Article

Evaluation of Critical Risk Factors and Development of a Predictive Model for Surgical Site Infection in Type 2 Diabetic Patients Undergoing Oral and Maxillofacial Surgery

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AIM: This study aims to explore the critical risk factors associated with surgical site infection (SSI) in patients with type 2 diabetes mellitus (T2DM) undergoing oral and maxillofacial surgery, and to develop a predictive model to support early risk stratification and guide targeted preventive approaches.
METHODS: This retrospective, case-control study enrolled patients with T2DM who underwent oral surgery at Nanjing Stomatological Hospital, Nanjing University between June 2022 and June 2025. A total of 110 patients who developed postoperative SSI were included in the infection group. A total of 110 patients without SSI were selected as the control group, matched 1:1 according to age and sex. Detailed demographic and clinical data, including patient history, perioperative blood glucose control levels, surgical type, oral environment, and antibiotic usage, were collected from both groups. Risk factors associated with SSI were analyzed and compared between groups, and a nomogram prediction model was developed. Internal validation was performed using 5000 bootstrap resamples, and model performance was assessed via the area under the receiver operating characteristic (ROC) curve (AUC) and calibration plots.
RESULTS: Among the 110 patients who developed SSI after oral surgery, microbiological assessment identified Gram-negative bacteria as the predominant pathogens (62.73%), with Pseudomonas aeruginosa accounting for 18.18% and Klebsiella pneumoniae for 14.55% of the isolates. This was followed by Gram-positive organisms, which account for 34.55% of the pathogens, predominantly Staphylococcus aureus (10.91%). Multivariable logistic regression analysis showed that a surgical incision classified as Type II or III (vs Type I; Odds Ratio [OR] = 3.789), severe periodontal calculus in the oral environment (Grade III vs Grade I–II; OR = 4.092), poor blood glucose control (vs good; OR = 3.347), and elevated serum C-reactive protein (CRP) levels (per unit increase; OR = 1.627) were independently associated with postoperative surgical site infection. A nomogram was constructed based on the equation: Logit (P) = 1.402 + 1.332 $\times$ (incision type) + 1.409 $\times$ (oral environment) + 1.208 $\times$ (blood glucose control) + 0.487 $\times$ (CRP). The maximum total score on the nomogram was 225 points, corresponding to a 90% predicted probability of postoperative SSI. The Hosmer-Lemeshow test (χ^2 = 2.088, p = 0.230 $>$ 0.05) demonstrated no significant difference between the observed and predicted outcomes of the nomogram model. The nomogram demonstrated excellent predictive performance, with an AUC of 0.897 (95% Confidence Interval [CI]: 0.855 to 0.939).
CONCLUSIONS: The oral environment, perioperative glycemic control, CRP levels, and surgical incision type are independent risk factors associated with postoperative SSI. Establishing a prediction model based on these factors and implementing targeted interventions can effectively reduce infection in this high-risk cohort.

Keywords: glycemic control; type 2 diabetes; oral surgery; surgical site infection; risk factors; prediction model

Introduction

Surgical site infection (SSI) following oral and maxillofacial surgery is a common postoperative complication. It can delay wound healing, exacerbate pain, and impair oral function. In severe cases, it can lead to fascial space infections of the head and neck or even induce systemic inflammatory responses. These manifestations increase the likelihood of reoperation, prolong hospitalization, and significantly raise the healthcare expenses and medication exposure for patients [1]. Patients with type 2 diabetes mellitus (T2DM) are a high-risk group for postoperative SSI. Chronic hyperglycemia and glycemic variability impair neutrophil chemotaxis, phagocytosis, and bactericidal activity, reducing innate immune responses. Concurrently, compromised collagen synthesis, impaired angiogenesis, diabetic microangiopathy, and reduced microcirculatory perfusion further diminish healing capacity and tissue resistance to infection [2]. In clinical practice, short-term perioperative blood glucose levels are often used to de-

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termine infection risk. However, isolated glucose measures may not accurately reflect the combined effects of chronic glycemic burden and glycemic variability, which may exert sustained adverse effects on immune responses and tissue repair.

Oral and maxillofacial procedures represent additional concerns compared with other surgical interventions. The oral cavity is a complex microenvironment characterized by a high bacterial load and persistent biofilm formation. Periodontal pathogens, dental plaque, and calculus can act as continuous sources of bacteria and inflammatory stimulation. Furthermore, additional factors such as the levels of surgical field contamination, operative duration, choice of suture material, and drainage management affect local microecology and wound homeostasis [3]. In individuals with diabetes, the combination of systemic immunometabolism susceptibility and a highly colonized local environment results in a setting in which wound infection is more readily initiated and propagated.

Current research predominantly focuses on antibiotic regimens or improvements in surgical technique, often failing to address the interactions between systemic inflammatory state, glycemic variability, and the distinct oral microenvironment. Moreover, there is a notable scarcity of practical and quantifiable bedside risk assessment tools tailored specifically for diabetic cohorts [4]. Based on this rationale, the present retrospective case-control study was designed to systematically assess the impact of various factors, including glycemic management parameters, on the incidence of SSI in patients with T2DM undergoing oral surgery. By identifying clinically relevant risk factors, this study aims to support early detection of high-risk individuals and inform targeted intervention strategies in routine clinical practice.

Methods

Study Design and Enrollment of the Study Subjects

This retrospective case-control study included patients with T2DM who underwent oral surgery at Nanjing Stomatological Hospital, Nanjing University, between June 2022 and June 2025. The required sample size was calculated based on a 95% confidence level and 80% statistical power, assuming an Odds Ratio (OR) of 2.0 for the primary risk factor. This calculation yielded a minimum required sample size of 149 cases. However, taking into account the accuracy of clinical data, potential missing information, and the need for stable model estimation, a total of 220 patients were ultimately enrolled in this study to ensure robust and reliable results. Among them, 110 patients who developed postoperative incision infections were included in the infection group, while 110 patients without postoperative infections were selected as the control group.

The diagnostic criteria of T2DM were established according to the “Clinical guidelines for prevention and treatment of type 2 diabetes mellitus in the elderly in China (2022 edition)” [5]. Furthermore, SSI was defined according to the “Diagnostic criteria for nosocomial infection (Trial)” [6].

Inclusion criteria for patient selection were as follows: (1) age ≥19 years; (2) a confirmed medical history of T2DM; (3) oral surgery performed by the same surgical team; and (4) availability of Fasting Plasma Glucose (FPG) and Glycated Hemoglobin A1c (HbA1c) data from both pre-surgery and one-week post-surgery. However, patients with (1) incomplete baseline data, (2) an active oral infection before surgery, and (3) human immunodeficiency virus (HIV) infections were excluded from the study cohort.

Microbiological Analysis of Surgical Site Infections

Samples were collected from individuals who developed confirmed postoperative SSI before the initiation of initial empirical antibiotic therapy. Each specimen was inoculated and cultured separately. The predominant colonies were selected for further identification. Microbial identification was conducted using the VITEK 2 Compact automated system (bioMérieux, Marcy l’Etoile, France). Antimicrobial susceptibility assessment results were interpreted according to the most recent Clinical and Laboratory Standards Institute (CLSI) M100 guidelines [7].

To maintain analytical accuracy, daily quality control procedures were performed using American Type Culture Collection (ATCC) reference strains, such as Escherichia *coli* ATCC 25922, Staphylococcus aureus ATCC 25923, Pseudomonas aeruginosa ATCC 27853, and Enterococcus faecium ATCC 29212. These measures ensured the reliability of culture, organism identification, and antimicrobial susceptibility testing (AST). In cases of suspected contamination or when results were inconsistent with the patient’s clinical presentation, samples were recollected, and testing was repeated in accordance with established standard operating procedures.

Glycemic Management Standards

Good glycemic control was defined as a perioperative mean FPG level between 6.1 and 7.8 mmol/L, together with a HbA1c level below 7.0%. Based on the institution’s clinical practice and previous research, individuals who did not meet either of these criteria were defined as having poor glycemic control.

Data Collection

Clinical data were collected by carefully reviewing medical records. Baseline variables included age, body mass index (BMI), duration of T2DM, sex, smoking history, alcohol consumption, hypertension, history of hyperlipidemia, operative time, surgical incision type, American Society of Anesthesiologists (ASA) classification, estimated intraoperative blood loss, duration of catheterization, underlying primary condition, use of prophylactic antibiotics, and evaluation of oral environment. Additionally, laboratory parameters, including white blood cell (WBC) count, hemoglobin (Hb), serum albumin (ALB), and C-reactive protein (CRP) levels, were recorded on postoperative day 3, prior to the clinical diagnosis of surgical site infection (SSI) in all cases. For patients who later developed SSI, this time point preceded the onset of clinical signs and the confirmatory diagnosis of infection.

Statistical Analysis

Data analyses were conducted using SPSS version 21.0 (IBM Corp., Armonk, NY, USA) and R version 4.0.0 (R Foundation for Statistical Computing, Vienna, Austria). Continuous variables were tested for normal distribution using the Kolmogorov-Smirnov test. As all variables followed a normal distribution, they were expressed as (mean $\pm$ standard deviation [$\bar{x} \pm$ SD]). Comparisons between groups were performed using independent samples *t*-tests. Categorical variables, such as medical and disease history, were presented as frequencies and percentages (%). Inter-group comparisons for categorical variables were conducted using the chi-square (χ^2) test.

Factors affecting postoperative incision infection were assessed using multivariate logistic regression analysis. Variables were incorporated into the model using a forward entry method with a stepwise selection approach. The final model included 110 outcome events and 4 predictors, yielding an event-per-variable ratio of 27.5, which exceeds the commonly recommended threshold and indicates a low risk of serious overfitting. Based on the final model, a nomogram prediction model was constructed. Model performance was evaluated using the Hosmer-Lemeshow test, and a calibration curve was plotted. The model's goodness-of-fit was validated using the bootstrap method with 5000 resamples. The clinical benefit of the model was assessed through decision curve analysis (DCA), and predictive performance was assessed by calculating the area under the receiver operating characteristic (ROC) curve (AUC). A *p*-value < 0.05 was considered statistically significant.

Results

Identification of Pathogens in Oral Surgical Site Infections

Among 110 patients who developed SSI after oral surgery, microbiological testing of wound secretions revealed Gram-negative bacteria as the primary cause (62.73%). The most frequently identified species were Pseudomonas aeruginosa (18.18%) and Klebsiella pneumoniae (14.55%). Gram-positive bacteria represented 34.55% of cases, with Staphylococcus aureus being the most frequent organism in this group (10.91%). See Table 1.

Table 1. Distribution of pathogens in oral SSI.

Pathogen type	Strain count	Percentage
Gram-negative bacteria	69	62.73%
Pseudomonas aeruginosa	20	18.18%
Klebsiella pneumoniae	16	14.55%
Enterobacter cloacae	11	10.00%
Proteus vulgaris	9	8.18%
Acinetobacter baumannii	9	8.18%
Other	4	3.64%
Gram-positive bacteria	38	34.55%
Staphylococcus aureus	12	10.91%
Enterococcus faecalis	10	9.09%
Staphylococcus epidermidis	8	7.27%
Staphylococcus haemolyticus	5	4.55%
Other	3	2.73%
Fungal infection	3	2.73%
Candida albicans	3	2.73%

SSI, surgical site infection.

Comparison of Baseline Characteristics Between the Infection and Control Groups

As presented in Table 2, no statistically significant differences were observed between the infection and control groups regarding age, BMI, duration of T2DM, sex, smoking history, alcohol consumption, hypertension, or dyslipidemia ($p > 0.05$).

Comparison of Blood Glucose Control and Laboratory Indicators Between the Infection and Control Groups

Patients in the infection group exhibited poor glycemic control compared with the control group. Furthermore, peripheral blood levels of WBC and CRP were significantly elevated, while Hb and ALB were significantly reduced in the infection group ($p < 0.05$, Table 3).

Comparison of Surgical Outcomes Between the Infection and Control Groups

Compared with the control group, patients in the infection group had significantly higher proportions of Class II and III surgical wounds, ASA physical status II and III, and Grade III dental calculus ($p < 0.05$). In contrast, no significant differences were found between groups in operative time, intraoperative blood loss, duration of postoperative catheterization, underlying surgical conditions, or the use of prophylactic antibiotics ($p > 0.05$, Table 4).

Analysis of Factors Affecting Postoperative Infection Following Oral Surgery

Statistically significant variables from the univariate analysis were included in the multivariate model as independent variables. These included blood sugar control status (Good = 0, Poor = 1), peripheral WBC count, serum CRP, peripheral Hb, serum ALB, surgical incision type (Class I = 0, Class II or III = 1), ASA classification (Grade I = 0, Grade II or III = 1), and oral environment (periodontal calculus Grade I or II = 0, Grade III = 1).

Initially, multicollinearity was assessed using the variance inflation factor (VIF). After excluding peripheral blood Hb and WBC due to collinearity concerns, the VIF values for the remaining independent variables were all below 5, indicating acceptable control of multicollinearity. Then, a

Table 2. Comparison of baseline characteristics between the infection and control groups.

General data	Infection group (n = 110)	Control group (n = 110)	t/χ^2	p-value
Age (years)	68.6 ± 7.0	67.0 ± 9.2	1.452	0.148
BMI (kg/m^2)	23.8 ± 2.4	24.2 ± 2.6	–1.186	0.237
Duration of T2DM (%)			3.712	0.054
≥10 years	73 (66.36)	59 (53.64)		
<10 years	37 (33.64)	51 (46.36)		
Gender (%)			1.178	0.278
Male	65 (59.09)	57 (51.82)		
Female	45 (40.91)	53 (48.18)		
Smoking history (%)			0.707	0.400
Yes	43 (39.09)	37 (33.64)		
No	67 (60.91)	73 (66.36)		
Alcohol consumption (%)			1.244	0.265
Yes	37 (33.64)	45 (40.91)		
No	73 (66.36)	65 (59.09)		
Hypertension (%)			2.309	0.122
Yes	45 (40.91)	34 (30.91)		
No	65 (59.09)	76 (69.09)		
Hyperlipidemia (%)			2.209	0.137
Yes	64 (58.18)	53 (48.18)		
No	46 (41.82)	57 (51.82)		

BMI, body mass index; T2DM, type 2 diabetes mellitus.

Table 3. Comparison of blood glucose control and laboratory indicators between the infection and control groups.

Variable	Infection group (n = 110)	Control group (n = 110)	t/χ^2	p-value
Blood sugar control situation (%)			45.938	<0.001
Good	51 (46.36)	98 (89.09)		
Poor	59 (53.64)	12 (10.91)		
WBC (×10^9/L)	10.2 ± 2.1	7.4 ± 1.8	10.618	<0.001
Hb (g/L)	129.9 ± 8.3	132.3 ± 9.2	2.031	0.043
ALB (g/L)	41.0 ± 3.8	44.1 ± 4.4	–5.592	<0.001
CRP (mg/L)	18.2 ± 3.2	9.0 ± 1.8	26.281	<0.001

WBC, white blood cell; Hb, hemoglobin; ALB, albumin; CRP, C-reactive protein.

logistic regression model was constructed using a forward conditional method for variable selection. The analysis identified the following variables as significant independent risk factors for postoperative infection after oral surgery ($p < 0.05$): Class II or III surgical incision (OR = 3.789); Grade III periodontal calculus (OR = 4.092); poor glycemic control (OR = 3.347); and elevated serum CRP (OR = 1.627). See Table 5.

Development and Analysis of the Prediction Model

Given the findings in section 3.5, the following logistic regression equation was developed: Logit (P) = 1.402 + 1.332 × surgical incision type + 1.409 × oral environment + 1.208 × blood sugar control situation + 0.487 × CRP. Employing this model, a nomogram was developed to provide a visual and clinically applicable risk assessment tool (Fig. 1). Within the nomogram, each independent variable corresponds to a specific score on the upper horizontal axis. The total score is calculated by summing the scores for each variable. A total score of 225 points (the sum of the maximum scores for all factors) corresponds to an estimated 90% probability of postoperative incision infection.

Assessing the Predictive Performance of the Nomogram Model

All 220 patients were included in the training set for model construction. The predictive performance of the nomogram-based risk prediction model was evaluated by plotting a calibration curve (Fig. 2). In this plot, the x-axis represents the predicted probability of postoperative infection, and the y-axis represents the actual probability. The red diagonal line indicates a perfect agreement between predicted and actual outcomes, whereas the solid green line represents the predictive performance of the present model. The internally validated C-index, corrected by 5000 bootstrap resamples, was 0.811 (95% Confidence Interval [CI]: 0.763–0.854). The Hosmer-Lemeshow goodness of fit test yielded a χ^2 value of 2.088 with p = 0.230, suggesting no

Table 4. Comparison of surgical outcomes between the infection and control groups.

Surgical details	Infection group (n = 110)	Control group (n = 110)	χ^2	p-value
Operation time (%)			1.164	0.281
<3 h	51 (46.36)	59 (53.64)		
≥3 h	59 (53.64)	51 (46.36)		
Surgical incision type (%)			17.496	<0.001
Class I	72 (65.45)	98 (89.09)		
Class II + Class III	38 (34.55)	12 (10.91)		
ASA grading (%)			4.242	0.039
Grade I	70 (63.64)	84 (76.36)		
Grade II + Grade III	40 (36.36)	26 (23.64)		
Intraoperative blood loss (%)			2.895	0.089
<200 mL	32 (29.09)	44 (40.00)		
≥200 mL	78 (70.91)	66 (60.00)		
Duration of catheterization (%)			1.518	0.218
<24 h	41 (37.27)	50 (45.45)		
≥24 h	69 (62.73)	60 (54.55)		
Primary disease (%)			2.263	0.163
Oral tumors	83 (75.45)	92 (83.64)		
Trauma	27 (24.55)	18 (16.36)		
Prophylactic antibiotic use (%)			0.032	0.857
Yes	91 (82.73)	92 (83.64)		
No	19 (17.27)	18 (16.36)		
Oral Environment (%)			16.410	<0.001
Grade III periodontal calculus	37 (33.64)	12 (10.91)		
Grade I + Grade II periodontal calculus	73 (66.36)	98 (89.09)		

ASA, American Society of Anesthesiologists.

Table 5. Analysis of factors affecting postoperative infection following oral surgery.

Influencing factors	β	SE	Wald χ^2	p-value	OR	95% CI
Surgical incision type	1.332	0.632	4.442	0.037	3.789	1.098–13.075
Oral environment	1.409	0.492	8.201	<0.001	4.092	1.560–10.733
Blood sugar control situation	1.208	0.512	5.567	0.011	3.347	1.227–9.130
CRP	0.487	0.188	6.710	<0.001	1.627	1.126–2.353
Constant term	1.402	0.904	2.405	0.185	-	-

OR, Odds Ratio; CI, Confidence Interval; SE, Standard Error.

significant difference between the observed and predicted outcomes and indicating adequate model calibration. Clinical utility of the model was further assessed using decision curve analysis (DCA) (Fig. 3). Within the threshold probability range of 0.01 to 1.00, the net benefit of using this nomogram model was consistently higher than that of the two extreme strategies of "treat all" or "treat none". Furthermore, a ROC curve was generated based on the nomogram-derived risk scores (Fig. 4). The area under the receiver operating characteristic (ROC) curve (AUC) for predicting postoperative infection in oral surgery was 0.897 (95% CI: 0.855–0.939), indicating strong predictive performance.

Discussion

The distribution of pathogens responsible for postoperative oral incision infections is significantly affected by the patient's immune status and the local oral microenvironment. Under normal conditions, the oral cavity is predominantly colonized by aerobic streptococci and staphylococci. However, in diabetic patients, reduced salivary flow and a persistently hyperglycemic environment facilitate the colonization of Gram-negative bacilli [8].

In this study, Gram-negative bacteria accounted for 62.73% of all detected pathogens. Among them, Pseudomonas aeruginosa and Klebsiella pneumoniae were the most highly isolated organisms. In contrast, Staphylococcus aureus was the predominant Gram-positive pathogen. The hyperglycemic environment can modify the local wound environment by altering exudate composition and pH, thereby influencing the spectrum of colonizing bacteria as well as the expansion of opportunistic pathogens [9]. In the present study, no statistically significant difference was observed between groups regarding prophylactic antibiotic use. The

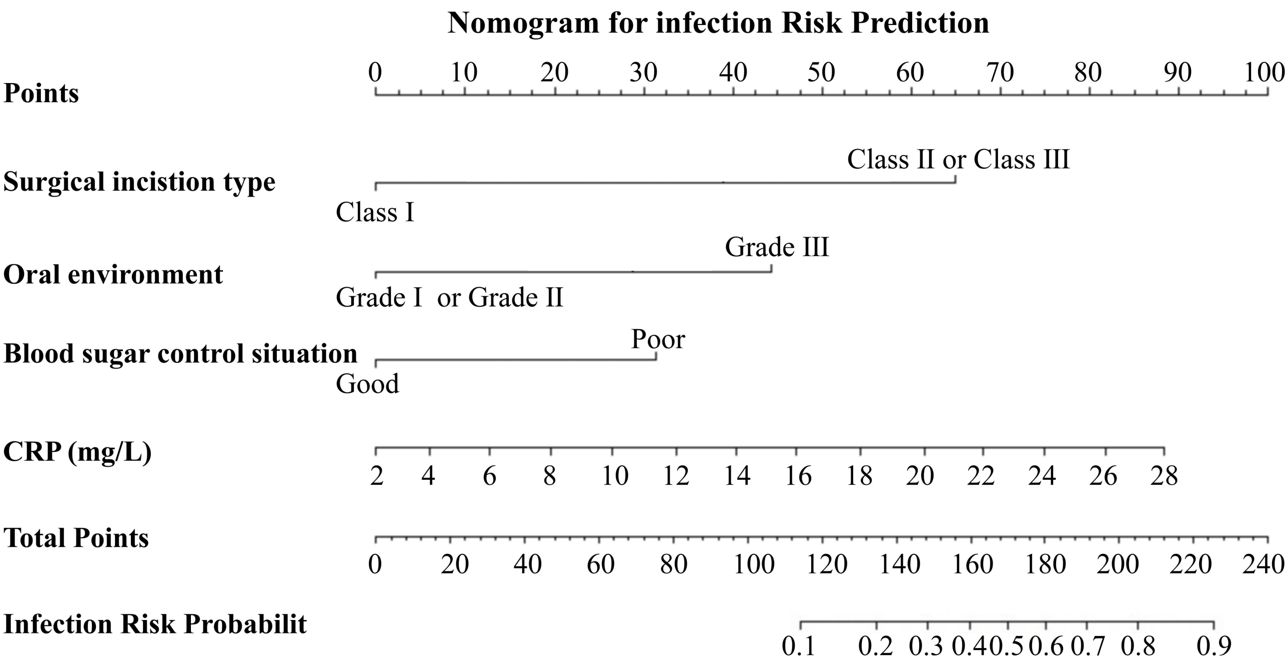

Fig. 1. A nomogram model was developed for risk assessment. CRP, C-reactive protein.

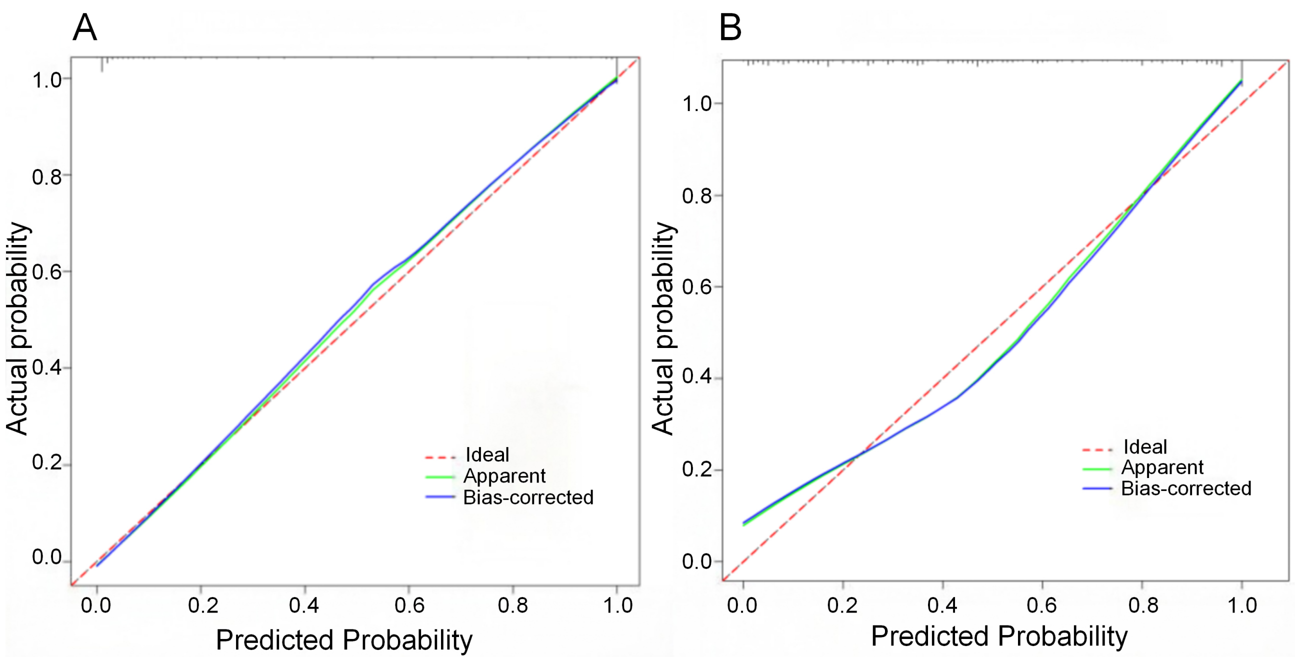

Fig. 2. Calibration curve for the predictive performance of the nomogram model. (A) training set. (B) bootstrap validation set.

association between this factor and the differences in microbial spectrum warrants further quantitative evaluation. In this study, no statistically significant differences were observed between groups regarding the prophylactic use of antibiotics.

Comparable results have been observed in other diabetic cohorts. For example, analysis of diabetic foot infections has revealed that Gram-negative bacteria account for about 57.6% of all cases, with Escherichia coli and Pseudomonas aeruginosa being the most commonly isolated organisms, while the Gram-positive bacteria, such as Staphylococcus aureus, are relatively less frequent [10]. Another study involving elderly individuals receiving home healthcare detected methicillin-resistant Staphylococcus aureus (MRSA) and multidrug-resistant Gram-negative bacteria in oral swabs, indicating that the oral cavity can serve as a reservoir for hospital-acquired drug-resistant organisms [11]. Overall, these findings consistently highlight the sus-

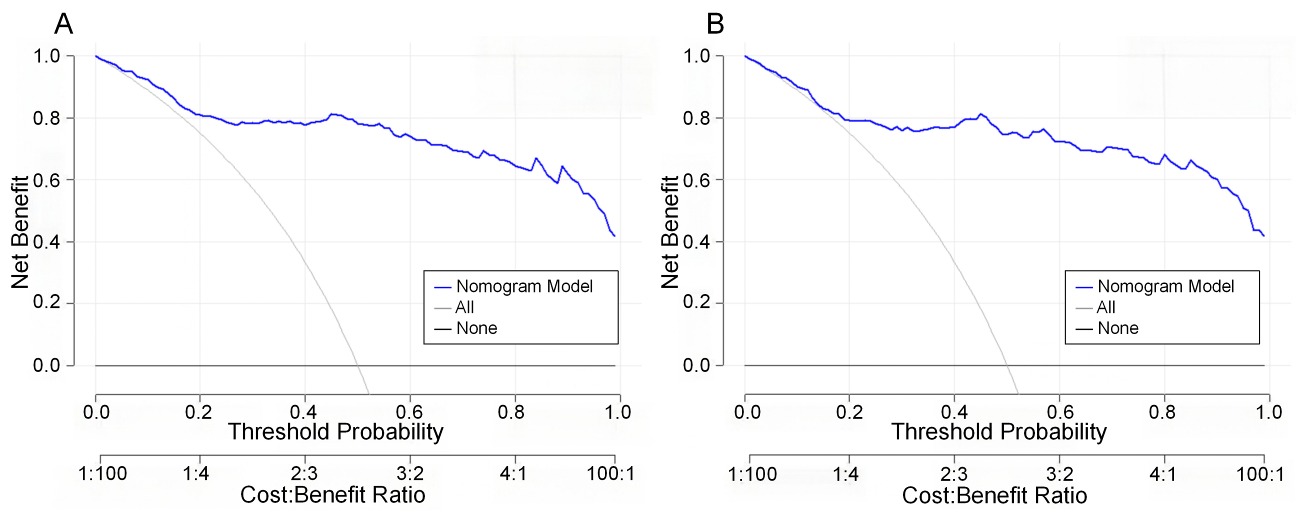

Fig. 3. Decision curve analysis (DCA) curve for assessing the clinical utility of the nomogram model. (A) training set. (B) bootstrap validation set.

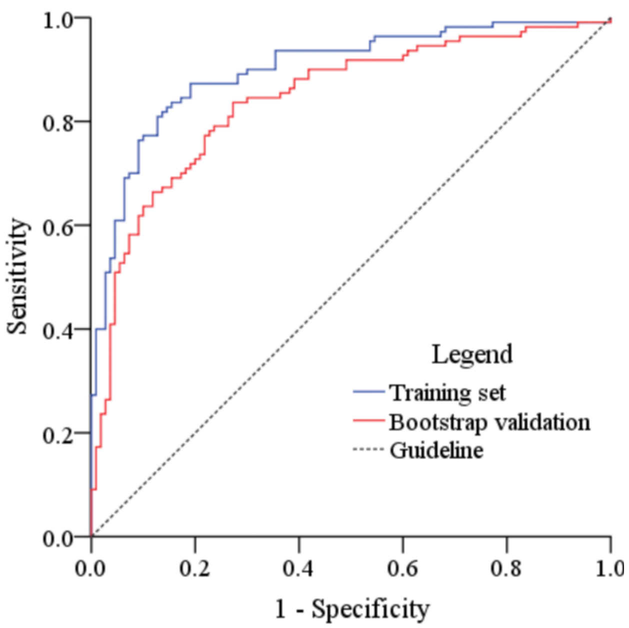

Fig. 4. ROC curve analysis for predicting the nomogram model's performance. ROC, receiver operating characteristic.

ceptibility of diabetic patients to oral microbial dysbiosis and colonization by drug-resistant bacteria, which aligns with the predominance of Gram- negative bacteria observed in the present study. Although anaerobic culture was performed, no typical anaerobic bacteria were detected. This may be due to specimen collection primarily from superficial secretions, limitations in maintaining a strict anaerobic environment during sample transport, or preoperative antibiotic exposure. These findings underscore the importance of optimizing preoperative oral hygiene and microbial sampling procedures to further enhance diagnostic accuracy and infection prevention approaches.

The baseline characteristics of surgical patients are widely known as significant determinants of postoperative infection risk [12]. Particularly, age has been reported as a critical indicator of surgical site infection [13]. A systematic review by Wang *et al.* [14] reported that advancing age is associated with a higher risk of postoperative complications, further exacerbated by elevated inflammatory markers. Similarly, Mihretie *et al.* [15] incorporated age into a predictive model for general surgery patients and observed high discriminative performance. However, in the present study, no statistically significant differences were observed between the infection and control groups in terms of age, sex, BMI, smoking history, alcohol consumption, hypertension, or hyperlipidemia. In this cohort, age did not emerge as an independent factor. Several explanations may account for this discrepancy. First, the age distribution of patients was relatively concentrated, which may have limited heterogeneity. Second, the matching process may have decreased age differences between the two groups. Third, the inclusion of glycemic control markers and inflammatory indicators in the multivariate model may have reduced the independent contribution of age.

Although the duration of diabetes did not reach statistical significance, a notable trend was observed in intergroup comparisons, implying that long-term hyperglycemic pathology may have a potential impact on the body's anti-infective capacity. However, the lack of statistical significance in this population should not be interpreted as evidence that age is not a risk determinant. Rather, it indicates the complexity of risk interaction in patients undergoing oral surgery. Hence, larger, multicenter studies are warranted to further elucidate the independent and combined effects of age and metabolic risk determinants on the postoperative risk of infection.

The level of blood glucose control in diabetic patients is directly related to the healing of surgical incisions and susceptibility to postoperative infection. Perioperative hyperglycemia impairs neutrophil chemotaxis and phagocytosis, leading to microvascular dysfunction, and disrupts collagen synthesis [16]. In this study, poor glycemic control was significantly higher in the infected group compared to the control group. Patients who developed infection also had elevated peripheral WBC counts and serum CRP, together with decreased Hb and ALB levels. This pattern indicates that the combination of hyperglycemia and malnutrition may exacerbate systemic inflammatory responses and weaken wound-healing capacity, thereby elevating the risk of infection.

Findings from other studies also support these outcomes. A prospective cohort study reported that when time in range (TIR) for blood glucose fell below 70% in T2DM patients, the risk of postoperative infection increased by 52.2%, and identified TIR, blood glucose fluctuations, incision type, and WBC count as significant predictors [17]. Similarly, a multi-marker analysis revealed that perioperative CRP level >10 mg/L and HbA1c levels >8% independently predict postoperative complications [18]. These findings confirm the crucial role of glycemic control and inflammatory markers in determining infection risk. Notably, CRP levels measured on postoperative day 3, before the clinical onset of SSI, were significantly elevated in patients who subsequently developed infection, suggesting that early postoperative inflammatory status may reflect underlying susceptibility or a subclinical response. This highlights the importance of rigorous perioperative glucose management and nutritional support in patients with diabetes undergoing oral surgery. Additionally, early postoperative CRP monitoring may support the timely identification of patients at higher risk for subsequent infection.

Surgical factors determine the microbial exposure of the incision and the physiological stress imposed on the patient. The present study revealed that infections occurred more commonly in patients with Class II or III incisions and in those classified as ASA II or III. Additionally, grade III periodontal calculus was significantly more frequent in the infection group compared with the control group. Catheterization time was included as an indicator of perioperative management, indicating elements such as surgical complexity, anesthetic care, and the intensity of postoperative monitoring. However, no statistically significant difference was observed between the two groups for this variable. These findings suggest that factors related to incision cleanliness and host oral hygiene conditions may play a more significant role in infection occurrence than procedural duration or perioperative logistics. Class II and III incisions are exposed to the abundant and diverse microbiota of the oral cavity. When extensive dental calculus is present, a thicker biofilm supports microbial proliferation and facilitates bacterial invasion into the surgical wound. Furthermore, a higher ASA grade indicates greater underlying diseases and reduced physiological resistance [19].

In the univariate analysis, ASA classification demonstrated a statistically significant association with postoperative infection. However, it did not remain an independent predictor in the multivariate model. This may be due to the overall systemic risk reflected by a higher ASA grade, which was already captured in more specific variables included in the model, particularly poor glycemic control and elevated CRP levels, suggesting that direct metabolic and inflammatory indicators may provide more accurate and independent predictive information than a composite anesthetic risk score. These findings are inconsistent with the study by Bhat *et al*. [20], which identified ASA grade III or higher as an independent risk factor for surgical site infection following abdominal surgery. The discrepancy may be attributed to differences in the study populations and the variables included in each analysis. Evidence published in the World Journal of Diabetes indicates that persistent periodontal infections can exacerbate systemic inflammation and impair blood glucose control, and periodontal disease has been reported as the sixth major complication of diabetes [21]. Consistent with these findings, the present study further reinforces the significance of refining periodontal status before surgery. Hence, careful preoperative periodontal cleaning and incision management are critical for preventing infections in diabetic patients undergoing oral and maxillofacial procedures.

Using multivariate logistic regression analysis, the present study identified four independent risk factors of postoperative incision infection in patients with T2DM undergoing oral surgery: Class II or III incisions (OR = 3.789), grade III periodontal calculus (OR = 4.092), poor glycemic control (OR = 3.347), and elevated CRP (OR = 1.627). These variables indicate key dimensions of infection risk, including local contamination load, oral microbial ecology, metabolic status, and systemic inflammatory response. These findings reinforce the concept that postoperative infection occurrence results from the interaction between local wound conditions and the patient's overall physiological state. Severe periodontal calculus (Grade III) is often associated with dense biofilm accumulation and increased anaerobic bacterial load. When surgical intervention is conducted in a contaminated field, this microbial reservoir may support bacterial invasion into the wound. On the other hand, elevated CRP measured on postoperative day 3, prior to the clinical diagnosis of SSI, may serve as an indicator of subclinical systemic inflammation and potentially signal an incipient inflammatory response [22]. It is important to note that CRP was measured on postoperative day 3, prior to the clinical diagnosis of SSI. An elevated CRP at this time point likely reflected the preoperative inflammatory status or an early subclinical response to surgical stress, rather than serving as a strictly independent causal risk factor. Therefore, CRP should be interpreted as a useful indicator for perioperative risk stratification and clinical alertness, guiding closer monitoring and timely intervention for patients at potentially higher risk, rather than being regarded as a definitive pathogenic factor for SSI.

A systematic review highlighted that diabetic patients have a 53% higher risk of SSI compared with non-diabetic individuals, primarily due to hyperglycemia-induced immunosuppression and impaired wound healing [23]. Another study analyzing deep maxillofacial infections found that diabetic patients had significantly higher WBC counts and CRP levels, required more extensive surgical interventions and tracheotomies, and experienced higher mortality rates than non-diabetic individuals [24]. These studies collectively emphasize the importance of glycemic control and inflammatory markers in affecting infection, which is highly consistent with the multivariate analysis results of this study. This suggests that clinical practice should comprehensively evaluate the above factors and implement targeted interventions.

Based on the identified risk factors, this study developed a nomogram model incorporating incision type, oral environment, blood glucose control, and CRP level. According to the scoring system of this nomogram, when all variables were present at their highest risk levels, the total score reached approximately 225 points, corresponding to an estimated 90% probability of postoperative infection. The AUC for the original dataset was 0.897, indicating excellent predictive ability. After internal validation using 5000 bootstrap resamples, the corrected C-index remained at 0.811. The Hosmer-Lemeshow test yielded a p-value of 0.230, indicating acceptable agreement between predicted and observed outcomes. Decision curve analysis further demonstrated that, within the threshold probability range of 0.01 to 1.00, using this model provided a higher net clinical benefit compared to the strategies of treating all patients or treating none.

Clinically, this model provides clinicians with a simple tool for preoperative risk stratification in diabetic patients undergoing oral surgery. By translating complex risk profiles into visual scoring, this model enables more personalized preventive approaches. A previous study highlighted that persistent periodontal infection could exacerbate systemic low-grade inflammation and disrupt glycemic control, emphasizing the importance of oral health in diabetes management [25]. Compared with models focusing on isolated factors, the model developed in this study integrates both local oral factors and systemic inflammatory status, demonstrating strong predictive accuracy. These findings suggest the need for further validation with multi-center data and exploration into incorporating metrics such as glycemic variability and detailed oral microecological indicators to further enhance its generalizability and clinical applicability.

This study developed a nomogram prediction model using retrospective case-control data and demonstrated favorable discriminative ability and calibration performance. Despite several promising outcomes, we acknowledged certain limitations that need to be considered while interpreting these results for clinical applications. Because the study adopted a retrospective observational design, it can only suggest potential associations between variables and infection risk rather than confirm definitive causal relationships. Moreover, the 1:1 matched case-control design means that the proportion of infected and non-infected individuals in the study sample does not capture the actual incidence observed in routine clinical practice. Therefore, this nomogram is primarily intended to assist in clinical risk stratification and identification of high-risk individuals, rather than for estimating the exact absolute probability of postoperative infection in the broader population. Although the sample size calculation indicated a minimum requirement of 149 cases, this study ultimately enrolled 220 patients. This decision was made for several reasons: first, the larger sample size enhanced statistical power and facilitated the detection of potential effects; second, it accounted for possible patient dropout or missing data during the study, thereby ensuring the validity of the results; finally, the increased sample size provided more adequate support for subgroup analyses, thereby strengthening the external validity of the study and ensuring broader applicability of the findings across different populations. Finally, this was a single-center retrospective study and did not incorporate additional information such as glycemic variability or continuous glucose monitoring data. These variables may further optimize risk stratification. Therefore, external validation in a larger, multicenter prospective cohort is required to confirm the model's stability and generalizability before clinical implementation.

Conclusions

Among T2DM patients undergoing oral and maxillofacial surgery, Gram-negative bacteria were the predominant pathogens in postoperative incision infections. Pseudomonas aeruginosa and Klebsiella pneumoniae were the most commonly isolated organisms. The hyperglycemic state characteristic of diabetes may alter the oral microenvironment, establishing conditions that favor the growth of opportunistic bacteria and subsequent infection. Local microbial burden and ecological imbalance interact with systemic metabolic control and inflammatory status to affect wound healing outcomes. Independent risk factors for infection included Class II or III surgical incisions, Grade III dental calculus, suboptimal perioperative glycemic control, and elevated preoperative serum CRP levels. Moreover, for T2DM patients undergoing oral surgery, prevention strategies should rely only on antimicrobial prophylaxis or optimization in surgical techniques. A broader and more coordinated approach, integrating optimized glucose management, preoperative oral hygiene improvement, and careful evaluation of inflammatory indicators, is warranted. Such a multidimensional approach may offer a more robust framework for reducing postoperative infection risk in this high-risk cohort.

Availability of Data and Materials

The data used and analyzed during the current study are available from the corresponding author on reasonable request.

Author Contributions

TS conceived and conducted the research and drafted the manuscript; CJW designed the study and supervised the research implementation; WQZ contributed to the study design and data analysis; JXG contributed to the study design and provided critical clinical interpretation of the data. All authors contributed to the critical revision of the manuscript for important intellectual content. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

This research strictly adheres to all the principles outlined in the Declaration of Helsinki. All patients in this study have given informed consent. This study was approved by the Medical Ethics Committee of Nanjing Stomatological Hospital, Nanjing University (approval number: NJSH-2025NL-21).

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Conflict of Interest

The authors declare no conflict of interest.

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