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Original Article

Simultaneous labial and lingual augmented corticotomy increase periodontal hard and soft tissues in 10 skeletal Class II patients — A preliminary study

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Labial and lingual augmented corticotomy;
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Digital measurement

Abstract *Background/purpose:* During pre-orthognathic orthodontic procedures in skeletal Class II patients, mandibular anterior tooth retraction could cause depletion of periodontal tissues on the labial and lingual sides. This study aimed to assess the changes in alveolar bone thickness, gingival thickness and keratinized gingiva width of the mandibular anterior teeth after labial and lingual augmented corticotomy (LLAC).

Materials and methods: 10 patients suffering from skeletal Class II malocclusion undergoing orthodontic-orthognathic combined treatment were included and LLAC was performed on their mandibular anterior teeth at the same time. Cone-beam computed tomography (CBCT) was performed at preoperatively (T0), 14 days postoperatively (Ts), and 6 months postoperatively (T1). Intraoral scanning was used at T0 and T1. The alveolar bone thickness, gingival thickness, keratinized gingiva width, and their changes were measured and analyzed.

Results: At 6 months after LLAC, the mean labial and lingual alveolar bone thicknesses were 0.91 ± 1.19 mm and 1.43 ± 1.52 mm at T0 and 1.96 ± 1.59 mm and 2.24 ± 1.75 mm at T1. The mean increase in thickness of the labial and lingual gingiva was 0.44 ± 0.46 mm and

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0.28 ± 0.45 mm. The mean keratinized gingiva width was 3.92 ± 1.55 mm at T0, and the mean width was 4.79 ± 1.38 mm at T1. There was a significant increase in periodontal soft and hard tissues at all measured sites postoperatively.

Conclusion: LLAC procedure improves the periodontal phenotype of skeletal Class II during decompensation. It provides adequate tooth movement distance during preoperative pre-orthognathic orthodontic treatment and ensures that healthy periodontal tissues are obtained during that period.

Introduction

Severe skeletal Class II malocclusion impacts the masticatory function, appearance, pronunciation, and psychology of the patient. It usually requires combined orthodontic-orthognathic treatment to improve the occlusal function.[1] Patients with skeletal Class II have maxillary overdevelopment with mandibular retrusion. It is usually accompanied by the lingual inclination of the maxillary anterior teeth and labial inclination of the mandible, which should be treated with decompensation and lingual movement of the mandibular anterior teeth in the pre-orthognathic orthodontic treatment.[1,2] The extensive tooth movement during decompensation in skeletal Class II with thinner alveolar bone might exacerbate the hard and soft tissue defects in the periodontium, which in turn causes gingival recession and even loosening and loss of teeth.[3,4]

Augmented corticotomy (AC), also known as periodontally accelerated osteogenic orthodontics (PAOO) has been widely used to provide adequate alveolar bone thickness and accelerated orthodontic tooth movement to ensure that the alveolar bone is sufficient during orthodontic tooth movement.[5–7] Most previous studies concentrated on one-sided AC in the mandibular anterior teeth,[8,9] yet it was found that the reduction in alveolar bone thickness not only lingually but also labially when anterior teeth are retracted.[10] A systematic review demonstrated no significant difference in lingual alveolar bone width between patients treated with labial-only accelerated periodontal orthodontic treatment.[6] These indicated that the risk of labial and lingual bone dehiscence and fenestration should not be overlooked when focusing on mandibular anterior tooth decompensation. Our previous study proposed simultaneous LLAC surgery for skeletal Class III malocclusion patients and confirmed the efficacy of LLAC surgery on the increases of periodontal soft and hard tissues.[11] However, few researches have reported the effect of LLAC surgery on skeletal Class II malocclusion patients.

Therefore, the objective of this study was to perform LLAC surgery on skeletal Class II malocclusion patients with insufficient amount of alveolar bone during pre-orthognathic orthodontic treatment and to further study the changes in alveolar bone, gingival thickness, and keratinized gingival width at baseline, 14 days postoperatively, and at 6 months postoperatively.

Materials and methods

This research protocol received ethical clearance from the Biomedical Ethics Committee of Peking University Stomatological Hospital (Approval No. PKUSSIRB-202498049) and was prospectively registered with the Chinese Clinical Trial Registry (Trial ID: ChiCTR2400086478). The study adhered to the ethical principles outlined in the Declaration of Helsinki (2013 revision). All experimental procedures conformed to institutional and national regulatory standards, and written informed consent was secured from each participant before enrollment.

Sample size

An appropriate sample size is required to distinguish changes in the gingiva tissue after the LLAC. Our previous study[12] showed that the thickness of the buccal gingiva was 0.91 ± 0.32 mm and 1.21 ± 0.38 mm in the preoperative period and 6 months after LLAC, respectively. Based on the above data, it was calculated by the PASS 15.0 software (NCSS; Kaysville, UT, USA) that at least 10 subjects could be provided with 80 % confidence at $\alpha = 0.05$.

Patient selection

Skeletal Class II malocclusion subjects undergoing orthodontic-orthognathic combined treatment were enrolled in the study when assessment revealed labial and lingual alveolar bone thickness requiring LLAC surgery before orthodontic decompensation, based on consensus among orthodontic, periodontal, and surgical specialists.

The inclusion criteria were: (1) aged 18–40 years; (2) skeletal Angle Class II malocclusion with the requirement for orthodontic and orthognathic treatment; (3) periodontal health, defined as probing depth ≤3 mm and bleeding on probing ≤15 %; (4) the thickness of the labial mandibular anterior cortical bone of <0.5 mm at 4 mm apical to the CEJ as demonstrated by CBCT; (5) insufficient lingual alveolar bone thickness, as judged by the orthodontist, could interfere with orthodontic decompensation treatment; (6) clinical examination: the root shape of the anterior teeth was prominently exposed and the root protrusion could be palpated; (7) no smoking history; and (8) systemic health. Exclusion criteria were: (1) pregnancy or lactation; (2) uncontrolled periodontal infection; (3) history of periodontal surgical treatment or orthodontics on the mandibular anterior teeth; (4) systemic disease; and (5) cleft lip/palate or maxillofacial abnormality.

Surgical procedures

All subjects received a preoperative oral examination, oral hygiene care, and periodontal treatment, including scaling and root planing as necessary. Each LLAC procedure was performed by the same experienced periodontist. The surgical procedure is shown in Fig. 1. The detailed surgical procedure is fully described in our previously published study.[13]

Postoperatively, patients were instructed to use amoxicillin (500 mg/thrice a day for 7 days) and 0.12 % chlorhexidine (South China Pharmaceutical, Shenzhen, China) (10 ml/dose twice a day for 14 days). Ibuprofen was administered at 0.3 g every 12 h for 3 days after surgery when the patient felt severe pain. Suture removal and orthodontic forces were performed 14 days after surgery.

Intraoral scanning and CBCT examinations

CBCT scans were performed preoperatively (T0), 14 days postoperatively (Ts) and 6 months postoperatively (T1) for LLAC. An intraoral scanner was used by a scanning-experienced periodontist (3Shape Trios, 3Shape, Denmark) to obtain digital impressions at T0 and T1. The standard tessellation language (STL) files of digital impression data, the polygon file format (PLY) of digital impression data, and digital imaging and communications in medicine (DICOM) files of alveolar bone three-dimensional reconstruction data were acquired and saved for subsequent hard and soft tissue preoperative and postoperative comparative analysis.

Alveolar bone thickness, gingival thickness, and keratinized gingiva width measurements

Intraoral scanning and CBCT images were automatically registered by 3Shape Design Studio software (3Shape, Copenhagen, Denmark) using the teeth as the registration area. After registration, the thickness of the gingiva was measured using the new model formed. The specific measurements were referred to in our previous study.[12] Measurement levels were 1 mm coronal to CEJ level, CEJ level, 1 mm, 2 mm, 3 mm, and 4 mm apical to CEJ (Fig. 2A). The width of the keratinized gingiva was measured directly on the color digitized model using Geomagic Control X software (Oqton, Rock Hill, SC, USA) to import the intraoral scanning data. The width of the keratinized gingiva was measured from the gingival margin and mucogingival junction on the midfacial of each anterior tooth (Fig. 2B).

The alveolar bone thickness was performed at three distinct distances from the CEJ: 2 mm, 4 mm, and 8 mm towards the apical by 3Shape Design Studio software (3Shape, Copenhagen, Denmark) at T0, Ts and T1. All variables were measured on the sagittal slices where the teeth were the widest labio-lingual side in the axial view. The bone formation rate is the calculated ratio of final bone formation to the initial bone graft. The bone formation rate was calculated as (T1 - T0)/(Ts - T0). All imaging measurements were performed independently by a periodontist.

Statistical analysis

All variables are shown as mean ± standard deviation (SD; normal distribution). Comparisons of alveolar bone thickness, gingival thickness, and keratinized gingiva width preoperatively and at different times postoperatively were

Figure 1 Surgical procedure of labial and lingual augmented corticotomy in a skeletal class II patient. (A—C) Preoperative views. (D—E) Labial and lingual flaps. (F) The vertical interproximal alveolar decortication was created below the alveolar crest to a depth of 2—3 mm. (G) Removal of stitches at 14 days postoperatively. (H—I) Intraoral photographs taken at 6 months postoperatively.

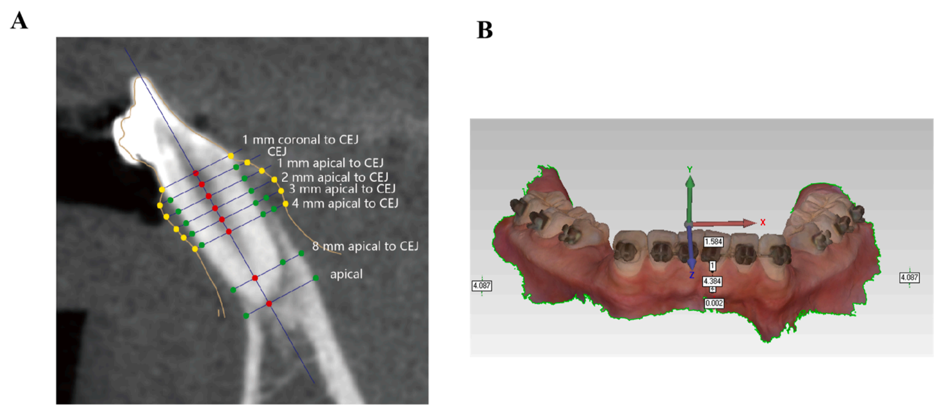

Figure 2 Illustration of measurements and reference points used in this study. (A) The measurement levels of gingival and alveolar bone thickness on the combination model. (B) The measurement of keratinized gingiva width on the intraoral scanning model. CEJ, cemento-enamal junction.

performed using the paired-samples t-test. Data were analyzed using SPSS 26.0 software (SPSS v26.0; Chicago, IL, USA). $P < 0.05$ was considered statistically significant.

Results

Patient population and surgical procedures

A total of 10 patients (5 males and 5 females, mean age 25.4 years old) were included in this study. The gingiva was well healed at the time of suture removal at 14 days postoperatively (Fig. 1G) and there was no gingival recession at 6 months postoperatively (Fig. 1H and I). CBCT of the anterior teeth from preoperative to 6 months after LLAC showed a significant increase in alveolar bone (Fig. 3).

The changes in alveolar bone thickness

The variation in alveolar bone thickness of the labial-lingual side of the lower anterior teeth of a skeletal Class II patient in the preoperative, 14-day postoperative, and 6-month postoperative CBCT images of the LLAC is shown in Fig. 3. For the labial measurement sites, the thickness of the alveolar bone changed from T0 to T1 was 0.36 ± 0.40 mm to 0.66 ± 0.63 mm at the 2 mm apical to CEJ, 0.37 ± 0.30 mm to 1.18 ± 0.67 mm at the 4 mm apical to CEJ, 0.26 ± 0.31 mm to 2.18 ± 1.21 mm at the 8 mm apical to CEJ, and 2.63 ± 1.15 mm to 3.82 ± 1.42 mm at the apical level. Corresponding to the lingual sites, the change in alveolar bone thickness from T0 to T1 was 0.24 ± 0.23 mm to 0.73 ± 0.60 mm, 0.69 ± 0.45 mm to 1.24 ± 0.64 mm, 1.24 ± 0.85 mm to 2.48 ± 1.02 mm, and 3.55 ± 1.36 mm to

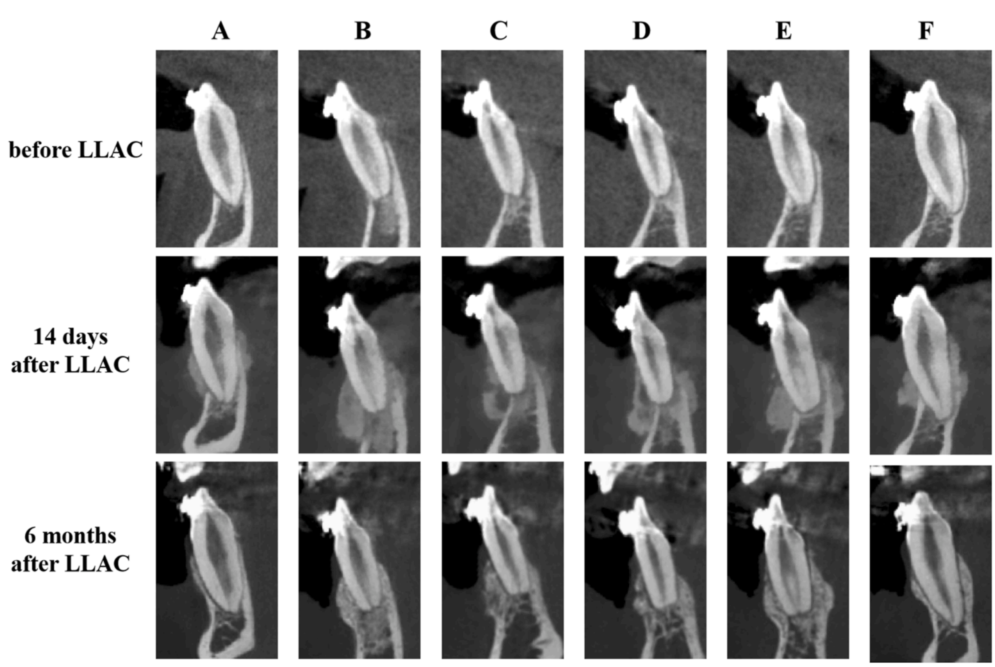

Figure 3 CBCT images of six lower anterior teeth of one subject before LLAC, 14 days after the LLAC, and 6 months after the LLAC. (A—F) From 43 to 33. LLAC, labial and lingual augmented corticotomy.

4.50 ± 1.42 mm, respectively, with statistically significant changes at all sites ($P < 0.001$; Table 1).

The mean alveolar bone thickness at all labial measurement sites was 0.91 ± 1.19 mm and 1.96 ± 1.59 mm at T0 and T1, respectively ($P < 0.001$). The mean alveolar bone thickness at lingual sites was 1.43 ± 1.52 mm and 2.24 ± 1.75 mm at T0 and T1, respectively ($P < 0.001$). Analysis by tooth level revealed that the increase in alveolar bone thickness on the labial side (T1-T0) of the central incisors, lateral incisors, and canines was 1.25 ± 1.23 mm, 1.43 ± 1.29 mm, and 0.49 ± 0.86 mm, respectively; the corresponding increase in thickness on the lingual side was 0.98 ± 0.89 mm, 0.84 ± 0.85 mm, and 0.60 ± 0.76 mm, respectively (Table 2).

We analyzed the rate of bone formation in different tooth positions and showed that the rates of bone formation in the labial and lingual sides of the central incisors were 67.29 ± 86.86 % and 68.59 ± 64.90 %, respectively. For lateral incisors, the bone formation rates were 57.47 ± 87.96 % and 71.95 ± 79.59 % for labial and lingual sides, respectively. The bone formation rates on both sides of the canine were 58.57 ± 83.60 % and 35.88 ± 83.22 %, respectively (Table 3).

The changes in gingival thickness

The increase in gingival thickness at 6 months postoperatively was statistically significant (Table 4). At all labial measurement sites, the mean gingival thickness of LLAC was 0.53 ± 0.53 mm preoperatively, and the mean increase in gingival thickness on the labial side was 0.44 ± 0.46 mm ($P < 0.001$); at all lingual measurement sites, the mean gingival thickness was 0.75 ± 0.49 mm preoperatively, and the mean increase at 6 months postoperatively was 0.28 ± 0.45 mm ($P < 0.001$).

At baseline, the labial gingival thickness at 1 mm coronal to CEJ level, CEJ level, 1 mm, 2 mm, 3 mm, 4 mm apical to CEJ were 0.32 ± 0.36 mm, 0.67 ± 0.37 mm, 0.66 ± 0.27 mm, 0.50 ± 0.26 mm, 0.47 ± 0.21 mm, and 0.46 ± 0.18 mm, respectively, and the lingual gingival thickness were 0.10 ± 0.24 mm, 0.49 ± 0.40 mm, 0.96 ± 0.38 mm, 1.09 ± 0.34 mm, 1.02 ± 0.36 mm, and 0.86 ± 0.31 mm at corresponding measurement levels. Six months after surgery, the labial gingival thickness increased by 0.13 ± 0.41 mm, 0.30 ± 0.47 mm, 0.48 ± 0.49 mm, 0.53 ± 0.48 mm, 0.64 ± 0.36 mm, and 0.57 ± 0.34 mm at each of the respective levels. The lingual gingival thickness increased by 0.22 ± 0.36 mm, 0.38 ± 0.48 mm, 0.28 ± 0.56 mm, 0.22 ± 0.45 mm, 0.23 ± 0.39 mm, and 0.37 ± 0.44 mm at each of the respective levels. The differences were statistically significant at all sites on both the labial and lingual sides (Table 4).

For different tooth sites, the increase of labial gingival thickness for central incisors, lateral incisors, and canines were 0.51 ± 0.45 mm, 0.47 ± 0.49 mm, and 0.35 ± 0.43 mm, and the increase of lingual gingival thickness was 0.28 ± 0.49 mm, 0.28 ± 0.42 mm, and 0.30 ± 0.46 mm, respectively (Table 5).

The changes in keratinized gingiva width

The mean keratinized gingiva width at T0 and T1 were 3.92 ± 1.55 mm and 4.79 ± 1.38 mm, respectively, and the

Table 1 The alveolar bone thickness on the labial and lingual sides of the lower anterior teeth in LLAC-treated subjects at different times.

	Labial				Lingual			
Measurement levels	**T0**	**Ts**	**T1**	**Difference (T1-T0)**	**T0**	**Ts**	**T1**	**Difference (T1-T0)**
2 mm apical to CEJ	0.36 ± 0.40	0.71 ± 0.54	0.66 ± 0.63	0.29 ± 0.65	0.24 ± 0.23	1.06 ± 0.64	0.73 ± 0.60	0.48 ± 0.58
4 mm apical to CEJ	0.37 ± 0.30	1.31 ± 0.76	1.18 ± 0.67	0.81 ± 0.72	0.69 ± 0.45	1.79 ± 0.84	1.24 ± 0.64	0.56 ± 0.57
8 mm apical to CEJ	0.26 ± 0.31	2.95 ± 1.11	2.18 ± 1.21	1.91 ± 1.15	1.24 ± 0.85	2.96 ± 1.06	2.48 ± 1.02	1.24 ± 0.96
Apical level	2.63 ± 1.15	4.80 ± 1.48	3.82 ± 1.42	1.19 ± 1.48	3.55 ± 1.36	4.79 ± 1.38	4.50 ± 1.42	0.95 ± 0.96
P	**Pa**	**Pb**	**Pc**		**Pa**	**Pb**	**Pc**	
2 mm apical to CEJ	Pa<0.001***	Pb < 0.001***	Pc = 0.49 ns		Pa<0.001***	Pb < 0.001***	Pc < 0.01**	
4 mm apical to CEJ	Pa<0.001***	Pb < 0.001***	Pc = 0.23 ns		Pa<0.001***	Pb < 0.001***	Pc < 0.001***	
8 mm apical to CEJ	Pa<0.001***	Pb < 0.001***	Pc < 0.001***		Pa<0.001***	Pb < 0.001***	Pc < 0.001***	
Apical level	Pa<0.001***	Pb < 0.001***	Pc < 0.001***		Pa<0.001***	Pb < 0.001***	Pc < 0.05*	

Data are presented as mean ± SD.
T0: before LLAC; Ts: 14 days after surgery; T1: 6 months after surgery; a: before LLAC compared to 14 days after surgery; b: before LLAC compared to 6 months after surgery; c: 14 days after surgery compared to 6 months after surgery; LLAC, labial and lingual augmented corticotomy; CEJ, cemento-enamal junction.
*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$; ns: not significant.

Table 2 The alveolar bone thickness on the labial and lingual sides of the lower anterior teeth in LLAC-treated subjects at different tooth positions.

	Labial				Lingual			
Tooth level	**T0**	**Ts**	**T1**	**Difference (T1-T0)**	**T0**	**Ts**	**T1**	**Difference (T1-T0)**
Central incisors	0.89 ± 0.92	2.64 ± 1.92	2.15 ± 1.57	1.25 ± 1.23	1.14 ± 1.16	2.59 ± 1.85	2.12 ± 1.55	0.98 ± 0.89
Lateral incisors	0.85 ± 1.06	2.76 ± 2.21	2.28 ± 1.79	1.43 ± 1.29	1.13 ± 1.17	2.43 ± 1.56	1.98 ± 1.43	0.84 ± 0.85
Canines	0.98 ± 1.51	1.93 ± 1.39	1.46 ± 1.26	0.49 ± 0.86	2.00 ± 1.94	2.92 ± 1.76	2.61 ± 2.13	0.60 ± 0.76
All sites	0.91 ± 1.19	2.44 ± 1.90	1.96 ± 1.59	1.05 ± 1.21	1.43 ± 1.52	2.65 ± 1.74	2.24 ± 1.75	0.81 ± 0.84
P	**Pa**	**Pb**	**Pc**		**Pa**	**Pb**	**Pc**	
Central incisors	Pa<0.001***	Pb < 0.001***	Pc < 0.001***		Pa<0.001***	Pb < 0.001***	Pc < 0.001***	
Lateral incisors	Pa<0.001***	Pb < 0.001***	Pc < 0.001***		Pa<0.001***	Pb < 0.001***	Pc < 0.001***	
Canines	Pa<0.001***	Pb < 0.001***	Pc < 0.001***		Pa<0.01**	Pb < 0.001***	Pc < 0.001***	
All sites	Pa<0.001***	Pb < 0.001***	Pc < 0.001***		Pa<0.001***	Pb < 0.001***	Pc < 0.001***	

Data are presented as mean ± SD.
T0: before LLAC; Ts: 14 days after surgery; T1: 6 months after surgery.
a: before LLAC compared to 14 days after surgery; b: before LLAC compared to 6 months after surgery; c: 14 days after surgery compared to 6 months after surgery; LLAC, labial and lingual augmented corticotomy.
**$P < 0.01$; ***$P < 0.001$.

Table 3 Bone formation rate of labial and lingual alveolar bone 6 months after LLAC.

Bone formation rate	Labial	Lingual	Average rate
Central incisors	67.29 ± 86.86 %	68.59 ± 64.90 %	67.93 ± 77.39 %
Lateral incisors	57.47 ± 87.96 %	71.95 ± 79.59 %	64.71 ± 83.89 %
Canines	58.57 ± 83.60 %	35.88 ± 83.22 %	47.38 ± 83.89 %

Data are presented as mean ± SD.
Bone formation rate (T1- T0)/(Ts - T0).
LLAC, labial and lingual augmented corticotomy; CEJ, cemento-enamal junction.

increased keratinized gingiva width for all measurement sites was 0.88 ± 1.37 mm by 6 months after LLAC ($P < 0.001$; Table 6). The increase of keratinized gingiva width for central incisors, lateral incisors, and canines were 1.06 ± 1.86 mm, 0.98 ± 0.91 mm, and 0.57 ± 1.17 mm, respectively ($P < 0.05$; Table 6).

Discussion

Clinically, patients with skeletal Class II malocclusion required pre- orthognathic decompensation treatment, with the lingual movement of the mandibular anterior teeth for helping the surgical movement to correct the inter-arch relationship.[14] In addition, skeletal Class II had a significantly higher rate of fenestration in the mandibular region than Class I and Class III patients.[15] The process of lingually inclined movement of the mandibular anterior teeth increases the risk of periodontal hard tissue defects. Previous studies have shown that not only the risk of periodontal hard tissue defects on the lingual side is significantly increased during retraction of the mandibular anterior teeth, but also the labial alveolar bone thickness at crest level is decreased to varying degrees.[16,17] Therefore, both safe and effective clinical treatment of the pressure side of tooth movement and the tension side of the periodontal tissues are needed for skeletal Class II teeth to circumvent the risks of the preoperative decompensation process. However, only one article has been published using labio-lingual PAOO surgery to improve the speed of recovery movement of upper and lower anterior teeth in skeletal Class II patients, and the postoperative periodontal tissue morphology changes have not been analyzed and discussed.[5] In this study, we performed the first systematic concurrent LLAC surgery on skeletal Class II with thin alveolar bone thickness in the labio-lingual side of the mandibular anterior teeth and evaluated the amount of periodontal hard and soft tissue change both preoperatively and at 6 months postoperatively. Through careful observation of the postoperative response and periodontal health of the patients, it has been shown that the LLAC surgery demonstrates reliable safety and efficacy in improving and maintaining the periodontal hard and soft tissues during the pre- orthognathic decompensation process.

In the current study, we measured the labial and lingual thicknesses of the alveolar bone and found that the thicknesses at all sites were significantly increased at T1 compared to T0. Among these, the increased thickness of the alveolar bone was greater on the labial side than on the

Table 4 The labial and lingual gingival thickness before LLAC and 6 months after surgery.

		Labial				Lingual			
Gingival thickness	**Measurement levels**	**T0**	**T1**	***P***	**Difference**	**T0**	**T1**	***P***	**Difference**
	1 mm coronal to CEJ	0.32 ± 0.36	0.46 ± 0.46	<0.05*	0.13 ± 0.41	0.10 ± 0.24	0.33 ± 0.49	<0.001***	0.22 ± 0.36
	CEJ	0.67 ± 0.37	0.98 ± 0.55	<0.001***	0.30 ± 0.47	0.49 ± 0.40	0.87 ± 0.61	<0.001***	0.38 ± 0.48
	1 mm apical to CEJ	0.66 ± 0.27	1.10 ± 0.47	<0.001***	0.48 ± 0.49	0.96 ± 0.38	1.24 ± 0.63	<0.001***	0.28 ± 0.56
	2 mm apical to CEJ	0.50 ± 0.26	1.13 ± 0.36	<0.001***	0.53 ± 0.48	1.09 ± 0.34	1.31 ± 0.40	<0.001***	0.22 ± 0.45
	3 mm apical to CEJ	0.47 ± 0.21	1.11 ± 0.30	<0.001***	0.64 ± 0.36	1.02 ± 0.36	1.24 ± 0.36	<0.001***	0.23 ± 0.39
	4 mm apical to CEJ	0.46 ± 0.18	1.02 ± 0.31	<0.001***	0.57 ± 0.34	0.86 ± 0.31	1.23 ± 0.39	<0.001***	0.37 ± 0.44
	All sites	0.53 ± 0.53	0.97 ± 0.48	<0.001***	0.44 ± 0.46	0.75 ± 0.49	1.02 ± 0.60	<0.001***	0.28 ± 0.45

Data are presented as mean ± SD.
T0: before LLAC; T1: 6 months after surgery; LLAC, labial and lingual augmented corticotomy; CEJ, cemento-enamal junction.
*$P < 0.05$; ***$P < 0.001$.

Table 5 The labial and lingual gingival thickness before LLAC and 6 months after surgery at different tooth sites.

		Labial				Lingual			
Gingival thickness	**Tooth level**	**T0**	**T1**	***P***	**Difference**	**T0**	**T1**	***P***	**Difference**
	Central incisors	0.47 ± 0.32	0.98 ± 0.47	<0.001***	0.51 ± 0.45	0.82 ± 0.55	1.10 ± 0.70	<0.001***	0.28 ± 0.49
	Lateral incisors	0.57 ± 0.31	1.04 ± 0.53	<0.001***	0.47 ± 0.49	0.65 ± 0.43	0.93 ± 0.60	<0.001***	0.28 ± 0.42
	Canines	0.56 ± 0.30	0.91 ± 0.43	<0.001***	0.35 ± 0.43	0.79 ± 0.45	1.09 ± 0.46	<0.001***	0.30 ± 0.46

Data are presented as mean ± SD.
T0: before LLAC; T1: 6 months after surgery; LLAC, labial and lingual augmented corticotomy.
***$P < 0.001$.

Table 6 The keratinized gingiva width before LLAC and 6 months after surgery.

Tooth level	T0	T1	Difference (T1-T0)	*P*
Central incisors	3.93 ± 1.48	5.00 ± 1.23	1.06 ± 1.86	<0.05*
Lateral incisors	4.02 ± 1.32	5.00 ± 1.16	0.98 ± 0.91	<0.001***
Canines	3.79 ± 1.88	4.36 ± 1.65	0.57 ± 1.17	<0.05*
All sites	3.92 ± 1.55	4.79 ± 1.38	0.88 ± 1.37	<0.001***

Data are presented as mean ± SD.
T0: before LLAC; T1: 6 months after surgery; LLAC, labial and lingual augmented corticotomy.
*$P < 0.05$; ***$P < 0.001$.

lingual side at all sites except for the 2 mm apical to CEJ. This result may be related to the loose and mobile soft tissues on the lingual side, and the forces generated by the lingual movement affect the stabilization of the bone graft material in the surgical area, which in turn affects osteogenesis to a certain extent. The greatest increase in thickness on the labial and lingual sides was 8 mm apical to CEJ at all sites (1.91 ± 1.15 mm and 1.24 ± 0.96 mm, respectively), and the least increase was 2 mm apical to CEJ (0.29 ± 0.65 mm and 0.48 ± 0.58 mm, respectively). In a study of labial augmented cortical osteotomy-assisted orthodontic treatment in patients with Class I, it was found that the alveolar bone was thickened labially in the mandibular central incisors 3 mm, 6 mm, and 9 mm up to the CEJ by 0.27 ± 0.75 mm, 0.59 ± 1.02 mm, and 0.76 ± 0.55 mm, respectively.[18] Basically, as in the present study, the increase in the alveolar bone was least in the cervical region, and the increase was greatest near the apical region of the root. This may be because bone grafting close to the cervical region is less likely to remain in situ, and the narrower alveolar bone thickness is more sensitive to stress concentrations around the cervical region caused by controlled tipping movements of the lower incisors.[10] Ma et al. also reported that less hard tissue thickening was obtained at the coronal portion of the alveolar crest after PAOO for dental Class II and skeletal Class III malocclusions, and they suggested that it may be related to soft-tissue tension at the incision site as well as the flap of the coronal portion of the postoperative repositioning that would have compressed the bone grafting.[9]

Based on the tooth level analyses, the alveolar bone thickness of all mandibular anterior teeth was significantly increased at T1 compared to T0. The largest increase in alveolar bone thickness at 6 months postoperatively on the labial side was observed in the lateral incisors and the greatest increase on the lingual side in the central incisors, whereas the canines had the least increase on both the labial and lingual sides. Also, canines have a lower rate of bone formation rate than mandibular incisors, especially lingually. This is consistent with our previous study of labial and lingual augmented corticotomy in skeletal Class III.[11] Zou's study also confirmed that after 4 years of PCRS, the bone gain in the mandibular anterior teeth of skeletal Class II patients was significant, and the increase in alveolar bone height and thickness remained stable from 3 years after PRCS.[8] These results reinforce the fact that for better bone augmentation at the canines postoperatively in both skeletal Class II and III, more attention should be paid to the degree of intraoperative soft tissue tension-reducing at the canines so that there is sufficient intraoperative space to allow for the implantation of bone grafting. Although the increase in alveolar bone thickness at the canine position was less on the labial and lingual sides compared to the other tooth levels, there was still a significant difference compared to T0 and the increases were 0.49 ± 0.86 mm and 0.60 ± 0.76 mm, respectively. The canine is located at the corner of the dental arch where alveolar bone augmentation is difficult, and its stable and successful bone augmentation at 6 months postoperatively reflects the validity and reliability of the surgical procedure.

Periodontal phenotype is determined by gingival phenotype and alveolar bone morphology.[19–21] Gingival thickness is commonly used as a reference index for quantitative gingival phenotype, which is clinically defined as thin if the gingival thickness is ≤ 1 mm and >1 mm if it is thick.[21–23] In the current study, a significant increase in gingival thickness at all measurement sites on the labial and lingual sides at T1 compared to T0 was demonstrated by our measurements, with a mean gain in thickening of 0.44 ± 0.46 mm at all labial sites and 0.28 ± 0.45 mm at all lingual sites. The results of this study show that the preoperative mean gingival thickness was less than 1 mm at all measurement sites on the labial side (0.53 ± 0.53 mm) and lingual side (0.75 ± 0.49 mm). After 6 months of LLAC treatment, the gingival thickness on the labial side tended to be 1 mm (0.97 ± 0.48 mm), and on the lingual side, the mean gingival thickness was >1 mm (1.02 ± 0.60 mm). Interestingly, the labial side with thinner mean preoperative gingival thickness obtained more increase in T1. Our previous study[12] also found that PAOO preoperative gingival thicknesses ≤1 mm increased more significantly at 6 months postoperatively in sites with gingival thicknesses of ≤1 mm than >1 mm sites, which is in general agreement with the present findings. These results emphasize that the thinner the preoperative gingival thickness, the greater the gingival increment induced by LLAC, demonstrating the necessary and efficacy of the LLAC procedure. From the analysis of the different tooth levels, the largest increase in the average thickness of the labial gingiva was in the central incisors, with an increase of 0.51 ± 0.45 mm, and the largest increase of the lingual gingival thickness was in the canines, with an average increase of 0.30 ± 0.46 mm. Studies have shown that the correlation between gingival thickness and keratinized gingival width remains controversial.[24–26] Here we found the maximum increase in keratinized gingiva width in the central incisors (1.06 ± 1.86 mm) and the minimum increase in keratinized gingiva width in the canines (0.57 ± 1.17 mm) at 6 months postoperatively in the LLAC, which is consistent with the increase in gingival thickness. The present study demonstrated that the more the gingival thickness gained, the greater the increase in keratinized gingiva width, which would help to predict the improvement in postoperative soft tissue phenotype. A case study on a skeletal Class II patient with 4 years of follow-up after labial periodontal corticotomy regenerative surgery (PCRS) found that PCRS was able to significantly increase gingival thickness and keratinized gingiva width in most of the mandibular anterior teeth.[8] All these results have confirmed the ability of the LLAC surgery to increase gingival thickness and keratinized gingiva width in skeletal Class II patients. In addition, a study concluded that periodontal accelerated orthodontics achieves less gingival recession compared to traditional orthodontic treatment.[6]

Interestingly, the studies are focusing on the ability of AC to increase not only alveolar bone thickness but also the gingival thickness and keratinized gingiva width.[5,7,12,27] Our study found a statistically significant increase in both hard and soft tissues of the mandibular anterior teeth 6 months after LLAC. The increase in soft tissue may be influenced by several mechanisms. In terms of clinical manipulation, performing corticotomy with a piezoelectric knife provides abundant blood vessels capable of promoting healing and increasing the potential for gingival tissue regeneration,[8,9] and guided tissue regeneration with a coronal flap could increase keratinized gingiva width.[28] Molecularly, bone metabolism-related molecules could affect the proliferation and differentiation of fibroblasts, thereby promoting the regeneration of gingival tissues. Proteomics assay was used to examine changes in key proteins in the gingival crevicular fluid of PAOO patients at multiple time points pre- and postoperatively, and the results showed that bone metabolism-related proteins, FBN1 (Fibrillin-1) and Notch1 were significantly upregulated compared to preoperative.[29] FBN1 deposition is thought to activate the ERK1/2 signaling pathway and promote fibroblast proliferation.[30,31] Notch signaling is the transmission of information between cells in contact with each other, and activated Notch signaling upregulates many types of collagen and further leads to fibrosis.[32] In addition, the local microenvironment is altered and macrophages and monocytes secrete a variety of cytokines that can activate proliferative signaling pathways in fibroblasts.[33]

The thickness of the alveolar bone on both the labial and lingual sides of patients with skeletal Class II malocclusion is quite thin, and when the mandibular anterior teeth are moved toward the lingual side, not only the thickness of the alveolar bone on the lingual side will decrease, but also on the labial side.[10] Handelman et al. indicated that during orthodontic treatment, the teeth should be moved within the boundaries of the alveolar bone, and avoid exceeding the boundaries of the alveolar bone, or else it may lead to dehiscence and fenestration, which may cause damage to the periodontal health of patients.[34] However, few studies have focused on simultaneous augmented corticotomy on the labial and lingual sides in patients with skeletal Class II malocclusion.

In this study, LLAC was able to significantly increase the labial and alveolar bone thickness, lingual gingival thickness, and keratinized gingiva width of the mandibular anterior teeth at 6 months postoperatively, which fulfilled the movement distance of decompensation of the mandibular anterior teeth. We also analyzed and discussed the potential causes of the increase in soft tissue after LLAC. However, there are some limitations in this study. First, the included patient sample size was relatively small, and we will conduct a prospective multicenter study in the future to increase the sample size and enhance the generalizability of the findings. Furthermore, for the analysis regarding hard and soft tissue increments, we only classified them based on different measurement sites and tooth levels. However different methods of tooth movement, the amount of orthodontic force, and the duration of orthodontic treatment all correlate with the amount of hard and soft tissue change during orthodontic treatment. In the future, we will analyze the results of our findings from multiple perspectives in conjunction with the orthodontist. Lastly, for our current sequence study, we will further explain the hard tissue affecting the increase of soft tissue in terms of molecular mechanism. All in all, these results indicate that LLAC has favorable safety and stable clinical efficacy in the treatment of decompensation in skeletal Class II patients undergoing orthodontic-orthognathic combined treatment.

Declaration of competing interest

The authors declare no conflicts of interest related to this study.

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