Am J Transl Res 2025;17(9):7344-7355
www.ajtr.org /ISSN:1943-8141/AJTR0167182

Original Article

Development and validation of a postoperative hypothermia risk model for minimally invasive transurethral surgery under general anesthesia

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Received July 2, 2025; Accepted September 10, 2025; Epub September 15, 2025; Published September 30, 2025

Abstract: Objective: To develop a risk prediction model for postoperative hypothermia in patients undergoing minimally invasive transurethral surgery under general anesthesia. Methods: This retrospective study collected data from hospital electronic medical records. The construction cohort included 1039 cases, and the validation cohort included 200 patients. Baseline characteristics and possibly significant preoperative and intraoperative factors were collected. Variables were selected using LASSO regression, followed by univariate and multivariate logistic regression to identify independent risk factors for postoperative hypothermia. A forest plot was created, and a predictive model was developed. Model performance was evaluated using the area under the receiver operating characteristic curve (AUC) and the Hosmer-Lemeshow test. Results: Seven predictors were identified: age, BMI, glucocorticoid use, anesthesia medications (non-depolarizing muscarinics), bleeding > 50 ml, ASA classification, and use of intraoperative thermal blankets. In the construction cohort, AUC was 0.829 (95% CI 0.793-0.866; P < 0.001), with a sensitivity of 70.1%, specificity of 83.3%, and Youden's index of 0.541. The internal validation C-index was 0.85. In the external validation, AUC was 0.799 (95% CI 0.735-0.863; P < 0.001), with sensitivity of 72.4%, specificity of 73.9%, and Youden's index of 0.558. All Hosmer-Lemeshow tests showed P > 0.05. Conclusion: The postoperative hypothermia risk prediction model for minimally invasive transurethral surgery demonstrated excellent discrimination and calibration by both internal and external validations, providing clinical value. It may aid clinicians in early identification of high-risk patients for personalized temperature management.

Keywords: Urology, minimally invasive transurethral surgery, hypothermia, prediction model, external validation

Introduction

With advancements in minimally invasive techniques and medical equipment, minimally invasive transurethral surgery has become a safer and more advanced treatment option [1]. Common urologic procedures, such as transurethral prostate electrocision, ureteroscopic lithotripsy for stone extraction, and percutaneous nephrolithotripsy for laser lithotripsy [2], can be performed without open incisions or with smaller puncture apertures. Compared to traditional open surgery, these procedures offer advantages such as reduced trauma, less postoperative pain, and quicker recovery [3], significantly enhancing the patient's surgical experience and postoperative quality of life [4]. However, the heat redistribution between the core body and peripheral tissues during surgery, along with the inhibitory effects of anesthetics on the thermoregulatory center [5], commonly leads to postoperative hypothermia. Defined as a core body temperature below 36°C after surgery for non-medical reasons, postoperative hypothermia is often not monitored routinely in anesthesia, though it is common in high-risk surgeries like cardiac procedures and organ transplants [6]. Studies have shown that the incidence of postoperative hypothermia in minimally invasive urologic surgery ranges from 20%-50%, with thermoprotection efforts in fewer than 10% of cases, resulting in an overall incidence of hypothermia as high as 60% in recovery rooms [7, 8]. As preci-

https://doi.org/10.62347/TQDB1754

sion and personalized medicine gain ground, more attention is being paid to this issue, prompting increasing research into surgery-related hypothermia.

Postoperative hypothermia has been shown to worsen functioning of several physiological systems [9], with even mild hypothermia worsening patient outcomes by increasing the risk of complications such as urinary tract infections, coagulation disorders, and delayed anesthetic recovery [10, 11]. Addressing postoperative hypothermia aligns with the principles of ERAS (Enhanced Recovery After Surgery), which aims to promote faster recovery, improve therapeutic outcome, and enhance patient comfort [12, 13]. Although previous studies have identified risk factors for postoperative hypothermia, there has been insufficient development and validation of risk prediction models specifically for patients undergoing minimally invasive transurethral surgery under general anesthesia. Existing models often generalize across diverse patient groups and surgical procedures, lacking the ability to provide tailored prediction for specific surgical populations. Therefore, there is an urgent need for an accurate and reliable postoperative hypothermia risk prediction model to assist clinicians in preoperative assessments and help develop individualized postoperative management plans [14, 15].

Therefore, this study aims to develop a postoperative hypothermia risk prediction model for patients undergoing transurethral minimally invasive surgery under general anesthesia, utilizing clinical data. We also seek to perform external validation and create a web-based online tool for risk assessment, enabling early identification of high-risk patients, facilitating early intervention, and minimizing the incidence of postoperative hypothermia and related complications.

Materials and methods

Patient selection

This retrospective study used a consecutive enrollment design. The development cohort comprised 1,039 patients who underwent minimally invasive transurethral surgery at in Jinhua Municipal Central Hospital Zhejiang Province between January 1, 2023, and April 4, 2024. The validation cohort included 200 patients who underwent the same procedure in Ruian People's Hospital Zhejiang Province from March to June 2024.

Inclusion criteria: (1) Age ≥ 18 years; (2) American Society of Anesthesiologists (ASA) physical status classification I-III (Class I: healthy patient, Class II: mild systemic disease, Class III: severe systemic disease); (3) Scheduled for transurethral minimally invasive urologic surgery under general anesthesia; (4) Baseline body temperature > 36°C.

Exclusion criteria: (1) History of severe allergy to general anesthesia; (2) Recent drug abuse; (3) Conversion from endoscopic to open surgery; (4) Cognitive or communication impairment preventing effective interaction (**Figure 1**).

The study was approved by the Ethics Committee of Jinhua Municipal Central Hospital (Approval No: 202410501).

Study design

The main anesthetic drugs used in the study were etomidate (0.2 mg/kg), sufentanil (2.0-5.0 μg/kg), cisatracurium (0.15 mg/kg) as a non-depolarizing muscle relaxant, succinylcholine (1.0-2.0 mg/kg) as a depolarizing muscle relaxant, propofol (0.1-0.5 mg/kg/min), remifentanil (0.1-0.2 μg/kg/min), and sevoflurane (0.5%-1.5%) for inhalational anesthesia. Intraoperative medications were adjusted to maintain heart rate and blood pressure within 20% of baseline values. Postoperatively, a self-controlled intravenous analgesic pump was used, containing 100 μg of sufentanil, 100 μg of dexmedetomidine, and 5 mg of tropisetron in 100 mL of saline. The operating room temperature was set at 22-24°C, and room-temperature intravenous fluids, warm blood products, and warm flushes were routinely used. A nasal temperature probe was used to monitor the patient's central temperature.

The primary outcome was the occurrence of postoperative hypothermia, identified based on core temperature readings from the patient monitor. If hypothermia was detected, the anesthesiologist initiated interventions, such as using fluid warmers and applying forced-air warming devices in the post-anesthesia care unit. Data were excluded if the temperature difference between consecutive measurements exceeded 0.5°C or if the recorded temperature was below 30°C. All patient data were anonymized and de-identified for the final analysis.

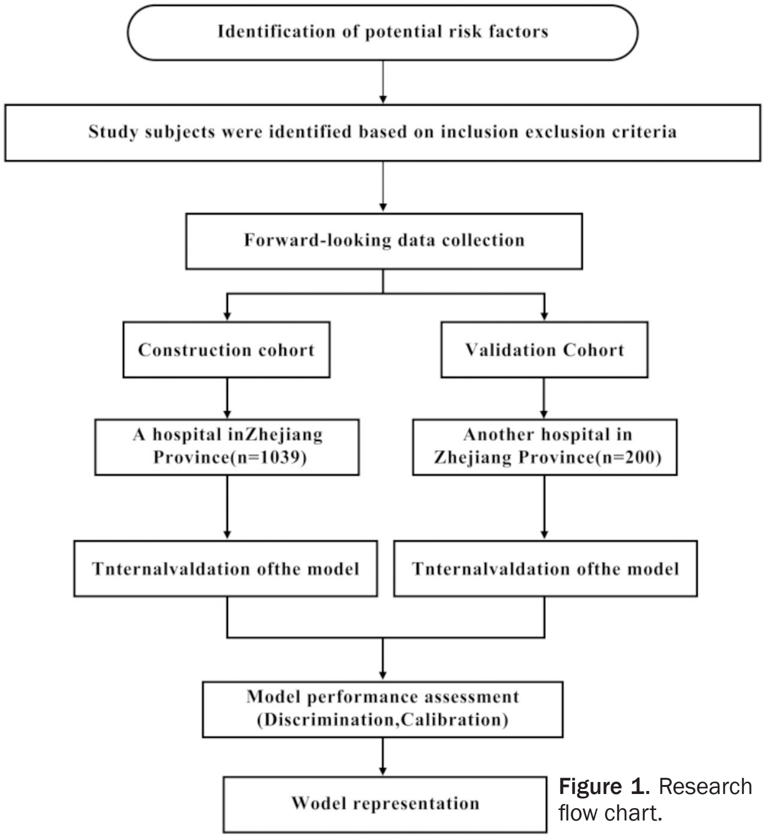

Figure 1. Research flow chart.

Data collection

A database of patients undergoing minimally invasive transurethral surgery was established using data from the Madison anesthesia system and the hospital's electronic medical record system. Patients were divided into two groups: the postoperative hypothermia group and the non-hypothermia group. Clinical data were systematically analyzed for constructing and validating the postoperative hypothermia risk prediction model.

A comprehensive literature search was conducted across multiple databases, including the China Biomedical Literature Service System, CNKI, Wanfang Database, VIP Chinese Database, Web of Science, PubMed, The Cochrane Library, and Embase. Relevant studies on hypothermia risk factors following minimally invasive urethral surgery were identified. Based on team discussions, 25 candidate risk factors for hypothermia were selected and categorized into three groups: ① General characteristics: gender, age, BMI, ASA classification; ② Preoperative factors: hypertension, diabetes, history of thyroid surgery, smoking history, and anxiety; ③ Intraoperative anesthesia and surgical variables: operation time, intraoperative glucocorticoids, blood loss, fluid infusion volume, anesthetic drugs, inhalation anesthesia use, analgesic pump application, preoperative hemoglobin, albumin, creatinine, blood urea nitrogen, thermal blanket use, irrigation volume, and history of stroke or urinary tract infection.

Statistical analysis

Statistical analysis was performed using R software version 4.4.0. Normally distributed data were presented as mean ± standard deviation, and intergroup comparisons were made using t-tests. Count data were presented as numbers (percentages), with chi-square tests used for comparisons. LASSO regression was applied to select the most relevant predictive factors, and univariate and multivariate logistic regression analyses identified influencing factors of hypothermia. A forest plot was generated, and a nomogram prediction model was constructed. The discriminative ability of the model was assessed using ROC curves, and the area under the curve (AUC) was calculated. A *p*-value < 0.05 was considered significant.

Results

Patient general characteristics

The baseline characteristics of both cohorts are presented in **Table 1**. The development cohort included 607 males and 432 females, with 427 patients aged > 60 years. The validation cohort comprised 119 males and 81 females, with 51 patients aged > 60 years.

Variable screening of the model

Influencing factors for postoperative hypothermia were identified using LASSO regression. The results showed that age, BMI, glucocorticoid use, anesthesia medications (non-depo-

Table 1. Baseline characteristics of the study population

Variable	Construction cohort (n = 1039)			Validation Cohort (n = 200)		
	Overall	No postoperative hypothermia occurred (n = 783)	Postoperative hypothermia occurred (n = 256)	Overall	No postoperative hypothermia occurred (n = 156)	Postoperative hypothermia occurred (n = 44)
Age						
> 60	428	309	119	51	30	21
≤ 60	611	474	137	149	126	23
Sex						
Male	607	476	131	104	80	24
Female	432	307	125	96	76	20
BMI						
> 18.5	762	614	148	173	142	31
≤ 18.5	277	169	108	27	14	13
Surgery time	69.72±23.69	65.52±21.95	82.39±30.06	59.29±22.84	57.08±21.85	78.96±27.55
Anesthesia time	70.38±25.47	66.93±23.7	91.28±31.77	65.62±25.08	61.54±24.06	87.88±29.43
Intraoperative irrigation volume (L)	8.5±0.9	8.2±0.8	8.5±0.9	8.4±0.8	8.5±0.7	8.4±0.8
Temperature of irrigation (°C)	37.0±0.1	37.0±0.1	37.0±0.1	37.0±0.1	37.0±0.1	37.0±0.1
Urinary tract infection						
Yes	69	60	9	69	42	27
No	970	723	247	131	114	17
High blood pressure						
Yes	264	185	79	45	38	7
No	775	598	177	155	118	37
Diabetes						
Yes	207	160	47	31	26	5
No	832	623	209	169	130	39
History of thyroid surgery						
Yes	364	248	116	23	21	2
No	675	535	140	177	135	42
History of stroke						
yes	56	44	12	10	6	4
No	983	739	244	190	150	40
Anxiety disorder						
yes	39	35	4	11	9	2
No	1000	748	252	189	147	42
Glucocorticoid use						
Yes	405	256	149	69	46	21
No	634	527	107	131	110	23

Intraoperative fluid volume						
< 500	373	277	96	72	59	13
501-1000	546	412	134	108	86	22
> 1000	120	94	26	20	11	9
Anesthesia drugs						
Depolarizing inotropes	613	491	122	95	55	40
Non-depolarizing muscarinic	426	292	134	105	101	4
Inhalation anesthetics						
Yes	714	522	192	143	122	21
No	325	261	64	46	34	12
Bleeding						
≥ 50	161	92	69	12	11	1
< 50	878	691	187	188	145	43
Analgesic pump						
Yes	277	214	63	35	25	10
No	762	569	193	165	131	34
Preoperative hemoglobin						
Normal	272	234	38	53	38	15
Low	577	414	163	131	107	24
High	190	135	55	16	11	5
Preoperative Albumin						
Normal	252	206	46	34	28	6
Low	685	503	182	86	58	28
High	102	74	28	80	70	10
Serum creatinine						
Normal	301	225	76	56	42	14
Below	581	431	150	114	89	25
below	157	127	30	30	25	5
Urea Nitrogen						
Normal	288	196	92	52	39	13
Below	642	516	126	133	104	29
Above	109	71	38	15	13	2
ASA Classification						
Grade 1	357	305	52	87	72	15
Grade 2	480	381	99	84	69	15
Grade 3	202	97	105	29	15	14
Insulation Blanket						
Yes	512	415	97	72	51	21
No	527	368	159	128	105	23

Table 2. Manner ofassigning values to the independent variables

Selected Predictors from LASSO Regression	
variable	coef
(Intercept)	-2.406
Age	0.562
BMI	0.550
Glucocorticoid use	0.611
Anesthesia medications	-0.052
Bleeding > 50 ml	0.964
ASA classification	0.471
Inoperative Thermal blankets	0.145

BMI: Body mass index; ASA: American Society of Anesthesiologists.

larizing muscarinics), bleeding > 50 mL, ASA classification, and the use of intraoperative thermal blankets were independent risk factors for postoperative hypothermia (**Tables 2**, **3**; **Figure 2**).

Establishment of nomogram prediction model

Significant risk factors (all $P < 0.05$) were used to construct a nomogram prediction model for postoperative hypothermia in patients undergoing minimally invasive transurethral surgery under general anesthesia. Based on multivariate binary logistic regression analysis, the identified factors included age, BMI, glucocorticoid use, non-depolarizing neuromuscular blockers, intraoperative blood loss > 50 mL, ASA classification, and the use of thermal blankets. Using R software and the rms package, a nomogram was developed to visualize the early risk prediction of postoperative hypothermia in this surgical context. In clinical practice, each independent risk factor is assigned a score, and by summing the scores and plotting a vertical line from the total score axis, the probability of postoperative hypothermia can be estimated (**Figure 3**).

Evaluation of model performance

In the development cohort, the AUC of the model (**Figure 4A**) was 0.829 (95% CI 0.793-0.866; $P < 0.001$), with a sensitivity of 70.1% and specificity of 83.3%. The Youden index was 0.541, corresponding to an optimal cutoff value of 0.409. Internal validation through bootstrap resampling (1,000 iterations) showed a C-index of 0.85. In the external validation cohort, the AUC (**Figure 4B**) was 0.799 (95% CI 0.735-0.863; $P < 0.001$), with a sensitivity of 72.4% and specificity of 73.9%. The Youden index was 0.558, corresponding to an optimal cutoff value of 0.427. These results suggest that the model performs well and exhibits good generalizability.

Verification of the nomogram prediction model

The calibration curve for the development cohort (**Figure 5A**) showed a Hosmer-Lemeshow chi-square test result of $\chi^2 = 8.10$, $P = 0.423$. The calibration curve for the validation cohort (**Figure 5B**) had a Hosmer-Lemeshow chi-square result of $\chi^2 = 6.07$, $P = 0.640$. Both calibration curves closely approximated the 45-degree diagonal line, indicating that the model's predictions closely align with actual outcomes, suggesting strong calibration performance.

Clinical applicability

Decision curve analysis (**Figure 6A**) indicated that, in the development cohort, the model offered good net benefit across a range of threshold probabilities for postoperative hypothermia. The DCA curve suggests that clinical decisions based on this model could be beneficial. The Clinical impact curve (**Figure 6B**) demonstrated that when the threshold probability exceeded 80%, the number of high-risk individuals identified by the model closely matched the actual number of postoperative hypothermia cases, indicating excellent clinical effectiveness.

Discussion

Due to social pressures and poor lifestyle habits (e.g., prolonged sedentary behavior, insufficient water intake, smoking), the age distribution of urological surgery patients has broadened [16]. Many urological disorders, traditionally prevalent in middle-aged and elderly populations, are increasingly affecting younger individuals, leading to a yearly rise in the proportion of young and middle-aged patients undergoing urological surgery [17]. In contrast, patients undergoing other types of surgery, such as thoracic surgery or osteoarthroplasty, are still predominantly elderly. This undersco-

Table 3. Multivariate analysis in the training set

Variable	Beta	SE	Wald X^2	OR (95% CI)	*P* value
(Intercept)	-1.997				
Age					
≤ 60				Reference	
> 60	1.075	0.208	26.79	2.93 (1.95-4.4)	< 0.001
BMI					
≤ 18.5				Reference	
> 18.5	-1.139	0.223	26.17	0.32 (0.21-0.5)	< 0.001
Glucocorticoid					
Unused				Reference	
Used	1.202	0.211	32.54	3.33 (2.2-5.03)	< 0.001
Anesthesia medications					
Non-depolarizing muscarinic				Reference	
depolarizing muscarinic	-0.630	0.217	8.4	0.53 (0.35-0.82)	0.004
Bleeding					
< 50				Reference	
≥ 50	1.566	0.276	32.15	4.79 (2.79-8.23)	< 0.001
ASA classificationGrade3					
Grade1				Reference	
Grade2	-0.065	0.252	0.07	0.94 (0.57-1.54)	0.798
Grade3	1.627	0.284	32.9	5.09 (2.92-8.88)	< 0.001
Thermal blankets					
No				Reference	
Yes	0.660	0.210	9.93	1.94 (1.28-2.92)	0.002

BMI: body mass index; ASA: American Society of Anesthesiologists.

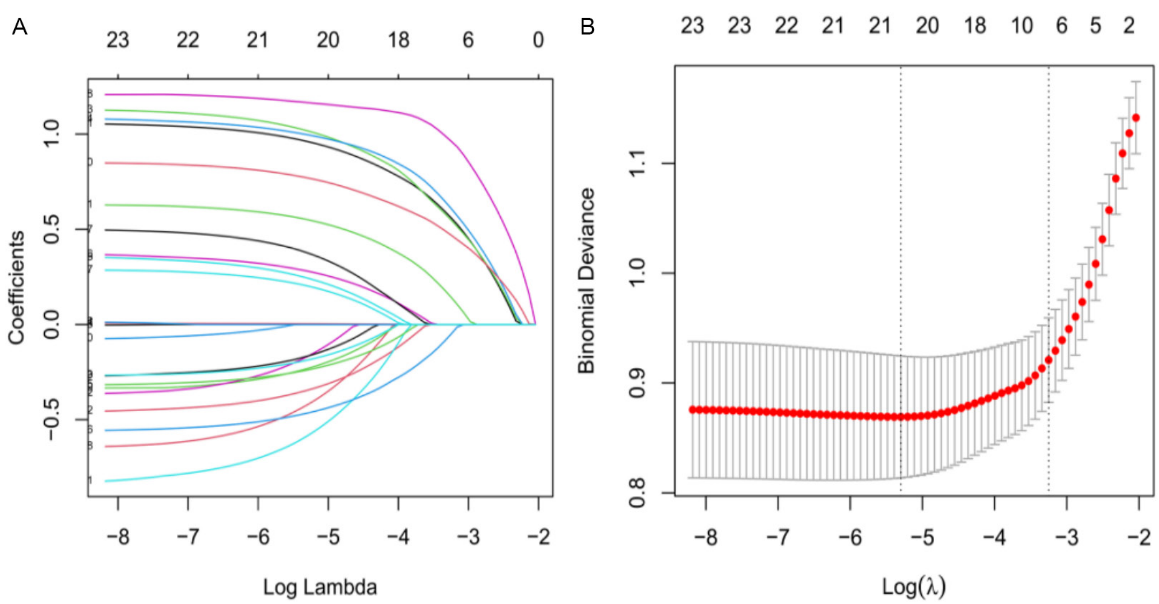

Figure 2. Cross-Validation Error Curve of LASSO Regression and Path Plot. A: Coefficient path diagram; B: Cross-validation error path diagram.

res the need for in-depth studies on the risk factors for postoperative hypothermia in the urologic surgery patient population. Even younger patients may face an increased risk of

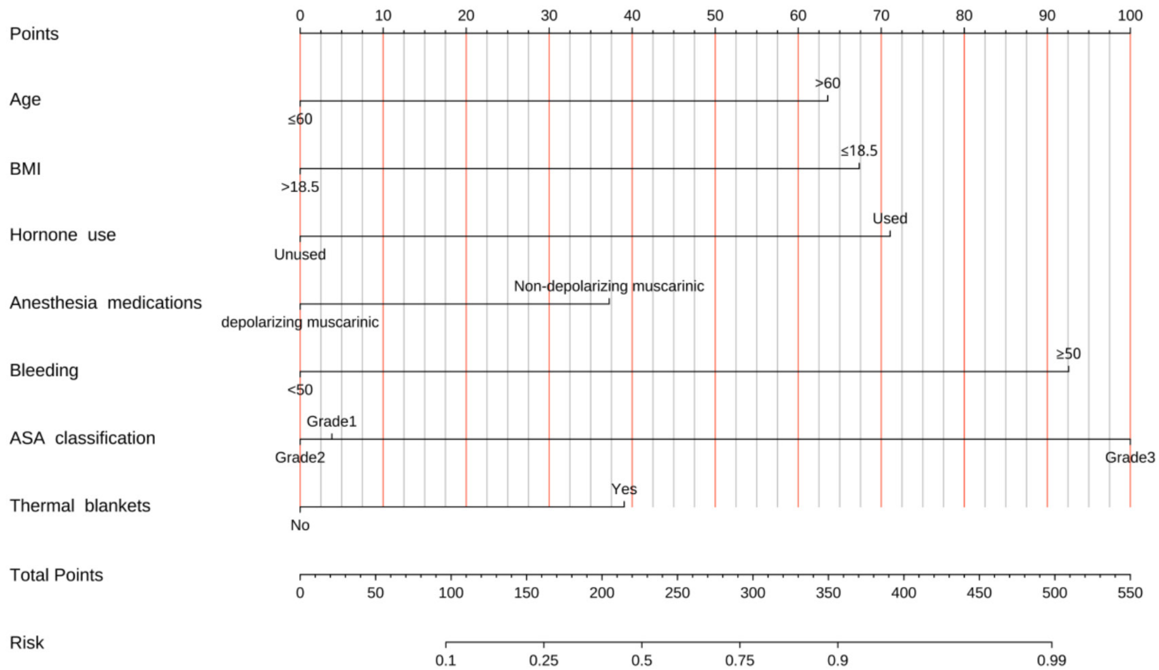

Figure 3. Nomogram of intraoperative hypothermia in patients undergoing minimally invasive transurethral surgery. BMI: body mass index; ASA: American Society of Anesthesiologists.

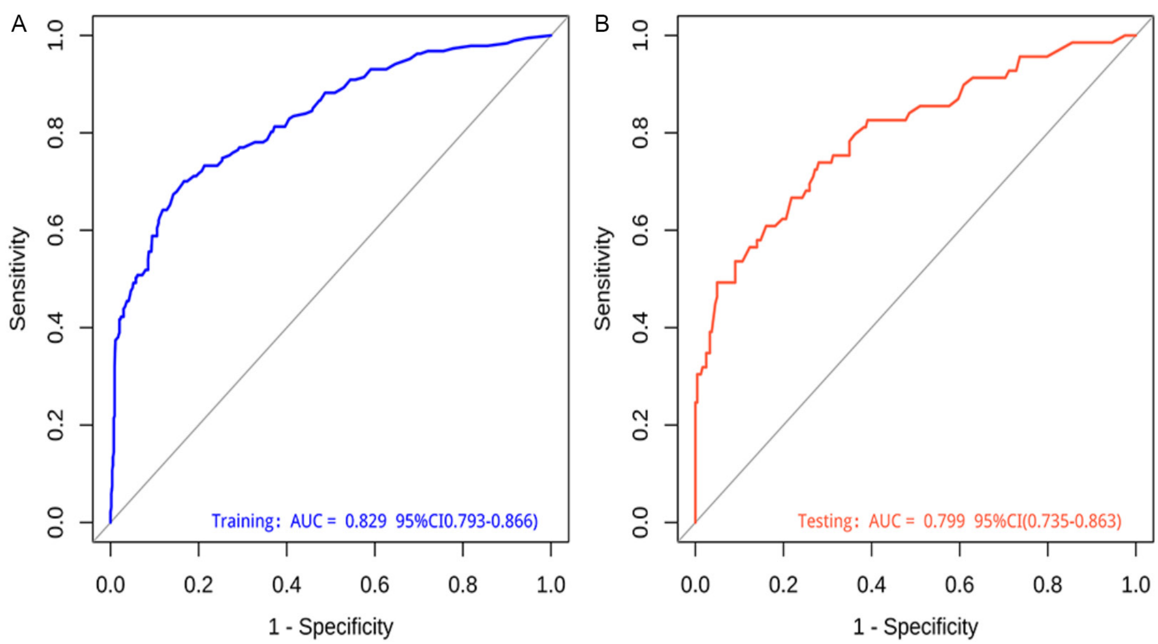

Figure 4. Diagnostic efficacy of the training set and validation set; A: Training set; B: Validation set. AUC: Area Under the Curve.

postoperative hypothermia due to prolonged anesthesia, drug use, and extensive intraoperative irrigation, all of which can disrupt temperature regulation [18, 19]. Given these factors, addressing postoperative hypothermia in patients undergoing minimally invasive transurethral surgery [20] and establishing a reliable predictive model for the condition is essential.

In addition to factors such as age > 60 years, low BMI, ASA classification grade II and above, and anesthesia medications (non-depolarizing

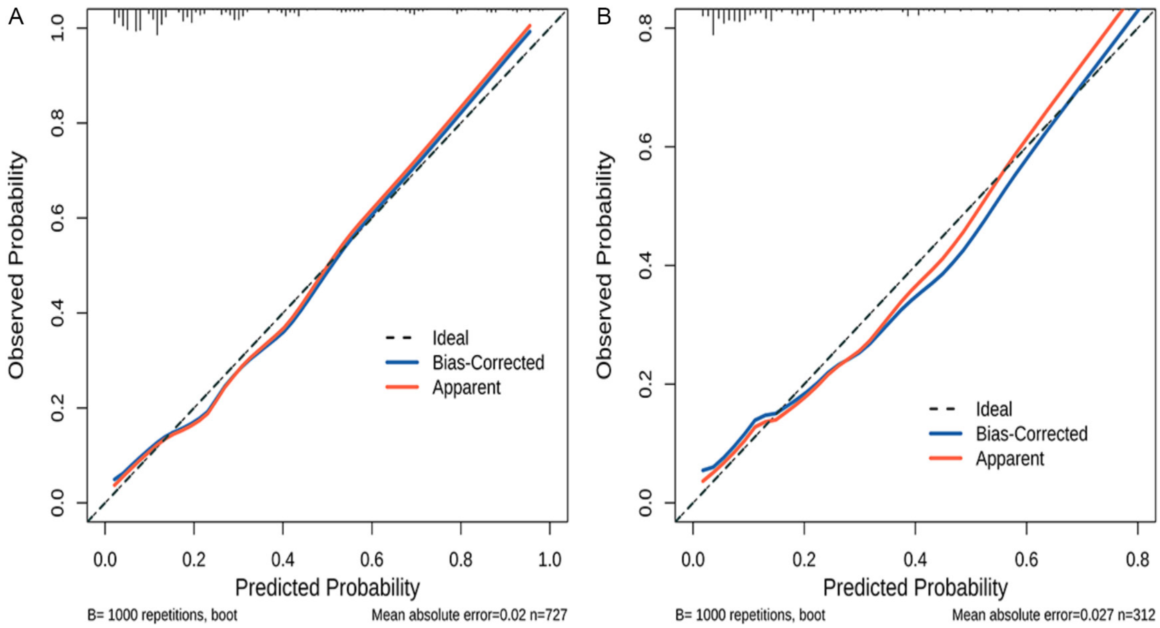

Figure 5. Calibration standards for training sets and validation sets; A: Training set; B: Validation set.

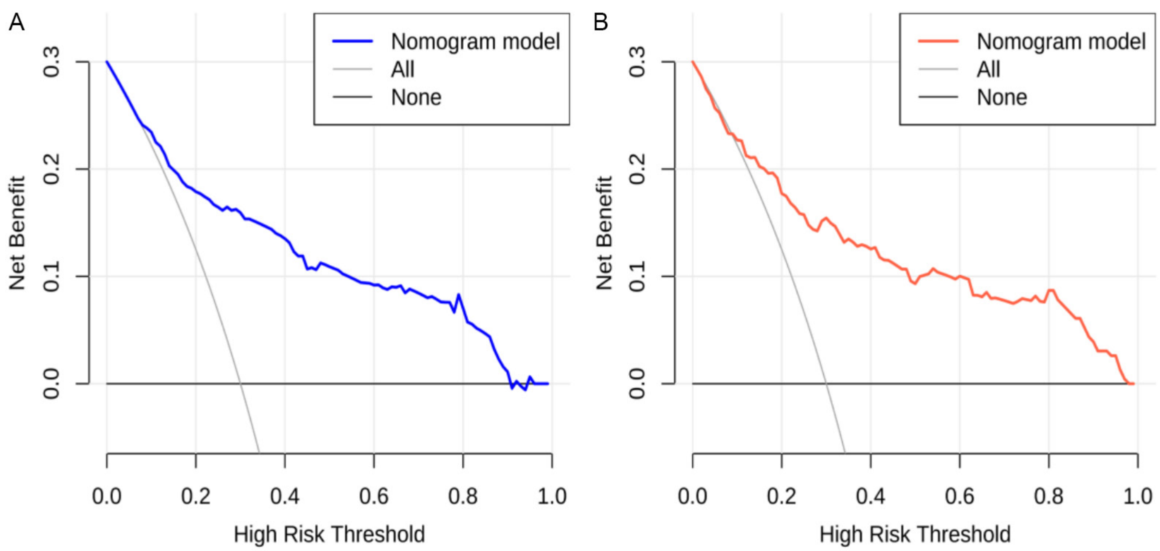

Figure 6. Calibration DCA diagrams of the training set and validation set; A: Training set; B: Validation set.

muscarinic agents), which have been identified in previous studies, advancing age is associated with a decline in the body's ability to regulate temperature. This reduced capacity leads to faster heat loss, making it more challenging to maintain body temperature. Furthermore, older adults often have a lower metabolic rate, limiting endogenous heat production and exacerbating the risk of postoperative hypothermia [6]. Research shows that elderly patients experience a more significant drop in body temperature during anesthesia and surgery, which can increase the risk of postoperative infections, prolong recovery time, and negatively affect overall surgical outcomes. BMI, as a standard indicator of weight status, reflects an individual's overall health and influences the risk of postoperative hypothermia. Both underweight and obese patients are at increased risk. Underweight individuals lack sufficient fat reserves, reducing their ability to retain heat, while obese patients may face thermoregulatory disruptions due to the distribution of anesthetic drugs in fatty tissues [11].

Anesthesia risk classification, based on the patient's physical condition and the complexity of the surgery, also plays a significant role in postoperative hypothermia. High-risk patients undergoing general anesthesia may experience thermoregulatory disruptions, leading to hypothermia. Additionally, the properties of anesthetic drugs, particularly depolarizing muscle relaxants, can affect temperature regulation by inducing muscle relaxation. Studies suggest that the use of depolarizing anesthetic agents significantly increases the risk of postoperative hypothermia. Therefore, careful selection of anesthetic drugs and enhanced monitoring of body temperature are crucial for ensuring patient safety during surgery [21, 22].

The use of glucocorticoids during surgery can inhibit hypothalamic temperature regulation and cause heat loss through vasodilation [23, 24]. In clinical practice, glucocorticoid dosages should be tailored to the patient's condition, with attention to potential side effects. In patients with low hemoglobin, decreased tissue oxygen supply and metabolism reduce heat production, worsening tolerance to anesthesia and surgery. To mitigate heat loss, strategies such as minimizing the area of intraoperative skin exposure, using thermal blankets, and administering warmed intravenous fluids can be employed. Additionally, continuous monitoring of core body temperature is essential to promptly address any temperature drops and ensure temperature stability [25].

Hypothermia is closely linked to excessive intraoperative bleeding, as blood loss not only reduces blood volume but also causes heat loss through the infusion of room-temperature or cold fluids and stored blood, exacerbating the risk of hypothermia [26, 27]. Thermal blankets are crucial for preventing and managing postoperative hypothermia. They function by forming an insulating barrier on the patient's body surface, reducing heat loss and providing passive warming. For patients with low body temperature or those exhibiting shivering postoperatively, thermal blankets should be applied immediately to maintain core temperature stability, improve comfort, and minimize complications. Close monitoring of body temperature and appropriate timing for blanket removal are essential to prevent overheating [28].

Although this study used a multicenter sample, it was confined to the same region, limiting the geographic diversity of the sample. Therefore, we recommend external validation of the model in different provinces, regions, or countries to enhance its predictive accuracy and clinical applicability. Future studies should also explore the effects of various anesthesia techniques, intraoperative medications, and other specialized surgeries on hypothermia risk, providing more precise risk predictions and therapeutic guidance for clinical practice.

In conclusion, this study developed a risk prediction model with excellent sensitivity, specificity, and clinical applicability for patients undergoing minimally invasive transurethral surgery. External validation confirmed the model's stable performance and good generalizability.

Acknowledgements

This study was supported by the Jinhua Public Welfare Projects (No. 2024-4-093).

Disclosure of conflict of interest

None.

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