Derivation of a Risk Score for High Caries Risk in 3- to 5-year-old Children in Sichuan Province

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Purpose: To explore potential caries risk indicators in 3- to 5-year-old children, and develop a simple risk-score model to screen the children at high risk of caries with decayed, filled, and missing teeth (dmft) > 2.

Materials and Methods: A cross-sectional study involving 2746 children 3 to 5 years of age was conducted in Sichuan province. Children were examined for dmft index, and sociodemographic and behavioural factors were acquried through a questionnaire completed by their caregivers. A prediction model was developed by backward multivariate logistic regression, and its overfitting degree was examined with 5-fold cross-validation. A simple risk-score model was derived to screen the children with dmft > 2 at high risk of caries with the β regression coefficient obtained from the multivariate regression model.

Results: A child's oral health status was identified as the highest risk indicator with a β regression coefficient of 1.093. The mean area under curve (AUC) from the 5-fold cross-validation was 0.7408 (95% CI: 72.21%, 75.95%), with a bias of only ca 1%. This result allowed us to eliminate substantial overfitting of the prediction model. The AUC of the risk scoring system was 0.7455 (95% CI: 72.70%, 76.40%), which indicated good screenability.

Conclusions: This risk score model has the advantages of simplicity, low cost and relatively high accuracy, and is suitable for use in developing countries, especially for primary screening for high risk of caries. It shows that certain child behaviours and parental attitude play an important role in dental caries among preschool children.

Key words: children, dental caries, epidemiology, high risk, risk score model

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Early childhood caries (ECC) is the most prevalent chronic infectious childhood disease and is a major public health problem.[19] ECC is defined by the American Academy of Pediatric Dentistry (AAPD) as the presence of one or more decayed (non-cavitated or cavitated lesions), missing (due to caries), or filled tooth surfaces in any primary tooth in a child under six years old.[2] Although ECC incidence has declined in some developed countries, it remains a serious problem in developing countries.[4] ECC is also becoming a diagnostic challenge, with changing diet and nutrition.[6] A study has shown a high prevalence in Asia (36%–85%), Africa (38%–45%) and the Middle East (22%–61%).[4] ECC prevalence was 65.5% and 66.1% in mainland China among 1- to 6-year-olds and 5-year-olds, respectively.[37] The World Health Organization's (WHO) target is that half of 6-year-old children should be caries-free.[9] To meet this criterion, many developing countries need to make a great effort. Several studies have reported that ECC can influence children's quality of life, in-

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cluding oral health, general health, growth, and even the quality of life of children's families and communities.[4,21] All of those studies have emphasised that poor oral health is an additional burden for children's health and underlined the importance of caries prevention in children.

Interestingly, there is a skewed caries distribution in many developed countries, with 25% of children bearing 75%–80% of affected surfaces.[11,20] Therefore, the National Institutes of Health (NIH) pointed out that caries prevention should target high-risk individuals.[18] In this study, a dmft index of two or more decayed, missing or filled primary teeth for 3- to 5-year-old children used to define high risk of dental caries according Gao's criteria.[7] Early, precise and low-cost selection of high-risk preschoolers through caries risk assessment for prevention and intervention is paramount for cost-effective caries control. Several conceptual models have been proposed by professional organisations, such as the Caries-risk Assessment Tool proposed by the International Caries Detection and Assessment System (ICDAS),[1] and the Caries Management by Risk Assessment programme advocated by the California Dental Association.[5] According to the data from China's National Health and Family Planing Commission, approximately 220,000 dental practitioners and assistants were available in 2018,[36] but there are 1.4 billion people and more than 20 million children aged 3–5 years in China.[15] This means that less than one dental practitioner and assistant is available for every 1000 people. Consequently, it is very difficult for dental practitioners and assistants to adequately screen such a large number of children. The aim of this study was to explore potential caries risk indicators, develop a simple risk-score model to screen the children with dmft > 2 for high risk of caries, and in the future provide more public health focus and dental resources to these in children with a higher risk.

MATERIALS AND METHODS

Sampling

Data were collected through oral examination and a questionniare with children and their caregivers at the kindergartens in Sichuan Province. Sichuan Province, located in southwest China, is inhabited by multiple ethnic groups, and has a population of 81.4 million people.[35] The economic aggregate of Sichuan ranks first in western China and sixth in China overall. Three oral health surveys were conducted in Sichuan in 1983, 1995, and 2005. A complex, multistage, cluster sampling design[30] was performed based on the Fourth National Oral Health Survey and a previous study.[34] Six areas (Guang'an District, Chuan'shan District, Jin'niu District, Da County, Yi'bin County, and Pi County) were selected for this study. Then, three kindergartens were ramdomly selected by probabilities proportional to size in each area.[13] Finally, children in the selected kindergartens were chosen using a quota sampling method. According to the following equation, the required sample size was 2472.

$$n = deff \; \frac{\mu^2\,(1-p)}{\varepsilon^2\, p(1-nonresponse)}$$

where n is the sample size, deff is the design effect (2.5), p is the prevalence of dental caries (66.0%) in children aged 3–5 years from the Third National Oral Health Survey,[32] μ is the level of confidence, and ε is the margin of error. The predicted non-response rate was 20% in 3–5 years old children.[34] Finally, 2746 children aged 3–5 years were selected in this study, which was slightly greater than the required sample size (2472). Approval was obtained from the Stomatological Ethics Committee of the Chinese Stomatological Association and the Ethics Committee of West China Hospital of Stomatology, Sichuan University (Approval No. 2014-003), and all caregivers of the children were required to sign an informed consent form.

Clinical Assessment

The caregivers of all the children enrolled in this study signed the informed consent form. The children received a clinical examination according to the basic methods and criteria issued by the WHO Oral Health Survey. The content of the clinical assessment included the numbers of decayed, missing and filled teeth.[34] Four trained and accredited dentists performed the examination. The mean Kappa values for the inter-examiner reproducibility was >0.85 for the caries examination.[34]

Questionnaire

The questionnaire requested the following information: dietary habits, oral hygiene practices, dental attendance, oral health status and caregivers' oral health knowledge and attitude. To ensure accuracy and reliability, every question in the questionnaire was filled out by trained investigators during a one-to-one interview with the children's caregivers.

Statistical Analysis

First, we conducted a univariate logistic regression to screen for the possible risk indicators potentially associated with the outcome variable; and the entry criterion was $p < 0.1$. The value was used with the aim of minimising residual confounding due to the risk of omitting relevant variables.[23] Second, a prediction model was developed by a backward multivariate logistic regression. The variables mentioned above were entered into the regression model if p was < 0.05 and removed if p was > 0.1. We calculated the tolerance and variance inflation factor of each covariate to test the collinearity between the covariates of the multivariable model. The Hosmer-Lemeshow goodness-of-fit test was performed to assess the calibration of the regression model. The area under the receiver operating characteristic (ROC) curve (AUC) was calculated to assess the discrimination of the final model. A k-fold cross-validation (k = 5) was conducted to examine the degree of overfitting of the prediction model. The diagnostic performance of the prediction model was assessed by comparing the mean AUC of the ROC from 5-fold cross-validation with that of the observations used to

Table 1 Potential risk indicators selected by univariate analysis (n = 2746)

Variables	Dmft > 2 (n%)	dmft ≤ 2 (n%)	OR 95% CI	p-value
Age (years)				
3	216 (7.87%)	592 (21.56%)	1	
4	397 (14.46%)	524 (19.08%)	2.08 (1.70, 2.54)	< 0.0001
5	519 (18.90%)	498 (18.14%)	2.86 (2.34, 3.48)	< 0.0001
Household type				
Non-agricultural family	295 (10.74%)	569 (20.72%)	1	
Agricultural family	837 (30.48%)	1045 (38.06%)	1.55 (1.31,1.83)	< 0.0001
Relatives				
Grandparents	501 (18.24%)	772 (28.11%)	1	
Parents	631 (22.98%)	842 (30.66%)	1.16 (0.99, 1.35)	0.065
Sugar-containing soft drink/soda consumption				
≤ 1/week	836 (30.44%)	1301 (47.38%)	1	
> 1/week	296 (10.78%)	313 (11.40%)	1.47 (1.23, 1.76)	< 0.0001
Dessert or sugar-containing drink consumption before sleep				
Never	510 (18.57%)	823 (29.97%)	1	
Occasionally	454 (16.53%)	572 (20.83%)	1.28 (1.09, 1.51)	0.003
Often	168 (6.12%)	219 (7.98%)	1.24 (0.98, 1.56)	0.068
Toothache in previous year				
No or unclear	744 (27.09%)	1460 (53.17%)	1	
Yes	388 (14.13%)	154 (5.61%)	4.94 (4.02,6.08)	< 0.0001
Dental visit history				
No	870 (31.68%)	1455 (52.99%)	1	
Yes	262 (9.54%)	159 (5.79%)	2.76 (2.22,3.41)	< 0.0001
Last dental visit				
> 12 months ago or never	937 (34.12%)	1502 (54.70%)	1	
6–12 months ago	76 (2.77%)	46 (1.68%)	2.65 (1.82,3.85)	< 0.0001
< 6 months ago	119 (4.33%)	66 (2.40%)	2.89 (2.12,3.95)	< 0.0001
Child's oral health status assessment				
Very good or good	319 (11.61%)	970 (35.32%)	1	
Fair, poor or very poor	813 (29.61%)	644 (23.45%)	3.84 (3.26, 4.52)	< 0.0001
Oral health knowledge and attitude score				
High	463 (16.86%)	733 (26.69%)	1	
Medium	590 (21.49%)	806 (29.35%)	1.16 (0.99, 1.36)	0.067
Low	79 (2.88%)	75 (2.73%)	1.67 (1.19, 2.34)	0.003

create the model. The β regression coefficient from the prediction model was used to derive a practical scoring system, as shown in previous studies.[28] We assigned weighted points to the predictors identified with regression analysis proportional to the β regression coefficient values. A risk score was then calculated for each child. The AUC was calculated to validate the predicted performance of the risk-score system. All the analyses were performed using SPSS v 20.0 (SPSS, IBM; Armonk, NY, USA) and R 3.3.1. A two-sided p-value < 0.05 was considered statistically significant.

RESULTS

Demographics

A total of 3000 children aged 3-5 years were selected for this study; the non-response rate was 8.45%. Thus, a final number of 2746 children participated in our study.[22,34] Among the children, 1362 (49.6%) were girls and 1384 (50.4%) were boys. The prevalence of caries was 63.47% (1743) and the mean dmft was 3.28.[22,34] Among all the participants, 1132 children had a dmft > 2. The results of

Table 2 Logistic regression analysis for the variables related to dmft > 2 and scoring system

Variables	β regression coefficient	OR	95%CI	p-value	Score*
Age (years)					
3		1			0
4	0.632	1.88	1.51, 2.34	< 0.0001	6
5	0.863	2.37	1.91, 2.94	< 0.0001	9
Household type					
Non-agricultural family		1			0
Agricultural family	0.428	1.53	1.27, 1.85	< 0.0001	4
Sugar-containing soft drink/soda consumption					
≤1/week		1			0
>1/week	0.303	1.35	1.11, 1.66	0.003	3
Toothache in previous year					
No or unclear		1			0
Yes	1.064	2.90	2.30, 3.66	< 0.0001	11
Dental visit history					
No		1			0
Yes	0.379	1.46	1.13, 1.88	0.004	4
Child's oral health status assessment					
Very good or good		1			0
Fair, poor or very poor	1.093	2.98	2.50, 3.55	< 0.0001	11
Oral health knowledge and attitude score					
High		1			0
Medium	0.099	1.10	0.93, 1.32	0.27	1
Low	0.494	1.64	1.13, 2.38	0.009	5

A reference risk indicator profile was selected by choosing a reference category for each risk indicator. The reference category was the category corresponding to 0 points in the scoring system. Risk indicators for poor health were assessed by a positive score, so that a higher point total conveys more risk. *Score assignment to risk indicators was based on a linear transformation of the corresponding β regression coefficient. The coefficient of subclassification of each variable was divided evenly by 0.099 (the lowest β value), except the reference category, multiplied by a constant (1), and rounded to the nearest integer.

univariate analysis to select potential indicators associated with the outcome variables (dmft > 2) are summarized in Table 1. Ultimately, ten variables were selected for the regression model with $p < 0.1$.

Multivariate Logistic Regression

The regression model was used to identify 7 significant ($p< 0.05$) variables as predictors (Table 2): age, household type, sugar-containing soft drink/soda consumption, toothache in previous year, dental visit history, child's oral health status assessment (by the parent/caregiver), caregivers' oral health knowledge and attitude score. Among them, the variable child's oral health status assessment was identified as the highest risk indicator, with a β regression coefficient of 1.093.

The tolerance of variables in the final multivariable model ranged from 0.79 to 0.98; the mean variance inflation factor was 1.10 (range: 1.01–1.27). The Hosmer-Lemeshow goodness-of-fit test statistic was 0.653, indicating good model calibration.

Cross-validation

A stratified k-fold (k = 5) cross-validation was performed by dividing the data into five parts. The mean AUC of the 5 k-fold cross-validation was 0.7408 (95% CI: 72.21%, 75.95%). The AUC for the prediction model built by all data was 0.7458 (95% CI: 72.73%, 76.43%), indicating a bias of about 1%. Hence, this result allowed us to eliminate substantial overfitting of the prediction model. In order to test the stability and reproducibility of the model with all the indicators, we investigated the five models created during cross-validation. The risk predictors such as age, household type, sugar-containing soft drink/soda consumption, toothache in previous year, dental visit history, and child's oral health status assessment occurred in all the models and the indicator 'caregiver oral health knowledge and attitude' score occurred in three of the five models.

Risk Scoring System

A number of points were assigned to each category of the seven predictor variables proportional to the β regression

Table 3 Total points and the corresponding risk estimation

Total points	Risk estimation	Total points	Risk estimation
0	0.0972	30	0.6552
5	0.1379	35	0.7571
10	0.2078	40	0.8364
15	0.3009	45	0.8935
20	0.4139	50	0.9383
25	0.5367		

Risk estimation = 1/(1+EXP [-2.229+0.099 (total points)]). In our study, the lowest score was 0 and the highest was 47. In this table, only some numerical scores and their corresponding estimate of risk were given.

coefficient to calculate the risk score (Table 2). When the β-coefficient of different variables (e.g. 3-year-old children, children of non-agricultural family, etc) in the multivariable model was used as a reference, although the scoring system was different, the discrimination of the final model was similar (data not shown). Table 3 shows the total point (range: 0-50) and corresponding estimated risk.

A score was calculated for each child by summing the points that corresponded to the risk indicators. We applied this scoring system to all children participating in this study (see Table 2 for application). An ROC curve was developed by using the weighted score (Fig 1). The AUC was 0.7455 (95% CI: 72.70%, 76.40%), showing good screenability of the risk-score system. The screen performance of the weighted score for determining dmft > 2 is shown in Table 4. The threshold score was 20.5, i.e. if the score was > 20.5, the child dmft might be > 2.

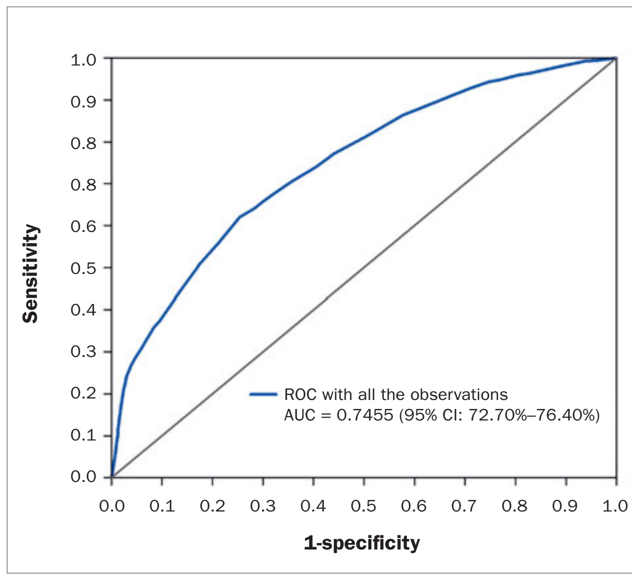

Fig 1 ROC curve developed using the weighted score. The AUC of the risk scoring system was 0.7455 (95% CI: 72.70%, 76.40%), indicating good screenability.

DISCUSSION

In this study, the variables obtained from clinical examination and a questionnaire survey of the enrolled children were systematically analysed and the risk indicators with dmft > 2 were determined. According to our results, age, household type, sugar-containing soft drink/soda consumption, toothache in previous year, dental visit history, child's oral health status assessment, caregivers' oral health knowledge and attitude scores resulted in independent risk indicators with dmft > 2, and the variable child's oral health status assessment was identified as the highest risk indicator, with a β regression coefficient of 1.093.

The prediction model showed good discrimination and calibration, and included the accepted variables for caries in children. We further converted the regression coefficient to a point-based scoring system to simplify screening for a high risk of caries (dmft > 2) in 3- to 5-year-old children; this method can be applied in developing countries for oral health surveys including primary screening. The point-based score derived by combining points for each of the indicators can be used for determine high risk of caries. As shown in Table 2, the researchers were able to obtain relevant data through questionnaires and then calculate the scores for each child based on the score of the sub-category score of each variable. As shown in Table 3, we evaluated the caries risk for each child. The advantages of our risk-scoring system are: (a) all the variables can be easily obtained by a simple questionnaire which contains a simple calculation at its end; (b) a minimum amount of clinical information was required; and (c) estimation of the specific high caries risk in a child by using a nomogram reference was possible.

In the present study, age was an important risk indicator (β regression coefficients 0.632 and 0.863 for 4 and 5 years, respectively), which has a high proportion of weight in the risk scoring system. This result resembled that found by Prakash et al.[21] The potential reason was the effect of a

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Table 4 Summary findings of the risk scoring system applied to all children

Performance measures	Estimation	Lower confidence limit	Upper confidence limit
Sensitivity	0.6201	0.5911	0.6485
Specificity	0.7460	0.7240	0.7671
PPV	0.6313	0.6022	0.6597
NPV	0.7368	0.7148	0.7581
LR+	2.4412	2.2195	2.6851
LR-	0.5092	0.4702	0.5515
Youden index	0.3661	0.3308	0.4015
Accuracy	0.6941	0.6765	0.7113

The threshold score was 20.50. PPV: positive predictive value; NPV: negative predictive value; LR+: positive likelihood ratio; LR-: negative likelihood ratio.

combination of unhealthy dietary habits and bad oral hygiene, over time leading to tooth decay and caries experience, which increased with age. Previous studies showed that the consumption of sugar-containing foods or beverages,[8] lower socioeconomic status,[12] toothache experience,[26,31] caregiver's assessment that the child's oral health is poor,[25,26] and little knowledge of and negative attitude toward oral health[14] increased the likelihood of caries. The present study did not include the 'income' variable, due to 361 answered questionnaires lacking income data. Generally, children who have visited a dentist should have less caries experience compared to those who have not. In this study, however, the opposite was true. We suspect that people in low-income countries seek medical or dental treatment when they experience discomfort or cannot tolerate the pain, which makes dental visit experience a risk indicator rather than a protective indicator. Other studies[24,26] have shown similar results. The univariate logistic regression analyses showed the p-value of the variables regarding brushing habits and caregivers' educational level to be > 0.1, indicating that these factors might not be risk indicators of the outcome variable. These findings did not agree with those of other authors.[3,17] Incorrect brushing methods might explain this difference between the current results and those of previous studies. Interestingly, caregivers' education level was not a risk indicator in our study. We postulate that the reason lies in predominantly poor health awareness, particularly regarding oral health, in many developing countries, including China.[33] Nevertheless, another study found caregivers' oral health knowledge attitude to be an important risk indicator.[14] Logically, if the caregivers judged the child's oral health to be poor or they realised that the child experienced toothache, a higher risk of caries might be present. It was striking that the children's caregivers were aware of children's oral health status, but filled teeth accounted for less than 5% of the total number of dmf teeth in our study. It is possible that the caregivers lacked access to dental services or just guessed because they did not understand the questions. In order to solve this problem and obtain obtain more accurate questionnaire results in the future and in other developing countries, it is important to enhance public oral-health education, and the investigator needs to explain the questionaire in more detail to the respondents.

To be effective, a risk-assessment programme should be simple and possess both high sensitivity and specificity.[27] However, with the trade-off between simplicity and accuracy, it may be impractical to achieve both simultaneously. Our study presents a simple, low-cost primary screening model with relatively high accuracy. The common caries risk assessments used in economically advanced country are CAMBRA (caries management by risk assessment), CAT (caries risk assessment tool) and Cariogram (caries risk assessment programme). However, these methods have some disadvantages. CAT and CAMBRA are verification forms composed of important risk indicators to qualitatively estimate individual risk. However, previous research has shown CAT and CAMBRA to have high sensitivity but low specificity, resulting in overestimating caries risk in children,[1] certainly causing overtreatment and inefficient use of medical resources. The enormous number of tables and guidelines, e.g. CAMBRA, might in fact increase the difficulty of performing caries risk assessment in children. Although CAT is easier to use, unfortunately, some of the items are unsuited to developing countries. Cariogram simplified the process of assessment, but its accuracy was limited to pre-school children.[10,16,29] Our risk score model is derived from Sichuan, China, and could be more suitable in developing countries for the primary screening of high caries risk.

Study Limitations

First, we used a cross-sectional study design. We used categorical variables and a limited number of variables instead of continuous variables to simplify the creation of a risk score. But compared to a longitudinal study and continuous variable acquistion, a cross-sectional study and categorical variable acquisition can save substantial amounts of time and costs. Secondly, some significant variables might not have been included in the model, as variable selection was performed hypothetically. It is not realistic for a model to include all the variables, and we could not increase the sensitivity of a model indefinitely. Finally, the cross-validation might have eliminated model overfitting due to differences between the study sample and the underlying population, but not the overfitting that might arise from differences between patient populations. This is aslo due to sampling and cannot be attributed solely to our model.

CONCLUSION

The present study developed a simple risk-score model to screen 3- to 5-year-old children at high risk of caries with dmft> 2 by using the β regression coefficient obtained from a multivariate regression model. This risk-score model has the advantages of simplicity low cost and relatively high accuracy, making it suitable for use in developing countries, especially in primary screening for high risk of caries.

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