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ORIGINAL RESEARCH

Development and validation of a dynamic nomogram for dental caries in Chinese children

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Abstract

Background: This study aimed to identify factors associated with dental caries in Chinese children and develop a validated risk prediction nomogram for this condition. **Methods**: A total of 450 pediatric outpatients from the Stomatology Department of the General Hospital of Northern Theater Command were enrolled and stratified into a caries group (n = 340) and a non-caries group (n = 110) based on clinical caries status. Univariable and multivariable logistic regression analyses, combined with Least Absolute Shrinkage and Selection Operator (LASSO) regression, were applied to screen independent predictors of dental caries, and a nomogram model was constructed based on the identified key factors, with internal validation using the original dataset. The discriminative power was measured by the receiver operating characteristic (ROC) curve's area under the curve (AUC), whereas calibration was assessed using calibration plots and the Hosmer-Lemeshow test. Clinical applicability was examined through decision curve analysis (DCA) and clinical impact curves (CIC). **Results**: The following three factors contribute to the occurrence of dental caries: liking to eat snacks ($p < 0.001$), Undesirable Behavioral Habits ($p = 0.039$), and brushing teeth for less than 2 minutes ($p < 0.001$). The nomogram showed excellent discrimination, with an AUC of 0.939 (95% Confidence Interval: 0.911–0.967) confirmed by bootstrapping, and good calibration (Hosmer-Lemeshow test, $p = 0.922$). DCA indicated that using the model to guide targeted interventions provided superior net benefit across a wide probability threshold range (0.02–0.98), compared to strategies of intervening in all or no children. CIC displayed good predictive ability and clinical application value for the model. **Conclusions**: Prediction nomograms identified frequent snacking, undesirable behavioral habits, and brushing time <2 minutes as key predictors of childhood dental caries. Both clinical and online dynamic nomograms can screen high-risk children, enabling dentists to deliver individualized management and timely, effective interventions for them.

Keywords

Dental caries; Nomogram; Prediction model; Risk factors

1. Introduction

Dental caries is a major public health problem affecting children worldwide, with a persistently high prevalence that imposes a substantial burden on individuals and families [1, 2]. Epidemiological patterns vary significantly across regions. In many parts of Africa, the Middle East, and South Asia, caries prevalence is notably high, often exceeding 80–90% in specific populations, as evidenced by studies in Syria, Iran, Afghanistan, and Brazil [3, 4]. In contrast, prevalence in several developed countries is frequently reported below 60% [5, 6]. Within China, the Fourth National Oral Health Epidemiological Survey reported a caries prevalence of 71.9% among 5-year-old children, underscoring a serious domestic challenge [7]. Furthermore, recent city-specific studies indicate that caries prevalence among school-aged children (typically defined as ages 6–12 years in these studies) in various Chinese urban centers remains substantial, ranging between 40% and 70% [8–10]. Beyond causing pain and discomfort, untreated caries can lead to difficulties in eating, impaired growth and development, reduced school performance, and diminished quality of life [11–14]. Although established preventive measures—such as fluoride application and oral health education—are available, their implementation often follows a non-targeted, population-wide approach. There is a growing consensus that identifying children at high risk for caries is crucial for implementing early interventions [15].

Numerous studies have investigated various risk factors associated with childhood caries, spanning dietary habits (sugar consumption), oral hygiene practices (brushing frequency and duration), and socio-behavioral aspects [16–18]. However, many previous studies have focused on analyzing individual factors or simply reporting associations without integrating them into a practical clinical tool [19–21]. This reality underscores the critical importance of developing a risk prediction model that can synthesize multiple risk factors for personalized caries assessment.

To address this need, we first aimed to objectively identify the most relevant predictors from a comprehensive set of potential risk factors. While mitigating the risk of overfitting, we utilized Least Absolute Shrinkage and Selection Operator (LASSO) regression. This method is particularly suited for settings with multiple correlated variables, as it performs automated variable selection by applying a penalty to less contributory predictors, thereby enhancing model simplicity and generalizability. Second, to transform the selected predictors into a practical clinical tool, we constructed a nomogram. A nomogram is a graphical calculation device that visualizes a statistical model, allowing for the easy estimation of an individual's disease risk by summing points assigned to each predictor level. This approach directly addresses the gap between complex statistical output and actionable clinical insight by providing a personalized, quantitative risk estimate at the point of care.

This study, therefore, aimed to develop and validate an intuitive risk prediction model using a nomogram. A nomogram is a graphical calculating device that transforms complex statistical models into an easy-to-use tool for estimating individual patient risk. By integrating significant predictors into a single visual scale, it facilitates personalized risk assessment and clinical decision-making at the point of care, thereby addressing the need for a practical tool in managing childhood dental caries.

2. Materials and methods

2.1 Study design and participants

This retrospective case-control study utilized clinical data from children who visited the Dental Clinic of the General Hospital of Northern Theater Command between January 2021 and June 2023. A total of 450 children were included, comprising 340 in the dental caries group and 110 in the non-caries group. Participants were selected using a consecutive sampling method from the clinical database, encompassing all children who met the eligibility criteria during the study period. Children who met the diagnostic criteria for dental caries as per the textbook "Pediatric Dentistry (5th Edition)" were assigned to the caries group. Children presenting for routine check-ups or other non-carious dental issues (*e.g.*, trauma, malocclusion consultation) and who were confirmed to be free of caries upon clinical examination were allocated to the non-caries group. The inclusion criteria were: (1) children aged 1–12 years; and (2) with fully erupted front teeth. The exclusion criteria were as follows: (a) children who had previously undergone dental treatment for caries; (b) with congenital dental developmental disorders; (c) children or their guardians with mental illnesses; (d) with severe bleeding tendencies, such as idiopathic thrombocytopenia or hemophilia; (e) with congenital immune disorders, such as Sjogren's syndrome; (f) with familial hereditary dental diseases; (g) taking medications with dental side effects, such as tetracyclines; and (h) with other severe chronic diseases or undergoing treatments that might affect the study outcomes. This study was approved by the Ethics Committee of the General Hospital of the Northern Theater Command (Y (2024)175). The research was conducted in accordance with the ethical principles of the Declaration of Helsinki (2013 revision). Informed consent was waived by the committee due to the retrospective design and the use of de-identified clinical data.

2.2 Collection of information

Data on demographic characteristics, dietary habits, oral hygiene practices, and socioeconomic factors were collected using a structured questionnaire administered to the children's parents or guardians in the clinic. The questionnaire was developed specifically for this study based on a comprehensive review of the literature to encompass widely recognized predictors for dental caries in children.

All the detailed information of the selected children was recorded, including:

Basic information: name, age, gender, and initial diagnosis.

Dietary habits: preference for sweet foods, carbonated beverages, and eating before sleep.

Oral care habits: regular dental check-ups, age of first tooth brushing, tooth brushing frequency (times/day), tooth brushing duration (minutes), tooth brushing techniques, use of fluoride toothpaste, toothbrush replacement frequency ($<$3 months or $\geq$3 months), and rinsing after meals.

Family situation: place of residence (urban or rural), and educational level of guardians (primary school or below, junior high school, senior high school, junior college, bachelor's degree or above).

2.3 Definition of variables

All variables collected in the questionnaire and used in the analysis were explicitly defined as follows:

Undesirable Behavioral Habits: This was defined as the presence of one or more of the following oral habits: prolonged pacifier use or finger-sucking beyond the age of 3 years, lip biting, or bruxism, as reported by the parents.

Dietary Frequency Variables (*e.g.*, preference for sweets, carbonated beverages, and snacking): The frequency of consumption for various food and beverage items was assessed based on parent-reported responses to the questionnaire. The categories were defined as:

Never: Consumption less than once per month.

Occasionally: Consumption between once per month and 3 times per week.

Often/Frequent: Consumption 4 or more times per week.

Specifically, "Frequent Snacking" (the variable "Likes to eat snacks") was defined as consuming snacks (*e.g.*, biscuits, candies, chips, or sugary drinks) between main meals 4 or more times per week.

Regular oral checkups: Was defined as having a dental examination at least once every 12 months, regardless of whether a problem was perceived.

Primary caregiver is parent: Defined as the child living with and being primarily cared for by one or both biological or adoptive parents.

Education level of primary caregiver: Was recorded as the highest academic qualification obtained.

2.4 Statistical analysis

2.4.1 Data description and baseline comparison

Continuous data are expressed as mean ± standard deviation ($\bar{x} \pm$ SD), and categorical data are presented as the number of cases (n, %). For comparisons between groups, continuous data were analyzed using the *t*-test, while categorical data were analyzed using the chi-square test or Fisher's exact test. Paired sample comparisons were performed using the Wilcoxon signed-rank test. Statistical significance was set at $p < 0.05$. All analyses were conducted using SPSS 29.0 (IBM Corp., Armonk, NY, USA).

2.4.2 Screening of predictors related to dental caries

A two-step statistical analysis was performed to identify key predictors for dental caries in children. First, univariable logistic regression was conducted for all candidate variables, with a screening criterion of $p < 0.10$. Subsequently, to select the most predictive variables, those initially screened were entered into a Least Absolute Shrinkage and Selection Operator (LASSO) regression using the "glmnet" package. The optimal penalty parameter λ was determined via 10-fold cross-validation following the 1-Standard Error (SE) rule, and only variables with non-zero coefficients were retained in the final model.

2.4.3 Construction and presentation of nomogram model

Based on the variables selected by LASSO, the final prediction model was constructed using multivariable logistic regression. To facilitate clinical application, the model was translated into two practical formats: a nomogram, created using the R's "rms" and "DynNom" package to visually represent the prediction model; and a point scoring system, in which the regression coefficient for each variable was standardized, rounded to the nearest integer, and then transformed into a simple point-based scoring system. The total points were then translated into corresponding predicted probabilities.

2.4.4 Validation and evaluation of model performance

The model performance was comprehensively evaluated across three dimensions: the concordance index (C-index), equivalent to the area under the receiver operating characteristic (ROC) curve (AUC), was calculated along with its 95% confidence interval (CI); a calibration curve was plotted to assess the agreement between predicted probabilities and observed outcomes; and the clinical net benefit of the model across various decision thresholds was evaluated using decision curve analysis (DCA) and clinical impact curves (CIC) implemented via the "rmda" package. All validation procedures were conducted internally using the bootstrap resampling method with 1000 iterations. The aforementioned modeling and advanced statistical analyses were conducted in R 4.1.2 (University of Auckland, New Zealand) [22].

3. Results

3.1 Univariable analysis of children's general information and influencing factors

A total of 450 children were included in this study, with 340 (75.5%) classified into the dental caries group and 110 into the caries-free group. The baseline characteristics and univariate analysis of potential influencing factors are summarized in Table 1. Significant differences between the two groups were observed in three oral health-related behaviors: frequent snacking, insufficient tooth brushing duration (<2 minutes), and the presence of undesirable behavioral habits (all $p < 0.05$).

3.2 Multivariable logistic regression and LASSO regression analysis

Variables with $p < 0.05$ in the univariate analysis were included as independent variables in a multivariable logistic regression model, with caries status as the dependent variable. The analysis identified three independent predictors for dental caries (Table 2): undesirable behavioral habits (Odds ratio (OR) = 4.32, 95% CI: 1.07–17.41, $p = 0.039$), frequent snacking (OR = 440.48, 95% CI: 128.89–1505.36, $p < 0.001$), and brushing time less than 2 minutes (OR = 6.48, 95% CI: 3.06–13.73, $p < 0.001$).

To enhance the robustness of variable selection and mitigate the risk of overfitting, we employed the Least Absolute Shrinkage and Selection Operator (LASSO) regression. The predictors identified by LASSO regression were consistent with those identified in the logistic regression analysis, thus enhancing the robustness of our predictive model (Fig. 1).

3.3 Establishment and application of nomogram model

Based on the three independent predictors identified through logistic and LASSO regression analyses, a nomogram risk prediction model for dental caries was established to visualize the individualized risk prediction model for dental caries (Fig. 2). This nomogram assigns a score to each level of the three predictors (bad behavior habits, snacks preferences, and brushing time less than 2 minutes). Each variable corresponds to a line segment, and the scale indicates the value. Total scores, obtained through summation of all variable-specific points, are transformed into caries probability estimates.

To overcome the clinical implementation constraints of static nomograms, we developed an interactive web-based prediction platform that dynamically calculates risk probabilities (Fig. 3). This platform, accessible at https://namoamituofo.shinyapps.io/DynNomapp/, simplifies the computational process and facilitates clinical decision-making.

TABLE 1. Comparison of information between the two groups.

	Non-caries group (n = 110)	Caries group (n = 340)	*p*
Gender			
Female	43 (39.1%)	164 (48.2%)	0.094
Male	67 (60.9%)	176 (51.8%)	
Age (yr)	6.69 ± 2.40	6.78 ± 2.20	0.723
Undesirable Behavioral Habits	8 (7.27%)	64 (18.80%)	0.004
Prefer sweets			
Never	2 (1.82%)	3 (0.88%)	
Occasionally	71 (64.5%)	198 (58.2%)	0.249
Often	37 (33.6%)	139 (40.9%)	
Prefer carbonated beverages			
Never	41 (37.3%)	96 (28.2%)	
Occasionally	63 (57.3%)	212 (62.4%)	0.127
Often	6 (5.45%)	32 (9.41%)	
Likes to eat snacks			
Never	76 (69.10%)	5 (1.47%)	
Occasionally	25 (22.7%)	99 (29.1%)	<0.001
Often	9 (8.18%)	236 (69.40%)	
Eat before going to bed			
Never	34 (30.9%)	95 (27.9%)	
Occasionally	61 (55.5%)	207 (60.9%)	0.579
Often	15 (13.6%)	38 (11.2%)	
Regular oral checkups			
Never	21 (19.1%)	70 (20.6%)	
Occasionally	60 (54.5%)	152 (44.7%)	0.168
Often	29 (26.4%)	118 (34.7%)	
Initial brushing age			
Less than 1 year	23 (20.9%)	80 (23.5%)	
1–3 years old	63 (57.3%)	204 (60.0%)	0.429
Greater than 3 years old	24 (21.8%)	56 (16.5%)	
Brushing frequency ≥2 times/d	54 (49.1%)	177 (52.1%)	0.588
Brushing time <2 min	36 (32.7%)	262 (77.1%)	<0.001
Brushing method			
By yourself	70 (63.6%)	229 (67.4%)	0.473
Parental guidance	40 (36.4%)	111 (32.6%)	
Whether to use toothpaste	110 (100.0%)	338 (99.4%)	1.000
Whether toothpaste contains fluoride	72 (65.5%)	209 (61.5%)	0.453
Toothpaste replacement			
More than 3 months	25 (22.7%)	74 (21.8%)	0.832
Less than 3 months	85 (77.3%)	266 (78.2%)	
Rinse mouth after meals	49 (44.5%)	150 (44.1%)	1.000
Primary caregiver is parent	99 (90.0%)	320 (94.1%)	0.138

TABLE 1. Continued.

	Non-caries group (n = 110)	Caries group (n = 340)	*p*
Importance of oral health education			
Not important	3 (2.73%)	13 (3.82%)	0.808
Emphasize	107 (97.3%)	327 (96.2%)	
Lectures on oral health care	27 (24.5%)	86 (25.3%)	0.900
Parents' attitude towards dental disease			
Not important	15 (13.6%)	50 (14.7%)	0.877
Emphasize	95 (86.4%)	290 (85.3%)	
Parental management after dental caries			
Not accept treatment	2 (1.82%)	13 (3.82%)	0.476
Receive treatment	108 (98.2%)	327 (96.2%)	
Education level of primary caregiver			
Elementary school and below	16 (14.5%)	46 (13.5%)	0.856
Middle School	5 (4.55%)	10 (2.94%)	
High School	10 (9.09%)	32 (9.41%)	
University and above	79 (71.8%)	252 (74.1%)	

Never: Consumption less than once per month.
Occasionally: Consumption between once per month and 3 times per week.
Often/Frequent: Consumption 4 or more times per week.

TABLE 2. Logistic regression analysis of risk factors for high prevalence dental disease.

	Univariable analysis		Multivariable analysis	
	OR	*p*	OR	*p*
Gender				
Female				
Male	0.69 (0.44–1.07)	0.095		
Age	1.02 (0.92–1.12)	0.710		
Undesirable Behavioral Habits	2.96 (1.37–6.38)	0.006	4.32 (1.07–17.41)	0.039
Prefer sweets				
Never				
Occasionally	1.86 (0.30–11.36)	0.502		
Often	2.50 (0.40–15.54)	0.324		
Prefer carbonated beverages				
Never				
Occasionally	1.44 (0.91–2.28)	0.123		
Often	2.28 (0.88–5.86)	0.088		
Likes to eat snacks				
Never			-	-
Occasionally	60.19 (22.02–164.54)	<0.001	67.54 (22.25–205.02)	<0.001
Often	398.58 (129.61–1225.70)	<0.001	440.48 (128.89–1505.36)	<0.001
Eat before going to bed				
Never				
Occasionally	1.21 (0.75–1.97)	0.432		
Often	0.91 (0.44–1.85)	0.788		

TABLE 2. Continued.

	Univariable analysis		Multivariable analysis	
	OR	*p*	OR	*p*
Regular oral checkups				
Never				
Occasionally	0.76 (0.43–1.35)	0.347		
Often	1.22 (0.65–2.30)	0.538		
Initial brushing age				
Less than 1 year				
1–3 years old	0.93 (0.54–1.60)	0.796		
Greater than 3 years old	0.67 (0.34–1.31)	0.240		
Brushing frequency ≥2 times/d	1.13 (0.73–1.73)	0.588		
Brushing time <2 min	6.90 (4.31–11.07)	<0.001	6.48 (3.06–13.73)	<0.001
Brushing method				
By yourself				
Parental guidance	0.85 (0.54–1.33)	0.473		
Whether to use toothpaste	0.00 (0.00–Inf)	0.983		
Whether toothpaste contains fluoride	0.84 (0.54–1.32)	0.454		
Toothpaste replacement				
More than 3 months Less than 3 months	1.06 (0.63–1.77)	0.832		
Rinse mouth after meals	0.98 (0.64–1.51)	0.937		
Primary caregiver is parent	1.78 (0.82–3.84)	0.143		
Importance of oral health education				
Not important Emphasize	0.71 (0.20–2.52)	0.591		
Lectures on oral health care	1.04 (0.63–1.71)	0.875		
Parents' attitude towards dental disease				
Not important Emphasize	0.92 (0.49–1.71)	0.782		
Parental management after dental caries				
Not accept treatment Receive treatment	0.47 (0.10–2.10)	0.320		
Education level of primary caregiver				
Elementary school and below				
Middle School	0.70 (0.21–2.34)	0.558		
High School	1.11 (0.45–2.76)	0.818		
University and above	1.11 (0.60–2.07)	0.744		

Never: Consumption less than once per month.
Occasionally: Consumption between once per month and 3 times per week.
Often/Frequent: Consumption 4 or more times per week.
OR, Odds Ratio.

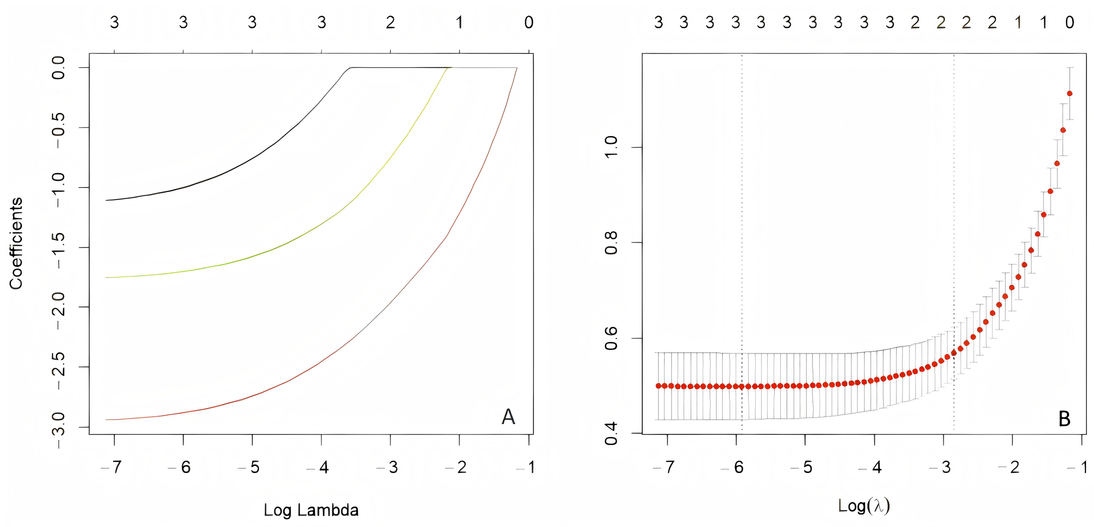

FIGURE 1. Screening of predictors of high incidence of dental disease by LASSO regression. (A) LASSO coefficient distribution map for each clinical feature. (B) Ten-fold cross-validation with 1-SE criteria identified the most parsimonious λ value for the LASSO model. LASSO, least absolute shrinkage and selection operator; SE, standard error.

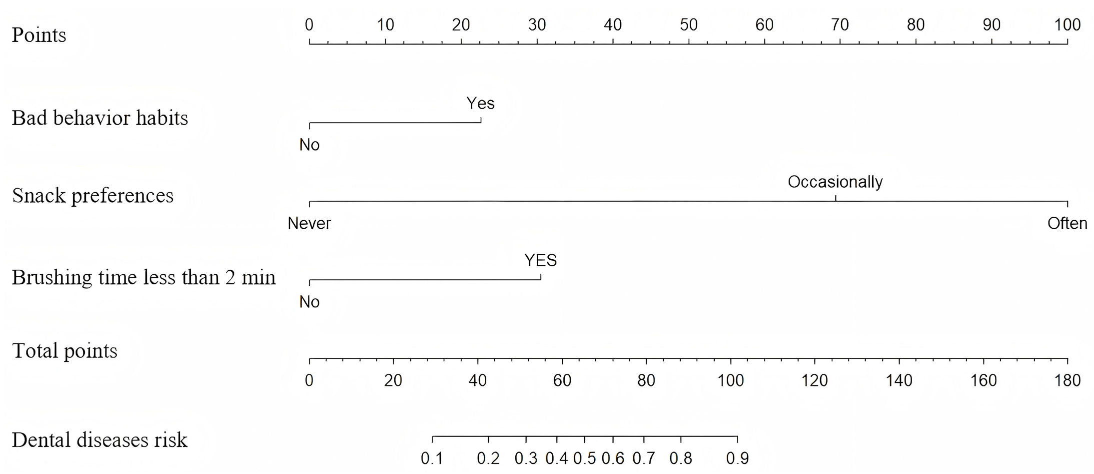

FIGURE 2. A nomogram risk model predicting dental caries in children.

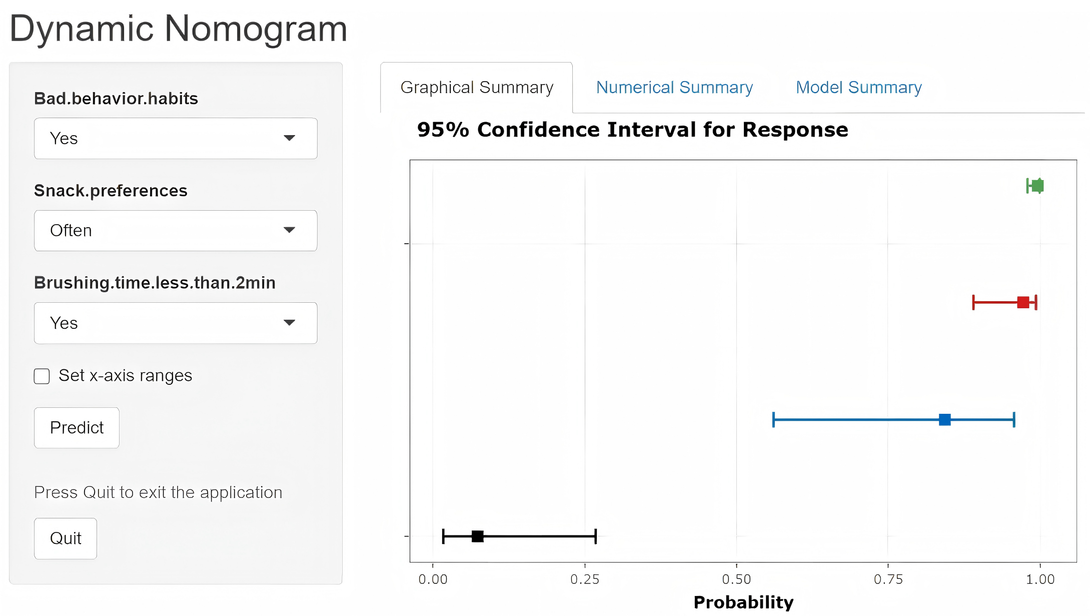

FIGURE 3. Web-based dynamic nomogram.

3.4 Assessment and validation of the nomogram model

The discriminative ability of the nomogram was first assessed on the original dataset, yielding an apparent area under the ROC curve (AUC) of 0.939 (95% CI: 0.911–0.967) (Fig. 4). To correct for potential over-optimism and estimate the model's likely performance in future similar samples, internal validation was performed using the bootstrap method with 1000 resamples. This process provided a bias-corrected performance estimate, reflected by a bootstrap-validated C-index of 0.939 (95% CI: 0.910–0.964). The optimal probability threshold determined from the ROC curve was 0.931, corresponding to a sensitivity of 0.924 and a specificity of 0.845.

The calibration curve demonstrated excellent alignment between predicted probabilities and actual clinical outcomes (Fig. 5). Additionally, the Hosmer-Lemeshow goodness-of-fit test was not statistically significant ($p = 0.922$), indicating no significant deviation between the predicted and observed outcomes and confirming good model calibration.

3.5 Clinical application of the nomogram model

Following the validation of the model's accuracy, we evaluated its potential clinical utility using DCA and CIC. DCA quantifies the net benefit of using the nomogram to guide clinical decisions across a range of threshold probabilities. The analysis (Fig. 6) demonstrated that basing the decision to offer targeted preventive measures on the model's prediction would provide a superior net benefit for threshold probabilities between approximately 0.02 and 0.98, compared to all children or to none.

CIC were plotted to visualize the clinical consequences of using the model at different risk thresholds (Fig. 7). The curves show, for every 1000 children, how many would be identified as high-risk by the model and how many true caries cases would be captured among them. Through CIC assessment, we evaluated the number of high-risk children and true high-risk children at multiple thresholds, demonstrating robust predictive accuracy with strong clinical utility.

4. Discussion

This study developed and internally validated a clinically applicable nomogram for predicting the individualized risk of dental caries in Chinese children, based on a retrospective analysis of 450 clinical cases. Through multivariable logistic regression and LASSO analysis, we identified three independent predictors significantly associated with caries risk: frequent snacking, inadequate tooth-brushing duration ($<$2 minutes), and the presence of undesirable behavioral habits. The integration of these predictors into a visual nomogram—and its implementation as a web-based dynamic platform—represents the primary contribution of this work. By translating complex statistical predictions into an accessible and quantifiable risk estimate, our model extends beyond conventional reporting of odds ratios to offer a practical tool for clinical decision-making. This represents a tangible step towards precision dentistry in pediatric oral health, where prevention can be proactively tailored to individual needs.

While several studies have identified predictors for childhood dental caries [23, 24], and some have developed statistical risk scores [25], our study advances caries prediction methodology by integrating LASSO regression for robust variable selection with nomogram construction for clinical translation—a combination less frequently employed in pediatric dental epidemiology. LASSO objectively shrinks redundant predictors, mitigating multicollinearity and overfitting risks, thereby yielding a more parsimonious and generalizable core predictor set. In terms of implementation, we moved beyond a static risk score or chart by developing an open-access, web-based dynamic nomogram. This directly addresses a key barrier to the clinical adoption of prediction models by offering immediate, individualized risk calculation without manual scoring, facilitating real-time preventive decision-making. While other caries risk models exist [26], our tool is distinctively calibrated for a Chinese clinical pediatric population and extends beyond a static score by being implemented as a web-based dynamic platform. This directly enhances its feasibility for real-time, point-of-care use in busy clinical settings.

Modern dietary trends have led to an increase in refined foods and a decrease in fibrous content. Within this context, sweets and snacks constitute a substantial portion of children's daily diets [27, 28], with intake levels often rising with age. Our study found that children with dental caries consumed more snacks, consistent with other research findings [29–32]. Snack products, typically rich in fermentable carbohydrates, serve as a substrate for cariogenic microorganisms such as Streptococcus mutans. These bacteria facilitate the formation of an adhesive plaque matrix on tooth surfaces, where carbohydrate metabolism generates acids that lead to enamel demineralization and subsequent caries development [33–35]. Our analysis revealed a dramatically elevated caries risk among frequent snack consumers (OR = 440.48), which may be attributed to the prolonged oral retention of snack residues, enabling sustained acid production by plaque biofilms. The resultant acidic environment disproportionately affects primary teeth due to their thinner enamel and comparatively lower resistance to acid challenge [36–38]. Interestingly, while snacking frequency was strongly correlated with caries, general sugar intake, as reported by parents, did not significantly differ between groups. This discrepancy may stem from reporting bias, wherein parents primarily identified obvious sugar sources such as candies and sugary beverages, while underestimating or overlooking the high sugar content in many commercial snack products [39].

Our research indicates that the unusually high OR value might be related to the following reasons. First, it underscores the primacy of dietary sugar frequency as a biological driver of caries, consistent with established etiology [40]. Second, this magnitude is characteristic of case-control designs with high disease prevalence and extreme exposure contrast, as seen in our clinic-based sample where snacking habits were vastly different between groups. While indicative of a potent risk factor within this specific population, such an effect size may be attenuated in broader, community-based cohorts with more graded exposure distributions. Therefore, it robustly confirms

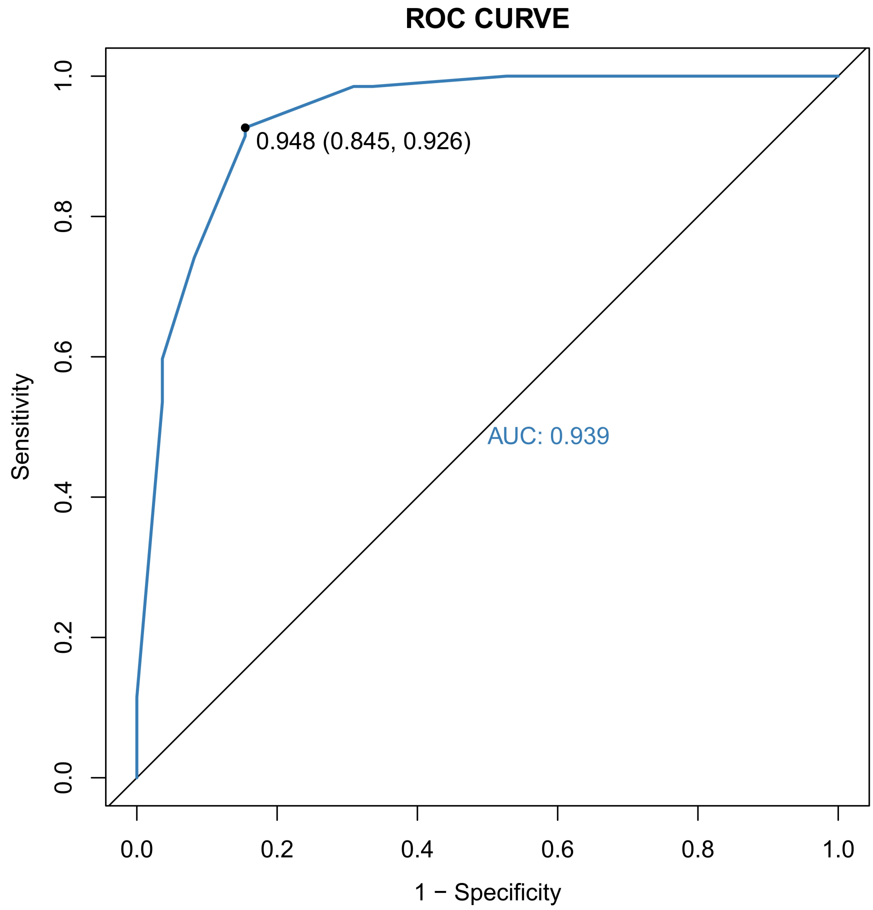

FIGURE 4. The predictive power of the nomogram was evaluated by drawing the ROC curve. ROC analysis yielded an AUC value of 0.939 (95% CI: 0.911–0.967). AUC, area under the curve; ROC, receiver operating characteristic.

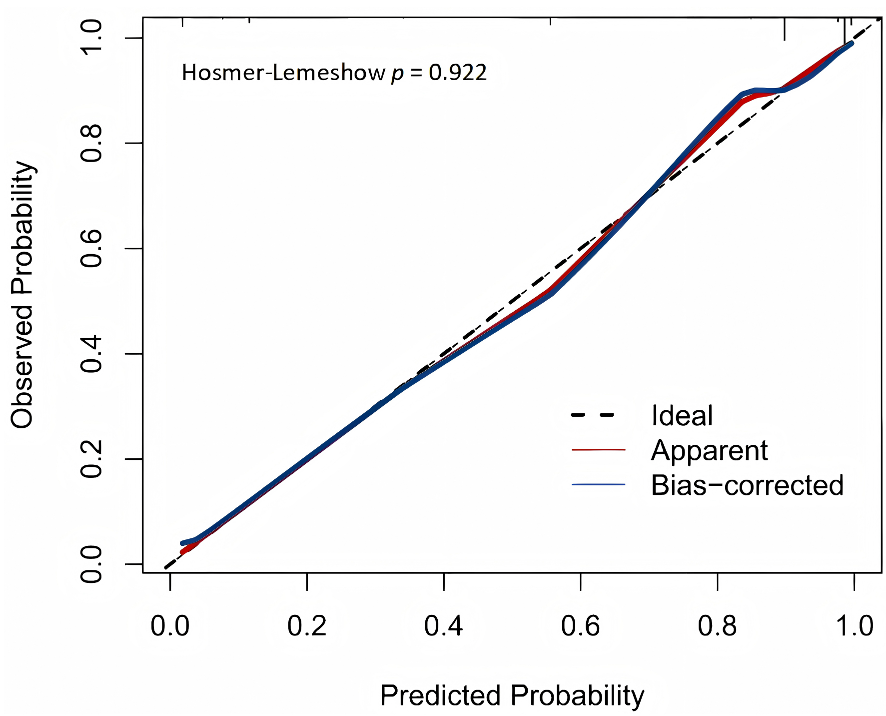

FIGURE 5. The calibration graph illustrates predicted (X-axis) *vs.* observed probabilities (Y-axis). The "Ideal" line marks the ideal prediction model. The blue line shows Bootstrap resampling-predicted probabilities from 1000 resamples of the original dataset. The "Apparent" line denotes the predicted probabilities.

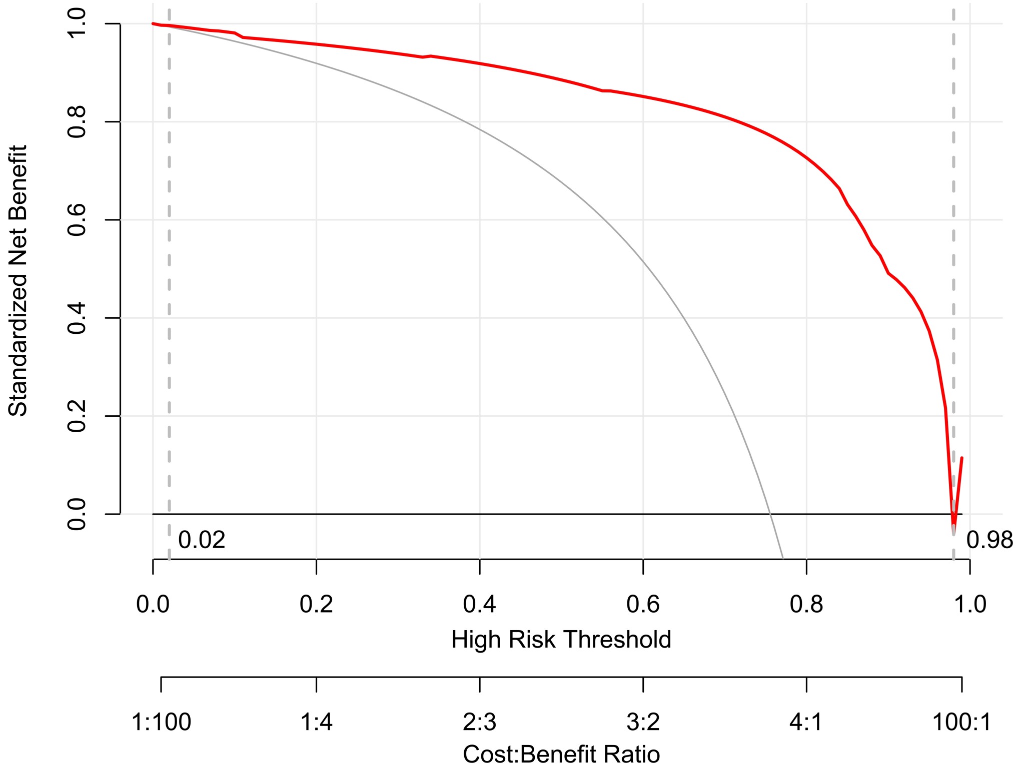

FIGURE 6. DCA for predictive nomogram. X-axis: Threshold. Y-axis: Net benefit. The "None" line shows the net benefit when no children receive the preventive measures. The "All" line corresponds to the net benefit when the preventive measures cover the entire child population. The solid red line reflects the net benefit of targeting only children who have dental caries. DCA, decision curve analysis.

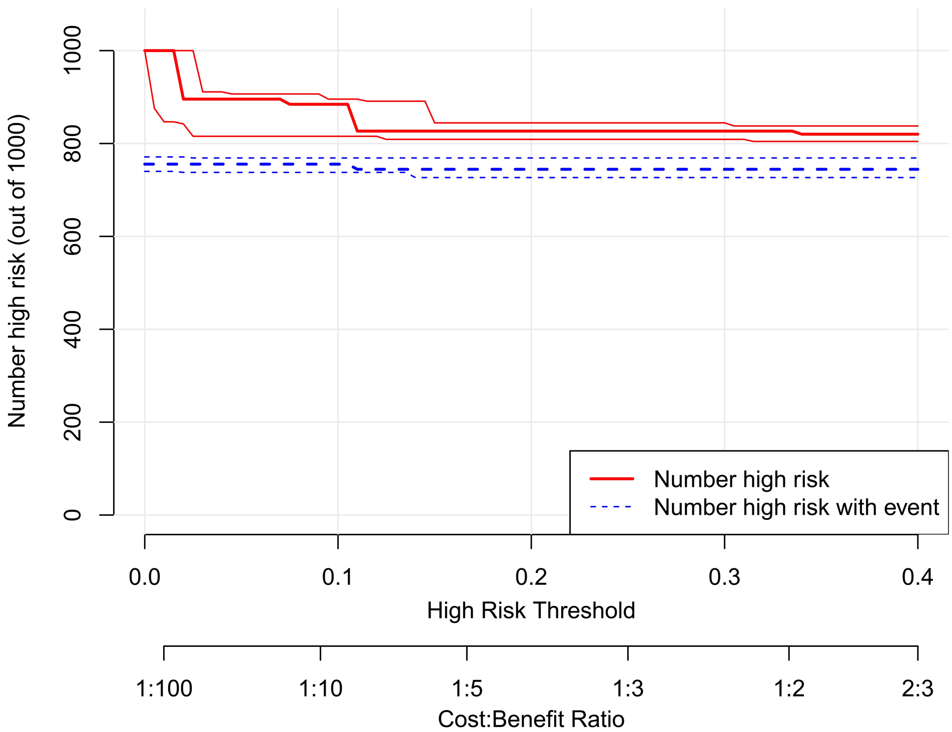

FIGURE 7. CIC of the nomogram. The two horizontal axes illustrate this relationship. The red line displays how many children are classified as high-risk across different thresholds (out of 1000). The blue dashed line represents the actual caries cases detected in these high-risk children. CIC, Clinical Impact Curves.

the factor's critical importance, while highlighting that the quantitative estimate is context-dependent.

Furthermore, the etiology of dental caries in children is closely related to behavioral habits [41–44]. Undesirable behavioral habits include using a pacifier before bed, finger-sucking, and night-time milk consumption. Our study identified undesirable behavioral habits as being more prevalent in the caries group and confirmed a significant association between these habits and caries status. These habits are particularly detrimental in the context of the physiological reduction in salivary flow during sleep, which diminishes the oral cavity's natural cleansing and buffering capacities, thereby facilitating bacterial proliferation and acid production [42]. The association between such behaviors and caries is mechanistically plausible, as prolonged oral retention of milk or other fermentable substrates overnight provides a sustained carbohydrate source for cariogenic bacteria. This pathophysiological link is corroborated by our multivariable analysis, which indicated that children with these behavioral patterns had a 4.32-fold higher risk of developing caries, a finding consistent with reports from other investigators [45–48].

Beyond diet and behavior, oral hygiene practices remain a cornerstone of caries prevention. Caries development in children arises from a confluence of intrinsic and extrinsic factors. Low mineralization, thin enamel, and weak acid resistance of primary teeth are intrinsic factors contributing to caries. Extrinsically, dietary preferences for sugary foods, improper brushing techniques, and inadequate oral hygiene further elevate the risk. The combined effect of these factors promotes bacterial growth and acid production, leading to tooth tissue destruction and caries. Consequently, maintaining good oral hygiene—through effective brushing and the use of fluoride toothpaste—is well established as a cornerstone of caries prevention [49–52]. In line with this, our findings indicate that tooth brushing for less than 2 minutes was associated with a substantially increased risk of caries (OR = 6.48), a result consistent with previously published reports [53–55]. Multiple studies have found that the shorter the brushing time, the worse the plaque removal effect. Brushing for only 1 minute, compared with the recommended 2 minutes, results in significantly greater plaque retention [56, 57]. When fluoride toothpaste is used, insufficient brushing time reduces the exposure of tooth surfaces to fluoride, thereby diminishing its cariostatic effect. Adequate brushing duration ($\geq$2 minutes) has been shown to significantly increase salivary fluoride concentration, which enhances caries prevention [58]. In addition, abbreviated brushing often leads to inadequate cleaning of certain tooth surfaces—such as the lingual aspects and posterior regions—where local plaque accumulation readily occurs, thereby elevating caries risk. Therefore, it is essential for healthcare providers and parents to enhance oral health education for children, improving their oral health awareness and behaviors.

5. Limitations and future perspectives

While our model demonstrated excellent predictive performance, several limitations warrant consideration. Firstly, the retrospective case-control design, while efficient for initial model development, precludes the establishment of causality and may be susceptible to selection and information biases. Secondly, the single-center nature of our study, conducted at a large general hospital, may limit the generalizability of our findings to other populations or primary care settings with different demographic and socioeconomic characteristics. Thirdly, our model was developed using an imbalanced dataset (340 caries *vs.* 110 caries-free children). Although this reflects the high prevalence of caries in clinical practice, the smaller control group can reduce the precision of risk estimates and affect how well the model's predictions match observed outcomes in populations with different disease rates. While bootstrap internal validation was used to provide adjusted performance metrics, it does not fully overcome the underlying issue of spectrum bias caused by the sample imbalance. Finally, the etiology of dental caries is caused by multiple factors, and its influencing factors are beyond the scope of associations involved in this study. Therefore, its complexity may limit the predictive range of the proposed nomogram.

6. Conclusions

This study analyzed the clinical data of children with dental caries and identified snacking habits, undesirable behavioral habits, and brushing for less than 2 minutes as independent predictors of dental caries in children. We developed and validated prediction models, including a simple bedside prediction model and an online dynamic prediction model, to identify children at high risk of dental caries. These models enable dentists to formulate personalized management strategies for children's oral health and provide timely and effective interventions.

ABBREVIATIONS

ROC, receiver operating characteristic; AUC, area under the curve; DCA, decision curve analysis; CIC, clinical impact curves; LASSO, Least Absolute Shrinkage and Selection Operator; SD, standard deviation, SE, standard error; CI, Confidence Interval; OR, Odds Ratio.

AVAILABILITY OF DATA AND MATERIALS

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

RC—conceptualization, methodology, data curation, writing-original draft, writing-review & editing. YZ and PH—software, validation, investigation, resources, visualization. YQB—formal analysis, investigation, resources, visualization. YM—conceptualization, data curation, writing-review & editing, supervision, project administration, funding acquisition.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The research protocol received ethical clearance from the Institutional Review Board of General Hospital of Northern Theater Command (Approval No. Y (2024)175) in accordance with Declaration of Helsinki principles. Informed consent was waived by the committee due to the retrospective design and the use of de-identified clinical data.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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