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A nomogram prediction for mandibular molar survival in Chinese patients with periodontitis: A 10-year retrospective cohort study

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Abstract

Aims: To develop a nomogram prediction model of mandibular molar survival by comprehensively analysing clinical and radiographic risk factors of mandibular molar loss.

Materials and Methods: Four hundred and seventy-eight mandibular molars of 139 subjects who underwent non-surgical periodontal treatment were examined retrospectively within a mean follow-up period of 11.1 years. The association of risk factors including clinical and radiographic parameters with mandibular molar loss was assessed using univariate and multivariate Cox regression analyses. A nomogram prediction model was developed, and the validation and discriminatory ability of it were analysed.

Results: Hundred and four molars were lost in this study. Probing depth (PD), attachment loss (AL), furcation involvement (FI), bleeding on probing (BOP), tooth mobility and radiographic bone loss were significantly associated with tooth loss ($p < .01$). A gradient effect of degree of FI on mandibular molar loss existed increasing from degree II (HR = 2.37, 95% CI: 1.48, 3.79) to III (HR = 5.61, 95% CI: 3.01, 10.45) versus none & degree I. The area under the curve (AUC) of the model was 0.891. The calibration curve and decision curve analysis demonstrated good performance and high net benefit of nomogram, respectively.

Conclusions: A specific nomogram could be adopted to predict the mandibular molar survival and formulate tailored treatment plans in Chinese.

KEYWORDS
mandibular molar, nomogram, periodontitis, survival

1 | INTRODUCTION

Periodontitis is an inflammatory disease leading to the loss of connective tissue attachment, formation of periodontal pockets and resorption of alveolar bone (Page Offenbacher, Schroeder, Seymour, & Kornman 1997). It is one of the most common diseases affecting oral health status and can even cause tooth loss in severe cases, especially in the elderly (Petersen and Baehni, 2012). Tooth loss can affect phonation, bolus creation and swallow and the struction of craniofacial bone (Zimmerman & Jenzer, 2020). Besides, it is also associated with some specific diseases such as cancer and Alzheimer' disease (Dioguardi et al., 2019; Gerritsen, Allen, Witter, Bronkhorst, & Creugers, 2010; Sadighi Shamami, Sadighi Shamami, & Amini, 2011).

Numerous studies have verified how various factors affect tooth loss (Costa et al., 2014; Dannewitz et al., 2016; Faggion, Petersilka, Lange, Gerss, & Flemmig, 2007; Pretzl, Kaltschmitt, Kim, Reitmeir, & Eickholz, 2008). A number of factors, such as tooth mobility, bone loss (BL) (Costa et al., 2012; Eickholz, Kaltschmitt, Berbig, Reitmeir, & Pretzl, 2008; Graetz et al., 2015), degree of furcation involvement (FI) (Graetz et al., 2015; McGuire & Nunn, 1996; Nibali et al., 2016, 2017; Salvi et al., 2014), tooth type and vitality (Faggion et al., 2007; Graetz et al., 2015; Muzzi et al., 2006; Pretzl et al., 2008), have shown great impact on tooth loss. Besides, the alveolar bone resorption related to destructive periodontal disease in multirooted teeth can reach the root furcation area, thus initiating microbial colonization, which formed FI. This area has some specific anatomical characteristics, such as grooves, furcation ridges and enamel projections (Al-Shammari, Kazor, & Wang, 2001; Lim et al., 2016), with consequent difficulties in self-performed and professional plaque removal (Fleischer, Mellonig, Brayer, Gray, & Barnett, 1989). Some recent studies have found that FI increased the risk of tooth loss in patients with or without regular periodontal care (Nibali et al., 2016, 2017). However, little studies have reported the radiographic data besides clinical examination on the association between FI and tooth loss, especially in Chinese with periodontitis during the supportive periodontal therapy (SPT) to our knowledge.

Dentists are keen on predicting tooth survival to make wise decisions whether retaining teeth or not in patients with periodontitis in advance: removing teeth may result in the need for dental restoration and associated risks of complications (Schwendicke, Graetz, Stolpe, & Dorfer, 2014), while retaining teeth with hopeless prognosis might hazard the maintenance of other (often adjacent) teeth (Graetz et al., 2013) and then produce large costs for treatment (Schwendicke, Stolpe, Plaumann, & Graetz, 2016). Some prediction models have been used in the previous studies, such as logistic regression, recursive partitioning, random forest, extreme gradient boosting and other multivariable models, but models predicting tooth loss in periodontitis were still limitedly possible (Krois et al., 2019; Martinez-Canut et al., 2018; Schwendicke et al., 2018). There is no nomogram prediction model to evaluate the risk of mandibular molar survival, especially in Chinese affected with periodontitis, although it can present an individualized evidence-based and highly accurate risk estimation.

The purpose of this study was to analyse the risk factors especially FI of mandibular molar loss in Chinese with periodontitis within 10 years after non-surgical periodontal treatment (NSPT), so as to develop a nomogram prediction model based on the clinical and radiographic data.

Clinical Relevance

Scientific rationale for the study: Periodontitis is one of the most common diseases leading to tooth loss, which is affected by many factors. However, evidence of the clinical and radiographic risk factors of mandibular molar loss in Chinese with periodontitis is limited, and no effective prediction model of it has been constructed.

Principal findings: A nomogram model has been constructed to predict the mandibular molar survival in Chinese patients with periodontitis based on clinical and radiographic data analyses of risk factors.

Practical implications: The nomogram can be used to help clinical periodontists with decision-making and subsequent arrangement.

2 | MATERIALS AND METHODS

2.1 | Patient population

Hundred and thirty-nine subjects who had received NSPT from 1998 to 2009 with a follow-up period of at least 7 years in the Department of Periodontology, Peking University School and Hospital of Stomatology (PKUSS) were selected. The personalized recall protocol was made based on the Periodontal Risk Assessment (Lang & Tonetti, 2003). The flow chart of patients' selection and screening was shown in Figure S1. The study was approved by the Ethics Committee of PKUSS (approval number: PKUSSIRB-201310066). All protocols were performed in accordance with approved guidelines and regulations.

Inclusion criteria were as follows:

- Patients who were diagnosed as chronic periodontitis (CP; Armitage, 1999);
- Patients had at least one re-evaluation and one record of full-mouth periapical radiographs besides the one at the initial visit;
- Patients with a follow-up period of at least 7 years.

Exclusion criteria were as follows:

- Systemic diseases except diabetes mellitus (e.g., acquired immune deficiency syndrome; nephrosis; hepatopathy; hypertension; neutropenia, etc.), pregnancy or under medication known to affect periodontium;
- Periodontal surgery history.

2.2 | Clinical examinations

The periodontal clinical data of all subjects were examined and recorded by trained, calibrated and licensed periodontists, and intraclass correlation (ICC) of clinical data before entering the clinic was up to 0.98, which showed high consistency. In addition, some clinicians are responsible for recording and sorting out the data of periodontal charts into the database. Each data were entered by two clinicians, respectively, and checked for calibration. If there was any inconsistency, it would be entered by the third clinician to ensure the accuracy of the data entry.

Patient level:

- Gender;
- Age;
- Observation period computed by the interval between the initial visit and the last re-evaluation;
- Frequency of periodontal maintenance (FPM, regular – receiving SPT at least once a year versus irregular – receiving SPT less than once a year);
- Smoking status (heavy-smoker classified as patients who smoked ≥10 cigarettes per day, mild-smoker classified as patients who smoked <10 cigarettes per day, non-smoker classified as patients who did not smoke at the initial visit);
- Systemic status (healthy vs. diabetes mellitus).

Tooth level:

- Bleeding on probing (BOP, positive vs. negative);
- Tooth mobility (none-III degree) (Lang & Lindhe 2015);
- FI (none-IV degree) (Glickman, 1972) (The higher FI between buccal and lingual surfaces of each tooth was recorded).

Site level:

- Probing depth (PD) measured at six sites (mesial, middle and distal sites of buccal and lingual surfaces, and the highest PD of each surface was recorded);
- Attachment loss (AL) measured at two sites (higher AL sites of buccal and lingual surfaces, respectively) by the distance from the cementoenamel junction to the bottom of the periodontal pocket.

Data from the third mandibular molars were excluded.

2.3 | Radiographic analyses

Full-mouth periapical radiographs of all subjects were taken by radiology technicians, but not a single expert, utilizing the same examiner. Radiographic images were scanned for digital documentation (UMAX Powerlook1000 manual control, 600 dpi). The iDentOne Dental PMS software was used to perform measurements of mandibular molars except third ones on the radiographic images by one periodontist. The data were measured twice with an interval of over 3 months, and the ICC was 0.99, showing extremely high reproducibility. The measured method used is depicted in Figure 1.

The ratio of BL height and full root length was calculated and defined as BL. Both mesial and distal sides of each tooth were analysed, which were defined as MBL (MM_1/CO*100%) and DBL (DD_1/CO*100%), respectively. EF and F_MF_D were identified as the vertical and horizontal BL in the furcation area, respectively. The ratio of vertical BL height and full root length was calculated and defined as VBL (EF/CO*100%). Considering the influence of the opening angle of root furcation, we combined vertical and horizontal BL into the

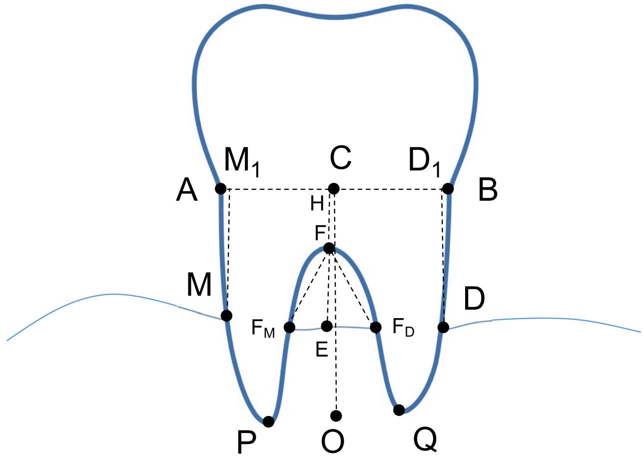


FIGURE 1 Measurement of periapical radiograph. Point A and B were the mesial and distal point of cementoenamel junction, respectively. Point P and Q were the apical point of mesial and distal root, respectively. Point O was identified as the midpoint of the line P-Q. Point C was identified as the foot of a perpendicular from L to line A-B. CO was identified as the root length. Point M and D were the bottom of the mesial and distal bone defect, respectively. Point M_1 and D_1 were the foots of perpendicular from M and D to the line A-B, respectively. MM_1 and DD_1 were identified as the mesial and distal bone loss (BL) height, respectively. Point F was the apex of the furcation fornix. Point F_M and F_D were the lowest point of BL in the mesial and distal furcation area, respectively. Point E was identified as the foot of a perpendicular from F to the line F_M-F_D. Point H was identified as the foot of a perpendicular from F to the line A-B

BL area of the furcation region ($S = 1/2*EF*F_MF_D$). So, BLA was defined as the ratio of BL area in the furcation region and the product of crown and full root length (S/[AB*CO]*100%). The ratio of root trunk length and full root length was defined as RT (FH/CO*100%). The ratios above were expressed in the form of percentages, and the methods of calibration had been used in our previous study (Shi et al., 2019).

2.4 | Statistical analyses

The tooth-level and site-level characteristics were compared between two groups divided by whether the tooth loss or not. Variables were presented as Mean ± *SD*/*N* (%). Student's *t*-test (normal distribution) and Mann–Whitney (non-normal distribution) were used for continuous variables, and chi-square tests were performed for categorical variables. Risk factors for mandibular molar loss were analysed by univariate and multivariate cox regression analyses. The nomogram prediction model was performed by full model from bootstrap, and some factors without significance were excluded from the full model. The performance of the model was evaluated by the calibration curve. The receiver operating characteristic (ROC) curve and decision curve analysis (DCA) were used to estimate the predictive accuracy and net benefit of the model, respectively. The statistical analyses were two-tailed, and p value < .05 was

TABLE 1 Baseline characteristics of study population

Variable	*N*	%	Mean (*SD*)	Range
Age (years)	–	–	41.8 (9.9)	21.8–67.4
Gender				
Male	80	57.55	–	–
Female	59	42.45	–	–
FPM				
Regular	13	9.35	–	–
Irregular	126	90.65	–	–
Observation period (years)	–	–	11.1 (4.3)	7.0–17.3
Smoking status				
Non–smoker	103	74.10	–	–
Mild–smoker	19	13.67	–	–
Heavy–smoker	18	12.95	–	–
Systemic status				
Healthy	116	83.45		
Diabetes mellitus	23	16.55		
Stage				
III	47	33.81		
IV	92	66.19		
Grade				
B	6	4.32		
C	133	95.68		
Total	139	100.00	–	–

Abbreviation: FPM, frequency of periodontal maintenance.

considered statistically significant. Besides, we calculated the power value according to the simulation method of statistical efficiency. All the statistical analyses were performed with R (http://www.R-project.org) and EmpowerStats software (www.empow erstats.com, X&Y solutions, Inc).

3 | RESULTS

3.1 | Baseline characteristics

According to the inclusion and exclusion criteria, 139 patients with CP were included in the present study. The median follow-up period was 10.0 years. Two thirds of the participants were Stage IV, and others were Stage III, while 95.68% of them were Grade C in the context of 2018 new classification of periodontal diseases and conditions (Papapanou et al., 2018; Tonetti, Greenwell, & Kornman, 2018). During the observation period, 64 of 139 (46.04%) patients lost at least one mandibular molar. The criteria for tooth extraction were based on the decision-making process for tooth extraction (Avila et al., 2009), which need to be interpreted level by level from level one to level six. All variables but initial assessment and clinician's skill were objective. A total of 104 mandibular molars in the study were lost. Among them, 89 teeth (85.58%) were extracted by dentists because of the severity of periodontal disease, FI and refractory periodontitis, while the rest were lost spontaneously by exfoliation. Details were showed in Tables S1 and S2. The baseline characteristics of study population are shown in Table 1.

The tooth-related and site-related characteristics of the 478 mandibular molars are divided into two groups by whether the tooth loss or not during SPT (Table 2). AL and PD of both buccal and lingual surfaces were significantly higher in TL (tooth loss) group than NTL (none-tooth loss) group ($p < .001$). FI and tooth mobility were significantly different between two groups ($p < .001$). Whether in the area of root furcation or not, BL was also significantly higher in TL group ($p < .001$). While there was no significant difference for BOP and RT between the two groups, the power value calculated was over 0.99, which showed good test efficiency of this study.

3.2 | Univariate and multivariate analyses of tooth loss

Table 3 shows univariate Cox regression analyses for the risk of tooth loss related to three-level factors. Age, PD, AL, BOP and tooth mobility were significantly associated with mandibular molar loss. And

TABLE 2 Tooth-related and site-related variables in NTL group and TL group

Variable	NTL	TL	*p* value
N	374 (78.24%)	104 (21.76%)	
AL			
Buccal surface (mm)	4.55 ± 2.61	4.57 ± 2.64	<.001*
Lingual surface (mm)	4.64 ± 2.87	6.62 ± 2.89	<.001*
PD			
Buccal surface (mm)	5.86 ± 1.76	5.89 ± 1.81	<.001*
Lingual surface (mm)	5.84 ± 1.61	6.15 ± 1.63	<.001*
FI			
None	122 (32.62%)	23 (22.12%)	<.001*
Degree I	73 (19.52%)	6 (5.77%)	
Degree II	163 (43.58%)	53 (50.96%)	
Degree III	14 (3.74%)	18 (17.31%)	
Degree IV	2 (0.53%)	4 (3.85%)	
BOP			
Negative	18 (4.81%)	2 (1.92%)	.271
Positive	356 (95.19%)	102 (98.08%)	
Tooth mobility			
None	300 (80.21%)	32 (30.77%)	<.001*
Degree I	46 (12.30%)	44 (42.31%)	
Degree II	27 (7.22%)	22 (21.15%)	
Degree III	1 (0.27%)	6 (5.77%)	
MBL	19.73 ± 12.54	47.10 ± 18.91	<.001*
DBL	16.80 ± 12.46	38.63 ± 17.85	<.001*
RT	32.40 ± 9.13	31.73 ± 7.66	.683
VBL	11.20 ± 10.28	28.69 ± 12.68	<.001*
BLA	1.18 ± 2.15	3.53 ± 2.69	<.001*

Abbreviations: AL, attachment loss; BLA, the ratio of bone loss area in furcation region and the product of root length and crown length; BOP, bleeding on probing; DBL, the ratio of distal bone loss and full root length; FI, furcation involvement; MBL, the ratio of mesial bone loss and full root length; NTL, none-tooth loss group; PD, probing depth; RT, the ratio of root trunk length and root length; TL, tooth loss group; VBL, the ratio of vertical bone loss in furcation region and full root length.
*p value < .05.

TABLE 3 Univariate Cox regression analyses for the risk of tooth loss

Covariate	Statistics	HR (95%CI)	*p* value
Gender			
Male	279 (58.37%)	Ref.	
Female	199 (41.63%)	0.78 (0.52, 1.18)	.2372
Age (years)	41.76 ± 9.85	1.03 (1.01, 1.05)	.0007*
PD_{max}			
Buccal surface (mm)	6.13 ± 1.90	1.36 (1.25, 1.48)	<.0001*
Lingual surface (mm)	6.08 ± 1.75	1.36 (1.25, 1.49)	<.0001*
AL			
Buccal surface (mm)	5.00 ± 2,78	1.20 (1.13, 1.28)	<.0001*
Lingual surface (mm)	5.06 ± 2.97	1.16 (1.09, 1.22)	<.0001*
FI			
None (ref.)	145 (30.33%)	1.00	
Degree I	79 (16.53%)	0.48 (0.19, 1.18)	.1103
Degree II	216 (45.19%)	2.10 (1.28, 3.44)	.0033*
Degree III	32 (6.69%)	5.18 (2.79, 9.64)	<.0001*
Degree IV	6 (1.26%)	5.17 (1.78, 14.96)	.0025*
BOP			
Negative(ref.)	20 (4.18%)	1.00	
Positive	458 (95.82%)	5.00 (1.21, 20.65)	.0260*
Tooth mobility			
None (ref.)	332 (69.46%)	1.00	
Degree I	90 (18.83%)	5.71 (3.61, 9.02)	<.0001*
Degree II	49 (10.25%)	7.12 (4.12, 12.30)	<.0001*
Degree III	7 (1.46%)	17.70 (7.11, 41.15)	<.0001*
MBL	25.30 ± 17.89	1.06 (1.05, 1.06)	<.0001*
DBL	21.31 ± 16.29	1.05 (1.04, 1.06)	<.0001*
RT	32.02 ± 8.96	0.99 (0.98, 1.01)	.6145
VBL	14.91 ± 12.86	1.06 (1.05, 1.07)	<.0001*
BLA	1.67 ± 2.41	1.17 (1.12, 1.22)	<.0001*

Abbreviations: CI, confidence interval; HR, Hazard ratio; ref., reference.
*p value < .05.

for tooth mobility, the hazard ratio compared to none-tooth mobility increased with the increase of degree (HR = 5.71, 95% CI: 3.61, 9.02, p < .0001; HR = 7.12, 95% CI: 4.12, 12.30, p < .0001; HR = 17.70, 95% CI: 7.11, 41.15, p < .0001). Besides, degree II to IV FI were significantly associated with tooth loss, while for degree I FI statistical significance was not reached (HR = 0.48, 95% CI: 0.19, 1.18, p = .1103). As for radiographic variables, BL in both furcation region and non-furcation region was significantly associated with tooth loss (p < .0001) except RT (HR = 0.99, 95% CI: 0.98, 1.01, p = .6145).

Multivariate cox regression analyses of tooth loss risk associated in different models are shown in Table 4. Considering the sample size, we combined none and degree I FI together to analyse. The statistical significance of RT was still not reached like the univariate analysis (HR = 1.00, 95% CI: 0.98, 1.02, p = .8934). Other factors were all positively associated with tooth loss according to the multivariate analysis. And the risk of tooth loss in molars of degree III FI (HR = 4.94, 95% CI: 2.64, 9.24, p < .0001) was higher than those of

TABLE 4 Multivariate Cox regression analysis of tooth loss risk associated in different models

Variable	Crude model (HR, 95%CI, *p*)	Minimally adjusted model (HR, 95%CI, *p*)	Fully adjusted model (HR,95%CI, *p*)
PD_{max}			
Buccal surface (mm)	1.36 (1.25, 1.48) <.0001*	1.35 (1.24, 1.46) <.0001*	1.39 (1.27, 1.52) <.0001*
Lingual surface (mm)	1.36 (1.25, 1.49) <.0001*	1.37 (1.25, 1.50) <.0001*	1.40 (1.27, 1.54) <.0001*
AL			
Buccal surface (mm)	1.20 (1.13, 1.28) <.0001*	1.20 (1.13, 1.28) <.0001*	1.28 (1.19, 1.37) <.0001*
Lingual surface (mm)	1.16 (1.09, 1.22) <.0001*	1.15 (1.09, 1.22) <.0001*	1.18 (1.12, 1.26) <.0001*
FI			
None & degree I (ref.)	1.00	1.00	1.00
Degree II	2.58 (1.63, 4.07) <.0001*	2.32 (1.46, 3.70) .0004*	2.37 (1.48, 3.79) .0003*
Degree III	6.34 (3.51, 11.46) <.0001*	5.98 (3.28, 10.90) <.0001*	5.61 (3.01, 10.45) <.0001*
Degree IV	6.31 (2.21, 17.99) .0006*	4.38 (1.48, 12.96) .0077*	4.57 (1.54, 13.55) .0061*
Tooth mobility			
None (ref.)	1.00	1.00	1.00
Degree I	5.71 (3.61, 9.02) <.0001*	5.41 (3.42, 8.56) <.0001*	5.59 (3.51, 8.91) <.0001*
Degree II	7.12 (4.12, 12.30) <.0001*	7.45 (4.28, 12.96) <.0001*	9.35 (5.12, 17.07) <.0001*
Degree III	17.10 (7.11, 41.15) <.0001*	16.38 (6.73, 39.90) <.0001*	23.64 (9.25, 60.43) <.0001*
BOP			
Negative (ref.)	1.00	1.00	1.00
Positive	5.00 (1.21, 20.65) .0260*	4.11 (0.99, 17.07) .0519	4.26 (1.02, 17.77) .0465*
MBL	1.06 (1.05, 1.06) <.0001*	1.06 (1.05, 1.06) <.0001*	1.06 (1.05, 1.07) <.0001*
DBL	1.05 (1.04, 1.06) <.0001*	1.05 (1.04, 1.06) <.0001*	1.06 (1.05, 1.07) <.0001*
VBL	1.06 (1.05, 1.07) <.0001*	1.07 (1.05, 1.08) <.0001*	1.08 (1.06, 1.09) <.0001*
BLA	1.17 (1.12, 1.22) <.0001*	1.19 (1.14, 1.25) <.0001*	1.26 (1.19, 1.34) <.0001*
RT	0.99 (0.98, 1.01) .6145	1.00 (0.98, 1.02) .9659	1.00 (0.98, 1.02) .8934

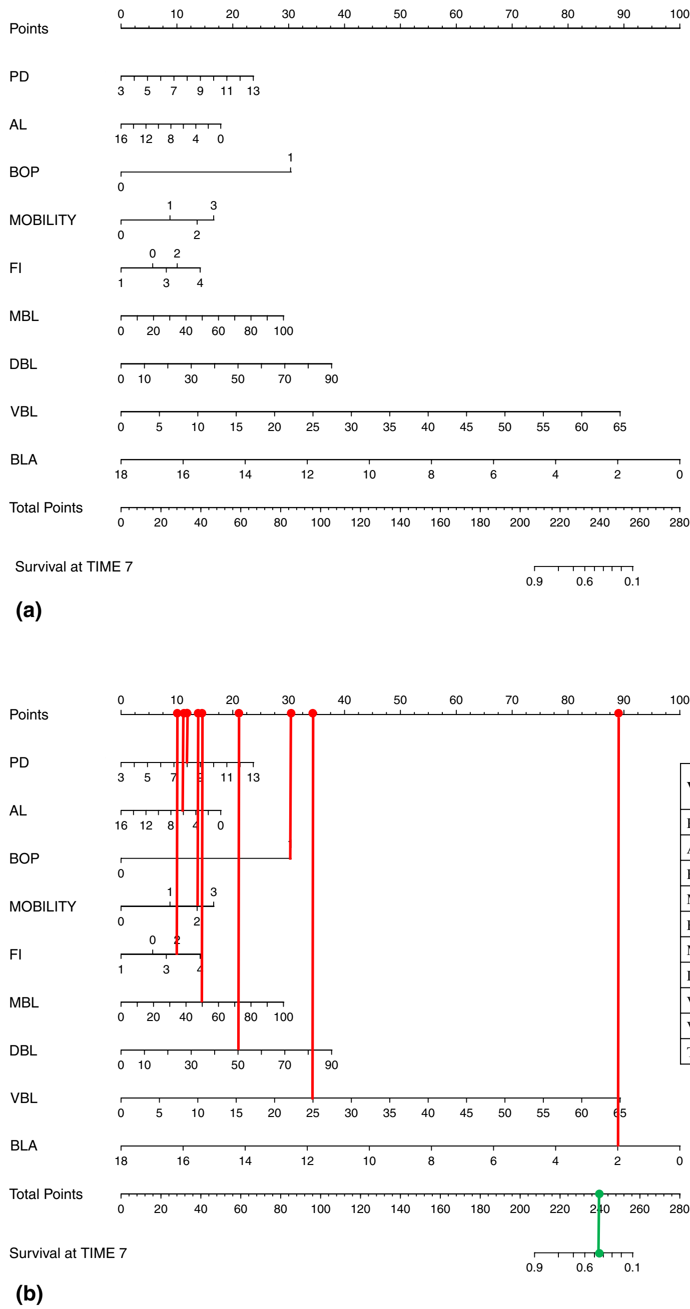
Note: Crude model: not adjusted with other covariants.
Minimally adjusted model: adjusted with age and gender.
Fully adjusted model: adjusted with age, gender, family history, systemic history, smoking status.
Abbreviations: CI, confidence interval; HR, Hazard ratio; ref., reference.
**p* value < .05.

degree IV FI (HR = 4.57, 95% CI: 1.54, 13.55, $p = .0061$), but there was no significant difference between them ($p = .9885$).

3.3 | Construction and validation of the nomogram prediction model

The nomogram predicting the mandibular molar survival in the seventh year is depicted in Figure 2. The nomogram was constructed based on the results of Cox regressions above. PD, AL, BOP, tooth mobility, FI and BL were all put into the model, while there was no significant difference between 0 and degree I of FI ($p = .1103$). The axes and labels of the nomogram were actually derived from all the data in the database. The usefulness of it was that it mapped the predicted probabilities into points on a scale from 0 to 100 in a user-friendly graphical interface. So, each factor in the nomogram was assigned a weighed point that denoted the survival prognosis. According to the data included in this study, BLA had the greatest influence on the prediction results. Therefore, the nomogram was based on this index to get the points axis. And the scales of other variables were calculated according to this standard. Detailed assignment processes were shown in Tables S3 and S4. The higher the mandibular molar scores, the lower the survival rate will be in the seventh year.

The sensitivity and specificity of the nomogram was measured by time-depended ROC curve analysis, and the area under the curve (AUC) for the model was 0.891, which showed high predictive accuracy of the model (Figure 3a). The accuracy of the nomogram was also assessed by the bootstrap (500 resample) validation. In addition, the calibration curve showed that the predicted line overlapped well with the reference line, demonstrating the good performance of the nomogram (Figure 3b). Furthermore, DCA was performed to evaluate the net benefit of the nomogram in order to verify whether the model was clinically useful or not. The result



Variable	Value	Point
PD (mm)	8	12
AL (mm)	6	12
BOP	1	31
Mobility	2	14
FI	2	10
MBL (%)	50	15
DBL (%)	50	22
VBL (%)	25	35
VBA (%)	2	89
Total Point		240

FIGURE 2 A nomogram prediction on mandibular molar survival in the seventh year of follow-up. (a) The value of each variable is given a score on the point scale axis in the first line. To use the nomogram, draw a vertical line to the point scale axis to determine how many points are attributed for each variable value. A total score can be easily calculated by adding each single score. Locate the sum on the total points axis, and project the total score to the bottom line of the nomogram, then we are able to estimate the probability of tooth survival. (b) For example, the clinical and radiographic data of one mandibular molar in this study are as follows: PD = 8mm, AL = 6mm, tooth mobility = 2, FI = 2, MBL = 50%, DBL = 50%, VBL = 25%, BLA = 2% and BOP (+). Project each value along the red line to the points axis to get the point of each variable, which is listed in the table on the right. Add each single point to get a total point of 240. Locate the sum 240 on the total points axis, and project it to the bottom line along the green line, then we can get around 45% probability of tooth survival in the seventh year. PD, probing depth; AL, attachment loss; FI, furcation involvement; BOP, bleeding on probing; MBL, the ratio of mesial bone loss (BL) and full root length; DBL, the ratio of distal BL and full root length; VBL, the ratio of vertical BL in furcation region and full root length; BLA, the ratio of BL area in furcation region and the product of root length and crown length

showed the nomogram offered a good clinical utility (Figure 3c). Consequently, the nomogram model is suitable for predicting mandibular molar survival in the seventh year, which might help periodontists with decision-making and subsequent arrangement.

4 | DISCUSSION

Periodontitis is mostly caused by the imbalance between bacterial colonization and the host response (Socransky & Haffajee, 2005), so areas such as furcation of multirooted teeth with limited access to clean are more susceptible to periodontal infections (Fleischer et al., 1989). This study examined the long-term survival of mandibular molars with BL and FI in Chinese affected with CP.

The results of this study showed that PD, AL, BOP, FI, tooth mobility and BL were all significantly associated with mandibular molar loss ($p < .05$), which was consistent with the previous studies (Costa et al., 2012; Graetz et al., 2015; Nibali et al., 2018; Salvi et al., 2014; Tonetti, Christiansen, & Cortellini, 2017). In addition, the average loss of molars per patient during the mean observation period of 11.1 years was 0.07 teeth/year, which was slightly higher than 0.06 teeth/year in a previous study during the follow-up of 13.2 years (Dannewitz et al., 2016). However, mean reductions of PD and percentage of BOP were 0.69 mm and 24.58%, respectively, in the present study, which was similar to the previous study (Jiao et al., 2017). Moreover, 11 subjects were downgraded from Grade C to B during SPT, so the treatment of the population was effective. Therefore, the high rate of tooth loss may due to the severe

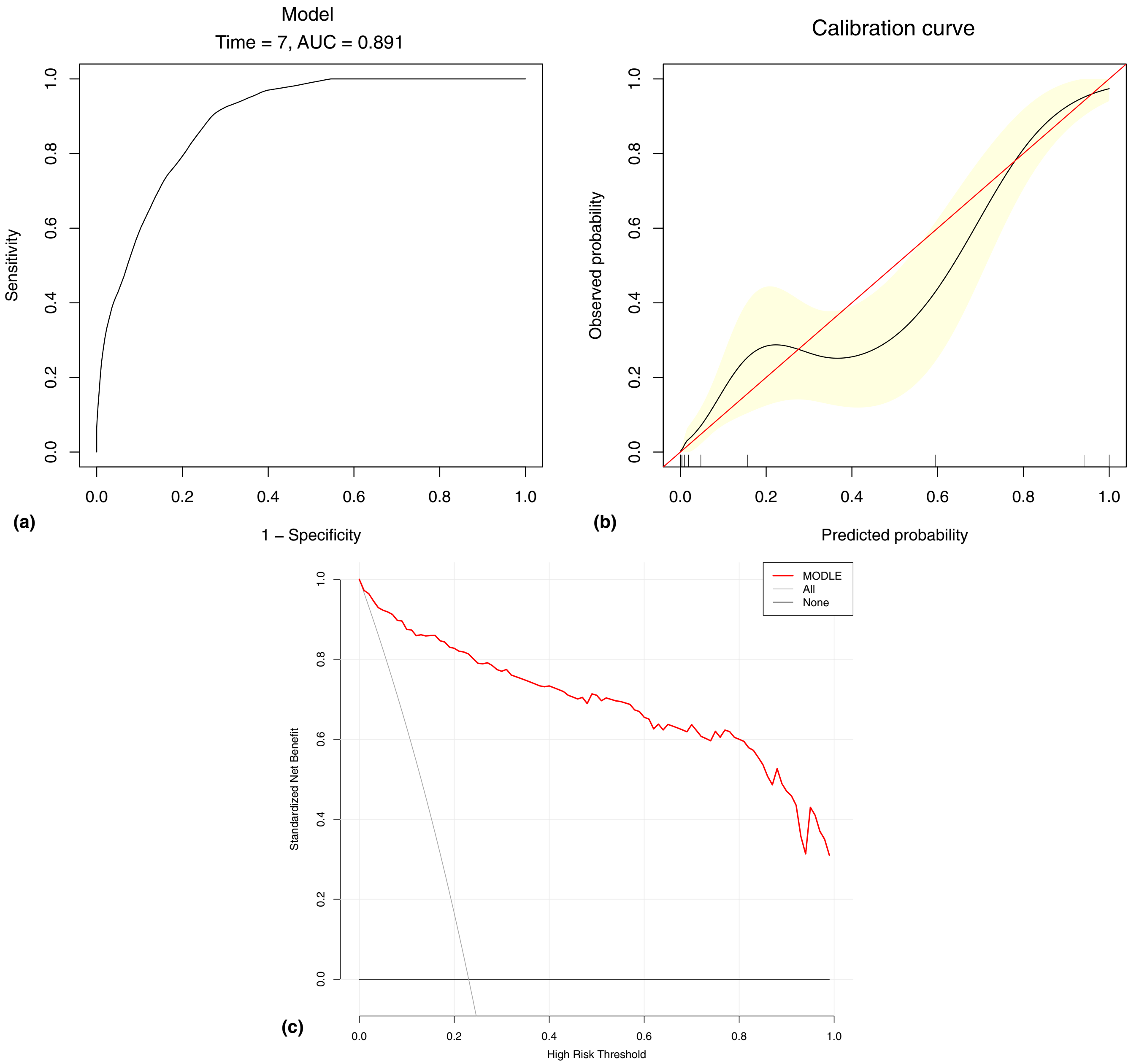


FIGURE 3 Validation of the nomogram predicting mandibular molar survival. (a) Time-depended ROC curve in predicting the survival of mandibular molar in the seventh year of follow-up. The AUC is 0.891. (b) Calibration curve to show the predicted probability of mandibular molar survival. The red line represents a perfect prediction by an ideal model. The black line represents the performance of the nomogram, of which a close fit to the diagonal red line represents a good prediction. (c) Decision curve analysis revealed that the prediction model provided a superior net benefit. The grey line labelled “all” assumes that all mandibular molars survive in the seventh year. The black line labelled “none” represents that no mandibular molars survive in the seventh year. The red solid line represents the nomogram model. AUC, area under the curve; ROC, receiver operating characteristic

condition and unique anatomy of molars of Chinese patients with periodontitis.

The prevalence of advanced periodontitis in China is greatly higher than developed countries (Jiao et al., 2017). Besides, the periodontal outpatients in Chinese specialized hospitals were mainly diagnosed as CP, with the average age of visits being older, the severity of conditions being heavier (72.66% of patients with severe periodontitis) and re-visits being less (Zhao, Shi, Zhang, Meng, & Cao, 2016). According to the results of the 4th National Oral Health Survey (Sun et al., 2018), the prevalence of BOP, PD ≥ 4mm and CAL ≥ 3 mm reached 87.4%, 52.7% and 33.2%, respectively, which were obviously higher than the last survey (Qi, 2008). The data of PD ≥ 4mm showed the prevalence of periodontal diseases was higher than that reported in other countries, such as Hungary and Denmark, which were 27.4% and 42%, respectively (Krustrup & Erik Petersen, 2006; Seo et al., 2003). In addition, most of the subjects in this study were re-evaluated once every 2–3 years, and only three of them interrupted SPT for at least 4 years. Mean annual dental visits of patients were merely 0.43 times/year, which was similar to previous study (0.34 times/year) (Meng, 2008). The serious condition and low consultation rate of Chinese with periodontitis may partly account for the high rate of tooth loss.

Furthermore, the unique anatomical characteristics of Chinese may be another reason. Some anatomical factors of root surfaces, such as furcation entrance dimensions (FED) (Chiu, Zee, Corbet, & Holmgren, 1991; Seo et al., 2003), cervical enamel projections (CEP) (Seo et al., 2003) and root trunk length (Hou, Hung, Tsai, & Weisgold, 2005), had different influence on the progression and management of periodontitis. As the previous studies showed that Chinese had narrow FED (Bower, 1979), high prevalence of CEP (Zee, Chiu, Holmgren, Walker, & Corbet, 1991), short root trunk length (Hou & Tsai, 1997), etc. (Goh & Ong, 2019) Consequently, it brought tremendous challenges to the management of periodontitis in Chinese, leading to the high rate of tooth loss.

A consistent conclusion of most previous studies investigating the influence of FI on tooth loss was that a gradient effect existed increasing from degree I to III (Dannewitz et al., 2016; Graetz et al., 2015; Salvi et al., 2014), and the result in the present study was similar to this conclusion. The results reminded us that once bone resorption occurred in the furcation region, the risk of tooth loss would increase exponentially. The regression analyses of radiographic bone resorption data ulteriorly confirmed this conclusion. Besides, when the BL increased by 10% of the full root length, no matter in the interproximal surfaces or the furcation region, the risk of tooth loss would increase around 10% (Table 4). And the nomogram prediction model showed that BL in the furcation region played an important role in the predictive evaluation.

Nomogram is an effective tool to calculate the probability of a specific clinical result for an individual patient. It is valuable for risk assessment, clinical decision-making and superior communication (Zhang et al., 2018). In this study, nomogram prediction model was developed to predict the survival of mandibular molars in Chinese with periodontitis with high diagnostic accuracy, reliability and net benefit (AUC = 0.891). To our knowledge, it was the first nomogram for predicting the survival of mandibular molars in Chinese with periodontitis. The model can provide useful clinical references for periodontists and show patients a more intuitive understanding the risk of mandibular molar loss. As a new concept to guide clinical decision-making, this nomogram is worthy of further verification and improvement.

The strength of the study lies in the innovation of a nomogram prediction model with risk factors especially FI and radiographic data, which was not used before. The main limitations are retrospective nature of the study with the consequent potential bias. But we strictly grasped the criteria of inclusion and exclusion to reduce the selection bias. Besides, we used objective clinical data and tested the consistency of measurement results to reduce information bias. In addition, multivariate cox regression analyses were performed using the minimally and fully adjusted models, and the final results were consistent, which further reduced the confounding bias. Furthermore, the population included in this study were patients with CP who were normally received and treated in the daily clinical work, which coincided with the actual situation and can be extended to a certain extent. However, we only analysed the risk factors of mandibular molar loss in one centre and predicted the condition of mandibular molar survival in the seventh year. Actual external validation was lacking due to the lack of another independent population sample data. Therefore, we will continue to collect data in the subsequent studies and expect to validate our model through more rigorous prospective trials and multicentre studies, extending it to different tooth sites, time and fields next.

5 | CONCLUSION

This study produces evidences that PD, AL, BOP, FI, tooth mobility and BL increase the risk of mandibular molar loss in Chinese with periodontitis. And a nomogram has been constructed to predict the mandibular molar survival in Chinese patients with periodontitis based on clinical and radiographic data analyses of above risk factors.

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CONFLICT OF INTEREST

The authors have stated explicitly that there are no conflicts of interest in connection with this article.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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