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Development and Validation of a Clinical Prediction Model for Postoperative Wound Infection in Patients Undergoing Spinal Tumor Surgery

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Abstract

Objective: To investigate risk factors for postoperative incisional infection after spinal tumor surgery, develop a risk prediction model, and evaluate its predictive performance. **Methods:** Using a retrospective design, 223 patients who underwent spinal tumor surgery at our hospital between December 2024 and March 2026 were enrolled. According to whether surgical wound infection occurred, patients were assigned to a surgical site infection-positive group and a surgical site infection-negative group. Baseline clinical data were collected, and univariate and multivariate analyses were performed; Firth penalized likelihood Logistic regression was adopted to avoid overfitting. A risk prediction model was then constructed based on the results of logistic regression analysis. **Results:** Among the 223 patients who underwent spinal tumor surgery, 11 developed postoperative surgical wound infection, yielding an overall postoperative incisional infection rate of 4.93%. Multivariate analysis indicated that age and surgical approach were independent risk factors for postoperative incisional infection after spinal tumor surgery. The area under the receiver operating characteristic (ROC) curve (AUC) of the prediction model was 0.9419, After correction via internal Bootstrap validation, the area under the curve (AUC) was 0.921. The calibration curve demonstrated satisfactory model fitting (Hosmer-Lemeshow test, P = 0.437); with a sensitivity of 100% and a specificity of 88.37%. **Conclusion:** The risk of incisional infection after spinal tumor surgery is relatively high. Influencing factors include age and surgical approach. The prediction model constructed based on Logistic regression exhibited good discrimination and calibration, with certain clinical application value.

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Keywords

Spinal Tumors, Wound Infection, Spinal Surgery, Risk Factors, Risk Prediction Model

1. Introduction

Spinal tumors comprise primary spinal tumors and spinal metastatic tumors. For most spinal tumors, when refractory pain, progressive neurological impairment, spinal instability, or failure of non-surgical treatment occurs, surgical resection is the preferred clinical option for curative or palliative management [1]. Surgical site infection (SSI) is a common complication of spine surgery [2]. The occurrence of SSI significantly prolongs hospital stay and increases treatment costs, and may also undermine patients' confidence in treatment and compromise therapeutic outcomes [3]. Because SSI risk is influenced by multiple factors, including tumor burden, systemic nutritional status, surgical technique, and perioperative management, postoperative infection risk varies markedly across individuals. Early identification of high-risk patients and implementation of targeted interventions are therefore crucial to reducing infection rates. At present, many domestic studies have examined postoperative infection after general spinal disorders and injuries; however, no prediction model for postoperative wound infection after spinal tumor surgery is currently available. In this study, we retrospectively included 223 patients who underwent surgery for spinal tumors at our hospital, analyzed risk factors for postoperative wound infection, and developed a risk prediction model, providing a theoretical basis for reducing the incidence of postoperative incisional infection in this patient population.

2. Materials and Methods

2.1. General Information

A retrospective study design was used, and 223 patients who underwent surgery for spinal tumors at our hospital between December 2024 and March 2026 were included. The sample size calculation was based on relevant literature [4]; allowing for a 20% attrition rate, the final sample size was determined to be 223 cases. Inclusion criteria were as follows: 1) pathologically confirmed spinal tumor; 2) first-time tumor lesion resection plus spinal internal fixation; 3) complete medical records, preoperative laboratory tests, operative records, and postoperative follow-up data; 4) postoperative follow-up ≥ 30 d, enabling definitive determination of incisional infection; and 5) informed consent provided by the patient and family members. This single-center retrospective case study extracted all data from archived electronic medical records of our hospital. No interventional procedures were performed on patients during the study. All personal information was anonymized and desensitized such that individual identities could not be traced back.

This study was approved by the Institutional Ethics Committee of our hospital, and informed consent was waived. Exclusion criteria were as follows: 1) active infection of the skin at the surgical site preoperatively or systemic sepsis; and 2) concomitant end-stage multiple organ failure or congenital immunodeficiency. Patients were assigned to an infection group or a non-infection group according to whether postoperative incisional infection occurred.

2.2. Diagnostic Criteria for Incisional Infection

With reference to the Clinical Evidence-Based Guideline for the Diagnosis and Treatment of Spinal Surgical Site Infection [5] and the Standard for the Prevention and Control of Surgical Site Infection: postoperative spinal surgical site infection (surgical site infection, SSI) refers to a surgery-related infection occurring within 30 days after procedures without implants and within 90 days after procedures with implants. Diagnostic Criteria: 1) Clinical manifestations: persistent postoperative fever, aggravated perincisional pain, erythema, wound dehiscence, and purulent drainage; 2) Microbiological evidence: positive bacterial culture of wound drainage or puncture fluid; 3) Imaging evidence: MRI or CT showing deep fluid collection with pus, intraspinal or paravertebral abscess. A confirmed diagnosis requires at least one of the following conditions: a) Clinical manifestations combined with positive bacterial culture; b) Clinical manifestations with supportive imaging findings, and pus confirmed via surgery or puncture. Superficial surgical site infection: erythema, increased local skin temperature and purulent discharge from the incision within 30 days after surgery, with positive bacterial culture of secretions. Deep surgical site infection: pus accumulation in the deep fascia and muscular layers, accompanied by fever and markedly elevated inflammatory markers; imaging reveals deep fluid and pus collection in the operative area.

2.3. Research Metrics

Eighteen clinical variables were collected and categorized into three groups: 1) baseline characteristics: age, BMI, preoperative serum albumin, hemoglobin, peripheral white blood cell count, neutrophil level, sex, history of diabetes, history of hypertension, smoking history, and alcohol consumption history; 2) intraoperative variables: surgical site, surgical approach, intraoperative blood loss, operative duration, and internal fixation implantation; and 3) postoperative variables: postoperative drainage duration and occurrence of postoperative cerebrospinal fluid leakage. The outcome variable in this study was whether a postoperative incisional infection occurred. Examples of variable assignment and coding: Surgical site: thoracolumbar spine = 1, cervical spine = 0 (reference group); Surgical approach: posterior approach = 1, anterior approach = 0 (reference group).

2.4. Statistical Methods

Statistical analyses were performed using SPSS 26.0. Quantitative data conforming to a normal distribution are presented as mean ± standard deviation ($\overline{x} \pm s$) and

were compared using the *t* test. Categorical data are presented as counts and percentages (%) and were compared using the χ^2 test. Between-group comparisons were performed using Fisher's exact test. Given that there were only 11 infected cases, the expected frequencies of most cells were less than 5, rendering the chi-square test inappropriate. Considering the limited number of 11 infection events, univariate analysis was first conducted to avoid overfitting and unstable parameter estimates. Continuous variables were compared via the t-test or Mann-Whitney U test, while categorical variables were analyzed with Fisher's exact test. Variables with $P < 0.10$ in univariate analysis or clinically important predictors (age, surgical site, surgical approach) were incorporated into the multivariable logistic regression model. To mitigate bias caused by sparse data, Firth's penalized maximum likelihood estimation was adopted for parameter estimation. Model performance was assessed from three dimensions: 1) Discrimination was evaluated using the receiver operating characteristic (ROC) curve and the area under the curve (AUC). The bias-corrected AUC and corresponding 95% confidence intervals (CIs) were calculated via Bootstrap resampling with 1000 replicates; 2) Calibration was assessed by the Hosmer-Lemeshow test and calibration curves; 3) The optimal cutoff value was determined according to the Youden index to calculate sensitivity and specificity. All reported indices were derived from the original modeling cohort, and internal validation results were presented simultaneously. A two-sided $P < 0.05$ was defined as statistically significant, with the screening threshold loosened to $P < 0.10$ for univariate variable selection.

3. Results

3.1. Univariate Analysis of Postoperative Wound Infection Following Spinal Tumor Surgery

Univariate statistical analyses were performed for all 18 clinical variables. Categorical variables were analyzed using Fisher's exact test, while continuous variables were compared with the t-test or Mann-Whitney U test. The results showed that age ($t = 2.391$, $P = 0.0175$), surgical site ($\chi^2 = 10.165$, $P = 0.0015$), and surgical approach ($\chi^2 = 23.111$, $P < 0.001$) differed significantly between groups ($P < 0.05$). In contrast, BMI, preoperative albumin, hemoglobin, white blood cell count, neutrophil count, intraoperative blood loss, operative time, postoperative drainage duration, sex, diabetes, hypertension, smoking and alcohol history, internal fixation, and cerebrospinal fluid leakage yielded $P > 0.05$, and no association with postoperative incisional infection after malignant spinal tumor surgery was identified. Therefore, only these three variables were included in the multivariable logistic regression analysis. See **Table 1**.

3.2. Multivariable Binary Logistic Regression Analysis

After incorporating variables identified in the univariable screening into the multivariable adjusted analysis, age (Coef. = −0.0483, S.E. = 0.023, Wald = 4.528, $P = 0.033$, OR = 0.953, 95% CI: 0.911 - 0.996) was an independent protective factor

and surgical approach (Coef. = 1.8932, S.E. = 0.758, Wald = 6.230, P = 0.013, OR = 6.647, 95% CI: 1.501 - 29.430) was an independent factors associated with postoperative spinal infection. See Table 2.

Table 1. Results of the univariate analysis (including t/χ^2 values).

Variables	Statistic	P-value
Age	t = 2.391	0.0175
BMI	t = 1.545	0.1246
Albumin	t = 1.196	0.2331
HGB	t = 1.465	0.1452
WBC	t = 0.420	0.6753
neutrophil	t = 0.233	0.8164
Intraoperative blood loss	t = 1.627	0.1076
Surgical duration	t = 1.725	0.0859
Postoperative drainage duration	t = 1.917	0.0567
Gender	Fisher	0.2178
diabetes	Fisher	1.0000
hypertension	Fisher	0.1448
Smoking	Fisher	1.0000
drinking	Fisher	1.0000
Surgical site	Fisher	0.0015
Surgical approach	Fisher	<0.001
Internal fixation	Fisher	1.0000
Cerebrospinal fluid leak	Fisher	0.1014

Table 2. Multivariable binary logistic regression analysis (including S.E., Wald, OR, and 95% CI).

Variables	Coefficient (Coef.)	Standard error (S.E.)	Wald χ^2	P value	OR value	95% CI
constant	−3.9001	1.563	6.230	0.013	-	-
Age	−0.0483	0.023	4.528	0.033	0.953	0.911 - 0.996
Surgical site	0.6116	0.399	2.356	0.125	1.843	0.843 - 4.030
Surgical approach	1.8932	0.758	6.230	0.013	6.647	1.501 - 29.430

3.3. Performance of the Prediction Model

The predictive model was constructed based on the above regression coefficients, with the formula as follows: Logit(P) = −3.9001 − 0.0483 × age + 0.6116 × surgical site (thoracolumbar spine = 1) + 1.8932 × surgical approach (posterior approach = 1). The constructed prediction model achieved an AUC of 0.9419, with 100% sensitivity and 88.37% specificity, demonstrating good discriminatory performance and clinical predictive value. See Table 3 and Figure 1. After internal Boot-

strap validation with 1000 resamples, the bias-corrected AUC was 0.921 (95% CI: 0.867 - 0.956), indicating no obvious overfitting of the model. The calibration curve demonstrated consistency between predicted probabilities and actual observed incidence. The Hosmer-Lemeshow test yielded $\chi^2 = 5.23$, P = 0.437, which suggested favorable calibration performance.

Table 3. Diagnostic performance of the predictive model.

Metrics	Numerical value(s)
AUC	0.9419
Optimal truncation value	0.346
Sensitivity	1.0000
Specificity	0.8837
Bootstrap-corrected AUC	0.921
Hosmer-Lemeshow P	0.437

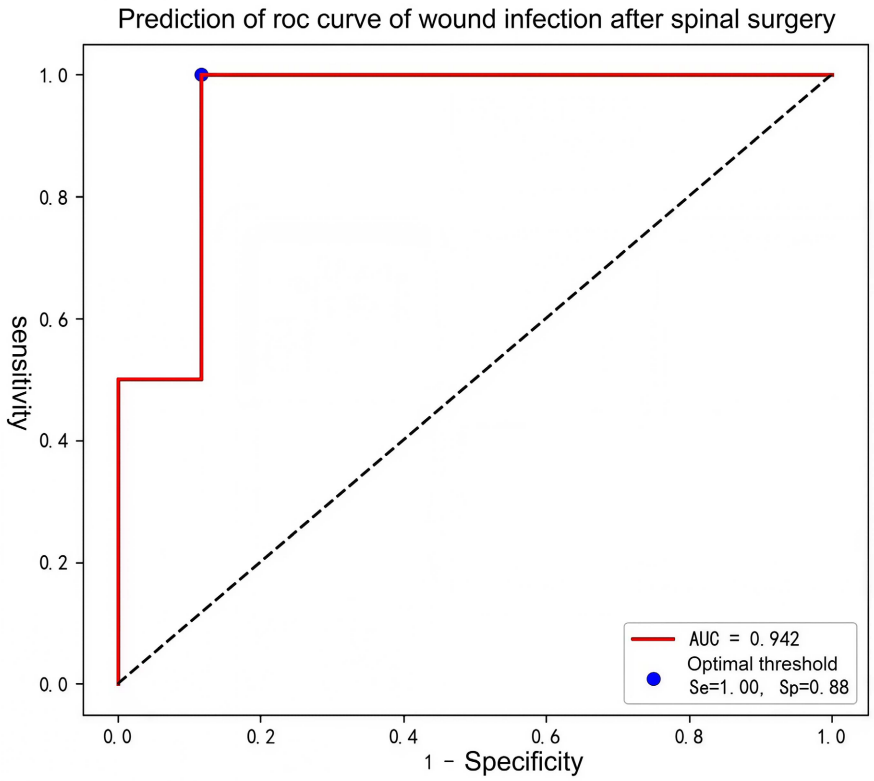

Figure 1. Receiver operating characteristic curve of the nomogram model for postoperative surgical site infection in spinal surgery, AUC = 0.942.

4. Discussion

Surgical site infection (SSI) is a common complication of spinal surgery, substantially increasing patients' length of hospital stay and financial burden and markedly worsening prognosis [6]. Therefore, it is necessary to investigate the risk fac-

tors for SSI to facilitate early identification of high-risk individuals, enable model-based preoperative individualized risk warning, guide clinically precise anti-infective nursing care, and improve postoperative recovery outcomes.

4.1. Incidence of Surgical Site Infections in Spinal Surgery

The results of this study showed that among 223 patients, 11 had positive surgical wound infections, yielding an overall postoperative incisional infection rate of 4.93%. This rate was higher than that reported by Liu Bin [7] *et al.* (0.93%) and by Ma Jiaojiao [8] *et al.* (0.43%).

4.2. Factors Influencing Surgical Wound Infection in Spinal Surgery

4.2.1. Age

Age was identified as a protective factor for postoperative infection (OR = 0.953), with the risk of infection decreasing slightly for each additional year of age, which differs from the conclusions of most studies on routine spinal surgery [7] [9]. Possible explanations are as follows: older patients with spinal tumors typically undergo comprehensive preoperative systemic evaluation, and those with concomitant diabetes or malnutrition receive early nutritional support and chronic disease management before surgery, with elective surgery scheduled only after relevant indices meet target thresholds. In contrast, tumors in young and middle-aged patients often progress rapidly, and surgery is frequently performed on an urgent, time-limited basis, leaving insufficient time for preoperative optimization. Therefore, infection prevention should not focus exclusively on older patients; postoperative incision care in young and middle-aged patients with malignant spinal tumors also requires close monitoring.

4.2.2. Surgical Approach

This study confirmed that the surgical approach is an independent risk factor for postoperative incisional infection after malignant spinal tumor surgery (OR = 6.647), indicating a 6.647-fold increase in infection risk among patients undergoing this type of approach. Related studies have also shown that [10] [11]: the infection rate is relatively high after posterior internal fixation, and clinically high-risk procedures are predominantly posterior spinal tumor resections. Posterior approaches for spinal tumors require extensive dissection of the paraspinal muscles, and tumor lesions invade surrounding soft tissues; consequently, intraoperative wound oozing is substantial and tissue damage is severe, and hematoma readily becomes a medium for colonization and growth of pathogenic bacteria. In contrast, anterior approaches can avoid extensive muscle dissection. For patients undergoing posterior surgery, preoperative optimization of skin preparation and correction of abnormal indicators such as hypoproteinemia and anemia are recommended; intraoperatively, meticulous hemostasis and avoidance of unnecessary soft-tissue dissection should be emphasized; postoperatively, ensure unobstructed drainage and select prophylactic antibiotics on an individualized basis

according to guidelines to reduce the risk of infection.

4.3. Development of a Risk Model for Postoperative Spinal Surgical Wound Infection

This study included 18 variables, including age, sex, body mass index, diabetes, hypertension, preoperative albumin, hemoglobin, and surgical approach. A risk prediction model for postoperative spinal wound infection was developed based on the regression coefficients from logistic regression analysis. The model stratification was evaluated using ROC curve analysis, indicating good predictive performance with both specificity and sensitivity at relatively high levels.

5. Summary

The surgical approach was an independent high-risk factor for postoperative incisional infection after spine tumor surgery, whereas age was a protective factor. A risk prediction model constructed based on these two variables achieved an AUC of 0.9419, with favorable sensitivity and specificity, demonstrating excellent predictive performance and potential clinical utility. However, this study has several limitations. First, it was a single-center retrospective study, with all cases derived from the same hospital, which may limit generalizability. Second, no independent external validation cohort was established; ROC performance was assessed only in the development sample, and the model's stability requires further validation and refinement through future multicenter, large-sample prospective studies.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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