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Research article

A nomogram prediction of gingival recession in mandibular incisors of orthodontic-orthognathic treated skeletal class III malocclusion with or without PAOO: A retrospective cohort study

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ABSTRACT

Background: To assess the alterations in gingival thickness and the occurrence gingival recession subsequent to orthodontic-orthognathic treatment of mandibular incisors in skeletal Class III and identify risk factors associated with gingival recession.
Methods: In this retrospective cohort study, we enrolled 33 patients exhibiting skeletal Class III malocclusion, totaling 131 mandibular incisors, who were undergoing orthodontic- orthognathic treatment that did not involve extraction of mandibular teeth. The subjects were categorized into surgery group (S; $n = 17$; ANB $= -5.55 \pm 3.26$; IOFTN $= 4.60 \pm 0.51$, scores ranging: 4.3–5.3) and non-surgery group (NS; $n = 16$; ANB $= -3.00 \pm 4.08$; IOFTN $= 4.63 \pm 0.50$, scores ranging: 4.3–5.4), based on if they had history of Periodontally Accelerated Osteogenic Orthodontics surgery (S) or not (NS). Patients in S group received orthognathic surgery about 1–1.5 years after Periodontally Accelerated Osteogenic Orthodontics surgery. Alterations in gingival thickness, gingival recession, and keratinized gingival width were compared before and after orthodontic-orthognathic treatment. Logistic regression analysis was used to construct a gingival recession prediction model and draw nomograms.
Results: After orthodontic-orthognathic treatment, the gingival thickness and keratinized gingival width in NS group decreased by 0.15 ± 0.21 mm and 0.74 ± 0.91 mm, whereas those in the S group increased by 0.32 ± 0.28 mm and 2.09 ± 1.51 mm ($P < 0.05$). After orthodontic-orthognathic, the percentage of gingival recession increased by 47.62 % in NS group, which was 14.77 times that of S group ($P < 0.05$). Multivariate regression analysis indicated that skeletal

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Class III patients with a gingival thickness below 0.72 mm, an alveolar bone height exceeding 2.36 mm, and an alveolar bone thickness under 0.45 mm might be at elevated risk for developing gingival recession following orthodontic - orthognathic therapy.

Conclusions: Drawing on the findings of our investigation, we concluded the risk of gingival recession of mandibular anterior teeth increased after orthodontic-orthognathic treatment in skeletal Class III, whereas Periodontally Accelerated Osteogenic Orthodontics surgery could significantly improve the periodontal phenotype and prevent gingival recession.

1. Introduction

Skeletal Class III malocclusion is a severe dentofacial deformity with an incidence of 3.4 %–12.6 % among different ethnic groups [1–3]. These patients, who typically have high aesthetic expectations, often require orthodontic and orthognathic procedures to enhance both their appearance and dental function [4]. Several recent studies have also shown that majority of orthognathic cases are Class III cases in different countries [5–7]. Recently, owing to the increase in patients' aesthetic and functional requirements, clinicians and patients have focused more on periodontal complications such as gingival recession (GR), tooth mobility, mucosal scar, and open gingival embrasure after treatment [8,9]. Skeletal Class III patients have insufficient periodontal hard and soft tissues when compared with other types of malocclusion, the gingival thickness (GT) is thinner; keratinized gingival width (KGW) is narrower also, especially in the mandibular anterior teeth [10,11], which may increase the risk of periodontal complications(including GR, aesthetic problems, fenestration, dehiscence, and root resorption) [12]. GR is characterized by the gingival tissue moving apically from the cementoenamel junction (CEJ) [13]. A variety of factors are thought to contribute to the incidence of GR following orthodontic treatment, such as inherent periodontal traits, the cumulative amount of tooth movement achieved through orthodontics, and the patient's oral hygiene practices [14–16].

Wilcko et al. [17,18] proposed the concept of Periodontally Accelerated Osteogenic Orthodontics (PAOO). Initially, PAOO included only cortical osteotomy and bone grafting; later, the concept of collagen membrane covering tissue regeneration evolved. Vestibular Incision Subperiosteal Tunnel Access (VISTA) technique has been proposed as a less invasive method for performing PAOO, which can be utilized to enhance the alveolar bone [19–21]. PAOO mainly causes improvements in soft and hard tissues in anterior teeth through periodontal tissue regeneration technology to avoid periodontal risks during the orthodontic treatment process. Recent research indicates that PAOO can effectively augment labio-alveolar bone thickness by an average of 0.19–1.56 mm following periodontal-orthodontic-orthognathic treatment [22–26] which can prevent GR after orthodontic treatment. A few studies have reported that the buccal KGW increases by about 0.32–1.28 mm[25-27] and GT by 0.19–0.43 mm after combined treatment [27,28].

Few studies have concentrated on assessing the changes in periodontal soft tissue before and after orthodontic-orthognathic treatment. Moreover, GR and related risk factors of these patients after orthodontic-orthognathic treatment remain less studied, and no studies have confirmed the preventative effects of PAOO on GR.

Hence, our objective was to examine the alterations in GT and GR status of mandibular incisors in skeletal Class III, while also identifying risk factors linked to the development of GR. Additionally, we developed a nomogram prediction model to estimate the likelihood of GR occurrence.

2. Materials and methods

This research project was granted ethical approval by the Research Ethics Committee of Peking University School and Hospital for Stomatology, Beijing, China, as indicated by the approval number PKUSSIRB-202162010. Prior to the retention of their data within the hospital's database and its utilization for research objectives, all volunteers provided their signed, informed consent to take part in this investigation.

2.1. Patient selection

A retrospective analysis was conducted on a series of patients who had completed orthodontic - orthognathic between March 2021 and March 2022. All patients in this study were included within 6 months after completion of orthodontic-orthognathic treatment (Supplement Fig. 1). Inclusion criteria: (1). Orthodontic and orthognathic combined treatment for skeletal Class III patients; (2). complete medical records, including general information, intraoral photos, oral scan data, imaging examinations, and periodontal examination data before and after orthodontic-orthognathic treatment; (3). Patients who underwent PAOO surgery had complete clinical data at 6 months after PAOO surgery; (4) good periodontal health; (5) no history of smoking. Exclusion criteria: (1) uncontrolled periodontal disease; (2) pregnancy or lactation; (3) systemic disease.

The medical records of these patients prior to the start of orthodontic-orthognathic therapy (January 2017 to June 2018) were reviewed, including clinical examination, intraoral photographs, oral scan data, and imaging examinations. Seventeen patients (5 males and 12 females, average age: 22.76 $\pm$ 4.25 years, orthognathic functional treatment need (IOFTN):4.60 $\pm$ 0.51) met inclusion criteria with PAOO history (S) were collected. Another 16 patients (9 males and 24 females, average age: 20.69 $\pm$ 2.60 years, IOFTN: 4.63 $\pm$ 0.50) have completed orthodontic-orthognathic without PAOO (NS) and matched well in terms of age, sex and IOFTN. This group also met the inclusion and exclusion criteria. Patient inclusion timeline was shown in Supplement Fig. 1.

2.2. PAOO surgery and presurgical orthodontic treatment

All recruited patients were treated by a collaborative team of periodontal-orthodontic- orthognathic specialist team. The periodontal specialist performed periodontal examination and treatment. These patients undergo periodontal support treatment every 3–6 months.

PAOO surgeries were performed for the patients in the S group by the same experienced periodontist (Li Xu). Among those who received PAOO, clinical examinations revealed a significant exposure of the root shape, and notable root protrusion was detectable upon palpation. Cone-beam computed tomography (CBCT) imaging detected that the labial bone thickness of the lower anterior teeth in patients undergoing PAOO surgery was less than 0.5 mm. Additionally, CBCT imaging allowed us to observe the occurrence of fenestrations or dehiscences on labial aspect. In S group, the mandibular incisor underwent cortical incision, bone grafting and GTR after full thickness flap. Orthodontic reinforcement began 4 weeks after surgery. The detailed surgical process and postoperative care are the same as our previous research [29,28]. Patients in PAOO group received orthognathic surgery about 1–1.5 years after periodontal surgery. The NS group received orthodontic-orthognathic routine treatment, and did not receive PAOO operation on mandibular incisors.

2.3. Three-dimensional scan and X-ray examinations

Examinations were collected before orthodontic treatment (T0), 6 months after PAOO surgery (T_{6m}), and after orthodontic-orthognathic treatment (T1) by an experienced surgeon. Collect digital impressions of T0, T_{6m}, and T1 by using an intraoral scanner (3Shape Trios3, 3Shape, Denmark). Lateral cephalogram and CBCT were obtained from our database. CBCT scans were acquired using a CBCT scanner machine (NewTom VG, QR s. r.l., Verona, Italy, 110 kV, 3.00 mA, fields of view: 12 cm by 8 cm, exposure

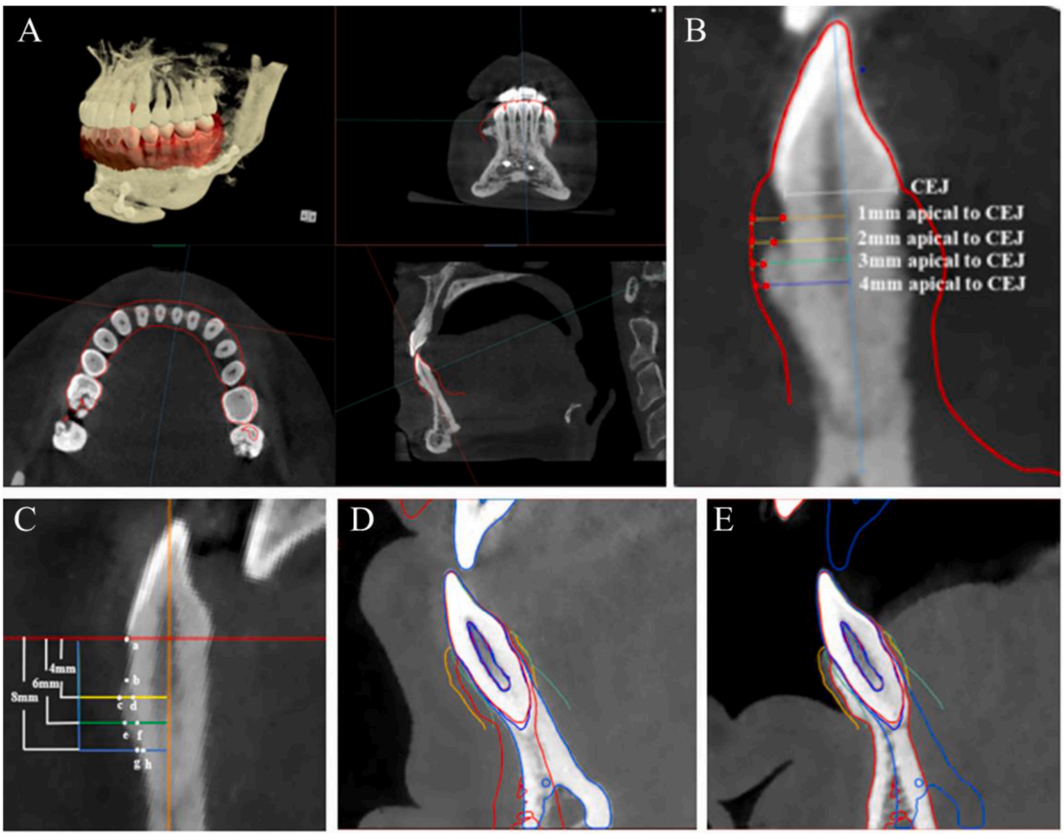

Fig. 1. Alveolar thickness and soft tissue measurements A The registration of three-dimensional impression and CBCT images; B The measurement levels of gingival thickness on the combination model; C The measurement levels of bone thickness of the labial aspect, a = labial aspect of the cemento-enamel junction (CEJ), b = labial alveolar crest, c, e, g = limit of the labial cortical surface at 4 mm, 6 mm, 8 mm under CEJ respectively, d, f, h = labial aspect of the root at 4 mm, 6 mm, 8 mm under CEJ respectively. The ab distance was measured as labial alveolar bone height (BH). The cd, ef, and gh distances were measured as the horizontal bone thickness of the labial aspect at 4 mm, 6 mm, and 8 mm apical to CEJ; D E registration of digital impression data and CBCT image of one PAOO patient, blue lines: contour of the pre-orthodontic teeth and alveolar bone; green lines: contour of the pre-orthodontic teeth and gingiva; red lines: contour of the post-orthodontic-orthognathic teeth and alveolar bone; orange lines: contour of the post-orthodontic-orthognathic teeth and the gingiva.

Table 1
Mean values of the gingival thickness and keratinized gingival width of mandibular incisors.

Periodontal soft tissue		GT 1 mm	GT 2 mm	GT 3 mm	GT 4 mm	KGW
NS	T0	0.63 ± 0.32	0.64 ± 0.26	0.56 ± 0.21	0.49 ± 0.17	4.94 ± 0.90
	T1	0.33 ± 0.41	0.46 ± 0.38	0.50 ± 0.24	0.45 ± 0.18	4.20 ± 1.07
	T1-T0	−0.29 ± 0.22	−0.18 ± 0.24	−0.067 ± 0.16	−0.047 ± 0.14	−0.74 ± 0.91
S	T0	0.55 ± 0.19	0.53 ± 0.18	0.45 ± 0.18	0.35 ± 0.11	3.27 ± 1.04
	T1	0.87 ± 0.35	0.96 ± 0.25	0.74 ± 0.23	0.63 ± 0.25	5.35 ± 1.28
	T1-T0	0.31 ± 0.33	0.42 ± 0.25	0.29 ± 0.25	0.29 ± 0.26	2.09 ± 1.51
Multiple Comparisons		NS(T1) < NS(T0),S(T0) <S(T1)**	NS(T1),S(T0) < NS(T0), <S(T1)**	S(T0) < NS(T0),NS(T1) < S(T1)**	S(T0) < NS(T0),NS(T1) < S(T1)**	S(T0) < NS(T1) < NS(T0) < S(T1)**

NS = no PAOO surgery group, S = PAOO surgery group, T0 = before orthodontic treatment, T1 = after orthodontic-orthognathic treatment, GT = gingival thickness, KGW = keratinized gingival width, **: P < 0.01.

time:1.8s). Each CBCT scan administers a radiation dose that falls within the range of 35–46 microsieverts, which aligns with the radiation protection guidelines set forth by the International Commission on Radiological Protection (ICRP).

2.4. Alveolar hard and soft tissue measurements, cephalometric analysis and IOFTN scores

Clinical records including probing depth (PD), KGW, and GR were reviewed at T0, T_{6m}, and T1.

Digital impression data and CBCT images were registered through Dragonfly Pro Workstation 2022.1 using teeth as the registration area. After registration, a new 3D model combining 3D scans and CBCT images was generated (Fig. 1A). GT dimension was defined as the linear interval from gingival edge to the nearest point of alveolar bone, assessed in the plane perpendicular to the tooth's long axis. (Fig. 1B). Measurements were taken at four distinct distances from the CEJ: 1 mm, 2 mm, 3 mm, and 4 mm towards apical region. (Fig. 1B). The bone width (BW) performed at three distinct distances from the CEJ: 4 mm, 6 mm, and 8 mm towards apex by Mimics software (21.0; Materialise Mimics Medical, Belgium). Concurrently, bone height (BH) was the distance between alveolar crest and CEJ, providing a comprehensive assessment of the dental alveolar architecture. (Fig. 1C).

Cephalometric measurements, including SNA, SNB, ANB, SN-MP, and L1-MP were performed. A comparison of IOFTN scores was conducted for the two groups under study [3,30–32].

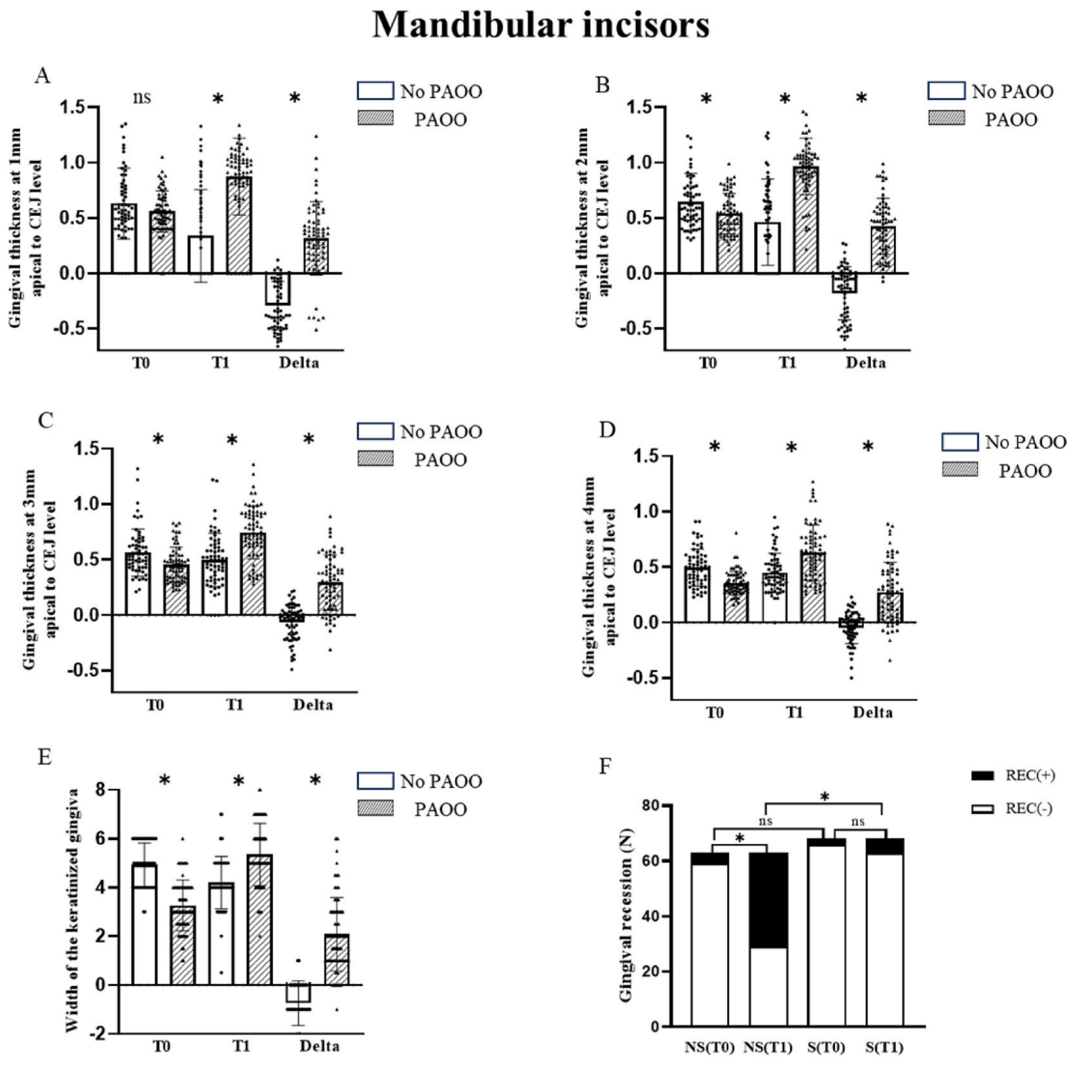

Fig. 2. Gingival changes of mandibular incisors NS: no PAOO surgery group, 16 patients (63 mandibular anterior teeth); S: PAOO surgery group, 17 patients (68 mandibular anterior teeth); T0 = before orthodontic treatment, T1 = after orthodontic treatment, Delta = value (T1)– value(T0). ns = no significant, *: $P < 0.05$, Student t-test. F Comparison of gingival recession before and after orthodontic-orthognathic treatment. REC (+) = present gingival recession, REC (−) = no gingival recession. ns = no significant, *: $P < 0.05$, Chi-square test.

2.5. Statistical analysis

All data accessed was thoroughly anonymized prior to data analysis. Data for the variables are reported as the average, accompanied by the standard deviation (SD). The distributional normality of each variable was evaluated through the application of the Shapiro-Wilk test. To quantify the reliability of the measurements, the intra-class correlation coefficient (ICC) was calculated. Perform statistical analysis using the Statistical Package for the Social Sciences Statistics version 25 software (IBM Corp, Armonk, NY, USA). Statistical graphs were created with R and GraphPad Prism 9. Continuous variables such as GT and KGW on the tooth level and SNA, SNB, ANB, SN-MP, and L1-MP, as well as IOFTN scores were compared between the two cohorts by *t*-test. Chi-square test was applied to ascertain whether there was a significant difference in the incidence of GR.

Parameters in T0 (NS) and T_{6m} (S) were used for logistic regression analysis to construct a GR prediction model and to draw nomograms. ROC curves were constructed to evaluate the diagnostic capabilities, with the areas under these curves (AUCs) serving as measures of discriminative ability. Additionally, various indices were employed to gauge the effectiveness of the selected cut-off values.

3. Results

There were 63 mandibular incisors in NS group and 68 in S group. In total, 131 mandibular incisors (one lateral incisor was congenitally missing) were included. IOFTN scores in S group and NS group ranged from 4.3–5.3 and 4.3–5.4 respectively which meant these patients were in great need or a significant demand for orthognathic treatment.

For all parameters assessed, intra-class correlation coefficients (ICCs) exceeded 0.9, indicating a high degree of measurement reliability. The Shapiro Wilktest results showed that the variables followed a normal distribution.

3.1. Orthodontic-orthognathic surgical treatment enhanced the facial profile

The duration of orthodontic-orthognathic treatment was 42.24 ± 9.74 and 44.50 ± 12.20 months in S group and NS group, respectively. The results of cephalometric measurements in the NS group at T0 were as follows: SNA, 79.92 ± 4.85°; SNB, 82.90 ± 3.27°; ANB, −3.00 ± 4.08°; SN-GoGn, 36.97 ± 5.43°; L1-MP, 77.64 ± 10.71°; in the S group, the measurements were as follows: SNA, 79.62 ± 4.75°; SNB, 85.17 ± 4.90°; ANB, −5.55 ± 3.26°; SN-GoGn, 37.01 ± 6.93°; L1-MP, 73.28 ± 9.70°. Mandibular incisors were inclined lingually. A notable discrepancy in the ANB angle was observed between the two cohorts. ($P < 0.05$).

The cephalometric measurements at T1 in the NS group were as follows: SNA, 81.43 ± 3.00°; SNB, 80.30 ± 4.71°; ANB, 1.76 ± 2.07°; SN-GoGn, 35.34 ± 4.48°; L1-MP, 90.49 ± 5.72°; in the S group, the measurements were: SNA, 83.60 ± 4.62°; SNB, 81.88 ± 4.87°; ANB, 1.61 ± 1.94°; SN-GoGn, 35.59 ± 5.10°; L1-MP, 86.99 ± 8.53°. After orthodontic- orthognathic treatment, SNA and ANB increase while SNB decreases, making the patient's facial contour more harmonious. ANB change (T1-T0) in S was more than that of NS ($P < 0.05$; Supplement Table 1).

3.2. PAOO surgery improved periodontal phenotype

The means and SDs for GT and KGW at T0 and T1 are presented in Table 1. The means and 95 % confidence intervals for these parameters in both timepoints and changes are shown in Fig. 1 (D, E) and Fig. 2 (A, B, C, D, E).

In the NS group, there was a notable reduction in GT measurements at both 1 mm and 2 mm, as well as a significant decrease in KGW. The changes observed were as follows: at 1 mm from the CEJ, GT reduced from 0.63 ± 0.32 mm to 0.33 ± 0.41 mm; at 2 mm from the CEJ, GT decreased from 0.64 ± 0.26 mm to 0.46 ± 0.38 mm; and KGW decreased from an average of 4.94 ± 0.90 mm to 4.20 ± 1.07 mm. At the 3 mm and 4 mm marks, the differences were not statistically significant, with measurements of 0.56 ± 0.21 mm compared to 0.50 ± 0.24 mm at 3 mm, and 0.49 ± 0.17 mm compared to 0.45 ± 0.18 mm at 4 mm. For the S group, there was a significant increase in GT thickness at 4 levels, as well as an enhancement in KGW. The comparisons revealed the following changes: at a distance of 1 mm from the CEJ, the average GT measurement rose from 0.55 ± 0.19 mm to 0.87 ± 0.35 mm. At 2 mm from the CEJ, there was an increase from an initial average of 0.53 ± 0.18 mm to 0.96 ± 0.25 mm. Progressing to 3 mm from the CEJ, the GT measurement saw a growth from 0.45 ± 0.18 mm to 0.74 ± 0.23 mm. Finally, at 4 mm from the CEJ, the GT measurement expanded from a starting average of 0.35 ± 0.11 mm to 0.63 ± 0.25 mm. KGW expanded from an average of 3.27 ± 1.04 mm to 5.35 ± 1.28 mm.

Prior to orthodontic intervention, no statistically significant variation was observed in the GT at 1 mm from CEJ between NS and S (0.63 ± 0.32 vs. 0.55 ± 0.19 mm); however, significant differences were observed after orthodontic treatment (0.33 ± 0.41 vs. 0.87 ± 0.35 mm). Differences in GT except 1 mm level from the CEJ, along with KGW, displayed statistically significant disparities between NS and S during initial (T0) assessment. However, at T1, the S group exhibited greater thickness in GT at 2 mm, 3 mm, and 4 mm compared to NS, and the KGW was also found to be wider (0.96 ± 0.25 mm versus 0.46 ± 0.38 mm, 0.74 ± 0.23 mm versus 0.50 ± 0.24 mm, and 0.63 ± 0.25 mm versus 0.63 ± 0.25 mm, as well as 5.35 ± 1.28 mm versus 4.20 ± 1.07 mm, respectively. The changes of GT and KGW between the two groups were significant. GT and KGW of the NS group decreased after orthodontic-orthognathic treatment; however, that of the S group increased.

3.3. PAOO prevents GR

The percentage of GR in mandibular incisors is shown in Fig. 2 (F) and Table 2. In the NS group, four teeth (6.35 %) presented GR, whereas two teeth presented GR (2.94 %) in the S group before treatment (T0). Before orthodontic treatment, upon analysis, no significant disparity was found in the odds ratios for GR when comparing the two distinct cohorts.; after orthodontic-orthognathic treatment (T1), GR was present in 34 (53.97 %) and 5 (7.35 %) patients from NS and S groups, respectively. Odds of GR were significantly higher after orthodontic-orthognathic treatment in NS (odds ratio *(OR):17.29, 95 % confidence interval (CI):5.60, 53.39, P < 0.01*). After orthodontic treatment, the odds of GR in the NS group were 14.77 times higher than that of the S group (*OR:14.77, 95 % CI:5.24, 41.66, P < 0.01*); however, there was no statistically significant difference in group S (*P=0.24*).

3.4. GR risks by nomogram prediction

Univariate and multivariate analytical results by logistic regression are shown in Table 3. GR was negatively associated with GT at 1 mm, 2 mm, and 3 mm and BW at 4 mm and 6 mm, but positively associated with BH. In multivariate logistic regression analyses, Inverse relationship was observed between the occurrence of GR and GT-1 mm, as well as BW-4 mm. Conversely, there was a positive correlation between GR and BH.

A nomogram predicting GR probability is shown in Fig. 3. We use a nomogram which was constructed based on the results of multivariate logistic regression analysis (Table 3) to visually assess the risk of GR in patients through scoring. Higher score meant there was a high risk of GR.

The accuracy of the nomogram was tested using ROC analyses (Supplement Fig. 2). The AUCs of the three effects, GT 1 mm, BH, and BW 4 mm, were 0.96, 0.93, 0.85, and 0.7. The cut-off values of GT 1 mm, BH, and BW 4 mm were 0.72 mm, 2.36 mm, and 0.45 mm, respectively (if the three parameters are less than the critical values before treatment, there may be a high probability of GR after orthodontic treatment in mandibular incisors [Supplement Table 2]). The accuracy of the three effects, GT 1 mm, BH, and BW 4 mm in predicting GR were re-evaluated through cut-off value.

4. Discussion

The findings of our investigation indicate that in skeletal Class III malocclusion, following orthodontic-orthognathic therapy, experienced a reduction in GT in mandibular incisors, coupled with an elevated incidence of GR. Contrarily, if the mandibular incisors involved PAOO, the soft tissue condition of the lower anterior teeth would be better than that of NS. In PAOO, GT and KGW were increased and GR was reduced (Tables 2 and 3; Supplement Fig. 2). Both univariate and multivariate regression analyses revealed that GR was significantly correlated with GT, BH, and alveolar bone thickness (Table 3, Fig. 3). This study suggested that when the GT less than 0.72 mm, alveolar BH more than 2.36 mm, BW less than 0.45 mm, the risk of GR after orthodontic-orthognathic treatment significantly increased. (Supplement Table 2, Supplement Fig. 2). This finding is worthy of clinicians' attention and consideration for risk avoidance by PAOO surgery.

Recently, clinicians and patients have been carefully considering the facial profile and tooth alignment after orthodontic-orthognathic treatment and have been focusing more on the health of the periodontal tissue and the gingival "pink" aesthetics. The gingival biotype is essential in both the immediate and long-term outcomes of orthodontic therapy. Thin gingiva, narrow keratinized gingiva, and gingival inflammation may increase the risk of GR after orthodontic treatment [14–16,33]. When orthodontic treatment involves tilted tooth movement, especially for lower incisor teeth, dehiscence of labial alveolar bone is more likely to occur, accompanied by GR [12,34]. Patients with Class III malocclusions exhibit a greater prevalence of lower incisor dehiscence compared to individuals with other malocclusion types, the alveolar bone thickness is lesser, the labial gingiva is thinner, and the KGW is narrower. During orthodontic treatment, mandibular incisors in skeletal Class III frequently undergo decompensation; thus, the risk of GR is higher [10,11]. Therefore, this study focused on the occurrence and prevention of high clinical-risk mandibular incisor teeth, especially GR.

Skeletal Class III malocclusion typically undergo a comprehensive orthodontic-orthognathic treatment plan that includes preoperative orthodontic-orthodontic surgery followed by postoperative orthodontic treatment, extending over a period of 2–3 years [35,36]. . Moreover, these patients are young, from different regions, with great changes in education and employment, and their periodontal status is easily ignored. Few studies have reported on the periodontal status of these patients in the past. Moreover, most previous studies focused on the changes in alveolar bone in these patients, whereas few studies focused on periodontal soft tissues. In this study, soft tissue conditions of these patients before and after orthodontic-orthognathic treatment were mainly reported, focusing on GT, KGW, and GR.

GT is an important indicator for evaluating the gingival phenotype. Various methods were attempted to measure GT, including

Table 2
Gingival recession in the region of the mandibular incisors.

		Recession		Adjusted OR (95%CI)
		Present	Absent	
NS	T0	4	59	17.29 [5.60, 53.39] *
	T1	34	29	
S	T0	2	66	2.61 [0.49, 13.99]
	T1	5	63	

NS = no PAOO surgery group, S = PAOO surgery group, OR = odds ratio, CI = confidence interval.

Table 3
Association analysis between gingival recession and potential influencing factors by logistic regression.

Variable	Univariable analysis		Multivariable analysis	
	OR (95 % CI)	P-value	OR (95 % CI)	P-value
Sex	1.46 (0.59, 3.60)	0.41		
Age	0.93(0.84, 1.04)	0.21		
SNA	0.90 (0.83, 0.98)	0.02		
SNB	0.86 (0.77,0.95)	0.01		
ANB	1.09 (0.98,1.22)	0.12		
SN-GoGN	1.04 (0.97,1.11)	0.28		
L1MP	1.05 (1.01,1.10)	0.02		
GT 1 mm	0.003(0,0.03)	<0.001	0 (0,0.02)	<0.001
GT 2 mm	0.001 (0,0.01)	<0.001		
GT 3 mm	0.01 (0,0.09)	<0.001		
GT 4 mm	0.07 (0,0.56)	0.01		
KGW	1.11 (0.79,1.57)	0.54		
BW 4 mm	0.01 (0,0.07)	<0.001	0.16 (0.03,0.90)	0.04
BW 6 mm	0.06 (0.02,0.22)	<0.001		
BW 8 mm	0.79 (0.55,1.132)	0.20		
BH	20.73 (6.79,63.33)	<0.001	7.90 (1.80,34.67)	0.01

GT = gingival thickness, BH = bone height, KGW = keratinized gingival width, BW = alveolar bone width.

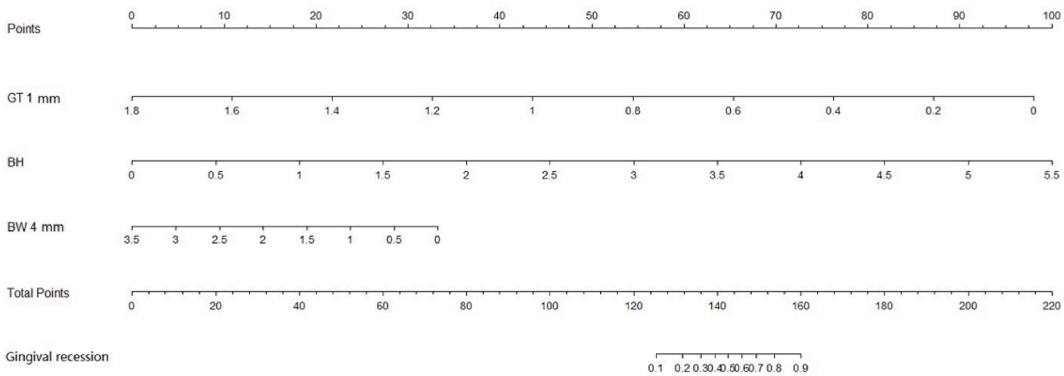

Fig. 3. nomogram prediction for gingival recession GT 1 mm = gingival thickness at 1 mm apical to cemento-enamel junction (CEJ), BH = bone height, BW 4 mm = Alveolar bone width at 4 mm apical to CEJ.

trans-gingival probing, probe transparency by periodontal probing or ultrasonographic devices. However, due to the invasiveness and complexity of these methods, no technology has been widely applied [37]. Eghbali et al. [38] discovered that the reproducibility of determining gingival biotypes solely through visual examination might not be high. With the application of digital technology in stomatology, we can now measure GT quantitatively and non-invasively [28,39].

Our research team has been conducting research on PAOO since 2017, and many research results have been published so far. Our first concern is the safety of PAOO surgery and whether it would cause trauma to periodontal tissues. The researches by Xu [40] and Jing [29] had shown that labial PAOO surgery would not cause periodontal attachment loss, gingival recession, and papilla embrasure. Secondly, we focused on the effectiveness of labial PAOO. In terms of hard tissue, Jing et al. [29] found a significant increase in labial alveolar bone thickness of approximately 0.649 mm 6 months after PAOO surgery. Ma et al. [41] revealed that labial bone area of PAOO group gained an average of 8.32 ± 5.91 mm^2, significantly higher than no PAOO group. It also improved anterior alveolar bone dehiscence and fenestration, avoiding the occurrence of orthodontic-orthognathic posterior alveolar bone dehiscence [42]. In terms of soft tissue, Jing et al. [29] found that the proportion of thick gingival biotype increased 6 months after PAOO surgery. Han et al. [28] showed that 6 months after PAOO, the GT increased by approximately 0.38 mm. However, our previous research on soft tissues only observed 6 months after PAOO, while this study observed that after orthodontic- orthognathic treatment, the average GT of the mandibular anterior teeth in patients undergoing PAOO was about 0.32 mm. The longitudinal observation time of this study is longer, about 3 years after PAOO. At the same time, we have paid attention to gingival recession in mandibular anterior teeth. We have summarized and analyzed that when the soft and hard tissues around mandibular anterior teeth are insufficient (GT < 0.72 mm, BH > 2.36, BW-4mm < 0.45 mm), the risk of gingival recession is increased in skeletal Class III patients. This provides great reference for our future clinical work.

In this study, the average GT of patients in NS group was reduced by about 0.15 mm after orthodontic treatment, with GT 1 mm and 2 mm level significantly reduced; this may be caused by the change in the mucogingival condition because of the movement of teeth and the decrease in the thickness of the labial tissue during proclination that occurred during orthodontic treatment [8]. In the PAOO group, we observed that GT increased significantly (Fig. 1D and E). Increased GT may be the result of bone grafting and guided tissue regeneration. Le BT and colleagues [43] determined that there is a strong positive correlation between labial soft tissue thickness and labial bone thickness. Thicker soft tissue biotypes are associated with less tissue recession.

Previous studies have confirmed that the KGW of lower anterior teeth increases after PAOO surgery. Jing [29] and Han et al. [28] showed that the KGW of lower anterior teeth increases by 0.50–1.09 mm 6 months after PAOO surgery. Wilcko et al. [25] also confirmed that the narrower the keratinized gingiva of lower anterior teeth, the more obvious the increase in keratinized gingiva after surgery (approximately 1.28 mm). In case studies reported by Federico et al. [43], the KGW was increased by approximately 2.7 mm; this may mean that the narrower the keratinized gingiva before surgery, the greater the increase after surgery. After orthodontic-orthognathic treatment in NS group, the KGW decreased by 0.74 mm, similar to that in previous studies [34,44], and the KGW increased by 2.09 mm in the S group, which may be related to the narrow KGW of the mandibular incisors before orthodontic treatment.

After orthodontic-orthognathic treatment, GR incidence increased by 47.62 % in the NS group, and was 14.77 times higher than that of the S group (Fig. 2F). The reason may be that soft and hard tissue insufficiencies existed in these patients before orthodontic treatment, and the movement range of teeth exceeded the labial cortex thickness during treatment, causing GR [8,15].

Many factors are associated with GR after orthodontic treatment, such as age, oral hygiene, inflammation, excessive proclination, and KGW [15,45]. The periodontal hard and soft tissue status of patients in the surgery group changed after PAOO. Finally, regression analysis was conducted using the clinical examination status of patients in the S group 6 months after surgery and the NS group before orthodontic treatment. Univariate logistic regression analysis revealed that GR after orthodontic-orthognathic was related to the extent of lower incisor decompensation. This is consistent with the findings of Pernet et al. [46] (the degree of decompensation of lower anterior teeth $\geq 10^\circ$ is related to GR of lower anterior teeth). Further multivariate regression analysis showed that the GR of lower incisor teeth was mainly related to three clinical indicators: GT, alveolar bone thickness and alveolar BH, which were mainly related to the soft and hard tissue periodontal conditions before orthodontic treatment and deserved more attention from orthodontists.

By using the above three indicators to construct a nomogram diagram (Fig. 3), we can more intuitively and conveniently predict the risk of GR after orthodontic-orthognathic treatment based on the status of periodontal hard and soft tissues. ROC analysis (Supplement Fig. 2) showed that these three indicators had high accuracy in predicting GR. When the GT less than 0.72 mm, BH more than 2.36 mm, and BW 4 mm less than 0.45 mm, there may be a high risk of GR after orthodontic-orthognathic treatment, which could provide a basis and specific reference index for patients to undergo PAOO surgery. Similarly, Karen et al. [33] discovered that orthodontic treatment could reduce the risk of GR when the GT is greater than 0.5 mm. When alveolar bone thickness <0.5 mm on labial side, it would be considered as a "quasi-defect," which increases treatment risk [47].

Supplement Fig. 3 showed some typical patients enrolled in this study. In the NS group I, patient A did not have GR before and after orthodontic-orthognathic treatment. Contrarily, the keratinized gingival narrowed, and GR presented to different degrees in the mandibular incisors of patient B and C after orthodontic-orthognathic treatment. In contrast, the GT and KGW of patients in group II who had previously received PAOO surgery increased significantly after PAOO-orthodontic-orthognathic treatment.

In our investigation, we pinpointed the risk factors for gingival recession at the outset of treatment for skeletal Class III malocclusion, enabling us to implement targeted pre-orthodontic interventions. This study is a retrospective cohort study, which lays the foundation for prospective cohort studies; however, prospective studies are needed to further confirm the results.

5. Conclusions

Drawing on the findings of our investigation, we concluded that the risk of GR of mandibular anterior teeth increased after orthodontic-orthognathic treatment in skeletal Class III, and PAOO surgery can significantly improve the periodontal phenotype and prevent GR. In the future, we can try to construct a multi-center and large-sample prediction model to predict orthodontic related gingival recession. Perhaps we will be able to use artificial intelligence to visually predict gingival recession after orthodontic treatment.

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There are no financial conflicts of interest to disclose.

Ethics declarations

This study was reviewed and approved by the Research Ethics Committee of Peking University Health Science Center, with the approval number: PKUSSIRB-202162010.

All participants/patients (or their proxies/legal guardians) provided informed consent to participate in the study.

All participants/patients (or their proxies/legal guardians) provided informed consent for the publication of their anonymized case details and images.

Data availability statement

Data associated with our study has not been deposited into a publicly available repository. All data used in the generation of the results presented in this manuscript will be made available upon reasonable request from the corresponding author.

CRediT authorship contribution statement

Jian Liu: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Xiao Xu:** Data curation. **Hui-Fang Yang:** Data curation. **Ye Han:** Data curation. **Meng-Qiao Pan:** Data curation. **Li Xu:** Writing – review & editing, Methodology, Data curation, Conceptualization. **Jian-Xia Hou:** Writing – review & editing, Data curation. **Xiao-Tong Li:** Writing – review & editing, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e33478.

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Abbreviations

IOFTN: Index of Orthognathic Functional Treatment Need
AUCs: areas under the curves
BW: Alveolar bone width
BH: alveolar bone height
CBCT: cone beam computed tomography
CEJ: cementoenamel junction
GR: gingival recession
GT: gingival thickness
ICC: intra-class correlation coefficient
KGW: keratinized gingival width
PAOO: Periodontally Accelerated Osteogenic Orthodontics
PD: probing depth
ROC:: Receiver operator characteristic
YI: Youden index