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Original Article

Construction of a logistic model and GBM model for infection after spinal canal resection of intraspinal tumors

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Abstract: Objectives: To identify risk factors for postoperative infection following intraspinal tumor (IT) resection, and to construct predictive models using a Logistic regression model and gradient boosting machine (GBM) algorithms. Methods: A retrospective study was conducted on 136 patients who developed postoperative infections after IT resection at Ziyang Central Hospital from November 2013 to October 2024. Logistic regression and GBM models were developed using R 4.3.2. Results: Logistic regression analysis identified age >55 years, type II diabetes, operation time >3.3 h, interleukin-6 (IL-6)>5.5 ng/L, and procalcitonin (PCT)>0.3 ug/L as independent risk factors for infection after IT resection (P<0.05). The logistic regression equation was: Logit (P) = -12.238 + 2.081 × Age + 1.118 × Type II diabetes + 1.381 × operation time + 2.131 × IL-6 + 1.843 × PCT. In the GBM model, the relative importance of variables was: age (23.13011), IL-6 (22.98775), type II diabetes (18.57776), PCT (17.86779), and operation time (17.73660). The areas under the ROC curves (AUC) was 0.886 for the logistic model and 0.907 for the GBM model. Calibration curves demonstrated good agreement between predicted and observed infection rates in both models. Conclusions: The identified risk factors and the predictive models offer valuable tools for early identification and prevention of postoperative infection following IT resection.

Keywords: Intraspinal tumor, postoperative infection, risk factors, logistic model, gradient boosting machine model, decision tree model

Introduction

Intraspinal tumors (IT) are relatively common tumors of the central nervous system, accounting for approximately 2% to 15% of all primary central nervous system neoplasms [1]. These tumors primarily originate within or adjacent to the spinal cord, with schwannomas, meningiomas, and neurofibromas being the most prevalent subtypes [2]. ITs are usually benign in the early stages and often asymptomatic. However, as the tumor grows and compresses neural structures, patients may present with sensory deficits, motor dysfunction, or persistent nocturnal pain. In severe cases, partial or complete paralysis may occur by the time of diagnosis [3]. Therefore, early surgical intervention is recommended once a diagnosis is confirmed, provided no absolute contraindications exist.

IT spinal canal resection is a key surgical approach within spinal oncology, aimed at relieving compression of the spinal cord and nerve roots, thereby improving clinical symptoms and neurological function [4]. However, due to the complex anatomy and dense distribution of nerve and blood vessels, this surgery is technically challenging and associated with a high risk of complications. Among these, postoperative infection is one of the most serious. It not only impairs surgical outcome and delays recovery, but also increases the risk of sepsis and poor prognosis [5]. Despite advances in surgical techniques and perioperative management, the incidence of postoperative infection of spinal cancer surgery remains high, with a reported incidence up to 20.37% [6]. Variability in tumor types, surgical approaches, and patient-related factors may lead to considerable heterogeneity in infection risk. Factors such as diabetes, chronic obstructive pulmonary disease, prolonged operative duration have been implicated [7]. However, there remains a paucity of studies focused on postoperative infections following IT resection.

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An in-depth understanding of the risk factors of infection after IT spinal canal resection and the development of predictive models may facilitate early identification of high-risk patients and implementation of preventive and therapeutic measures accordingly, ultimately improving patient outcomes. In view of this, this study aimed to analyze the risk factors for postoperative infection in IT resection and to develop predictive models using machine learning algorithms, thereby providing a robust framework for clinical decision-making in infection prevention and management.

Subjects and methods

Research subjects

In this retrospective study, 68 patients who developed postoperative infections after IT spinal canal resection at Ziyang Central Hospital from June 2013 to October 2024 were designated as the infection group. Meanwhile, another 68 patients who didn't develop postoperative infection during the same period were selected as the non-infection group. This study was approved by the Medical Ethics Committee of Ziyang Central Hospital.

Inclusion criteria: (1) Diagnosis of IT confirmed by clinical symptoms, imaging examinations, and postoperative pathological examinations; (2) Successful completion of IT spinal canal resection; (3) Postoperative infection group met established diagnostic criteria for surgical site or systemic infection; (4) Complete medical records and follow-up data. Exclusion criteria: (1) Coexisting systemic infectious diseases (e.g., sepsis, pneumonia); (2) Coexisting severe dysfunction of vital organs (e.g., heart, liver, or kidneys); (3) Immunologic disorders or current immunosuppressive therapy; (4) Coexisting malignancies other IT; (5) Recurrent IT; (6) Undergoing surgical treatments other than spinal canal resection.

Postoperative infection were diagnosed in accordance with the *Diagnostic Criteria for Nosocomial Infections (Trial)* issued by the Ministry of Health of China in 2001 [8]. Diagnosis was based on clinical symptoms and signs, supplemented by microbiological examination of samples including wound secretions, urine, blood, sputum and drainage fluid. A comprehensive analysis was conducted to determine the presence of postoperative infection, including incision infection, pulmonary infection, and urinary system infection.

Data collection

Based on clinical experience and literature regarding postoperative infection risk factors, the following data were collected: age, gender, body mass index (BMI), smoking history, history of type II diabetes, tumor nature, tumor type, length of preoperative hospital stay, history of preoperative radiotherapy or chemotherapy, tumor resection method, operation time, intraoperative blood loss, and levels of interleukin-6 (IL-6), tumor necrosis factor-α (TNF-α), high-sensitivity C-reactive protein (hs-CRP), and procalcitonin (PCT). Fasting venous blood was collected from the cubital vein in the early morning 24 hours before surgery. IL-6 was measured using enzyme-linked immunosorbent assay (ELISA), TNF-α double antibody sandwich ELISA, hs-CRP by immunoturbidimetry, and PCT by electrochemiluminescence.

Statistical methods

Statistical analysis was performed using SPSS 26.0. Categorical variables were expressed as counts or percentages (n, %), and the chi-square test was used for comparison between groups. Logistic regression analysis was used to identify independent risk factors for postoperative infection after IT spinal canal resection. The Logistic model and Gradient boosting machine (GBM) model for predicting postoperative infection after IT laminectomy were constructed using the rms package and gbm package in R 4.3.2, respectively. The discrimination and calibration of the models were evaluated by drawing receiver operating characteristic (ROC) curves and calibration curves. The comparison of the area under the ROC curve (AUC) between models was conducted using the DeLong test. $P<0.05$ was considered statistically significant.

Results

Univariate analysis of factors associated with postoperative infection

Postoperative infection was set as the dependent variable. Cutoff values for continuous variables were determined and converted into

Table 1. Calculation of the optimal truncation value

	Youden index	Cutoff values	Sensitivity (%)	Specificity (%)
Age	0.427	55 (years)	80.88	61.76
BMI	0.074	23.6 (kg/m^2)	47.06	60.29
Preoperative hospital stay	0.103	9 (d)	38.24	72.06
Operation time	0.309	3.3 (h)	61.76	69.12
Intraoperative blood loss	0.132	2751 (mL)	73.53	39.71
IL-6	0.397	5.5 (ng/L)	63.24	76.47
TNF-α	0.118	7.3 (ng/L)	35.29	76.47
hs-CRP	0.162	3.6 (mg/L)	69.12	47.06
PCT	0.294	0.3 (ug/L)	45.59	83.82

BMI: body mass index; IL-6: interleukin-6; TNF-α: tumor necrosis factor-α; hs-CRP: high-sensitivity C-reactive protein; PCT: procalcitonin.

binary categorical variables (**Table 1**). The proportion of patients with age >55 years, type II diabetes, operation time >3.3 h, IL-6>5.5 ng/L, and PCT>0.3 ug/L was significantly higher in the infection group than those in the non-infection group (all $P<0.05$) (**Table 2**).

Construction of predictive model

Logistic regression model: Postoperative infection was used as the dependent variable, and variables with statistical significance in the univariate analysis (age, type II diabetes, operation time, LI-6, PCT) were included as independent variables in a multivariate Logistic regression analysis. Variable assignment details are provided in **Table 3**. The results indicated that age >55 years, type II diabetes, operation time >3.3 h, IL-6>5.5 ng/L, and PCT>0.3 ug/L were independent risk factors for postoperative infection after IT spinal canal resection ($P<0.05$) (**Table 4**). The logistic regression model was expressed as: Logit (P) = -12.238 + 2.081 × Age + 1.118 × Type II diabetes + 1.381 × operation time + 2.131 × IL-6 + 1.843 × PCT. A nomogram was drawn to visualize the model, as shown in **Figure 1**. Each variable corresponds to a score in the nomogram; the total score corresponds to the predicted probability of postoperative infection.

GBM model: The gradient boosting algorithm was used to score the importance of the indicators with statistical significance (age, type II diabetes, operation time, LI-6, PCT) in the univariate analysis. The parameter settings were as follows: shrinkage = 0.01, cv.folds = 10, n.trees = 5000, interaction.depth = 1. The optimal number of iterations was 675. The relative importance of each independent variable was obtained and ranked from high to low as follows: age (23.13011), IL-6 (22.98775), type II diabetes (18.57776), PCT (17.86779), operation time (17.73660) (**Figure 2**). A higher importance score indicates a greater predictive contribution of the variable within the model.

Comparison of predictive model performance

The AUC of the Logistic model was 0.886 (95% CI: 0.831-0.941), and that of the GBM model was 0.907 (95% CI: 0.856-0.958). There was no significant difference in the AUC between the two model ($Z=0.550$, $P=0.583$). The threshold at the highest Youden index was selected as the optimal cutoff value. At this threshold, the logistic model demonstrated a sensitivity of 95.6% and a specificity of 69.1%, whereas the GBM model achieved a sensitivity of 89.7% and a specificity of 82.4% (**Figure 3**). Calibration curves showed good agreement between predicted probabilities and observed infection rates for both models (**Figure 4**).

Discussion

After a confirmed diagnosis of IT, early surgical intervention remains the cornerstone of treatment, as timely surgical intervention can significantly improve patient prognosis [9]. With ongoing advances in surgical techniques, methods such as intraoperative neurophysiological monitoring and the use of microscopes have been increasingly adopted in clinical practice. These technologies have yielded favorable outcomes in improving neurological functions following IT resection. Despite the overall success of surgical management, variability in individual

Table 2. Univariate analysis of factors associated with postoperative infection (n)

Data	Infection group (n=68)	non-infection group (n=68)	χ^2	*P*
Age			25.674	<0.001
≤55 years	13	42		
>55 years	55	26		
Gender			0.030	0.863
Male	38	39		
Female	30	29		
BMI			0.748	0.387
≤23.6 kg/m^2	36	41		
>23.6 kg/m^2	32	27		
Smoking			0.474	0.491
No	35	39		
Yes	33	29		
Type II diabetes			10.039	0.002
No	43	59		
Yes	25	9		
Tumor nature			0.962	0.327
Benign	53	48		
Malignant	15	20		
Tumor type			1.571	0.456
Intradural extramedullary tumors	47	40		
Intramedullary tumor	14	19		
Extradural tumor	7	9		
Preoperative hospital stay			1.627	0.202
≤9 days	42	49		
>9 days	26	19		
Preoperative chemoradiotherapy			0.052	0.819
No	56	57		
Yes	12	11		
Tumor resection methods			0.314	0.575
Total resection	19	22		
Segmental resection	49	46		
Operation time			13.041	<0.001
≤3.3 h	26	47		
>3.3 h	42	21		
Intraoperative blood loss			2.690	0.101
≤2751 mL	41	50		
>2751 mL	27	18		
IL-6			21.823	<0.001
≤5.5 ng/L	25	52		
>5.5 ng/L	43	16		
TNF-α			2.267	0.132
≤7.3 ng/L	44	52		
>7.3 ng/L	24	16		
hs-CRP			3.741	0.053
≤3.6 mg/L	21	32		
>3.6 mg/L	47	36		
PCT			13.779	<0.001
≤0.3 ug/L	37	57		
≤0.3 ug/L	31	11		

BMI: body mass index; IL-6: interleukin-6; TNF-α: tumor necrosis factor-α; hs-CRP: high-sensitivity C-reactive protein; PCT: procalcitonin.

Table 3. Variable assignment

Variable	Assignment
Postoperative infection	0=No, 1=Yes
Age	0=≤55 years, 1=>55 years
Type II diabetes	0=No, 1=Yes
Operation time	0=≤3.3 h, 1=>3.3 h
IL-6	0=≤5.5 ng/L, 1=>5.5 ng/L
PCT	0=≤0.3 ug/L, 1=>0.3 ug/L

IL-6: interleukin-6; PCT: procalcitonin.

response leads to inconsistent postoperative outcomes, and a range of complications may occur [10]. Postoperative infection is a critical factor adversely affecting early prognosis and rehabilitation. Therefore, the prevention and management of postoperative infection remain central challenges in the surgical treatment of IT and a key focus of current research and clinical efforts.

This study retrospectively analyzed the risk factors for postoperative infection after IT spinal canal resection, and identified age >55 years, type II diabetes, operation time >3.3 h, IL-6>5.5 ng/L, and PCT>0.3 ug/L as independent risk factors for postoperative infection after IT spinal canal resection. These results are consistent with findings from previous studies.

Regarding age, El-Kadi M et al. [11] reported that patients with age >60 years had a significantly higher postoperative infection rate after spinal surgery. This threshold is close to that identified in our study, confirming the impact of aging on the risk of postoperative infection. Aging is associated with a progressive decline in organ function and an increased prevalence of chronic comorbidities, which may adversely affect surgical outcome and postoperative recovery. At the same time, tissue repair ability is reduced in elderly patients, resulting in delayed wound healing and prolonged vulnerability period to infection [12]. Age-related immune system decline, or immunosenescence, characterized by T cell and B cell function decline, impairs the body's ability to recognize and respond to pathogens [13, 14].

From a comorbidity perspective, Deng H et al. [15] identified diabetes as a risk factor for postoperative infection after spinal tumor surgery, aligning with our findings. In patients with type II diabetes, persistent hyperglycemia creates an environment conducive to bacterial growth. Both tissue resistance to infection and regenerative capacity are compromised, enabling rapid bacterial proliferation and significantly increasing infection risk [16, 17]. In terms of operation time, Tavares-Junior MCM et al. [6] demonstrated that a surgical duration exceeding 4 hours was associated with a 2.61-fold higher risk of postoperative infection, which is consistent with our findings. Prolonged surgical time result in prolonged exposure of the surgical field to the external environment, increasing the risk of pathogen invasion. Moreover, prolonged surgical time is associated with extensive tissue damage, which induces a stronger inflammatory responses, impairing local and systemic immunity [18]. Extended anesthesia duration also suppresses respiratory and circulatory functions, disrupts metabolic and immune regulation, and increases the risk of infections [19, 20].

In terms of inflammatory biomarkers, IL-6 and PCT are well-established indicators for infections. Lenski M et al. [21] demonstrated that IL-6 has excellent diagnostic potential for surgical site infections after spinal surgery, with an AUC of 0.954. Aljabi Y et al. [22] reported that PCT has excellent diagnostic performance for early postoperative infection, with a sensitivity and specificity of 100% and 95.2%, respectively. Elevated preoperative IL-6 levels may reflect underlying chronic inflammation or tumor-associated immune activation [23]. PCT, typically undetectable in healthy individuals, rises significantly in the presence of severe bacterial infection or systemic inflammatory response; levels ≥0.4 μg/L suggest a high likelihood of systemic infection [24, 25]. Elevated preoperative IL-6 and PCT levels may reflect an activated inflammatory state that compromises host immunity. Excessive inflammatory responses can disrupt physiological homeostasis and immune regulation, leading to immune cell dysfunction and impaired pathogen defense following surgical trauma [26]. Furthermore, inflammation-induced endothelial dysfunction increases vascular permeability, facilitating bacterial dissemination while impairing tissue perfusion and healing at the surgical site - factors that jointly increase infection risk [27-29].

Based on the identified risk factors, targeted measures should be implemented in clinical practice. For patients aged ≥55 years, a com-

Table 4. Logistic regression analysis of infection after IT resection

Variable	*B*	*SE*	*Wald*	*P*	*OR (95% CI)*
Age	2.081	0.510	16.672	<0.001	8.009 (2.950-21.742)
Type II diabetes	1.118	0.545	4.206	0.040	3.060 (1.051-8.913)
Operation time	1.381	0.478	8.341	0.004	3.979 (1.559-10.157)
IL-6	2.131	0.516	17.071	<0.001	8.426 (3.066-23.158)
PCT	1.843	0.561	10.775	0.001	6.314 (2.101-18.974)
Constant	-12.238	2.057	35.409	<0.001	-

IT: intraspinal tumor; IL-6: interleukin-6; PCT: procalcitonin.

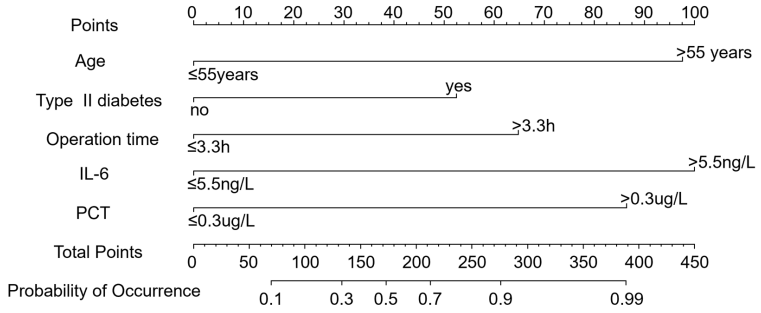

Figure 1. Nomogram for predicting infection after IT resection. IT: intraspinal tumor; IL-6: interleukin-6; PCT: procalcitonin.

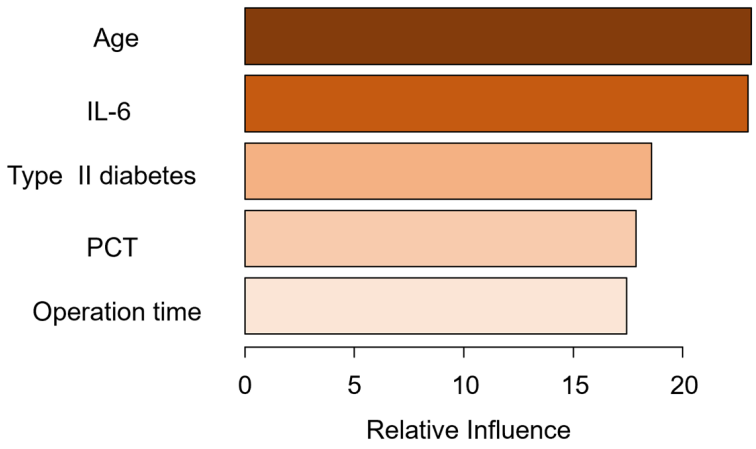

Figure 2. GBM for predicting infection after IT laminectomy. IL-6: interleukin-6; PCT: procalcitonin.

prehensive preoperative assessment of physical status and comorbidities is essential, and appropriate intervention measures should be implemented as needed. For patients with type II diabetes, strict perioperative glycemic control should be maintained to minimize infection risk. Inflammatory markers such as IL-6 and PCT should be closely monitored prior to surgery. Their abnormal elevations may indicate latent infection or an ongoing inflammatory process. In such cases, further investigation is warranted, and appropriate treatment should be administered to ensure normalization of these parameters before surgery.

Logistic regression and GBM models were developed in this study for predicting postoperative infection after IT laminectomy. Both models exhibited comparable discrimination, as evidenced by similar AUC values, and demonstrated good calibration. The GBM model, an ensemble learning model based on the gradient boosting algorithm, employs decision trees as base learners. It iteratively adds new decision trees to fit the gradient direction of residuals, thereby continuously improving model performance [30]. Additionally, the GBM model can effectively handle complex nonlinear relationships among independent variables. In this study, the combined effect of age, IL-6, operation time, PCT, and type II diabetes was accurately identified, enabling high-precision prediction of postoperative infection risk. Although the Logistic regression model is essentially a linear model with limited ability to fit complex nonlinear data distributions, it still performed well in prediction due to the reasonable inclusion of key independent risk factors. A major advantage of logistic regression lies in its high interpretability [31], allowing clinicians to intuitively understand the influence of each variable's contribu-

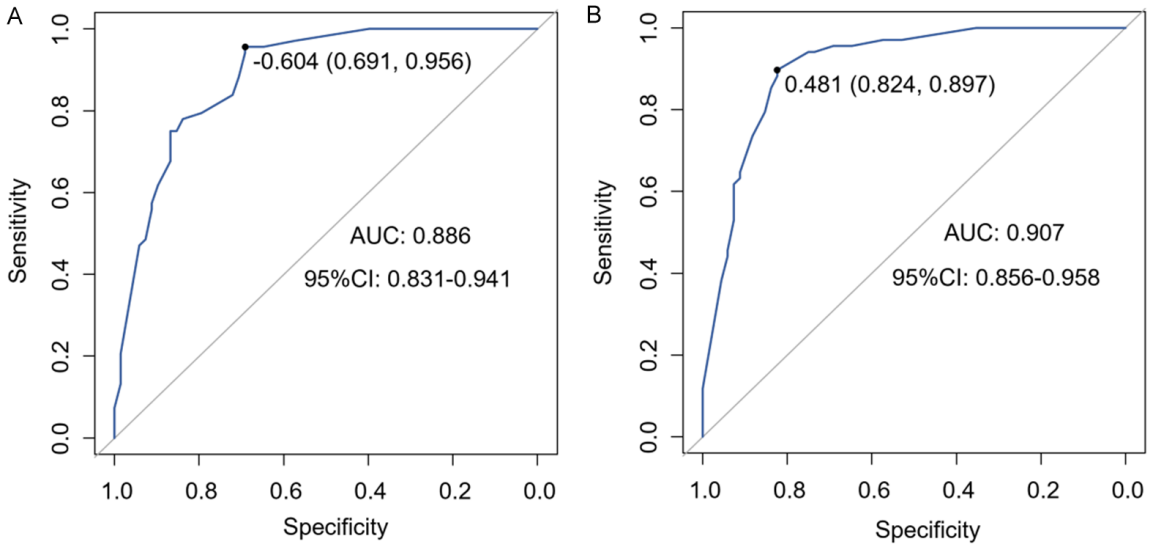

Figure 3. ROC curve analysis for prediction models. A: Logistic model; B: GBM model.

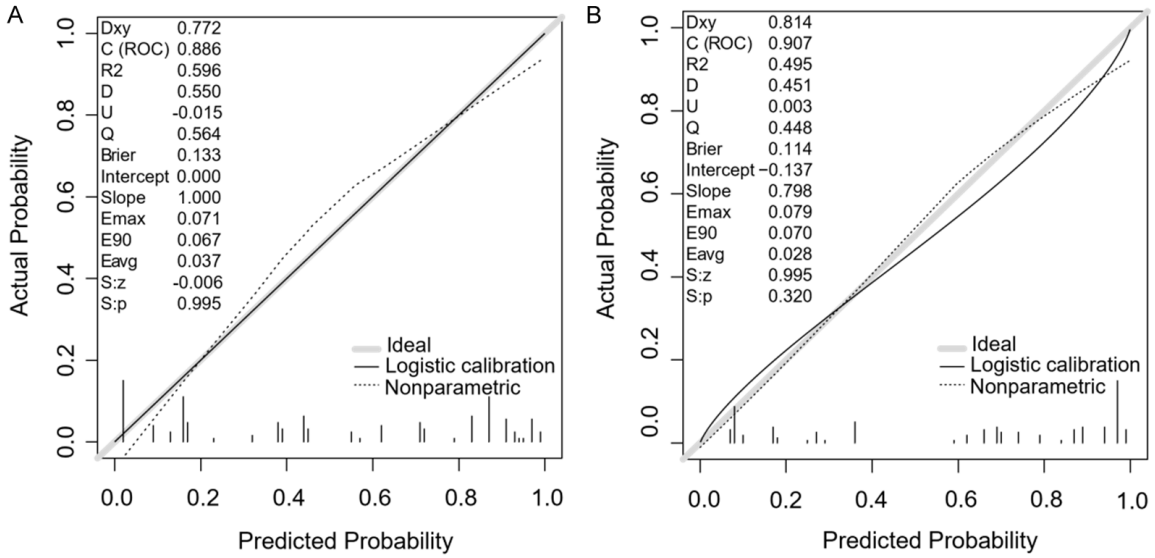

Figure 4. Calibration curve analysis for prediction models. A: Logistic model; B: GBM model.

tion to infection risk, thus facilitating clinical decision-making. Therefore, in clinical practice, model selection should be guided by specific clinical needs. Furthermore, it is also possible to integrate these two models, leveraging the high accuracy of the GBM model and strong interpretability of the Logistic model, to further enhance the prediction performance.

This study has several limitations. First, the sample was derived from a single center with a relatively small sample size, which may limit the generalizability of the findings and affect the stability of the predictive models. Second, the study considered only a limited number of variables, excluding potentially important factors such as the baseline immune status and postoperative care, which may have influenced model performance and reduced its predictive accuracy. Third, the model construction involved only two commonly used algorithms, and hyperparameter optimization was not comprehensively performed. Other advanced machine learning models with potentially superior

performance were not explored. Future studies should aim to include a larger, multicenter cohort, incorporate a broader range of predictive variables, and further optimize or compare modeling techniques to enhance model robustness and clinical applicability.

Conclusion

This study identified age >55 years, type II diabetes, operation time >3.3 h, IL-6>5.5 ng/L, and PCT>0.3 ug/L as independent risk factors for postoperative infection after IT spinal canal resection. Based on these variables, a Logistic model and GBM model were constructed. Both models showed good discrimination and calibration performance, indicating their potential utility in supporting early risk identification and guiding preventive strategies in clinical practice.

Disclosure of conflict of interest

None.

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