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Original Article

Periodontal tissue increase induced by simultaneous labial and lingual augmented corticotomy for skeletal Angle Class III malocclusion patients—A preliminary study

Xiaochi Chang [a†], Ye Han [a†], Min Xu [b], Zhiqiang Luo [c], Yi Li [d], Yuzhe Sun [a], Cheng Lin [a], Yi Feng [a], Li Xu [a], Jianxia Hou [a*]**

[a] *Department of Periodontology, National Center of Stomatology, National Clinical Research Center for Oral Diseases, National Engineering Laboratory for Digital and Material Technology of Stomatology, Peking University School and Hospital of Stomatology, Beijing, China*
[b] *Department of Stomatology, Beijing TongRen Hospital, Capital Medical University, Beijing, China*
[c] *Department of Biologic and Materials Sciences & Prosthodontics, University of Michigan School of Dentistry, Ann Arbor, MI, USA*
[d] *Fourth Clinical Division, Peking University School and Hospital of Stomatology, National Center of Stomatology, National Clinical Research Center for Oral Diseases, National Engineering Laboratory for Digital and Material Technology of Stomatology, Beijing Key Laboratory of Digital Stomatology, Beijing, China*

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KEYWORDS
Labial and lingual augmented corticotomy;
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Periodontal soft and

Abstract *Background/purpose:* During orthodontic decompensation in skeletal Angle Class III patients, a disruption of the periodontal tissues on the labial and lingual sides often occurs. This study aimed to assess the changes in the periodontal tissues of the mandibular anterior teeth after simultaneous labial and lingual augmented corticotomy (LLAC) surgery by digital measurements.
Materials and methods: The present study enrolled 11 adult patients with skeletal Class III malocclusion, with a total of 66 anterior teeth, who underwent LLAC surgery. Cone-beam computed tomography (CBCT) and intraoral scanning were obtained before surgery, at the immediate postoperatively and at 6 months postoperatively. The gingival thickness, keratinized gingiva width and alveolar bone thickness were measured.

* Corresponding author. Department of Periodontology, Peking University School and Hospital of Stomatology, No. 22, Zhongguancun South Avenue, Haidian District, Beijing, 100081. China.
** Corresponding author. Department of Periodontology, Peking University School and Hospital of Stomatology, No. 22, Zhongguancun South Avenue, Haidian District, Beijing, 100081, China.
E-mail addresses: xulihome@263.net (L. Xu), jxhou@163.com (J. Hou).
† Contribute equally as the first authors in this work.

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hard tissue increase;
Digital measurement

Results: The mean labial and lingual gingival thicknesses were 0.51 ± 0.31 mm and 0.66 ± 0.48 mm preoperatively, and 0.80 ± 0.42 mm and 0.84 ± 0.66 mm at 6 months after LLAC. The mean keratinized gingiva width was 3.10 ± 1.20 mm preoperatively and increased by 0.65 ± 0.66 mm at 6 months after LLAC. The mean labial and lingual alveolar bone thicknesses were 0.84 ± 1.05 mm and 1.57 ± 1.65 mm preoperatively, and 2.28 ± 1.43 mm and 2.38 ± 1.58 mm at 6 months after LLAC. The patients showed significant increases in periodontal soft and hard tissues after surgery. In addition, there was a significant negative correlation between the gain of alveolar bone and gingival thickness.
Conclusion: LLAC could increase periodontal soft and hard tissue, including gingival thickness, keratinized gingiva width and alveolar bone thickness to provide more stable and healthier periodontal tissue for patients with insufficient alveolar bone thickness during orthodontic treatment.

Introduction

The patients with skeletal Class III malocclusion are performed with combined orthodontic-orthognathic treatment to restore occlusal function and enhance aesthetics, and the process usually involves orthodontic decompensation.[1] The teeth movement during orthodontic decompensation might lead to loss of the total amount of alveolar bone and reduction of the bone thickness, even leading to loosening and loss of teeth in serious situations.[2] Of all the teeth sites, the mandibular anterior teeth are most prone to gingival recession, bone dehiscence, and fenestration after orthodontic treatment.[3–5] It has been shown that the thickness of the labial and lingual alveolar bone of the mandibular anterior teeth in skeletal Class III malocclusions is less than that of skeletal Class I and II malocclusions and the mandibular anterior teeth of skeletal Class III malocclusions need to be moved more carefully and with more difficulty.[6] Therefore, it is crucial to provide an adequate movement space of the lower anterior teeth for orthodontic treatment to maintain the periodontal hard and soft tissues healthy.

Augmented corticotomy (AC)-assisted orthodontic treatment developed from periodontal accelerated osteogenesis orthodontics (PAOO) is widely used to increase the alveolar bone thickness of the mandibular anterior teeth to ensure periodontal stabilization during the decompensation.[7,8] Normally, most of the current regular AC treatments are labial AC for the lower anterior teeth and studies have confirmed its relatively satisfactory results in improving the labial periodontal hard and soft tissue thickness.[9,10] However, after orthodontic decompensation, studies have reported that alveolar bone loss on the lingual side is also quite common.[11,12] Therefore, our previous study proposed simultaneous LLAC surgery for skeletal Class III malocclusion patients during presurgical orthodontics and further confirmed the safety and efficacy of LLAC surgery on the increases of alveolar bone in the mandibular anterior teeth.[13] However, it is still unknown whether LLAC surgery could induce periodontal soft tissue increases including gingival thickness and keratinized gingiva width, and whether there is a correlation between the changes of gingiva and bone tissues.

Therefore, in this study, we performed LLAC surgery for skeletal Class III malocclusion patients with insufficient alveolar bone during presurgical orthodontic treatment, and we further investigated the changes of periodontal soft tissue and alveolar bone and their correlations at baseline, immediately after LLAC, and at 6 months postoperatively.

Materials and methods

This study was approved by the Ethics Committee of Peking University Health Science Center (approval no. PKUSSIRB-202498049), registered in the Chinese Clinical Trial Registry (no. ChiCTR2400086478) and conducted by the Helsinki Declaration of 1975, as revised in 2013. All protocols were performed following approved guidelines and regulations, and written informed consent was obtained from all participants.

Sample size

This study was a prospective exploratory self-controlled clinical trial of a new surgical procedure and an appropriate sample size is required to distinguish changes in the gingiva tissue after the surgery. According to our previous study,[10] the mandibular anterior keratinized gingiva width at preoperative and postoperative periods of 6 months were 3.88 ± 1.22 mm and 4.92 ± 1.01 mm, respectively. Based on this data, we used the PASS 15.0 (NCSS; Kaysville, UT, USA) software to determine that at least 10 subjects were required for this study under the conditions $\alpha = 0.05$ and $\beta = 0.2$. Considering the potential loss to follow-up rate, the sample size of this study was determined to be 11 patients.

Patient selection

Subjects with skeletal Class III malocclusion who were advised by orthodontists, periodontists, and maxilla-facial surgeons to undergo LLAC surgery due to the thinness of their labial alveolar bone before orthodontic decompensation were enrolled in the present study.

The inclusion criteria were: (1) aged 18—40 years; (2) skeletal Angle Class III 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 and lingual mandibular anterior cortical bone of <0.5 mm at 4 mm apical to the CEJ as demonstrated by CBCT; (5) clinical examination: the root shape of the anterior teeth was prominently exposed and the root protrusion could be palpated; (6) no smoking history; and (7) systemic health. Exclusion criteria were: (1) pregnancy or lactation; (2) uncontrolled periodontal infection; (3) history of periodontal surgical treatment or orthodontics on the anterior teeth; (4) systemic disease; and (5) cleft lip/palate or maxillofacial abnormality.

Surgical and orthodontic procedures

All subjects underwent oral examination, oral hygiene care, and periodontal therapy, including scaling and root planing as needed. Periodontal surgeries were performed by the same experienced periodontist. The surgical procedure is shown in Fig. 1. Under local anesthesia administration, crevicular incisions with vertical release were performed on the labial and lingual aspect (from canine to canine) using microsurgical instruments. At the base of the labial papilla, a modified papilla retention incision was made. The full-thickness flaps were minimally invasive elevated on the labial and lingual sides, and ended at the root apical region, but not more than 15 mm apical to CEJ on either side. Using the Piezo-Surgical knife (Mectron, Carasco, Italy), a vertical interproximal alveolar decortication was performed, which was below the alveolar crest to a depth of 2—3 mm. The length of vertical decortication was approximately 5 mm and the depth was approximately 1.5 mm. Alveolar decortication at the labial and lingual sides was not located on the same sagittal plane to prevent alveolar bone penetration. A total of 0.75 g of bone substitute material (Bio-Oss; Geistlich, Wolhusen, Switzerland) was grafted onto both aspects of the decorticated anterior cortical bone and into dehiscence and fenestrations in the coronal-apical direction. A 25 mm × 25 mm bioresorbable collagen membrane (Bio-Gide; Geistlich) was indicated for complete coverage of the graft site, which reflexed inward toward the root to avoid movement of the bone graft material towards the root. Flaps were coronally repositioned with double-sling sutures and interrupted interdental sutures using non-absorbable 5.0 Prolene (Ethicon, Irvine, CA, USA). Amoxicillin (500 mg/thrice a day for 7 days) and 0.12 % chlorhexidine (South China Pharmaceutical, Shenzhen, China) (10 ml/twice a day for 14 days) were recommended after surgery. Ibuprofen was used at 0.3 g every 12 h within 3

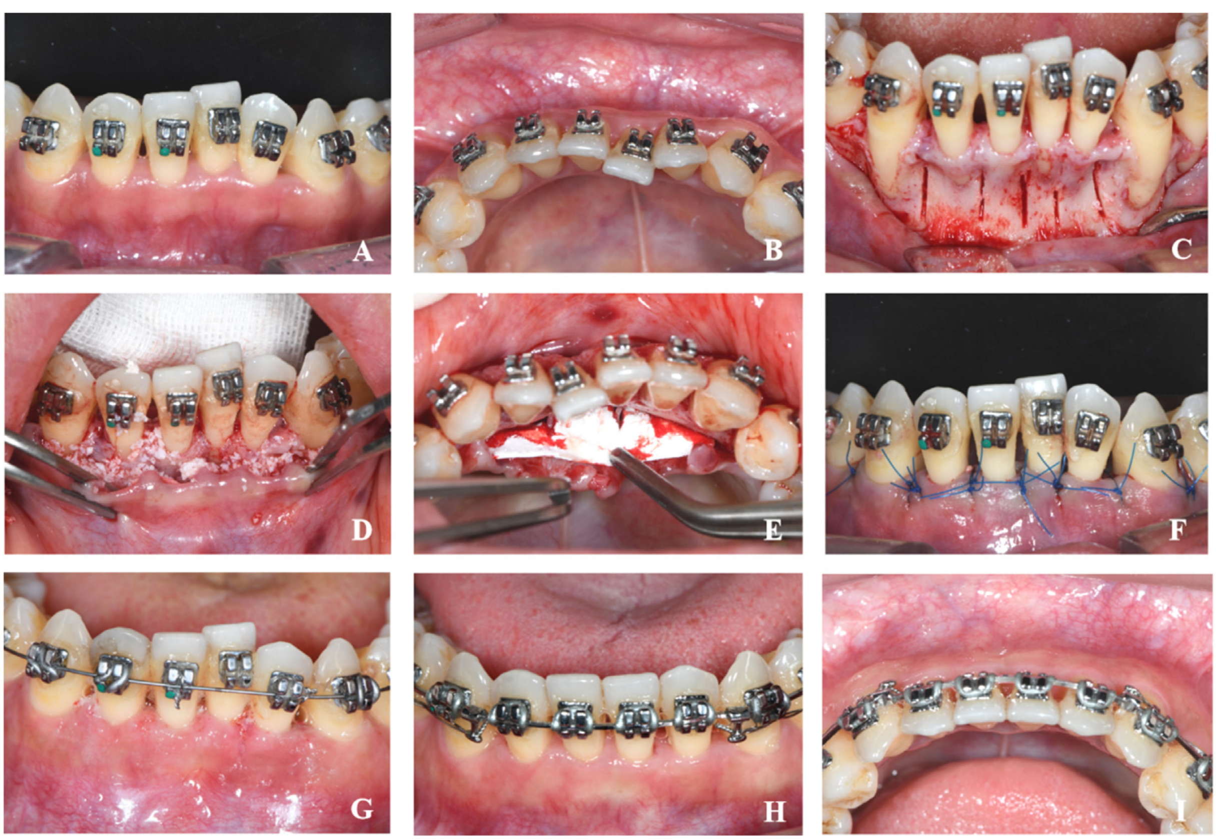

Figure 1 Surgical procedure for labial and lingual augmented corticotomy in a patient with skeletal Class III malocclusion. A—B: Presurgical view of labial and lingual side; C: The vertical interproximal alveolar decortication were created below the alveolar crest to a depth of 2—3 mm; D: Bone derivative material was placed in the exposed mandibular area, and bioabsorbable collagen membrane covered the graft site; F: Flaps were coronally repositioned with double-sling sutures and interrupted interdental sutures; G: Sutures were removed 14 days after surgery; H—I: Intraoral photograph at 6 months postoperatively.

days after surgery when the patient felt intense pain. Sutures were removed and orthodontic forces were applied 14 days after the periodontal surgery.

Intraoral scanning and CBCT examinations

CBCT scans were taken before LLAC (T0), 14 days after surgery (Ts), and 6 months after surgery (T1). An experienced operator used an intraoral scanner (3Shape Trios, 3Shape, Denmark) to get the digital impression 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.

Gingival thickness and keratinized gingiva width measurement

Intraoral scanning and CBCT images were automatically registered through the 3Shape Design Studio software (3Shape, Copenhagen, Denmark) using teeth as the registration area. After registration, a new model was formed to quantify the accuracy of the registration through different colors (Fig. 2A). The gingival thickness was recorded as the distance between the gingiva surface and the alveolar bone surface at the planes made perpendicular to the long axis of the teeth (Fig. 2B). The measurement levels were at 1 mm coronal to CEJ level, CEJ level, 1 mm, 2 mm, 3 mm, 4 mm apical to CEJ (Fig. 2B).

The keratinized gingiva width was measured on the color digitalization model using the Geomagic Control X software (Oqton, Rock Hill, SC, USA). The demarcation between the attached gingiva and alveolar mucosa was the mucogingival junction. The keratinized gingiva width was measured from the gingival margin and the mucogingival junction at the midfacial aspect of each anterior tooth (Fig. 2C).

Alveolar bone thickness measurement

Alveolar bone contour area was recorded perpendicular to the long axis of each mandibular anterior tooth at 4 mm, and 8 mm levels apical to CEJ and at the root apical level (Fig. 2B). All variables were measured on the sagittal slices where the teeth were the widest labio-lingual side in the axial view. The alveolar bone thickness was measured at T0, Ts and T1 Bone formation rate is the ratio of final bone formation to initial bone grafting calculated. The bone formation rate was calculated as (T1 - T0)/(Ts - T0). All imaging measurements were performed independently by one periodontist.

Statistical analysis

Variables are presented as mean $\pm$ standard deviation (SD; normal distribution). Comparisons of gingival thickness, keratinized gingiva width, and alveolar bone thickness were performed using paired samples t-test. The Pearson correlation coefficient analyzed the correlation between soft and hard tissue changes before and after LLAC treatment. Data were analyzed with the software SPSS 26.0 (SPSS v26.0; Chicago, IL, USA). A 2-sided value of $P < 0.05$ was considered statistically significant.

Results

Patient population and surgical procedures

In this study, 11 patients (3 men and 8 women, average age of 25.5 years old) with 66 anterior teeth were included. The intraoral images showed that the gingiva healed well 14 days after surgery (Fig. 1G) and there was no gingival recession 6 months after surgery (Fig. 1H–I). The CBCT sagittal views of anterior teeth from baseline to 6 months after LLAC showed the effect of alveolar bone increase (Fig. 3).

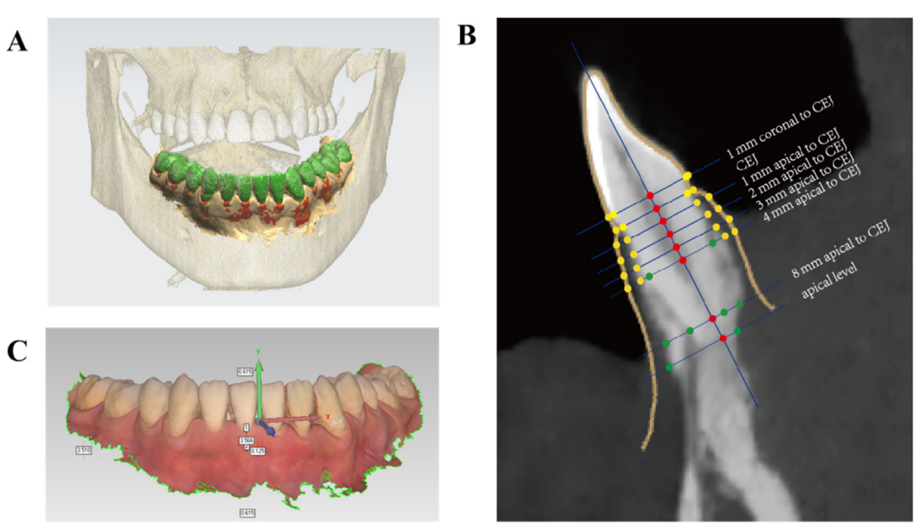

Figure 2 Illustration of measurements and reference points used in this study. A: The registration of intraoral scanning and CBCT data; B: The measurement levels of gingival and alveolar bone thickness on the combination model; C: The measurement of keratinized gingiva width on the intraoral scanning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

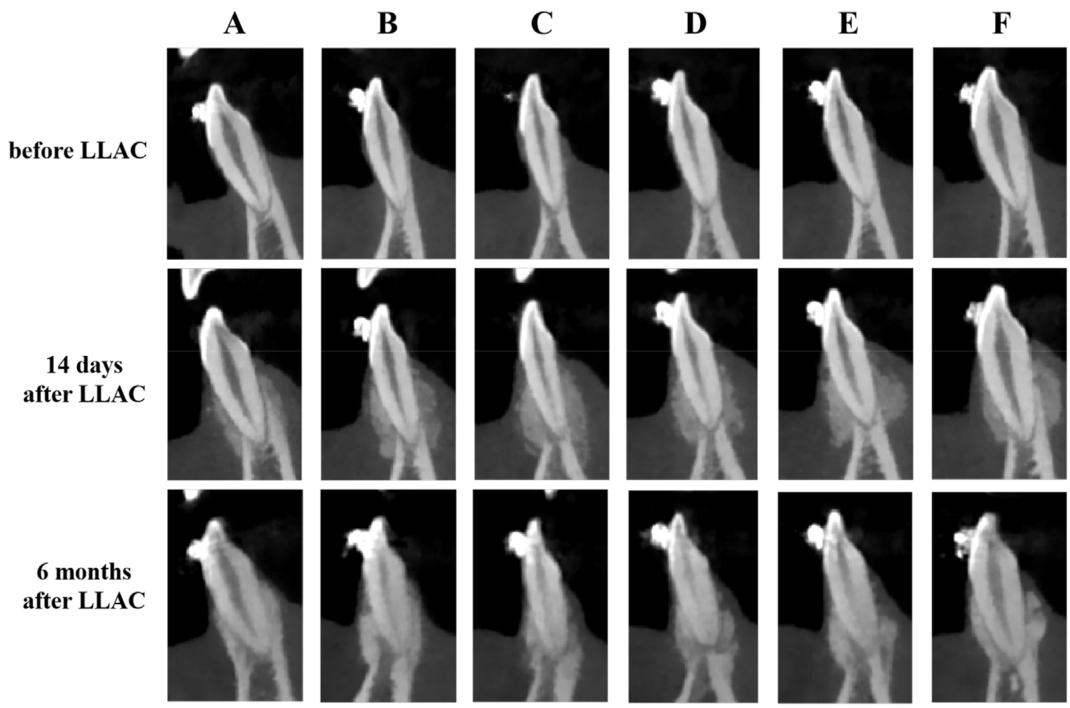

Figure 3 CBCT images of six lower anterior teeth of one subject before LLAC, 14 days after the LLAC, and 6 months after the LLAC. A—F: From 43 to 33. LLAC, labial and lingual augmented corticotomy.

The changes in gingival thickness

The gain of gingival thickness was observed 6 months after LLAC surgery (Table 1). For all labial measurement sites, the mean gingival thickness before LLAC was 0.51 ± 0.31 mm, and a mean gain of labial gingival thickness was 0.29 ± 0.37 mm; for all lingual measurement sites, the average gingival thickness was 0.66 ± 0.48 mm preoperatively, and the average increase at 6 months postoperatively was 0.18 ± 0.53 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 0.17 ± 0.21 mm, 0.59 ± 0.29 mm, 0.62 ± 0.29 mm, 0.65 ± 0.23 mm, 0.56 ± 0.25 mm, and 0.50 ± 0.29 mm, respectively, and the lingual gingival thickness were 0.11 ± 0.23 mm, 0.40 ± 0.39 mm, 0.76 ± 0.37 mm, 0.95 ± 0.43 mm, 0.91 ± 0.41 mm, and 0.81 ± 0.37 mm at corresponding measurement levels. Six months after surgery, the labial gingival thickness increased by 0.05 ± 0.30 mm, 0.14 ± 0.34 mm, 0.30 ± 0.38 mm, 0.40 ± 0.34 mm,

Table 1 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	0.17 ± 0.21	0.22 ± 0.24	0.160 ns	0.05 ± 0.30	0.11 ± 0.23	0.12 ± 0.22	0.547 ns	0.01 ± 0.15
	CEJ	0.59 ± 0.29	0.73 ± 0.37	<0.01**	0.14 ± 0.34	0.40 ± 0.39	0.42 ± 0.36	0.743 ns	0.02 ± 0.40
	1 mm apical to CEJ	0.62 ± 0.29	0.92 ± 0.40	<0.001***	0.30 ± 0.38	0.76 ± 0.37	0.84 ± 0.56	0.271 ns	0.08 ± 0.60
	2 mm apical to CEJ	0.65 ± 0.23	1.04 ± 0.31	<0.001***	0.40 ± 0.34	0.95 ± 0.43	1.15 ± 0.61	<0.05*	0.20 ± 0.59
	3 mm apical to CEJ	0.56 ± 0.25	1.00 ± 0.30	<0.001***	0.44 ± 0.32	0.91 ± 0.41	1.26 ± 0.62	<0.001***	0.35 ± 0.59
	4 mm apical to CEJ	0.50 ± 0.29	0.89 ± 0.23	<0.001***	0.39 ± 0.36	0.81 ± 0.37	1.24 ± 0.50	<0.001***	0.43 ± 0.58
	All sites	0.51 ± 0.31	0.80 ± 0.42	<0.001***	0.29 ± 0.37	0.66 ± 0.48	0.84 ± 0.66	<0.001***	0.18 ± 0.53

Data are presented as mean ± SD/N.
T0: before LLAC; T1: 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 labial and lingual gingival thickness before LLAC and 6 months after surgery at different tooth sites.

		Labial				Lingual			
Gingival	Tooth level	T0	T1	*P*	Difference	T0	T1	*P*	Difference
thickness	Central incisors	0.49 ± 0.34	0.84 ± 0.47	<0.001***	0.35 ± 0.40	0.71 ± 0.54	0.80 ± 0.66	<0.05*	0.09 ± 0.49
	Lateral incisors	0.54 ± 0.32	0.84 ± 0.43	<0.001***	0.30 ± 0.36	0.52 ± 0.39	0.72 ± 0.63	<0.001***	0.20 ± 0.48
	Canines	0.52 ± 0.25	0.73 ± 0.34	<0.001***	0.22 ± 0.33	0.74 ± 0.47	0.10 ± 0.66	<0.001***	0.25 ± 0.59

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

Table 3 The keratinized gingiva width before LLAC and 6 months after surgery.

Tooth level	T0	T1	Diference (T1-T0)	*P*
Central incisors	3.15 ± 1.36	4.01 ± 1.41	0.86 ± 0.61	<0.001***
Lateral incisors	3.19 ± 1.31	3.81 ± 1.35	0.63 ± 0.65	<0.001***
Canines	2.98 ± 0.93	3.43 ± 0.91	0.45 ± 0.68	<0.01**
All sites	3.10 ± 1.20	3.75 ± 1.25	0.65 ± 0.66	<0.001***

Data are presented as mean ± SD/N.
T0: before LLAC; T1: 6 months after surgery; LLAC, labial and lingual augmented corticotomy.
**$P < 0.01$; ***$P < 0.001$.

0.44 ± 0.32 mm, and 0.39 ± 0.36 mm at each of the respective levels, and the differences were statistically significant at all sites on the labial side except at 1 mm coronal to CEJ level. Six months after surgery, the lingual gingival thickness increased by 0.01 ± 0.15 mm, 0.02 ± 0.40 mm, 0.08 ± 0.60 mm, 0.20 ± 0.59 mm, 0.35 ± 0.59 mm, and 0.43 ± 0.58 mm at each of the respective levels, and the differences were statistically significant at 2 mm, 3 mm and 4 mm apical to the CEJ levels (Table 1).

For different tooth sites, the increase of labial gingival thickness for central incisors, lateral incisors, and canines were 0.35 ± 0.40 mm, 0.30 ± 0.36 mm, and 0.22 ± 0.33 mm, and the increase of lingual gingival thickness was 0.09 ± 0.49 mm, 0.20 ± 0.48 mm, and 0.25 ± 0.59 mm, respectively (Table 2).

The changes in keratinized gingiva width

The mean keratinized gingiva width at T0 and T1 were 3.10 ± 1.20 mm and 3.75 ± 1.25 mm, respectively, and the increased keratinized gingiva width for all measurement sites was 0.65 ± 0.66 mm by 6 months after LLAC ($P < 0.001$; Table 3). The increase of keratinized gingiva width for central incisors, lateral incisors, and canines were 0.86 ± 0.61 mm, 0.63 ± 0.65 mm, and 0.45 ± 0.68 mm, respectively ($P < 0.01$; Table 3).

The changes in alveolar bone thickness

Fig. 3 shows CBCT images of 6 lower anterior teeth of a subject before LLAC, 14 days after the surgery, and 6 months after the surgery. For the labial measurement sites, the thickness of the alveolar bone changed from T0 to T1 was 0.20 ± 0.22 mm to 0.90 ± 0.41 mm at the 4 mm apical to CEJ, 0.18 ± 0.20 mm to 2.05 ± 0.74 mm at the 8 mm apical to CEJ, and 2.11 ± 0.85 mm to 3.85 ± 1.01 mm at the apical level. As for the corresponding lingual side, the alveolar bone changed from T0 to T1 was 0.36 ± 0.34 mm to 0.97 ± 0.57 mm, 0.91 ± 0.67 mm to 2.23 ± 0.81 mm and 3.41 ± 1.51 mm to 3.93 ± 1.41 mm respectively, and all of them were statistically significant (Table 4).

The alveolar bone thickness for all labial measurement sites were 0.84 ± 1.05 mm and 2.28 ± 1.43 mm at T0 and T1 ($P < 0.001$). The total lingual sits were 1.57 ± 1.65 mm and 2.38 ± 1.58 mm at T0 and T1 ($P < 0.001$). The labial and lingual alveolar bone thickness for central incisors, lateral incisors, and canines at T0 were 0.74 ± 0.83 mm, 0.78 ± 0.94 mm, 0.99 ± 1.31 mm, 1.43 ± 1.49 mm, 1.29 ± 1.53 mm and 1.98 ± 1.85 mm; at T1 the thicknesses were 2.34 ± 1.45 mm, 2.46 ± 1.50 mm, 2.06 ± 1.32 mm, 2.32 ± 1.53 mm, 2.16 ± 1.47 mm and 2.64 ± 1.70 mm, respectively. The thickness of the alveolar bone of all anterior teeth was statistically different at T0 and T1 (Table 5).

The bone formation rate at all labial sites was 77.34 ± 72.33 % at 4 mm apical to CEJ and 58.61 ± 70.09 % at the lingual side. At 8 mm apical to CEJ, the bone formation rate at labial and lingual sites were 75.07 ± 29.10 % and 73.64 ± 62.34 %, respectively. For central incisors, the bone formation rates were 75.68 ± 44.14 % and 60.42 ± 69.34 % for the labial and lingual sides. For the lateral incisors, the bone formation rates on the labial and lingual sides were 85.47 ± 61.25 % and 63.27 ± 83.66 %. The bone formation rate of canines on both sides was 71.74 ± 73.17 % and 24.53 ± 43.05 % (Table 6).

The correlation between the changes in alveolar bone thickness and gingival thickness

The Pearson's coefficients for alveolar bone thickness changes and gingival thickness changes at 4 mm apical to CEJ were −0.38 on the labial side ($P < 0.01$) and −0.29 on the lingual side ($P < 0.05$). The gain of gingival thickness and alveolar bone thickness showed a weak negative correlation ($-0.2 < r < -0.4$) (Table 7).

Discussion

At present, only few case report[14] and our recent study[13] reported lingual augmented corticotomy. A case report

Table 4 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)**
4 mm apical to CEJ	0.20 ± 0.22	0.91 ± 0.41	0.90 ± 0.41	0.71 ± 0.41	0.36 ± 0.34	1.74 ± 0.75	0.97 ± 0.57	0.61 ± 0.66
8 mm apical to CEJ	0.18 ± 0.20	2.79 ± 0.77	2.05 ± 0.74	1.87 ± 0.78	0.91 ± 0.67	2.91 ± 1.18	2.23 ± 0.81	1.32 ± 0.77
Apical level	2.11 ± 0.85	4.07 ± 1.22	3.85 ± 1.01	1.74 ± 1.14	3.41 ± 1.51	4.21 ± 1.62	3.93 ± 1.41	0.52 ± 1.20
P	**Pa**	**Pb**	**Pc**		**Pa**	**Pb**	**Pc**	
4 mm apical to CEJ	Pa<0.001***	Pb < 0.001***	Pc < 0.001***		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 < 0.05*		Pa<0.001***	Pb < 0.001***	Pc < 0.01**	

Data are presented as mean ± SD/N.
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.
*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

Table 5 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	0.74 ± 0.83	2.86 ± 1.49	2.34 ± 1.45	1.60 ± 1.01	1.43 ± 1.49	3.14 ± 1.76	2.32 ± 1.53	0.89 ± 1.01
Lateral incisors	0.78 ± 0.94	2.92 ± 1.72	2.46 ± 1.50	1.67 ± 1.02	1.29 ± 1.53	2.93 ± 1.69	2.16 ± 1.47	0.87 ± 0.95
Canines	0.99 ± 1.31	2.39 ± 1.03	2.06 ± 1.32	1.07 ± 0.77	1.98 ± 1.85	2.80 ± 1.31	2.64 ± 1.70	0.67 ± 0.95
All sites	0.84 ± 1.05	2.72 ± 1.45	2.28 ± 1.43	1.44 ± 0.97	1.57 ± 1.65	2.95 ± 1.59	2.38 ± 1.58	0.81 ± 0.97
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 < 0.01**		Pa<0.001***	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/N.
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 6 Bone formation rate of labial and lingual alveolar bone 6 months after LLAC.

Bone formation rate	Labial	Lingual	Average rate
4 mm apical to CEJ	77.34 ± 72.33 %	58.61 ± 70.09 %	67.97 ± 71.51 %
8 mm apical to CEJ	75.07 ± 29.10 %	73.64 ± 62.34 %	74.36 ± 48.41 %
Central incisors	75.68 ± 44.14 %	60.42 ± 69.34 %	68.27 ± 57.98 %
Lateral incisors	85.47 ± 61.25 %	63.27 ± 83.66 %	74.37 ± 73.81 %
Canines	71.74 ± 73.17 %	24.53 ± 43.05 %	48.14 ± 64.15 %

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

Table 7 The Pearson's coefficient for hard and soft tissue changes in the labial and lingual side.

	Soft tissue thickness changes	Hard tissue thickness changes	r	*P*
Labial	0.39 ± 0.36	0.71 ± 0.41	−0.38	<0.01**
Lingual	0.43 ± 0.58	0.61 ± 0.66	−0.29	<0.05*

Data are presented as mean ± SD/N.
$-0.2 < r < -0.4$: weak negative correlation.
*$P < 0.05$; **$P < 0.01$.

showed an increase in alveolar bone area on the labial and lingual sides at 1 year after lingual augmented corticotomy in a patient with skeletal Class I malocclusion.[14] Our recent study found LLAC surgery could induce the increase of alveolar bone compared to traditional orthodontic treatment without surgery.[13] In this present study, we added the analyses of periodontal soft tissue changes, and it is the first time to analyze the changes in both periodontal soft tissue and periodontal hard tissue induced by LLAC surgery to our best knowledge. Notably, the results indicated that LLAC surgery could increase periodontal hard tissue and periodontal soft tissue including gingival thickness and keratinized gingiva width, which to our knowledge has hardly been reported before. According to these, LLAC could be considered as a safe and effective surgery capable of significantly increasing the soft and hard tissues of mandibular anterior teeth for skeletal Angle Class III patients with insufficient alveolar bone. Meanwhile, LLAC surgery could ensure the health and aesthetics of periodontal tissues during orthodontic decompensation and provide sufficient space for decompensation before orthognathic surgery.

Clinically, patients with skeletal Class III tend to have insufficient alveolar bone at labial and lingual sides,[9] moreover fenestration and dehiscence also appear more frequently.[15] Considering the labially inclined movement of the lower anterior teeth in orthognathic preoperative decompensation with skeletal Class III patients, previous scholars focused on the therapeutic efficacy of labial periodontal bone augmentation surgery for defects in the alveolar bone to reduce the risk of lingual periodontal destruction after teeth movement.[16,17] Besides, the difficulty of the lingual side of the mandibular anterior teeth with numerous blood vessels and nerves tends to cause postoperative tissue swelling and bleeding in the patient, which makes it difficult to develop lingual AC. It has been shown that almost all patients have at least one lingual foramen, with the mean distance from the median lingual foramen to the alveolar crest is about 15.49 mm, whereas the mean distance from the lateral lingual foramen to the alveolar crest is 20.93 mm.[18] In case of damage to the lingual foramen, the patient may be at risk of severe bleeding, even affecting breathing.[19]

To avoid adverse reactions after LLAC, we took a CBCT of each subject at T0, and the distance from the root apical to the median lingual foramen or the lateral lingual foramen was clarified by measuring the position. During operative flap flipping, the depth of the flap was not more than 5 mm in the direction of the root apical, to make sure that the blood vessels in the mandibular central lingual canal would not be damaged. Meanwhile, intraoperative blunt detachment was used to preserve as much as possible the blood vessels, nerves, and glandular ducts present in the lingual soft tissues. These preserved blood vessels and nerves would provide a certain degree of support for the graft material, effectively preventing the graft material from shifting to the root apical region. In this study, none of the 11 subjects had any significant complications such as bleeding or neurosensory abnormalities, either intraoperatively, at 14 days postoperatively, or at 6 months postoperatively, which suggested the safety of LLAC surgery.

Both labial and lingual movement of the mandibular anterior teeth during orthodontic treatment could jeopardize periodontal health.[20] A study reported that preoperative orthodontic decompensation treatment leads to soft tissue recession.[21] As well, other research has found that after preoperative decompensation was completed in skeletal Class III patients, there was a significant loss of alveolar bone thickness in the middle labial and lingual sides of the mandibular central incisor roots, from 0.70 ± 0.21 mm to 0.27 ± 0.39 mm on the labial side, and from 0.95 ± 0.58 mm to 0.60 ± 0.61 mm on the lingual side.[11] In our previous study, we found that only treatment of the mandibular labial side indeed improved the labial bone thickness, but it did not improve the lingual side bone tissue.[9]

In this present study, we analyzed the soft tissue changes induced by LLAC. It was shown that gingival thickness increased at almost all measured sites on the labial and lingual sides. The mean soft-tissue increase on the labial side was greater than on the lingual side, 0.29 ± 0.37 mm and 0.18 ± 0.53 mm. The most increased site on the labial side was at 3 mm apical to CEJ, with an increase of 0.44 ± 0.32 mm, and on the lingual side, the most increased amount was at 4 mm apical to CEJ, with an increase of 0.43 ± 0.58 mm. Compared with our previous study,[10] which showed the subjects requiring dual-sided treatment had a thinner gingival thickness preoperatively (T0), with a mean thickness of 0.51 ± 0.31 mm, whereas in labial-only treatment, the mean thickness was 0.79 ± 0.25 mm. We found no significant change in gingival thickness at the lingual root sites near the coronal side, which is probably due to the labial movement of the teeth and the tension side of the gingiva is thinner,[22] which in turn affects the increase in gingival thickness of the lingual side of the teeth. As analyzed by different tooth positions, the most increased gingival thickness on the labial side was at the central incisors, with a gain of 0.35 ± 0.40 mm, and on the lingual side it was at the canines, with a gain of 0.25 ± 0.59 mm. The biological process of AC is similar to the healing process of bone injury. The local microenvironment is altered and macrophages and monocytes secrete different growth factors and cytokines that can activate proliferative signaling pathways that promote fibroblasts. It might be responsible for the thickening of gingival tissues.[23–26] It has been found in other studies that the thin gingival type of mandibular anterior teeth shifted to a thicker gingival type after AC treatment.[9,27]

The previous study has reported that a significant correlation was found between the keratinized gingiva width and the progression of gingival recession.[28] In this study, we also measured the keratinized gingiva width at different tooth positions and found that all anterior teeth showed a significant widening of keratinized gingiva width 6 months after LLAC treatment. The average increase in width was 0.65 ± 0.66 mm, with the highest increase of 0.86 ± 0.61 mm at the central incisors. This trend is also consistent with previous studies.[29,30]

Along with soft tissue, we found significant gains in bone tissue thickness at both labial and lingual sites 6 months postoperatively in the present study. Interestingly, we also found that all the bone gain at each point on the labial side was more than the lingual side, which may be related to the tilting of the teeth to the labial side in the decompensation treatment and provide better stabilization on the labial side of the bone grafting material. The lesser increase in bone thickness at the lingual apical site may be related to the lingual movement of the apical site of the lower anterior teeth. In addition, the soft tissues on the lingual side are loose and susceptible to lingual movement, which also affected the stabilization of the bone graft material. This finding is also consistent with our recent research.[13]

Depending on the positions of the teeth, we found that the lateral incisors had the greatest bone thickness increase on the labial side and the central incisors had the largest increase on the lingual side. The canines had the smallest increase in alveolar bone thickness on both the labial and lingual sides. We hypothesize that the reason for this may be the long roots of the canines and the relatively better preoperative conditions for bone thickness on the labio-lingual side of the canines, which results in less bone gain compared to the incisors. In addition, the canines tend to have a poorer soft-tissue tension-reducing effect, and the amount of intraoperative bone grafts implanted is comparatively less. This finding highlights that clinicians should pay more attention to the amount of labio-lingual bone grafting at the canine site when performing LLAC to ensure that adequate postoperative movement is gained and to prevent canine bone fenestration or dehiscence.

Numerous studies have shown that thinner alveolar bone thickness could be associated with a thinner periodontal phenotype, which is a positive correlation between the alveolar bone thickness and the gingival thickness at baseline.[31,32] While the relationship between the postoperative gingival and bone changes have received little attention in clinical studies. Different from previous studies, we found a significant increase in gingival thickness and alveolar bone thickness after the treatment of LLAC, and analyzed a negative correlation between the both change. A similar finding was proven in V. Chappuis et al. study, where the soft tissue thickness increased significantly with the alveolar bone within 2 weeks following tooth extraction. In particular, the increase in soft tissue thickness was significantly greater in the thin bone phenotype than in the thick bone phenotype as the healing duration prolonged.[33] Furthermore, after mandibular distraction osteogenesis, the significant improvement was observed not only in the bone tissue defects but also the soft tissues.[34] On the molecular mechanism level, it has been found that positive cells labeled with osteocalcin and BMP-7 increased during the rapid phase of soft tissue healing.[35] Thus, the molecular and cellular mechanisms that regulate bone formation may also affect the increase in soft tissue. In our future study, we will remain focus on the relationship between gingival and alveolar bone thickness and try to find the regulatory molecular and cellular mechanisms in the feature.

In this study, we found that the sites with more increase in soft tissue have relative less increase in hard tissue. Combined with the analysis of bone formation rates, sites with high bone formation rates had less soft tissue increase, and vice versa. We hypothesize that this may be because that the sites with slightly poorer bone formation provide more space for soft tissue remodeling. We expect the preliminary results of this study to determine the ratio of hard and soft tissue changes after LLAC and to provide a reference for the future prediction of soft and hard tissue changes after LLAC. However, the small sample size in this study may be a biasing factor that affects the soft and hard tissue analyses. Therefore, in future studies, a database with a larger sample is needed to minimize errors due to instability.

In summary, LLAC is a relatively new surgical strategy, and we demonstrated its safety and efficacy in this study. LLAC was able to increase the thickness of the gingival on the labial and lingual sides and increase the keratinized gingiva width. It also increased the loss of hard tissue on both the labial and lingual sides in patients with skeletal Class III malocclusion. It has positive clinical significance in maintaining the stability of periodontal tissues of the lower anterior teeth in orthodontic treatment.

Declaration of competing interest

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

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