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ORIGINAL ARTICLE

Nomogram prediction of vulnerable periodontal condition before orthodontic treatment in the anterior teeth of Chinese patients with skeletal Class III malocclusion

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ABSTRACT

Objective: To establish and verify models predictive of thin periodontal phenotype and alveolar fenestration/dehiscence in the anterior teeth of patients with skeletal Class III malocclusion.

Material and methods: Retrospective data of 669 anterior teeth (305 in maxillae and 364 in mandibles) from 80 patients with skeletal Class III malocclusion before augmented corticotomy were collected. Distribution of thin periodontal phenotype and alveolar fenestration and dehiscence were evaluated and their associations with potential influencing factors were explored using univariate and multivariate analyses. The predictive models were visualized as nomograms, the accuracy of which was tested by receiver operating curve analyses.

Results: Thin phenotype was associated with Mazza bleeding index, sex, tooth type, probing depth and width of keratinized gingiva (WKG). Labial dehiscence was associated with age, jaw, labial bone thickness, mandibular plane angle, sagittal root position (SRP), sex, tooth type, and WKG. Labial fenestration was associated with sex, tooth type, SRP, and periodontal phenotype. The areas under the curves of nomogram prediction models for periodontal phenotype, alveolar dehiscence, and alveolar fenestration were 0.84, 0.81, and 0.73, respectively.

Conclusions: Female sex, lateral incisor, and limited WKG may be risk factors for thin periodontal phenotype. Age, canine, male sex, mandible, thin labial bone thickness, and root positioned against the labial plate may be risk factors for labial dehiscence; and female sex, thick phenotype, root positioned against the labial plate, lateral incisor, and canine may be risk factors for labial fenestration. The predictive performance of the models was acceptable.

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Skeletal Class III malocclusion; periodontal phenotype; alveolar dehiscence; alveolar fenestration; nomogram prediction

Introduction

Orthodontic treatment can greatly impact the periodontium, particularly in patients with a limited amount of periodontal soft and hard tissue. Orthodontic movement of teeth with a thin gingiva and/or a thin labial alveolar bone (even an alveolar dehiscence or fenestration) may result in iatrogenic sequelae manifesting as loss of periodontal support and/or gingival recession or even tooth loss [1].

Patients with skeletal Class III malocclusion have a high prevalence of thin gingiva. Kaya et al. [2] evaluated the gingiva in the mandibular anterior region of subjects with different malocclusion; the gingival thickness (GT) of the mandibular anterior teeth of patients with Angle Class III ranged from 0.59 mm to 0.78 mm. Periodontal phenotype (previously known as biotype) is often used to evaluate GT. Kaya et al. classified a GT of $\leq$1 mm and $>$1 mm as thin and thick phenotype, respectively. The mean GT of the mandibular anterior region was only 0.71 $\pm$ 0.17 mm, moreover, displayed the thin gingival biotype. On the other hand, a simpler and more convenient classification defined a thin phenotype if the outline of the underlying periodontal probe could be seen through the gingiva, and thick if it could not [3]. Using the latter classification, the prevalence of thin periodontal phenotype was $>$50% in central incisors (CIs) of Saudi Arabians [4]. In addition, $>$30% of anterior teeth and $>$50% of mandibular anterior teeth were with thin periodontal phenotype in Chinese patients [5]. Therefore, prior reports show that an insufficient GT is a typical finding in the anterior teeth of patients with skeletal Class III malocclusion.

Regarding alveolar bone, a retrospective study based on cone-beam computed tomography (CBCT) images showed

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that nearly one-third of Turkish patients with Class III malocclusion exhibited alveolar fenestration and/or dehiscence defects in the maxilla, and half of those patients had defects in the mandible [6]. In a Chinese population, a high prevalence of alveolar fenestration and/or dehiscence was found (41.5% in the maxilla and 58.5% in the mandible) [7].

Therefore, for patients with skeletal Class III malocclusion, careful evaluation of the periodontal phenotype and presence of a labial alveolar defect is crucial before and during orthodontic treatment. In addition, preventative or interceptive periodontal augmentation (soft tissue and/or bone augmentation) therapies may be planned based on an accurate assessment of the periodontal condition [1].

Thin gingiva phenotype was associated with, for instance, dental arch, tooth position, and keratinized gingiva width [2,5,8,9]. Alveolar fenestration and/or dehiscence are associated with age, sex, and a history of orthodontic treatment [10]. Several factors might affect the periodontal condition of a patient before orthodontic treatment utilizing the existing knowledge from the previous studies. Most of these risk factors have been identified in univariate rather than multivariate analyses. Therefore, bias may have affected the reliability of the results. In addition, no model is available for predicting the probability of a vulnerable periodontium. It is difficult for general practitioners or non-periodontists to assess periodontal risk without a proper tool. Therefore, based on clinical and radiographic data, the aim of this study was to develop nomograms for predicting thin periodontal phenotype and alveolar defects for patients with skeletal Class III malocclusion before orthodontic treatment.

Materials and methods

This retrospective study was approved by the Research Ethics Committee of Peking University Health Science Centre (approval number: PKUSSIRB-201735074). All protocols were performed in accordance with approved guidelines and regulations, and informed consent was obtained from all participants.

Study population

Patients with skeletal Class III malocclusion advised by orthodontists and periodontists to undergo augmented corticotomy because of the thinness of their labial alveolar bone before orthodontic decompensation in the clinic of the Periodontology Department, Peking University School and Hospital of Stomatology, from August 2012 to December 2019 were enrolled in this study.

The inclusion criteria were age 18–40 years; skeletal Class III malocclusion with the requirement for orthodontic and orthognathic treatment; full-mouth periodontal health, defined as no sites with probing depth (PD) $\geq$4 mm and BOP% $<$20% according to the 2018 new classification [11]; no smoking history; and systemically healthy.

The exclusion criteria were pregnancy or lactation; history of periodontal surgery on the anterior teeth; and cleft lip/palate or maxillofacial abnormality.

Clinical and radiographic examinations

Several clinical and radiographic parameters were measured at the anterior teeth of the surgical jaw before augmented corticotomy.

The following clinical data were collected:

1. Periodontal phenotype, categorized as thick or thin based on transparency (visibility or non-visibility, respectively, of the outline of a Williams periodontal probe [with a blunt, rounded tip and marked at 1, 2, 3, 5, 7, 8, 9, and 10 mm] through the gingival margin while probing the sulcus at the midfacial aspect of each anterior tooth) [3];
2. Width of keratinized gingival (WKG, mm), defined as the distance between the mucogingival junction and the gingival margin at the midfacial aspect of the tooth;
3. Probing depth (PD, mm), measured as the distance between the gingival margin and the base of the sulcus or pocket at the midfacial aspect of the tooth;
4. Gingival recession (Rec, mm), measured as the distance between the cementoenamel junction (CEJ) and the gingival margin at the midfacial aspect of the tooth;
5. Mazza bleeding index (BI) measured 30 s after probing (graded from 0 to 5: 0 = normal appearing, healthy gingiva; 1 = colour changes related to inflammation but no bleeding; 2 = slight bleeding remaining at the sampling point; 3 = bleeding extending from sampling point and flowing around the gingival margin; 4 = profuse bleeding that overflows the gingival margin; and 5 = spontaneous bleeding.) [12];
6. Alveolar dehiscence measured during periodontal open-flap surgery, defined as a defect measuring at least 4 mm apical to the crest of the interproximal bone (Figure 1) [13];
7. Alveolar fenestration measured during periodontal open-flap surgery, defined as a localized defect in the alveolar bone that exposed the root surface but did not involve the alveolar margin (Figure 1) [13].

The following radiographic data were collected:

1. Mandibular plane angle (MPA) measured on lateral cephalometric radiographs, classified as low (SN-MP $\leq$28°), average (28°$<$SN-MP$<$38°), or high (SN-MP $\geq$38°) [14];
2. Sagittal root position (SRP) measured via CBCT in relation to its osseous housing, categorized as class I (root positioned against the labial cortical plate), class II (root centred in the middle of the osseous housing without engaging either the labial or the palatal cortical plates at the apical third of the root), class III (root positioned against the palatal cortical plate), or class IV (at least two-thirds of the root engages both the labial and palatal cortical plates) [15];
3. Basal bone thickness (BBT, mm), measured using CBCT evaluated where the tooth was widest labio-lingually in the axial view, and the thickness of alveolar bone perpendicular to the long axis of the tooth at the apex level [16].

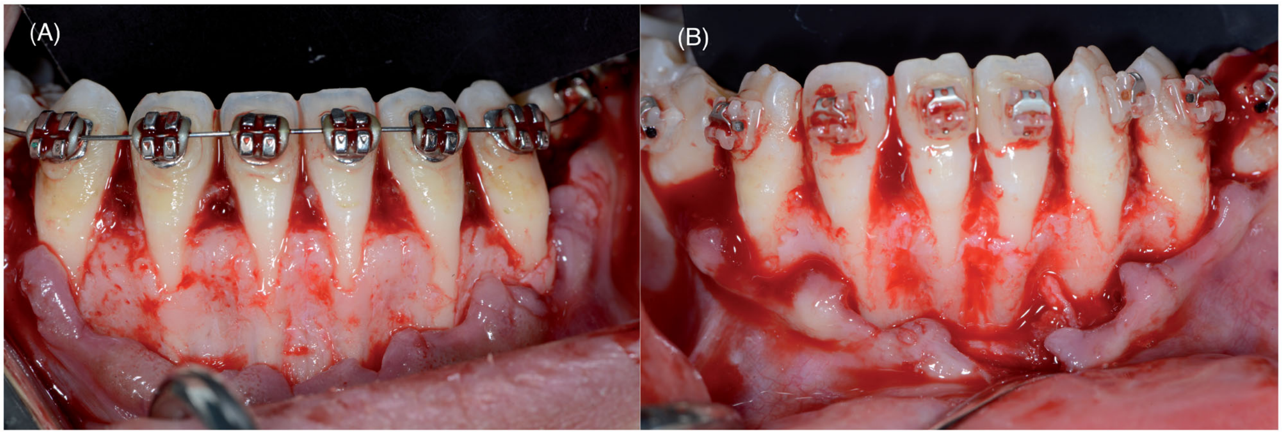

Figure 1. (A) Alveolar fenestration of the mandibular lateral incisors, localized defects in the alveolar bone that expose the root surface but do not involve the alveolar margin. (B) Alveolar dehiscence of the mandibular central incisors and lateral incisors; defects measured at least 4 mm apical to the crest of the interproximal bone.

Clinical measurements were performed without local anaesthesia by a single experienced clinical professor of periodontology before periodontal surgery. The measurements were rounded down. Calibrations were performed and the kappa statistics and intra-class correlation coefficients (ICCs) for intra-examiner agreement were 0.89–0.91. Radiographic measurements from lateral cephalometric radiographs and CBCT were performed by a single experienced periodontist; the kappa value ranged from 0.89 to 0.95 and the ICC ranged from 0.88 to 0.93.

Statistical analyses

Quantitative data were reported as means and standard deviations and were compared by Student's *t*-test; categorical data were compared by chi-square test. Risk factors for periodontal phenotype, alveolar dehiscence, and fenestration were subjected to univariate and multivariate logistic regression analyses (backward LR). Nomogram prediction models of periodontal phenotype, alveolar dehiscence and fenestration were developed. Receiver operating characteristic (ROC) analyses and decision curve analyses (DCA) were conducted to estimate the predictive accuracy and net benefit of the model, respectively. The accuracy of the nomogram was assessed by bootstrap (500 resamples) validation. The significance level of all tests was established at $p < .05$. Data were evaluated using IBM SPSS Statistics 19 (SPSS; Chicago, IL, USA) or R 3.6.1 (Comprehensive R Archive Network; http://CRAN.R-Project.org) software and plots were created using Prism 8 (GraphPad Software Inc., La Jolla, CA, USA).

Results

Demographic characteristics and clinical parameters

The demographic characteristics of included patients and clinical and radiographic parameters of the teeth are listed in Table 1. In total, 669 anterior teeth were included. One CI and two lateral incisors (LI) in three patients were

Table 1. Demographic characteristics at subject level and periodontal parameters at tooth level.

	N (%)
Subject level	
Sex	
Female	59 (73.80%)
Male	21 (26.30%)
Previous orthodontic history	
No	60 (75.00%)
Yes	20 (25.00%)
Mandibular plane angle	
High	64 (80.00%)
Average	10 (12.50%)
Low	6 (7.50%)
Jaw	
Maxilla	51 (45.50%)
Mandible	61 (54.50%)
Tooth level	
Alveolar dehiscence	
No	515 (77.00%)
Yes	154 (23.00%)
Alveolar fenestration	
No	586 (87.60%)
Yes	83 (12.40%)
Periodontal phenotype	
Thin	360 (53.80%)
Thick	309 (46.20%)
Bleeding index	
0	160 (23.90%)
1	373 (55.80%)
2	126 (18.80%)
3	6 (0.90%)
4	4 (0.60%)
Sagittal root position	
I	470 (70.30%)
II	96 (14.30%)
III	17 (2.50%)
IV	86 (12.90%)
Tooth	
Central incisor	223 (33.30%)
Lateral incisor	222 (33.20%)
Canine	224 (33.50%)
	Mean (SD)
Subject level	
Age (years)	23.89 (4.47)
Tooth level	
Gingival recession (mm)	0.07 (0.32)
Probing depth (mm)	1.55 (0.57)
Width of basal bone (mm)	7.43 (2.53)
Width of keratinized gingiva (mm)	4.01 (1.61)

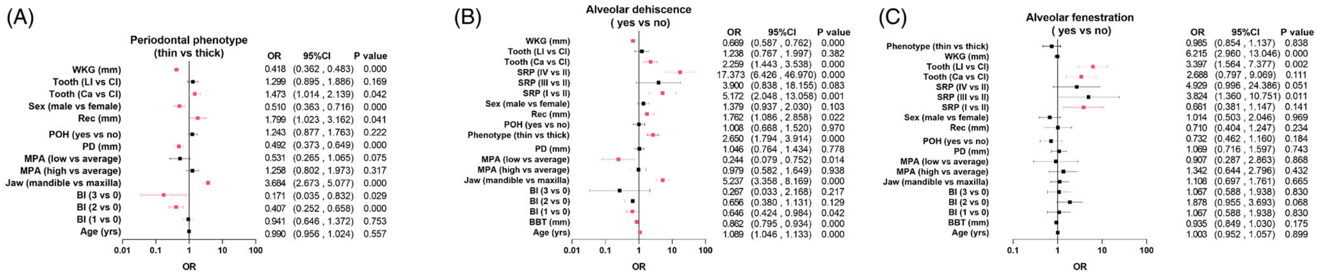

Figure 2. Forest plots of the associations between (A) periodontal phenotype, (B) alveolar dehiscence, and (C) alveolar fenestration and potential influencing factors detected by univariate logistic regressions. WKG: width of keratinized gingiva; LI: lateral incisor; CI: central incisor; Ca: canine; Rec: gingiva recession; POH: previous orthodontic history; PD: probing depth; MPA: mandibular plane angle; BI: bleeding index; SRP: sagittal root position; BBT: basal bone thickness.

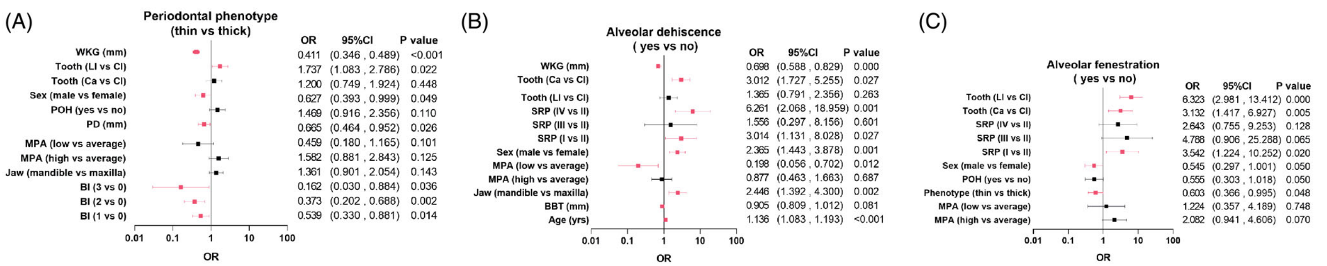

Figure 3. Forest plots of the associations among (A) periodontal phenotype, (B) alveolar dehiscence, and (C) alveolar fenestration and potential influencing factors by multivariate logistic regressions (backward LR). WKG: width of keratinized gingiva; LI: lateral incisor; CI: central incisor; Ca: canine; POH: previous orthodontic history; PD: probing depth; MPA: mandibular plane angle; BI: bleeding index; SRP: sagittal root position; BBT: basal bone thickness.

congenitally missing. In addition, 29 maxillae and 19 mandibles did not need surgery and were excluded. Moreover, 53.8% of the teeth were of the thin periodontal phenotype, 23.0% exhibited labial alveolar bone dehiscence, and 12.4% exhibited labial alveolar bone fenestration.

Univariate and multivariate analyses

The results of univariate analyses by logistic regression are shown in Figure 2. Thin phenotype was positively associated with the amount of Rec and negatively associated with PD and WKG. The proportion of thin phenotype was higher in females, mandibular teeth, canines (Ca), and teeth with a lower BI. The presence of alveolar dehiscence was positively associated with age and Rec and negatively associated with BBT and WKG. The proportion of alveolar dehiscence was higher in mandibular teeth, buccally placed teeth (SRP I), teeth engaging both the labial and palatal cortical plates (SRP IV), teeth with a thick phenotype and Ca. The proportion of alveolar dehiscence was lower in patients with a low MPA. The proportion of alveolar fenestration was higher in Ca, LI, and buccally placed teeth (SRP I).

The results of multivariate logistic regression analyses (backward LR) are shown in Figure 3. Thin phenotype was negatively associated with PD and WKG. The frequency of thin phenotype was higher in females, LI, and teeth with lower BI. Alveolar dehiscence was positively associated with age and negatively associated with BBT and WKG. The proportion of alveolar dehiscence was higher in males, mandibular teeth, Ca and buccally placed teeth (SRP I), and teeth engaging both the labial and palatal cortical plates (SRP IV). The proportion of alveolar dehiscence was lower in patients with low MPA. The proportion of alveolar fenestration was higher in females, Ca, LI, buccally placed teeth (SRP I) and teeth with thick phenotype.

Construction and validation of the nomogram prediction model

Nomograms predicting a probability of thin periodontal phenotype, alveolar dehiscence, and alveolar fenestration are shown in Figures 4–6. The nomograms were constructed based on the results of multivariate logistic regression (Figure 3). The nomograms mapped the predicted probabilities into points on a scale from 0 to 100 in a user-friendly graphical interface. Each factor in the nomogram was assigned a weighed point that denoted its probability. The higher the score, the higher the probability of thin periodontal phenotype, alveolar dehiscence, or alveolar fenestration.

The accuracy of nomograms was tested by receiver operating curve (ROC) analyses. The areas under the curve (AUCs) of periodontal phenotype, alveolar dehiscence, and alveolar fenestration were 0.84, 0.81, and 0.73, respectively. The accuracy of the nomograms was also assessed by bootstrap (500 resamples) validation. The bootstrap-corrected concordance indices of the nomograms were 0.85 (95% confidence interval [ConIn] 0.81–0.87) for periodontal phenotype, 0.81 (95% ConIn 0.78–0.85) for periodontal alveolar dehiscence, and 0.73 (95% ConIn 0.67–0.78) for periodontal alveolar fenestration. DCA was performed to evaluate the benefits of the nomograms to verify their clinical utility. The results showed that the nomograms had good clinical utility.

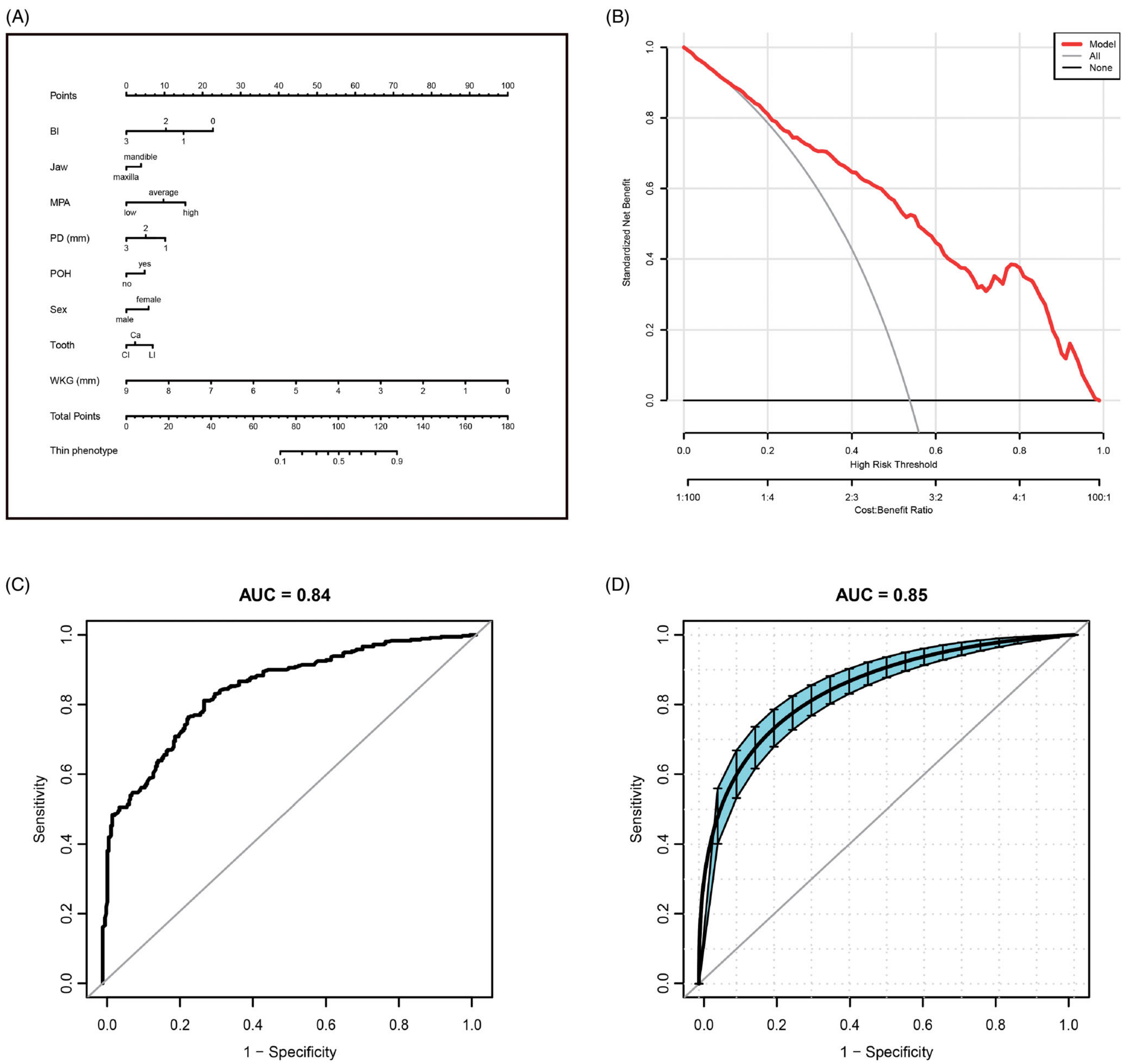

Figure 4. (A) Nomogram prediction of thin periodontal phenotype based on multivariate logistic regression (backward LR). The value of each variable is shown as a score on the point scale axis. The total score was calculated by summing the scores. By projecting the total score to the lower total point scale, we estimated the probability of thin periodontal phenotype. BI: bleeding index; MPA: mandibular plane angle; PD: probing depth; POH: previous orthodontic history; CI: central incisor; Ca: canine; LI: lateral incisor; WKG: width of keratinized gingiva. (B) Decision curve analyses revealed that the prediction model provided a superior net benefit. The grey line labelled 'all' assumed that all teeth were of thin phenotype and the black line labelled 'none' that no tooth was of thin phenotype. The red solid line represented the nomogram model. (C) Validation of the nomogram predicting thin phenotype by receiver operating curve (ROC) analyses. (D) The accuracy of the nomogram was also assessed by the bootstrap (500 resamples) validation.

Discussion

The risk factors of periodontally vulnerable anatomic conditions in patients with skeletal Class III malocclusion were explored and analysed by univariate and multivariate logistic regressions. For periodontal phenotype, thin gingiva was more likely in females and teeth with less WKG, a smaller PD, and lower BI and LI compared to CI (Figures 2 and 3). Similarly, a cross-sectional study of 550 students aged 17–19 years showed that periodontal phenotype was associated with the anatomical parameters of the anterior teeth, including PD and WKG [17]. Another cross-sectional study of the anterior teeth of 21 patients showed that mean GT at the CI was larger than the LI and Ca (1.37 ± 0.32 mm, 1.33 ± 0.32 mm and 1.08 ± 0.25 mm, respectively) [18]. A study involving 16 male and 16 female Indians showed that the GT of the mandibular teeth was significantly thinner in females than in males [9]. Univariate and multivariate analyses showed that mandibular teeth were more likely to have a thin periodontal gingiva; however, only the univariate logistic regression results were significant.

The thickness of the gingiva and the WKG may vary according to the type of malocclusion. Kalina et al. reported a relationship between the periodontal parameters of mandibular incisors and cephalometric parameters. GT was

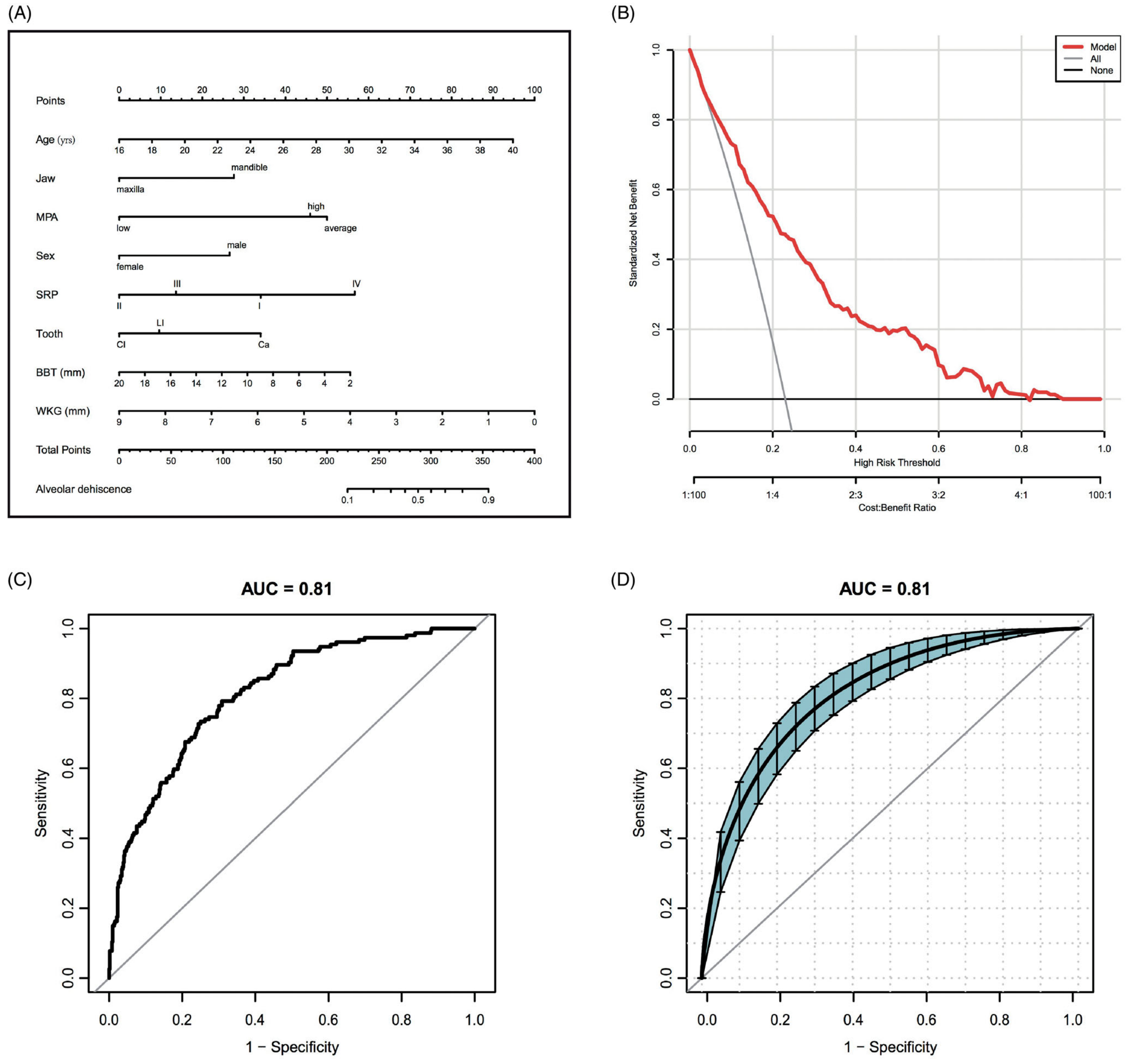

Figure 5. (A) Nomogram prediction of alveolar dehiscence based on multivariate logistic regression (backward LR). MPA: mandibular plane angle; SRP: sagittal root position; CI: central incisor; LI: lateral incisor; Ca: canine; BBT: basal bone thickness; WKG: width of keratinized gingiva. (B) Decision curve analyses showed that the prediction model provided a superior net benefit. (C) Validation of the nomogram predicting alveolar dehiscence by receiver operating curve (ROC) analyses. (D) The accuracy of the nomogram was assessed by the bootstrap (500 resamples) validation.

significantly correlated with the WITS value (Spearman's correlation coefficient = 0.475, $p = .004$) and WKG was significantly correlated with the ANB value (Spearman's correlation coefficient = 0.469, $p = .004$). The two values were important determinants of skeletal class. The GT (Spearman's correlation coefficient = 0.450, $p = .025$) and WKT were correlated with symphysis length (Spearman's correlation coefficient = 0.557, $p = .001$) [19].

For alveolar defects detected during periodontal open-flap surgery, males, mandibular teeth and teeth with a root positioned against the labial cortical plate (SRP I) or both the labial and palatal cortical plates (SRP IV) tended to have labial alveolar dehiscence. In addition, alveolar dehiscence is positively associated with age and negatively associated with BBT and WKG. The LI and Ca, compared to CI, and teeth whose root is positioned against the labial cortical plate (SRP I) tended to have labial alveolar fenestration. Females and teeth with a thick phenotype also tended to have alveolar fenestration in multivariate analyses adjusted for confounders. SRP was proposed by Kan in 2011 to assist in treatment planning for immediate implant placement [15]. Buccal-bone thickness reportedly varies according to the SRP [20]. In this study, we described the sagittal root position in relation to its osseous housing. The results showed that the teeth positioned buccally and/or with a thin palatal bone plate (SRP I and SRP IV) were more likely to have alveolar dehiscence and fenestration (Figures 2 and 3).

These findings were also supported by previous studies based on CBCT. Coskun and Kaya reported a significantly

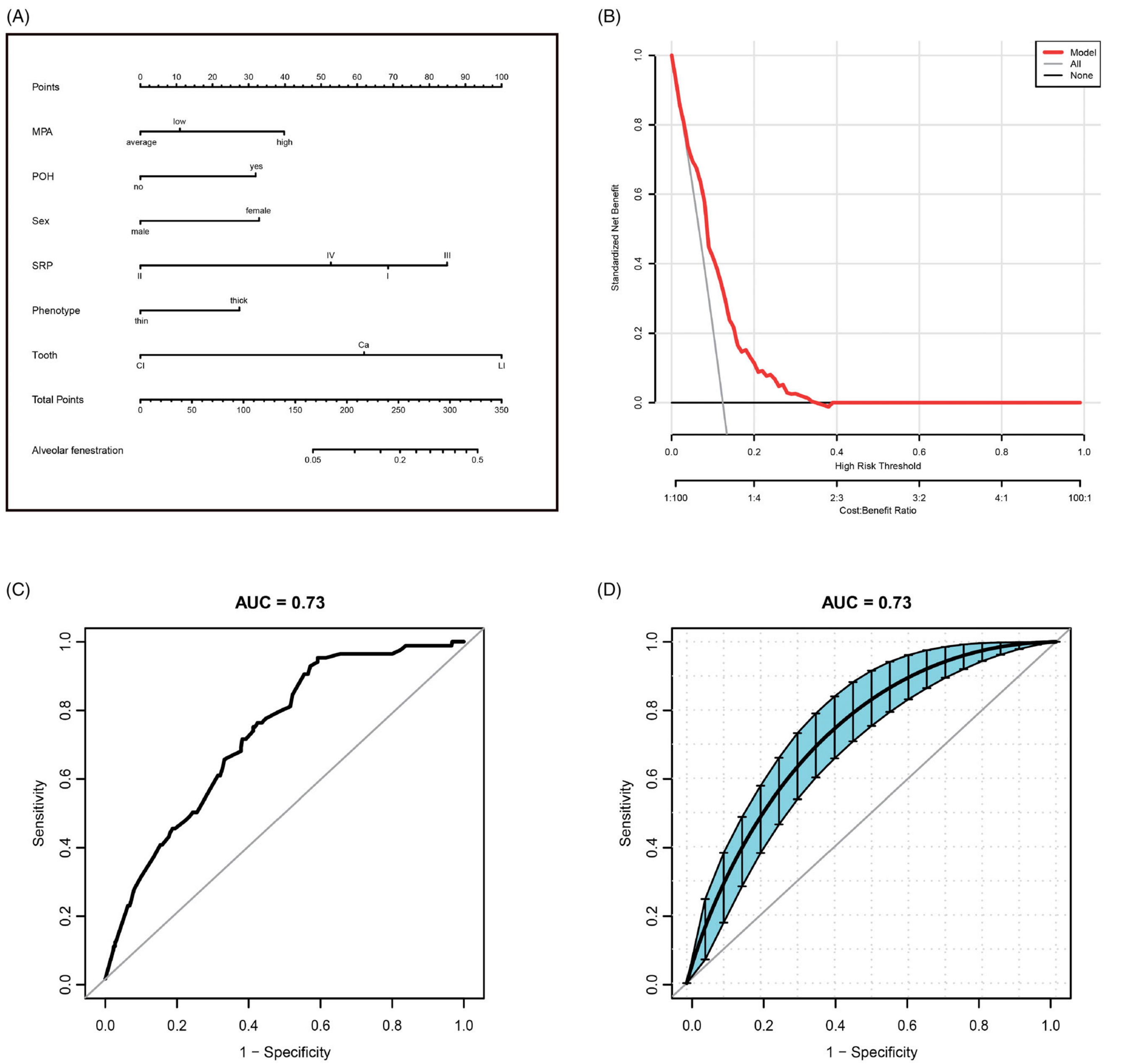

Figure 6. (A) Nomogram prediction of alveolar fenestration based on multivariate logistic regression (backward LR). MPA: mandibular plane angle, POH: previous orthodontic history; SRP: sagittal root position; CI: central incisor; Ca: canine; LI: lateral incisor. (B) Decision curve analyses showed that the prediction model provided a superior net benefit. (C) Validation of the nomogram predicting alveolar fenestration by receiver operating curve (ROC) analyses. (D) The accuracy of the nomogram was assessed by the bootstrap (500 resamples) validation.

higher prevalence of buccal dehiscence in lower than in upper teeth (25.7% vs. 8.6%), and a nonsignificant difference in the prevalence of buccal fenestration (17.1% vs. 14.3%) [21]. Yagci et al. [6] reported a higher prevalence of fenestration in LI and Ca (7.69% and 6.15% in the maxilla and 9.09% and 9.09% in the mandible) compared to CI (both 0% in the maxilla and mandible). A study involving a representative sample of 146 dentate modern American skulls showed that dehiscence/fenestration was not significantly associated with sex or age [22]. However, in this study, both dehiscence and fenestration were associated with sex, and dehiscence with age. The inconsistency between our and previous studies may result from the different samples and statistical methods.

A principle of orthodontic movement is keeping roots in the alveolar housing, and properly managed orthodontic therapy does not pose a significant risk to periodontal health [23]. However, for patients with skeletal Class III malocclusion, who need both orthodontic and orthognathic treatment and commonly have proclined upper incisors and retroclined lower incisors, orthodontic decompensation is often applied before orthognathic surgery to correct interference by the anterior teeth. Changes in tooth inclination during orthodontic treatment are associated with a higher risk for gingival recession [23], particularly in the presence of thin periodontal phenotype, alveolar dehiscence, and fenestration [24,25].

However, to the best of our knowledge, there was no proper model for assessing the condition of periodontal soft and hard tissues and the risk for periodontal damage before orthodontic treatment. Nomograms enabled calculation of the probability of a specific clinical outcome for an individual patient and facilitate risk estimation, clinical decision-making, and patient communication. We developed simple and easy-to-use prediction nomograms based on multivariate regressions predicting the thin periodontal phenotype and alveolar dehiscence and fenestration. Reasonable clinical decisions, for example whether a phenotype modification therapy is needed, can be made by clinicians according to the model predictions [26].

The nomograms show acceptable to good performances for predicting the thin periodontal phenotype (AUC = 0.84) and alveolar defects (AUC = 0.81 and 0.73, respectively). In most cases, the accuracy of a model can be improved by introducing more variables (in other words, considering more influencing factors). Too many parameters, however, may lead to over-fit of the model; i.e. the model performs well with training data but badly with test data, and affects its generalizability. In this study, only parameters included in the multivariate logistic regression model (backward LR), not all potential influential factors, were incorporated into the final nomograms. Internal validity was tested by bootstrap (500 resamples) validation. However, further studies are needed to test the external validity of the nomograms.

This study had several strengths. The study had a sufficient sample size and identified the periodontal risk factors for future orthodontic treatment in patients with skeletal Class III malocclusion. The easy-to-use tools may help orthodontists and general dentists determine the periodontal risk and perform preventive measures before orthodontic treatment. Moreover, alveolar dehiscence and fenestration was detected by direct observation during periodontal surgery. This means of identifying alveolar defects is more reliable than CBCT or other methods.

This study also had limitations. One limitation relates to its retrospective design, which is associated with a risk of selection bias. The prevalence of thin periodontal phenotype and alveolar fenestration/dehiscence may be overestimated because the patients were candidates for periodontal surgery for soft and hard tissue augmentation. However, this potential bias did not affect the accuracy of the nomogram models because its effect was minimized by multivariate regression. In addition, sample size calculation was not carried out before enrolment. Therefore, a power simulation model was performed after the statistical analyses to evaluate the power of the test statistics; the results showed that the sample size was sufficient to reach a conclusion. Only patients with skeletal Class III malocclusion were included. Other parameters, e.g. cephalometric parameters, may be associated with GT/periodontal phenotype and alveolar dehiscence/fenestration. Therefore, further studies involving patients with other types of malocclusion or healthy individuals included and more parameters are needed to assess the generalizability of the models and improve their accuracy.

In conclusion, female sex, LI, and limited WKG may be risk factors for thin periodontal phenotype. Age, Ca, male sex, mandible, thin labial bone thickness, root positioned against the labial plate may be risk factors for labial dehiscence; and female sex, thick phenotype, root positioned against the labial plate, LI, and Ca may be risk factors for labial fenestration. The easy-to-use nomogram with acceptable accuracy enables prediction of the risk for soft and hard tissue in the anterior teeth and may improve clinical decision-making.

Disclosure statement

The authors report no conflict of interest.

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