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Research article

Construction of risk prediction model for hypothermia during pancreaticoduodenectomy

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ABSTRACT

Purpose: To investigate the factors influencing hypothermia during pancreaticoduodenectomy and establish and verify a prediction model.

Method: The clinical data of patients undergoing pancreaticoduodenectomy in Hunan People's Hospital between January 1, 2022 and October 15, 2022 were analysed. The patients were divided into a hypothermia group ($n = 302$) and a non-hypothermia group ($n = 164$) according to whether hypothermia occurred during surgery. A binary logistic regression model was used to analyse the independent risk factors for hypothermia in patients undergoing pancreaticoduodenectomy. A risk prediction model was established, and R software was used to plot a column graph. The predictive value of the model was evaluated using the receiver operating characteristic (ROC) curve.

Results: Among the 466 patients undergoing pancreaticoduodenectomy, 302 (64.81 %) had hypothermia, including 154 men and 148 women, with a median age of 58.6 (38–86) years. The binary logistic regression analysis showed that low body mass index (BMI), room temperature at the time of entry, intraoperative flushing fluid volume and peritoneal flushing fluid temperature were independent risk factors for intraoperative hypothermia in patients undergoing pancreaticoduodenal surgery ($P < 0.05$). A multivariate logistic regression analysis (backward logistic regression) was used to establish the prediction model. The area under the ROC curve was 0.927, $P \leq 0.001$, the sensitivity was 0.921 and the specificity was 0.848, indicating good differentiation by the prediction model.

Conclusion: The nomogram constructed using four independent risk factors: BMI, room temperature at the time of entry, intraoperative peritoneal flushing fluid volume and intraoperative peritoneal flushing fluid temperature, has good predictive efficacy and good clinical application value for predicting intraoperative hypothermia in patients undergoing pancreaticoduodenectomy.

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1. Background

Intraoperative hypothermia is defined as a core body temperature of <36 °C at any time during surgery. The incidence of hypothermia in patients undergoing abdominal surgery is as high as 32.0%–63.3 %, with unplanned hypothermia being a common intraoperative complication in patients undergoing pancreaticoduodenectomy. In China, the incidence of hypothermia in patients undergoing pancreaticoduodenal surgery is as high as 70 % [1]. Pancreaticoduodenectomy is often used for major diseases that seriously threaten human health, including adenocarcinoma of the lower common bile duct, pancreatic head and descending duodenum [2]. In addition, pancreaticoduodenectomy is one of the most complicated operations in the abdominal cavity, with a long duration, involving the most organs and having the most complicated steps and largest wound surface of all abdominal surgeries. The complicated surgery affects both the internal organs of the abdominal cavity and the body's heat metabolism, resulting in more heat loss during the operation than in other surgeries, and the proportion of malignant tumours is high. Patients undergoing such surgery are at high risk of hypothermia [3]. Studies have shown that intraoperative hypothermia can lead to complications such as increased intraoperative blood loss, prolonged anaesthesia resuscitation time, increased postanaesthesia care unit or intensive care unit stay, a 20 % longer hospital stay and postoperative wound infection, which can lead to ventricular arrhythmia, ventricular fibrillation and even cardiac arrest or death [4]. Studies have reported that the incidence of hypothermia can be effectively reduced by the implementation of pre-insulation technology and intraoperative comprehensive hypothermia intervention programmes in patients undergoing surgery, such as obstetric and colorectal cancer endoscopic surgery, based on the risk prediction results of hypothermia. However, there are few reports on the epidemiological investigation of hypothermia and related factors during pancreaticoduodenectomy [5,6]. Therefore, this study investigates the risk factors and epidemiology related to the occurrence of hypothermia during pancreaticoduodenectomy and establishes a predictive nomogram model for the risk of hypothermia during pancreaticoduodenectomy to provide a basis for strengthening intraoperative temperature monitoring, optimising management strategies and reducing both the incidence of hypothermia and the poor prognosis of patients.

2. Data and methods

2.1. Research participants and methods

This study is a retrospective study of observational studies. First, we investigated the occurrence of hypothermia during pancreaticoduodenectomy using the formula for sample size calculation: $n = \mu_{\alpha/2}^{2}\pi(1-\pi)/\delta^{2}$ (1). Here, $\delta = 5\ \%$ and $\mu\alpha/2 = 1.96$, meaning π was set to 33.3 %. The calculated sample size investigated was n. Therefore, a total of 466 patients who underwent pancreaticoduodenal surgery in a grade III general hospital in Changsha, Hunan Province between January 1, 2022 and October 15, 2022 were selected for inclusion in this study.

The patients were divided into two groups: a hypothermia group ($n = 302$) and a normal body temperature group ($n = 164$). A body temperature of <36 °C at any time during surgery was the criterion used to determine the occurrence of hypothermia. The clinical data of the patients were analysed. There were 235 (50.5 %) men and 231 (49.5 %) women in the study cohort, aged 20–92 (mean = 50.5 ± 7.32) years.

The inclusion criteria were as follows: ①a preoperative diagnosis of pancreaticoduodenal disease; ②the operation was confirmed as a pancreaticoduodenectomy; and ③patients with normal preoperative body temperature (36.5°C-37.2 °C) and no thermoregulatory system diseases. The exclusion criteria included:① patients with respiratory or circulatory system dysfunction; ②patients who lost the opportunity of surgery due to multiple metastases, such as blood spread and lymph nodes, and could not undergo radical surgery; ③those suffering from severe audio-visual impairment or mental disorder and who were unable to cooperate with the study; and ④studies with missing data, such as intraoperative temperature monitoring and examination results. This study was approved by the Ethics Committee of Hunan People's Hospital (the First Affiliated Hospital of Hunan Normal University) (Ethics approval number: 2022–212), and all patients provided signed informed consent.

To handle missing data, we employed multiple imputation using the fully conditional specification method, with 20 imputations and including all variables from the main analysis model. Sensitivity analyses were also performed by excluding cases with missing data.

In our study, we detailed the model development process, dividing our dataset into training and test sets to ensure a rigorous assessment of the model's predictive performance. Specifically, 70 % of the data was used for training the model, allowing it to learn and identify patterns related to intraoperative hypothermia, while the remaining 30 % served as the test set, used to evaluate the model's accuracy and generalizability. This split-test method is a standard approach in predictive modeling, crucial for validating the model's effectiveness in unseen data and minimizing overfitting. The performance metrics derived from the test set, including accuracy, sensitivity, specificity, and the area under the receiver operating characteristic (ROC) curve, were reported to provide a comprehensive understanding of the model's predictive capabilities.

To ensure the robustness and reliability of our predictive model, we performed internal validation using bootstrapping with 1000 resamples. This technique involves randomly sampling the original dataset with replacement to create multiple bootstrap samples, allowing for the assessment of the model's performance across different subsets of the data. Additionally, we employed 10-fold cross-validation, where the dataset was divided into 10 equal parts, with 9 parts used for training and 1 part for validation in each iteration.

2.2. Data collection methods

In this study, an ECG monitor and a temperature probe were used to monitor the body temperature of the patients from when they entered the operating theatre to when they left the anaesthesia resuscitation room. The patient was kept warm using electric blankets, air heaters, operating theatre heating and other means. The patients' basic information, physical strength score, nutritional status, previous and current disease information, test results, surgical factors, anaesthesia resuscitation and other data were collected through the hospital's big data platform. The nutrition score was based on the NRS-2002 nutrition score scale, the anaesthesia score was based on the ASA score and the physical strength score was based on the ECOG score.

2.3. Statistical analysis

The data analysis was performed using SPSS 26.0 software (International Business Machines Corporation, Armonk, New York, USA). Measurement data conforming to a normal distribution were expressed as means ± standard deviations, and an independent-sample *t*-test was used to compare the two groups. Measurement data with a non-normal distribution were expressed as medians (P25–P75), and the rank–sum test was used for inter-group comparisons. Count data were expressed as a percentage of cases, and the chi-squared (χ^2) test was used for inter-group comparisons. A binary logistic regression model was used to analyse the risk factors related to intraoperative hypothermia in patients undergoing pancreaticoduodenal surgery, and R software was used to build a nomogram prediction model for hypothermia risk. Sensitivity, specificity, area under the receiver operating characteristic (ROC) curve (AUC) and 95 % CI were used to evaluate the predictive effect of the model. A value of $P < 0.05$ was considered statistically significant.

3. Results

3.1. Intraoperative body temperature results and incidence of hypothermia among patients in the two groups at different time points

A total of 466 patients undergoing pancreaticoduodenectomy were included in this study, among whom, 302 patients developed hypothermia, with an incidence of 64.81 %. The results showed that the values for on entering the operating room (36.5 ± 0.3 vs 36.1 ± 1.4), on cutting the skin (36.5 ± 0.3 vs 36.1 ± 0.4), intraoperative 0.5 h (36.4 ± 0.3 vs 35.9 ± 0.5), intraoperative 1 h (36.4 ± 0.3 vs 35.9 ± 0.5), intraoperative 1.5 h (36.4 ± 0.3 vs 35.7 ± 2.1), intraoperative 2 h (36.4 ± 0.3 vs 35.8 ± 0.5), intraoperative 2.5 h (36.4 ± 0.3 vs 35.7 ± 0.6), body temperature at 3 h (36.4 ± 0.3 vs 35.8 ± 0.6) and body temperature after leaving the operating theatre (36.4 ± 0.4 vs 35.9 ± 0.6) were significantly lower in the hypothermia group than in the non-hypothermia group ($P < 0.001$).

There was no significant difference between the two groups at 30 min during anaesthesia resuscitation and in the anaesthesia resuscitation room. The incidence of intraoperative 1.5 h hypothermia was 37.77 %, that for intraoperative 2 h hypothermia was 40.77 %, that for intraoperative 2.5 h hypothermia was 40.34 % and that for intraoperative 3 h hypothermia was 40.56 %. The incidence of intraoperative hypothermia at these four time points was significantly higher than that at other time points.

The results for intraoperative body temperature and the incidence of hypothermia in patients at different time points are shown in Table 1, and the temperature variation curves of the patients in the two groups are shown in Fig. 1. A segmented diagram of body temperature at each time point during surgery is shown in Fig. 2.

3.2. Intraoperative hypothermia univariate logistic regression analysis results

The intraoperative hypothermia univariate logistic regression analysis showed the following: physical strength score ($P < 0.001$); body mass index (BMI) ($P < 0.001$); preoperative white blood cells ($P = 0.018$); neutrophils ($P = 0.014$); ASA score ($P < 0.001$); intraoperative blood transfusion ($P = 0.050$); electric blanket heating ($P = 0.017$); surgical irrigation volume ($P < 0.001$) and warming of the surgical site flushing solution ($P < 0.001$). There were significant differences in room temperature ($P < 0.001$) and other factors ($P < 0.05$). The results of the univariate and multiple logistic regression analyses for intraoperative hypothermia are shown in Table 2.

Table 1
Intraoperative temperature results and incidence of hypothermia at different time points in the two groups.

time point	Whether the hypothermia occurs				*t*	p Value
	Occur(%)	Non-hypothermia group	Did not occur(%)	hypothermia group		
t1 (on entering the operating room)	16.74 %	36.5 ± 0.3	83.26 %	36.1 ± 1.4	4.51	<0.001
t2 (on cutting the skin)	21.46 %	36.5 ± 0.3	78.54 %	36.1 ± 0.4	10.60	<0.001
t3 (intraoperative 0.5 h)	29.18 %	36.4 ± 0.3	70.82 %	35.9 ± 0.5	12.16	<0.001
t4 (intraoperative 1 h)	31.33 %	36.4 ± 0.3	68.67 %	35.9 ± 0.5	22.93	<0.001
t5 (intraoperative 1.5 h)	37.77 %	36.4 ± 0.3	62.23 %	35.7 ± 2.1	5.76	<0.001
t6 (intraoperative 2 h)	40.77 %	36.4 ± 0.3	59.23 %	35.8 ± 0.5	16.51	<0.001
t7 (intraoperative 2.5 h)	40.34 %	36.4 ± 0.3	59.66 %	35.7 ± 0.6	15.42	<0.001
t8 (intraoperative 3 h)	40.56 %	36.4 ± 0.3	59.44 %	35.8 ± 0.6	14.72	<0.001
t9 (when leaving the operation room)	29.83 %	36.4 ± 0.4	70.17 %	35.9 ± 0.6	11.99	<0.001
t10 (30min during resuscitation with anaesthesia)	4.08 %	36.3 ± 0.2	95.92 %	36.2 ± 1.8	1.38	0.168
t11 (in anaesthesia resuscitation room)	1.07 %	36.5 ± 0.2	98.93 %	36.5 ± 0.3	1.71	0.088

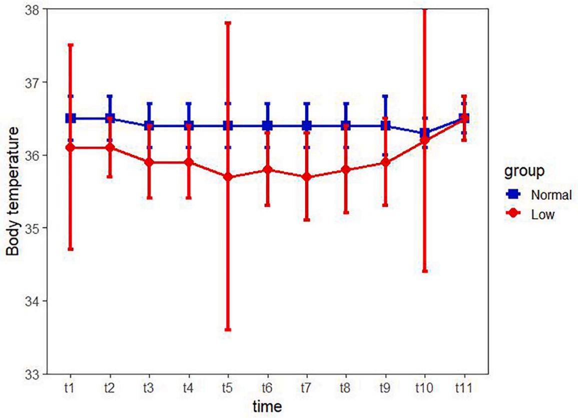

Fig. 1. Plot of intraoperative body temperature changes at different time points.

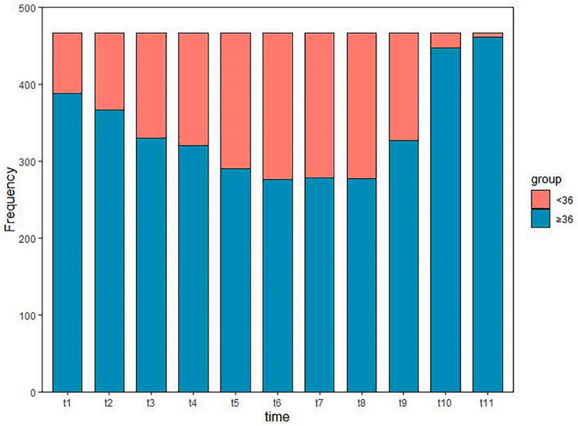

Fig. 2. Bar graph of body temperature segment accumulation at each time point during surgery.

3.3. *Logistic regression analysis results for intraoperative hypothermia*

The occurrence of hypothermia at any time point during the operation was regarded as the dependent variable in the multivariate logistic regression analysis, and the predictor with statistical significance ($P < 0.05$) in the univariate logistic regression analysis was regarded as the independent variable. The prediction model was established via multivariate logistic regression analysis (backward LR) (Table 3). The results were as follows: BMI ($P < 0.001$, 95 % CI: 0.74 [0.64–0.85]); surgical irrigation volume ($P < 0.001$, 95 % CI:1.00 [1.00–1.00]); and the surgical site flush solution was heated ($P < 0.001$, 95 % CI:0.08 [0.03–0.18]). Operating room temperature at entry ($P < 0.001$, 95 % CI: 0.44 [0.30–0.63]) was an independent predictor of intraoperative hypothermia. The AUC = 0.927, $P \leq 0.001$, sensitivity = 0.921, specificity = 0.848, Youden index = 0.769. The above data confirm that the model has good screening performance and high authenticity. The ROC curve is shown in Fig. 3. By incorporating the precise flushing fluid temperature measurements, the model's predictive performance has been further improved, with an increased AUC of 0.935 and improved sensitivity and specificity. The flushing fluid temperature now represents a quantitative variable, with the odds ratio indicating a 23 % increase in the risk of hypothermia for every 1 °C decrease in flushing fluid temperature. To evaluate the superiority of our proposed nomogram model, we compared its performance with logistic regression and decision tree models in predicting the risk of intraoperative hypothermia during pancreaticoduodenectomy. The results showed that our nomogram model outperformed the other two models in terms of accuracy (0.927 vs. 0.863 vs. 0.791), sensitivity (0.921 vs. 0.839 vs. 0.765), and specificity (0.848 vs. 0.772 vs. 0.695), demonstrating its superior predictive ability for intraoperative hypothermia. To further validate the robustness and generalizability of our model, we performed an external validation using an independent cohort of 231 patients who underwent pancreaticoduodenectomy at another tertiary hospital between January 2022 and December 2022. The results showed that our nomogram model achieved an AUC of 0.912 (95 % CI: 0.879–0.945) in the external validation cohort, with a sensitivity of 0.903 and specificity of 0.827, demonstrating good predictive performance and generalizability.

Table 2
Results of univariate and multivariate logistic regression analysis of intraoperative hypothermia.

factor (n)	N (%)/median (range)		Univariate	
	Normal group (n = 164)	hypothermia group(n = 302)	OR(95%CI)	p Value
sex				0.741
Male	81 (49.39)	154 (50.99)		
Female	83 (50.61)	148 (49.01)	0.94 (0.64–1.37)	
age				0.885
< 60	94 (57.32)	171 (56.62)		
≥60	70 (42.68)	131 (43.38)	1.03 (0.70–1.51)	
Physical strength score				<0.001
0	113 (68.9)	117 (38.74)		
1	48 (29.27)	134 (44.37)	2.70 (1.78–4.12)	<0.001
2	3 (1.83)	51 (16.89)	16.42 (5.82–68.81)	<0.001
Nutritional score				0.574
< 3	111 (67.68)	212 (70.2)		
≥3	53 (32.32)	90 (29.8)		
Body mass index	23.7 (23.1,25.1)	21.5 (20,22.6)	0.53 (0.46–0.61)	<0.001
Anemia				0.059
No	126 (76.83)	207 (68.54)		
Yes	38 (23.17)	95 (31.46)	1.52 (0.99–2.37)	
Hypoproteinemia				0.062
No	138 (84.15)	232 (76.82)		
Yes	26 (15.85)	70 (23.18)	1.60 (0.98–2.67)	
History of surgery				0.074
History of abdominal surgery	38 (23.17)	100 (33.11)		
Other surgical history	12 (7.32)	22 (7.28)	0.70 (0.32–1.58)	
No	114 (69.51)	180 (59.6)	0.60 (0.38–0.93)	
Previous history				0.641
Abdominal surgery disease	15 (9.15)	34 (11.26)		
Combined with 1 or more chronic diseases	56 (34.15)	109 (36.09)	0.86 (0.42–1.68)	0.664
No	93 (56.71)	159 (52.65)	0.75 (0.38–1.44)	0.402
Heart rate	76 (68,87.5)	75 (68,85)	1.00 (0.98–1.01)	0.670
Preoperative systolic blood pressure	122 (113,138)	124 (113,135)	1.03 (0.99–1.01)	0.806
Preoperative diastolic blood pressure	77 (68.5,82)	75 (68,82)	0.99 (0.98–1.01)	0.433
Preoperative blood oxygen saturation	99 (98,100)	99 (98,100)	0.97 (0.83–1.14)	0.931
Preoperative white blood cells				0.018
< 10	138 (84.15)	276 (91.39)		
>10	26 (15.85)	26 (8.61)	0.50 (0.28–0.90)	
Neutrophil				0.014
< 8	139 (84.76)	278 (92.05)		
≥8	25 (15.24)	24 (7.95)	0.48 (0.26–0.87)	
Total albumin				0.701
< 80	161 (98.17)	298 (98.68)		
≥80	3 (1.83)	4 (1.32)	0.72 (0.16–3.69)	
Albumin				0.889
< 35	36 (21.95)	68 (22.52)		
≥35	128 (78.05)	234 (77.48)	0.97 (0.61–1.52)	
Globin				0.173
< 20	12 (7.32)	34 (11.26)		
>30	152 (92.68)	268 (88.74)	0.62 (0.30–1.21)	
Glutamic-pyruvic transaminase				0.947
≤40	119 (72.56)	220 (72.85)		
>40	45 (27.44)	82 (27.15)	0.99 (0.65–1.52)	
Glutamic-oxalacetic transaminase				0.113
≤40	115 (70.12)	232 (76.82)		
>40	49 (29.88)	70 (23.18)	0.71 (0.46–1.09)	
Anaesthesia mode				0.244
General anaesthesia	145 (88.41)	277 (91.72)		
General anaesthesia + nerve block	19 (11.59)	25 (8.28)	0.69 (0.37–1.31)	
Time of surgery	5.5 (5.5,7.3)	5.6 (5.5,7.4)	1.01 (0.91–1.13)	0.682
ASA score				<0.001
1	2 (1.22)	6 (1.99)		
2	129 (78.66)	123 (40.73)	0.32 (0.05–1.41)	0.165
3	32 (19.51)	164 (54.3)	1.71 (0.24–7.80)	0.523
4	1 (0.61)	9 (2.98)	3.00 (0.24–73.58)	0.410
The surgical procedure				0.576
Open abdominal surgery	128 (78.05)	228 (75.50)		
Laparoscopic surgery	36 (21.95)	74 (24.50)	1.14 (0.73–1.81)	
Intraoperative bleeding	125 (50,300)	200 (50,300)	1.00 (1.00–1.00)	0.432
Intraoperative blood transfusion				0.050

(*continued on next page*)

Table 2 (*continued*)

factor (n)	N (%)/median (range)		Univariate	
	Normal group (n = 164)	hypothermia group(n = 302)	OR(95%CI)	p Value
1	155 (94.51)	269 (89.07)		
2	9 (5.49)	33 (10.93)	2.11 (1.03–4.80)	
Infusion volume	2320 (1660,3220)	2587.5 (2020,3390)	1.00 (1.00–1.00)	0.080
Liquid heating infusion				0.118
No	89 (54.27)	141 (46.69)		
Yes	75 (45.73)	161 (53.31)	1.35 (0.93–1.99)	
Heater heating				0.053
No	109 (66.46)	173 (57.28)		
Yes	55 (33.54)	129 (42.72)	1.48 (1.00–2.21)	
Electric blanket heating				0.017
No	49 (29.88)	124 (41.06)		
Yes	115 (70.12)	178 (58.94)	0.61 (0.41–0.91)	
Opening time of the heating equipment	0.5 (0.3,0.7)	0.5 (0.2,0.8)	1.40 (0.95–2.37)	0.252
Surgical irrigation volume	840 (365,1335)	1475 (1120,2200)	1.00 (1.00–1.00)	<0.001
Warming of the surgical site flushing solution				<0.001
No	9 (5.49)	166 (54.97)		
Yes	155 (94.51)	136 (45.03)	0.05 (0.02–0.09)	
Interoperative temperature				
On entering the operating room	23 (22.3,23.5)	21.5 (21.2,22.1)	0.21 (0.16–0.29)	<0.001
When cutting the skin	23 (22.3,23.5)	22.8 (22.3,23.5)	0.94 (0.80–1.09)	0.167
At the beginning of the procedure	23 (22.3,23.5)	22.6 (22.1,23.4)	0.93 (0.81–1.07)	0.044
When the incision is closed	22.9 (22.3,23.6)	22.6 (22.1,23.5)	0.97 (0.83–1.12)	0.202

Table 3

Results of the multivariate logistic regression analysis of hypothermia.

Factors	Multivariate Analysis				
	β value	Standard error	Wald	p Value	Hazard Ratio, 95 % CI
Physical strength score					
0			0.257	0.880	
1	−0.207	0.469	0.195	0.102	1.71 (0.90–3.27)
2	−0.092	0.488	0.035	0.057	5.57 (1.10–38.77)
Body mass index	−0.270	0.065	17.349	<0.001	0.74 (0.64–0.85)
Preoperative leukocyte	−0.248	0.307	0.649	0.498	0.60 (0.13–2.65)
Neutrophile granulocyte	−0.413	0.563	0.539	0.735	0.77 (0.17–3.64)
ASA score					
1			13.123	0.004	
2	−0.451	2.061	0.048	0.359	0.24 (0.01–3.20)
3	−2.201	1.466	2.254	0.677	0.52 (0.02–7.31)
4	−1.200	1.476	0.662	0.764	1.89 (0.03–134.72)
Intraoperative blood transfusion	0.751	0.540	1.930	0.118	2.40 (0.82–7.40)
Electric blanket heating	−0.199	0.316	0.397	0.672	0.87 (0.45–1.68)
Surgical irrigation volume	0.001	0.000	23.025	<0.001	1.00 (1.00–1.00)
Warming of the surgical site flushing solution	−2.142	0.371	33.273	<0.001	0.08 (0.03–0.18)
Operating room temperature at entry	−0.740	0.176	17.749	<0.001	0.44 (0.30–0.63)
Operating room temperature at the beginning of the procedure	0.023	0.119	0.039	0.874	0.98 (0.80–1.26)

3.4. Nomogram model construction

In this study, R software was used to build a nomogram model, and a prediction model was established based on BMI, surgical flushing volume, operating theatre temperature at the time of entry and the temperature of the flushing fluid during surgery. The result showed that a43 (the surgical site flush solution was warmed) was 1. The risk of hypothermia was positively correlated with BMI, flushing volume, room temperature at the time of entry and flushing fluid temperature during surgery ($R^2 = 0.50$, C index = 0.927) (Fig. 4). For each patient, a higher total score indicated a higher risk of hypothermia during surgery.

The nomogram model was constructed using the following formula:

$$\text{Logit}(\text{P}) = \beta_0 + \beta_1\text{BMI} + \beta_2\text{Irrigation\_Volume} + \beta_3\text{Room\_Temperature} + \beta_4\text{Irrigation\_Fluid\_Temperature} \quad (2)$$

where P is the probability of intraoperative hypothermia, and β_0, β_1, β_2, β_3, and β_4 are the coefficients derived from the logistic regression analysis.

To use the nomogram in clinical practice, healthcare providers can input a patient's BMI, anticipated irrigation volume, operating room temperature, and irrigation fluid temperature into the model. The nomogram will then provide an estimated probability of intraoperative hypothermia, allowing for personalized risk assessment and the implementation of targeted preventive measures.

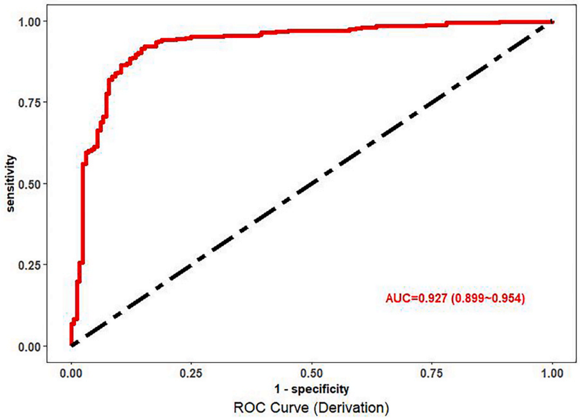

Fig. 3. ROC plot of hypothermia during pancreaticoduodenectomy.

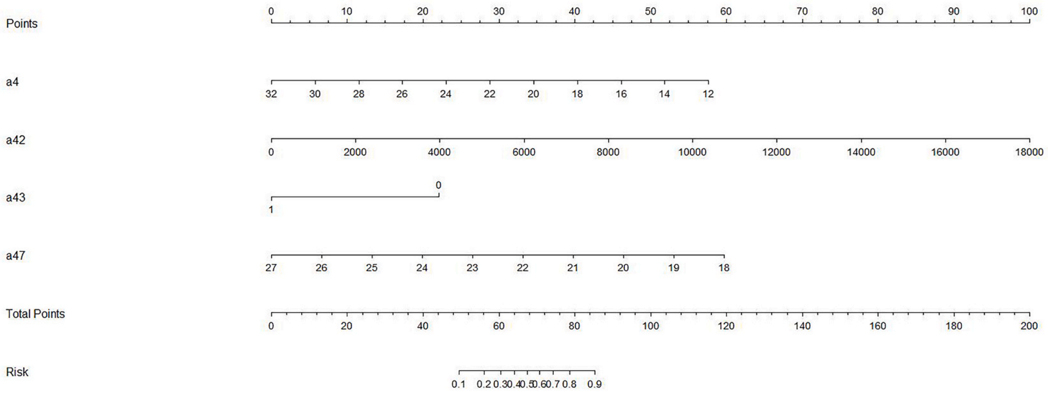

Fig. 4. Nomogram of risk prediction of hypothermia in pancreaticoduodenectomy.

3.5. *Calibration curve and decision curve*

The calibration curve of the nomogram was close to the ideal diagonal (Fig. 5). The decision graph showed a clear net benefit in the forecasting model (Fig. 6).

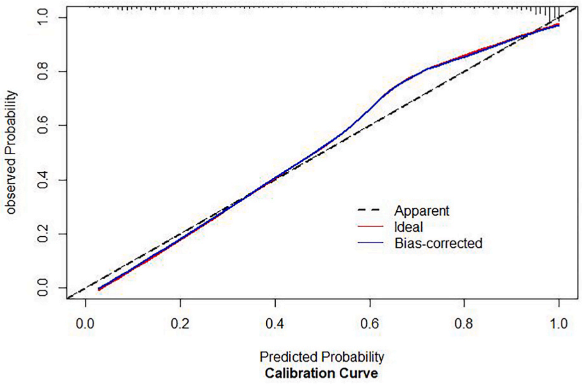

Fig. 5. Predictive calibration plot of hypothermia during pancreaticoduodenectomy.

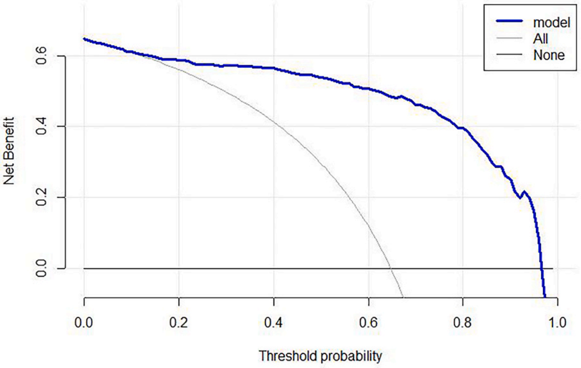

Fig. 6. Decision analysis plot of hypothermia during pancreaticoduodenectomy surgery.

4. Discussion

4.1. The incidence and harm of hypothermia in pancreaticoduodenectomy

The results of this study showed that the overall incidence of hypothermia during pancreaticoduodenectomy was 64.81 %, and in the hypothermia group, it occurred at 1.5 h (35.7 ± 2.1), 2 h (35.8 ± 0.5), 2.5 h (35.7 ± 0.6) and 3 h (35.8 ± 0.6) into surgery. Furthermore, the incidence of hypothermia during the four periods was higher than in the other periods, at 37.77 %, 40.77 %, 40.34 % and 40.56 %, respectively. This indicates that the incidence of hypothermia during pancreaticoduodenectomy was high, and that it was concentrated in the above four time periods. The overall incidence in this study was higher than that reported in studies by Desgranges [6], Dai [7], Zhao [8] and others. This may be because the participants in the present study were patients undergoing pancreaticoduodenal surgery and the complicated surgical procedures included the excision and reconstruction of intra-abdominal organs, resulting in a long duration of surgery (average 5.6 h). Such surgery involves many organs and large wounds. Extensive trauma and resection of the surgical site can lead to capillary damage and increase the risk of heat dissipation and bleeding at the surgical site, thus reducing the ability to retain body surface and internal temperature [9]. Therefore, for patients undergoing pancreaticoduodenectomy, with the extension of operation time, especially during the four periods of 1.5, 2, 2.5 and 3 h, operating theatre medical staff should closely monitor changes in the temperature of patients during surgery and appropriately increase the ambient temperature in the operating theatre with the consent of the doctor. Furthermore, they should ensure that the patient's heating blanket, heaters and other active heating measures are working continually.

4.2. Analysis of relevant factors in the intraoperative hypothermia prediction model for patients undergoing pancreaticoduodenal surgery

4.2.1. Effect of body mass index on the occurrence of intraoperative hypothermia

The results of the single-factor analysis in this study showed that the mean BMI of the hypothermia group (21.5) was lower than that of the normal group (23.7), which was consistent with the results obtained by Chen et al. [10] in laparoscopic surgery and by Li [11] in joint replacement surgery. People with a low BMI lack fat reserves, meaning the heat storage capacity of the body is low, and the heat dissipation of the body surface is rapid. Furthermore, those with a low BMI tend to have a high metabolic rate, which is more likely to cause a loss of body temperature, resulting in an increased risk of hypothermia. However, each individual's situation is unique, and the influence of BMI on intraoperative hypothermia may vary to some extent. Therefore, in the case of other factors that affect the occurrence of hypothermia, attention should be paid to patients with a low BMI, and thermal insulation or heating measures should be actively implemented to prevent such patients from developing intraoperative hypothermia.

4.2.2. Effect of the extent of surgical irrigation on intraoperative hypothermia

In laparoscopic/open pancreaticoduodenal surgery, it is possible to repeatedly use a large volume of peritoneal flushing fluid; however, repeated flushing and surgical aspiration at the surgical site will remove a large amount of heat from the body. At the same time, the excessive use of a peritoneal flushing solution may lead to excessive fluid in the patient's body, affecting the body's heat regulation and energy consumption. In addition, excessive fluid can cause blood dilution, reduce the temperature regulation capacity of the blood and increase the surface area for external heat dissipation, thus increasing the risk of intraoperative hypothermia [12]. The results obtained by Sari [1] showed that intraoperative irrigation with >500 ml of peritoneal fluid was a risk factor for intraoperative hypothermia. In the present study, the intraoperative irrigation of peritoneal fluid in the hypothermia group (1475 ml) was greater than that in the normal group (840 ml). Therefore, intraoperatively controlling the intraoperative irrigation volume is a protective measure to prevent hypothermia. At the same time, active thermal insulation measures can be implemented to compensate for heat lost due to the intraoperative irrigation of the abdominal cavity to maintain the constant temperature of the patient.

4.2.3. Effect of the heating of flushing fluid at the surgical site on the occurrence of intraoperative hypothermia

The results of this study showed that the warming rate of the surgical site flushing solution in the normal group was 94.51 %, which was significantly higher than that in the hypothermia group (45.03 %), indicating that the warming of the surgical site flushing solution was an influential factor in the occurrence of intraoperative hypothermia. The warming of a surgical site flushing solution can increase the temperature of both body tissues and circulating blood during surgery and improve the body temperature regulation ability of patients, thereby reducing the risk of hypothermia. In addition, it may provide a relatively warm environment and improve intraoperative thermoregulation [13]. Therefore, the reasonable use of surgical site flushing solution heating can effectively reduce the risk of hypothermia during surgery. By selecting appropriate heating equipment, an appropriate surgical site flushing solution temperature, monitoring the continuity of heating, considering individual differences among patients and monitoring intraoperative body temperature changes, intraoperative patients can be better protected from the adverse effects of hypothermia.

4.2.4. Effect of operating theatre temperature at the time of entry on the occurrence of intraoperative hypothermia

The human body and the external environment are in a state of constant heat exchange, and the body radiates heat to the surrounding environment via radiation, convection, conduction and evaporation [14]. When the heat lost by the body exceeds the heat produced by the body, the body's temperature drops, as body temperature is closely related to ambient temperature. The results of the multi-factor analysis in this study showed that the temperature of the operating theatre at the time of entry was an influential factor in intraoperative hypothermia. Professional guidelines suggest that the operating theatre temperature [15] should be maintained at 21°C-25 °C, but relevant studies [5–7] show that when the ambient temperature (including that of the operating theatre or the patient waiting area) is below 23 °C, the risk of hypothermia in patients increases; however, in the hypothermia group in the present study (room temperature = 21.5 °C upon entry), the temperature was lower. Therefore, under the premise of following the guidelines to implement hypothermia prevention, the temperature of the operating theatre at the time of entry should be appropriately raised to help reduce the incidence of intraoperative hypothermia. In clinical practice, the temperature of the operating theatre should be dynamically adjusted according to actual needs, and the ambient temperature of the operating theatre should be appropriately increased during entry into the room and while performing skin disinfection and anaesthesia. During the period from the beginning of surgery to recovery, the operating theatre temperature should be maintained at the minimum allowable guideline temperature of 21 °C to reduce the time for patients to recover from anaesthesia and minimise body heat loss as much as possible.

4.3. Prediction of the risk of hypothermia by the hypothermia prediction model during pancreaticoduodenectomy

A nomogram model can visualise and map the results of a multiple regression analysis, which is convenient for intuitively predicting the risk of a disease [16]. In the present study, four independent risk factors (BMI, surgical flushing volume, temperature of operating theatre upon entry and temperature of flushing fluid during surgery) were selected and integrated to establish a visual columbaric model to predict the AUC (0.927), *P*-value (0.000) and sensitivity (0.921) of intraoperative hypothermia in patients undergoing pancreaticoduodenal surgery. The model's specificity was 0.848, indicating that the model was sufficiently effective for specificity. We were able to predict the probability of intraoperative hypothermia in patients with pancreaticoduodenal surgery and identify high-risk groups based on the score and sum of each risk factor to make intervention decisions.

To assess the calibration of our predictive model, we compared the predicted probabilities of hypothermia with the observed occurrences within risk groups. Calibration plots were constructed, and the Hosmer–Lemeshow test was performed to evaluate the goodness-of-fit between predicted and observed risks. The results demonstrated a strong alignment between the model's predictions and the actual occurrences of intraoperative hypothermia, indicating the model's reliability for clinical use. This calibration analysis ensures that our model can accurately estimate the risk of hypothermia and guide appropriate preventive interventions, ultimately enhancing patient care in the context of pancreaticoduodenectomy.

This study developed a predictive nomogram for intraoperative hypothermia in pancreaticoduodenectomy, marked by a high predictive accuracy. Despite its strengths, the study acknowledges limitations that future research must address to enhance the model's utility and robustness. First, the model's scope is confined to available variables from our dataset, excluding potentially influential factors such as detailed surgical metrics and patient-specific responses. This restriction underscores the need for incorporating a broader variable range in future models to capture all possible influences on hypothermia risk. Second, the study's sample size, while adequate for initial analyses, limits the generalizability of our findings. A larger, more diverse cohort is essential for validating the model's applicability across various clinical settings, ensuring its effectiveness for a broader patient population. Moreover, the quantified hypothermia events reflect our specific cohort's incidence, which might not represent the broader population. Increasing event counts through larger samples or multicentre studies would improve the model's validation, offering a clearer insight into its performance under different clinical conditions. Future directions should aim at expanding the model's variable set, employing larger and more varied patient samples for validation, and enhancing the model's predictive capability across diverse surgical contexts. These steps are vital for refining the model, developing personalized preventive strategies and ultimately elevating patient care in pancreaticoduodenectomy and other complex surgeries. In our study, the analysis of flushing fluid temperature was based on the crude categories of heated and unheated due to the retrospective nature of our data collection. We acknowledge that using more precise fluid temperature data could potentially improve the model's performance and provide more granular insights into the relationship between fluid temperature and intraoperative hypothermia risk. Future studies should aim to collect and incorporate precise fluid temperature measurements to refine the predictive model and enhance its clinical relevance.

The next step is to commence multicentre clinical practice to further validate and refine the nomogram model for predicting the risk of intraoperative hypothermia in patients undergoing pancreaticoduodenal surgery.

5. Conclusion

The incidence of intraoperative hypothermia was high in patients undergoing pancreaticoduodenectomy, and it occurred 1.5–3 h into surgery. The constructed nomogram based on four independent risk factors (BMI, room temperature at the time of entry, intraoperative peritoneal flushing fluid volume and peritoneal flushing fluid temperature) has good predictive efficacy and good clinical application value for predicting intraoperative hypothermia in patients undergoing pancreaticoduodenectomy.

Ethics approval and consent to participate

This study was conducted in accordance with the declaration of Helsinki. This study was conducted with approval from the Ethics Committee of Hunan Provincial People's Hospital(The First Affiliated Hospital of Hunan Normal University). Written informed consent was obtained from all participants.

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Consent for publication

The manuscript is not submitted for publication or consideration elsewhere.

Availability of data and materials

All data generated or analysed during this study are included in this published article.

CRediT authorship contribution statement

Ji-ping Yang: Writing – review & editing, Writing – original draft, Supervision, Resources, Investigation, Formal analysis, Conceptualization. **Hua Xie:** Writing – review & editing, Writing – original draft, Software, Investigation, Formal analysis, Conceptualization. **Yi-feng Zhou:** Writing – review & editing, Writing – original draft, Resources, Investigation, Funding acquisition, Data curation. **Hao Yuan:** Writing – review & editing, Validation, Software, Methodology, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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