy was associated with an increased risk of postoperative shivering, consistent with previous findings[28]. This may be attributed to delayed metabolism and clearance of anesthetics during prolonged emergence, which not only suppresses central nervous system arousal but also impairs hypothalamic thermoregulatory function, thereby reducing the body's capacity to regulate core temperature fluctuations[29]. Furthermore, unstable neurological recovery, increased muscle tone with uncoordinated contractions, and potential postoperative pain stimuli collectively trigger shivering responses during this period[27].

The results of this study showed that postoperative analgesic measures can reduce the incidence of shivering in patients undergoing VATS lobectomy, which is in line with the conclusions of a previous study on pain stimulation and postoperative shivering[16]. The reason may be that effective postoperative analgesia can significantly reduce or eliminate the sympathetic nerve response activated by surgical trauma and reduce the release of stress hormones such as norepinephrine, thereby weakening the muscle shivering and shivering response induced by pain[30]. Therefore, the implementation of timely and effective multimodal analgesia strategy after VATS lobectomy has important clinical significance for the prevention and control of postoperative shivering.

Through model evaluation and validation, the postoperative shivering risk prediction model developed in this study for VATS lobectomy patients demonstrated favorable calibration, discrimination, and clinical utility, providing a basis for accurately identifying high-risk individuals and enabling earlier targeted interventions. To further enhance model accessibility and practicality, an online visualization tool was developed, significantly improving the efficiency of clinical implementation.

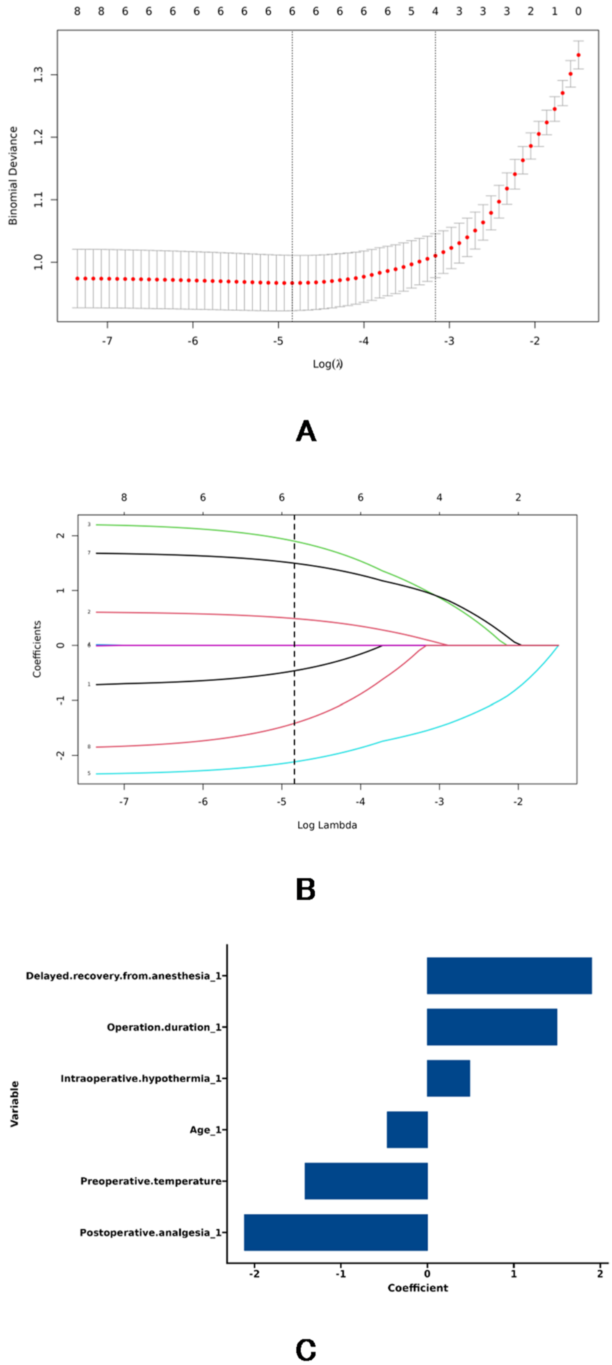

Fig. 2. **A** Lasso regression cross-validation plot. **B** Lasso regression coefficient path plot. **C** Lasso regression coefficient plot.

Variables	Independent variables assignments
Age	0 = "Age <60 years"; 1 = "Age ≥ 60 years"
Intraoperative hypothermia	0 = "No"; 1 = "Yes"
Delayed recovery from anesthesia	0 = "No"; 1 = "Yes"
Postoperative analgesia	0 = "No"; 1 = "Yes"
Operation duration	0 = "≤180 min"; 1 = ">180 min"
Preoperative temperature	Raw data entry

Table 3. Independent variables assignments.

Variables	β	Standard error	Waldc^2	OR	95% CI	*P*
Age	-0.730	0.297	6.055	0.48	0.27 ~ 0.86	0.014
Intraoperative hypothermia	0.614	0.261	5.549	1.85	1.11 ~ 3.08	0.018
Delayed recovery from anesthesia	2.228	0.427	27.254	9.28	4.02 ~ 21.43	< 0.001
Postoperative analgesia	-2.358	0.290	66.124	0.09	0.05 ~ 0.17	< 0.001
Operation duration	1.696	0.287	35.012	5.45	3.11 ~ 9.56	< 0.001
Preoperative temperature	-1.890	0.827	5.222	0.15	0.03 ~ 0.76	0.022
Constant	68.780	30.180	5.194	-	-	0.023

Table 4. Logistic regression analysis of postoperative shivering in patients undergoing VATS lobectomy.

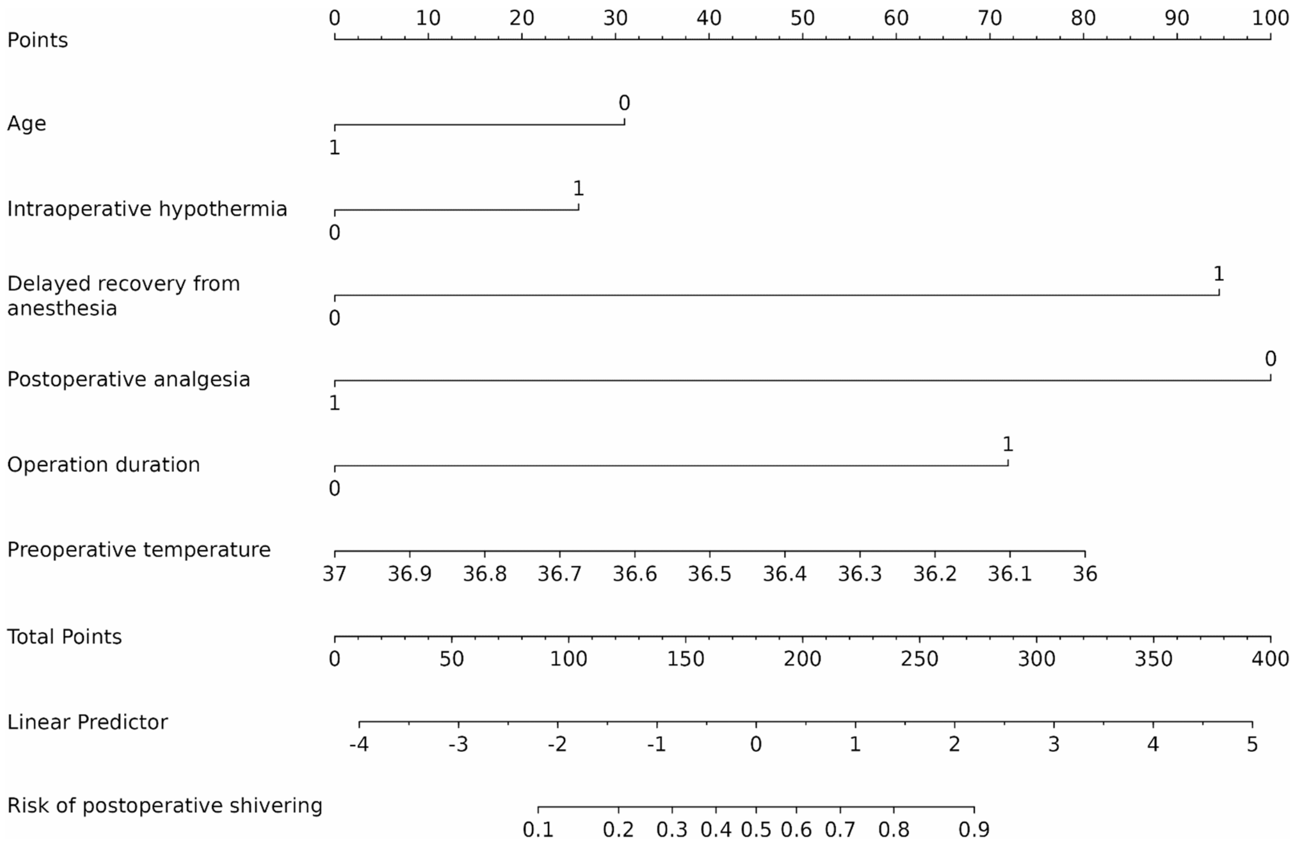

Fig. 3. A nomograph model of postoperative shivering.

Based on the results of this study, the following clinical implications are proposed for managing postoperative shivering in patients undergoing VATS lobectomy. The primary focus of this model lies in risk assessment during the immediate postoperative period (in the PACU), where early risk stratification enables timely and targeted interventions. This approach aligns with the core principles of perioperative hypothermia management[31]. The clinical utility of the model can be summarized in the following two aspects. According to the nomogram-based risk prediction model, patients can be categorized into three distinct risk levels for postoperative shivering: low, medium, and high. Targeted interventions are initiated promptly upon patient awakening. For low-risk patients, passive insulation measures are implemented. Temperature monitoring involves body temperature being monitored immediately after admission to the recovery room, then every 30 min, and reconfirmed before leaving the room. Environmental control requires maintaining room temperature at or above 23 °C. Interventional measures provide passive insulation using materials such as cotton blankets and reflective warming blankets. For medium-risk patients, a composite insulation strategy is applied. The core intervention includes, in addition to passive insulation, introducing active warming modalities such as intravenous fluid warming systems, forced-air warming (FAW) devices, and conductive warming fans. For high-risk patients, a combination of the composite insulation strategy and pharmacological support is used. The preferred intervention utilizes FAW

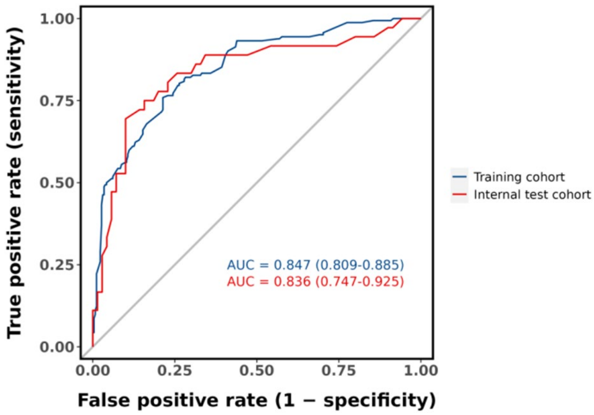

Fig. 4. ROC curves of the training and validation sets.

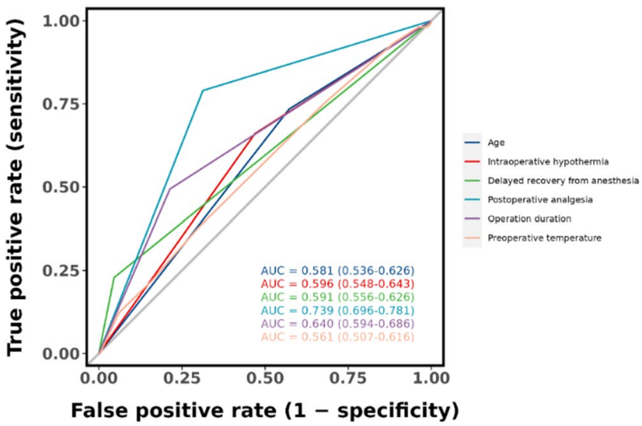

Fig. 5. Predictive efficacy of a single indicator for postoperative shivering.

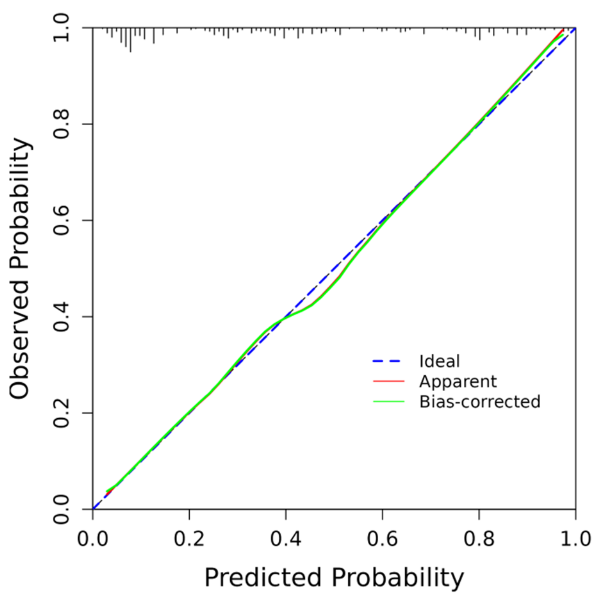

Fig. 6. Calibration curve of the nomograph prediction mode for the training set.

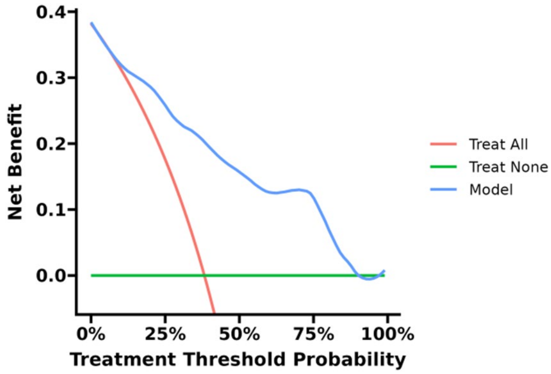

Fig. 7. DCA of the nomograph of the training set.

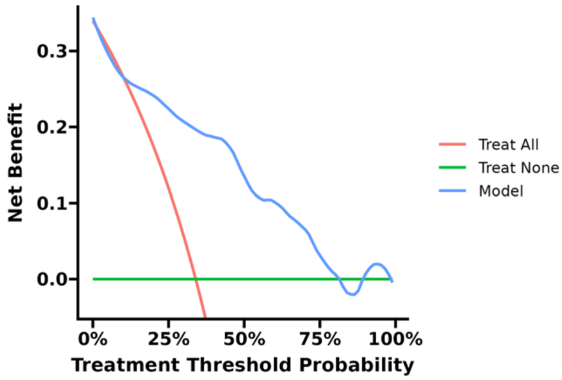

Fig. 8. DCA of the nomograph of the internal validation set.

devices for enhanced insulation. Pharmacological support involves administering medications such as tramadol, magnesium sulfate, or dexmedetomidine if shivering persists despite non-pharmacological interventions[32]. Furthermore, the risk stratification framework can be extended throughout the 24-hour postoperative recovery period, encompassing transitions across the general ward, and intensive care unit (ICU). During patient transfer, high-risk individuals should continue to receive warming support via portable thermal devices, such as inflatable warming blankets. In the ward or ICU phase, the frequency of temperature monitoring and intensity of warming interventions should be adjusted according to the initial risk classification assigned in the PACU. For example, high-risk patients may require prolonged active warming and ongoing evaluation for potential pharmacological treatment.

This study has the following limitations. First, the participants were from a single medical center, which increases the possibility of selection bias. Second, although the model was validated internally, it was not validated in an external, independent cohort (e.g., centers with different geographic regions or standard of practice) or in prospective data. The performance of this prediction model in other environments still needs to be evaluated. Third, the relationship between age and postoperative shivering needs to be further explored. Fourth, the relationship between postoperative analgesia and postoperative shivering needs to be further verified before promotion. In the future, it needs to be further improved by prospective multicenter cohort validation, including dynamic monitoring data and including anesthetic drug factors. Nevertheless, this study still provides an important tool basis for the precise prevention and control of shivering after VATS, and the model has significant clinical translation value.

Conclusion

This study established the first risk prediction model for postoperative shivering in patients undergoing VATS lobectomy, integrating six perioperative variables into a clinically applicable nomograph and online tool. The model facilitates early identification of high-risk patients, enabling targeted interventions to mitigate shivering-related complications.

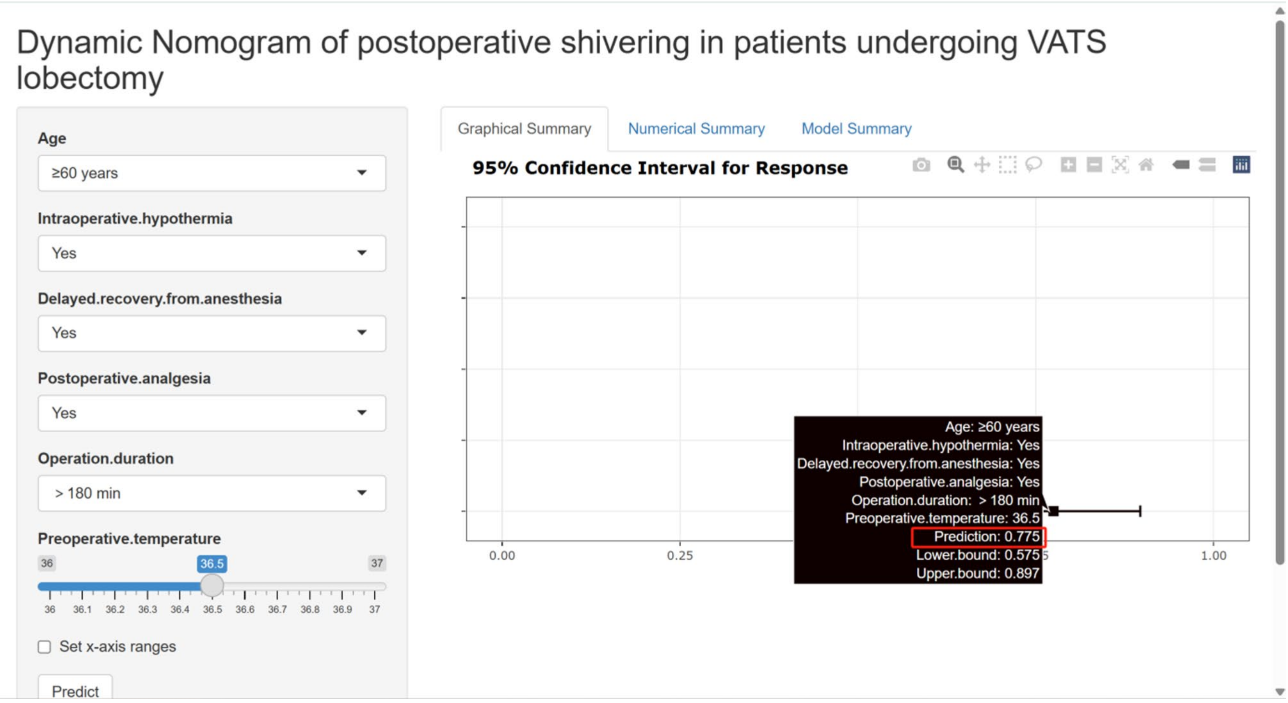

Fig. 9. **A** Visualization tool for risk prediction of postoperative shivering in patients undergoing VATS lobectomy (High-risk outcome). **B** Visualization tool for risk prediction of postoperative shivering in patients undergoing VATS lobectomy (low-risk outcome).

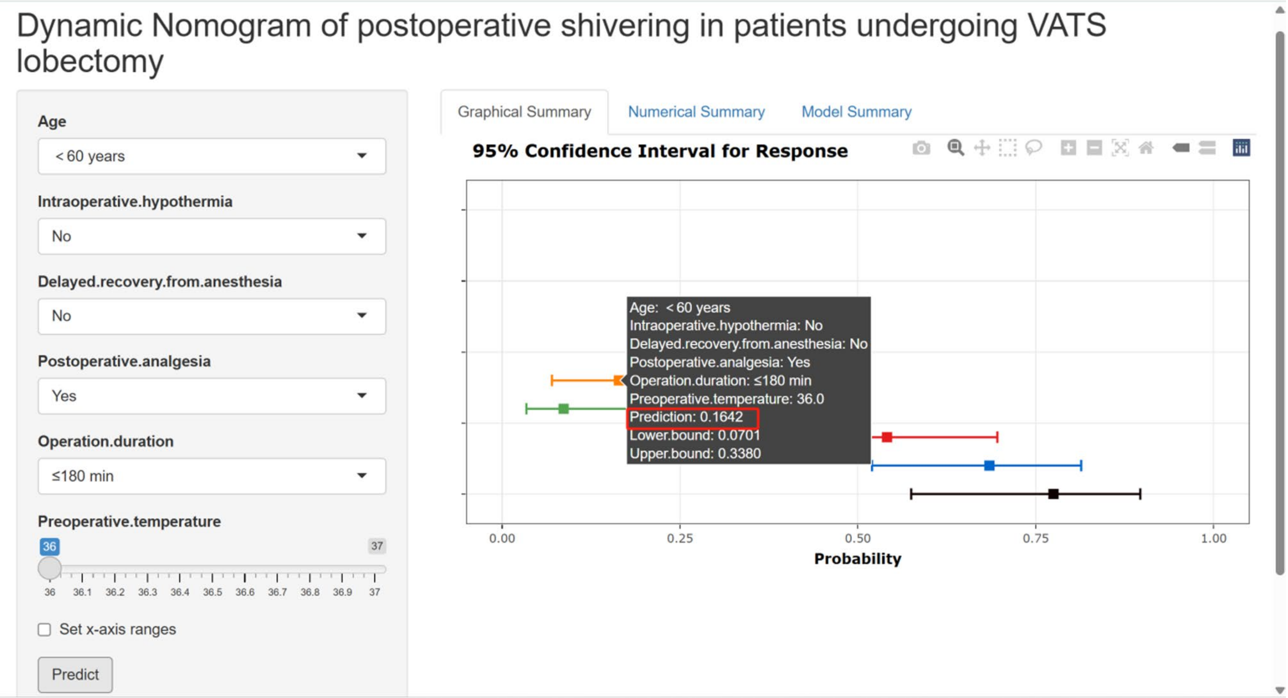

Fig. 9. (continued)

Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

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Author contributions

XFH and LQ conceived study, participated in design and coordination, read and approved the final manuscript. LJ, CR and ZJ read and approved the final manuscript. CZN, YQ, HJ, LJS and LG participated in data collection and data analysi.

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Competing interests

The authors declare no competing interests.

Additional information

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