ORIGINAL ARTICLE

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Augmented corticotomy-assisted presurgical orthodontic treatment to prevent alveolar bone loss in patients with skeletal Class III malocclusion

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Introduction: The objective of this study was to explore the effect of augmented corticotomy (AC) on anterior alveolar bone morphology in presurgical orthodontic treatment for skeletal Class III malocclusion. **Methods:** Thirty-six surgical patients with skeletal Class III malocclusion with high-angle were included: 18 (AC group) accepted AC surgery during presurgical orthodontic treatment, and 18 (control group) accepted traditional presurgical orthodontic treatment. Cone-beam computed tomography scans were obtained before treatment (T0) and after presurgical orthodontic treatment (T1). The alveolar bone morphology, root length, dehiscence, and movement of mandibular central incisors were measured by cone-beam computed tomography using Dolphin software. Statistical analyses were performed with independent-sample *t* tests, paired *t* tests, and multiple linear regression. **Results:** After presurgical orthodontic treatment, the whole alveolar bone thickness at each level, alveolar bone area, and alveolar bone height decreased significantly in the control group but increased or remained unchanged in the AC group. In the AC group, the lower the labial alveolar bone height at T0 was, the greater the increase after T1; the change in alveolar bone thickness was related to ΔL1-MP and sex. At T0, the incidences of dehiscence were similar in the 2 groups, ranging from 11.11% to 16.67%. At T1, the labial and lingual incidences of dehiscence in the AC group were 0% and 27.78%, compared with 55.56% and 66.67% in the control group. **Conclusions:** During presurgical orthodontic treatment, AC is effective in preventing alveolar bone resorption and dehiscence without additional root resorption. AC can be recommended for high-angle skeletal Class III patients with thin alveolar bone around anterior teeth during presurgical orthodontic treatment. (Am J Orthod Dentofacial Orthop 2022;■:■-■)

The increasing esthetic requirement and social desirability of patients with skeletal Class III malocclusion make them more willing to choose surgical orthodontic treatment. The incidence of skeletal Class III malocclusion among Chinese populations is higher than that among Caucasian populations.[1] After surgical orthodontic treatment in numerous patients, periodontal complications such as gingival recession and tooth loosening around the mandibular anterior tooth were gradually exposed. Because the mandibular

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All authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest, and none were reported.
This study was financially supported by the Beijing Municipal Science and Technology Commission (Z181100001718111) and the National Program for Multidisciplinary Cooperative Treatment on Major Diseases (PKUSSNMP-201902).
This study was approved by the Biomedical Ethics Committee of the Peking University School and Hospital of Stomatology (approval no. PKUSSIRB-201839156).
This study was registered on the Chinese Clinical Trials Registry Platform of the World Health Organization (ChiCTR1900021778).
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Submitted, August 2021; revised and accepted, October 2021.
0889-5406/$36.00
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https://doi.org/10.1016/j.ajodo.2021.10.021

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anterior alveolar bone is generally thin in patients with skeletal Class III malocclusion before treatment,[2-5] especially in patients with high-angle malocclusion.[2,6] Compared with other malocclusions, Yagci et al[7] found the incidence of mandibular alveolar bone defects (45.02% dehiscence and fenestration) was the highest in Class III malocclusion, mainly consisting of dehiscence (42.64%).[7]

During presurgical orthodontic treatment for skeletal Class III malocclusion, one of the decompensation goals is to correct the lingually tipped mandibular incisors, which could influence the results of orthognathic surgery.[8] However, the labial movement of mandibular incisors is more susceptible to causing further bone resorption during treatment. Previous studies[5,9,10] have found that the anterior mandible has suffered a severe alveolar bone loss after surgical orthodontic treatment, especially during presurgical treatment. Artun and Krogstad[11] found a significantly greater increase in the clinical crown height and number of teeth that developed gingival recession in patients with excessive proclination during presurgical orthodontic treatment. Therefore, the prevention of alveolar bone loss for orthodontic patients with skeletal Class III malocclusion is crucial.

In recent years, augmented corticotomy (AC) has been increasingly used in orthodontic treatment to increase treatment safety and improve accelerated osteogenic orthodontics (AOO). Wilcko et al[12] successively proposed AOO, periodontally accelerated osteogenic orthodontics (PAOO),[13] on the basis of the regional acceleratory phenomenon.[14] Although the purpose of AOO and PAOO was to reduce the time of orthodontic treatment, it was later found that this technique can maintain and improve the alveolar housing by increasing alveolar bone remodeling and periodontal tissue regeneration.[15,16] Many different refinements and designations were developed in >10 years, and AC was one of them. AC in this study focuses more on increasing the amount of alveolar bone rather than accelerating orthodontic treatment, combining modified decortication, bone grafting materials, and periodontal tissue regeneration technology.

In 2011, AC was firstly performed in 2 patients with skeletal Class III malocclusion, and the effect of AC-assisted presurgical orthodontic treatment on soft- and hard-tissue improvement was demonstrated by Kim et al.[17] Later, some retrospective studies[18-20] on AC combined with presurgical orthodontic treatment were reported, but the results were inconsistent. Studies exploring the therapeutic effect of AC on alveolar bone dehiscence are scarce. In addition, previous studies did not measure the amount of tooth movement by cone-beam computed tomography (CBCT) and analyze the relationship between tooth movement and alveolar bone remodeling. This study aimed to evaluate the effect of AC on improving alveolar bone morphology and dehiscence around the mandibular anterior teeth of surgical patients with skeletal Class III malocclusion and to analyze relevant factors influencing the effect of AC.

MATERIAL AND METHODS

This study was performed as a prospective nonrandomized controlled trial. Thirty-six patients with high-angle skeletal Class III malocclusion requiring surgical orthodontic treatment participated in the study at Peking University School and Hospital of Stomatology from September 2018 to October 2019. All patients signed informed consent forms. This study was approved by the Biomedical Ethics Committee of the Peking University School and Hospital of Stomatology (approval no. PKUSSIRB-201839156) and registered on the Clinical Trials Register as ChiCTR1900021778 (Chinese Clinical Trials Registry Platform of the World Health Organization).

The inclusion criteria were as follows: (1) age: male >18 years and female >16 years; (2) ANB angle <0°, overjet <0 mm, and SN-MP angle >37.7°; (3) crowding of the maxillary and mandibular dental arch ≤4 mm; (4) periodontal health, with no more than 2 sites with probing depth (PD) ≥5 mm, bleeding on probing (BOP) ≤20%, and plaque score ≤30%; (5) labial alveolar bone thickness (ABT) of mandibular central incisors (MCIs) <1 mm, as measured by CBCT; and (6) presurgical orthodontic design as follows: bilateral first premolars extracted from the maxilla, no extraction from the mandible, and orthognathic surgery designed as bimaxillary surgery (LeFort I maxillary osteotomy and bilateral sagittal split mandibular setback surgery).

The exclusion criteria were as follows: (1) significant facial deviation (chin point deviation from the midline ≥ 4 mm); (2) congenital missing teeth or supernumerary teeth; (3) poor oral hygiene and uncontrolled periodontal disease; (4) history of orthodontic treatment and maxillofacial injury; and (5) history of trauma or root canal treatment of MCIs.

The study sample consisted of 2 groups according to the patient's intention, with 18 patients (11 women, 7 men) in the AC group and 18 patients (10 women, 8 men) in the control group. Assessors and statisticians in this study were blinded to the allocation. The baseline characteristics of 2 groups are shown in Table I.

Patients underwent routine initial periodontal therapy and were given oral hygiene instructions before orthodontic treatment, and the periodontal condition of the patients was monitored during treatment.

All patients were treated by the same orthodontist with fixed straight-wire orthodontic appliances (Roth

Table I. Baseline patient characteristics (n = 36)

Variables	*AC group, n = 18*	*Control group, n = 18*
Age, y	21.27 ± 2.74 (17-25)	20.83 ± 2.63 (17-26)
SNA (°)	75.77 ± 4.00	74.89 ± 2.95
SNB (°)	80.48 ± 4.64	79.64 ± 3.02
ANB (°)	−4.72 ± 3.17	−4.92 ± 2.48
SN-MP (°)	44.14 ± 4.36	43.68 ± 3.85
L1-MP (°)	72.22 ± 9.49	74.99 ± 8.95
Treatment duration of mandibular teeth, mo	8.8 ± 2.96	13.98 ± 4.85
Treatment duration of maxillary and mandibular teeth from T0 to T1, mo	15.65 ± 4.13	23.3 ± 4.52

AC, augmented corticotomy.

system). The archwire sequences involved 0.014, 0.016, 0.018, and 0.018 × 0.025-in nickel-titanium wires followed by a 0.018 × 0.025-in stainless steel wire. Patients in the control group were scheduled for orthodontic revisits every 4 weeks. AC was performed on the mandibular anterior teeth after bracket bonding without an archwire in the AC group. Two weeks after periodontal surgery, aligning and leveling started with 0.014-in nickel-titanium wires, and orthodontic force was applied every 2 weeks after that.

AC was performed by the same periodontist with surgical loupes for patients in the AC group. The AC procedure was as follows[21]: crevicular incisions were made, and a full-thickness flap on the labial side was turned from 1 side of the canines to the contralateral side; longitudinal decortication was performed between roots with a piezosurgical knife (OT7S-4; Piezo Surgery, Mectron, Italy), starting at 2-3 mm from the alveolar ridge crest and extending 5-7 mm toward the apex; approximately 0.5 g of Bio-Oss (Geistlich Pharma, Geistlich, Switzerland) bone material was grafted onto the labial cortical bone and the root surface (dehiscence and fenestration); the Bio-Oss surface was covered with a Bio-Gide membrane (25 mm × 25 mm, Geistlich, Switzerland); and the flaps were coronally repositioned with single-sling and interrupted interdental sutures using nonabsorbable 5.0 Prolene (Ethicon, Johnson & Johnson, New Brunswick, NJ; Fig 1).

CBCT scans were obtained before treatment (T0) and after presurgical orthodontic treatment (T1). CBCT images were acquired with the New Tom VG device (Aperio Services, Italy) at these settings: 3.0 mA, 110 kV, exposure time of 1.8 s, voxel size of 0.25 mm, and scanning area of 15×12 cm. CBCT data were imported into Dolphin Imaging software (version 11.8; Dolphin Imaging and Management Solutions, Chatsworth, Calif). The measurements in this study were modified on the basis of those reported by Lee et al[10] and Ma et al.[5]

The alveolar bone morphology and root length (RL) of the right MCIs were measured by CBCT (Fig 2). The images were oriented along the root long axis, the line from the midpoint of the cementoenamel junction to the apical point. As shown in Table II, the specific measurement variables included RL, vertical alveolar bone level (VBL), ABT, and alveolar bone area (ABA). The ABT was measured at 4 levels (4 mm, 6 mm, and 8 mm under the cementoenamel junction and at the root apex level). The VBL included the labial side (VBL-a), lingual side (VBL-l), mesial side (VBL-m), and distal side (VBL-d). Positive alveolar bone dehiscence was defined as a value of D-a or D-l >4 mm,[22,23] in which D-a is the distance between the crest of the alveolar ridge on the interproximal side and the crest of the labial alveolar ridge parallel to the root long axis and D-l is the distance between the crest of the alveolar ridge on the interproximal side and the crest of the lingual alveolar ridge parallel to the root long axis. All variables were measured on the sagittal slices where incisors were the widest labiolingually in the axial view, except that VBL-m, VBL-d, D-a, and D-l were measured on coronal slices

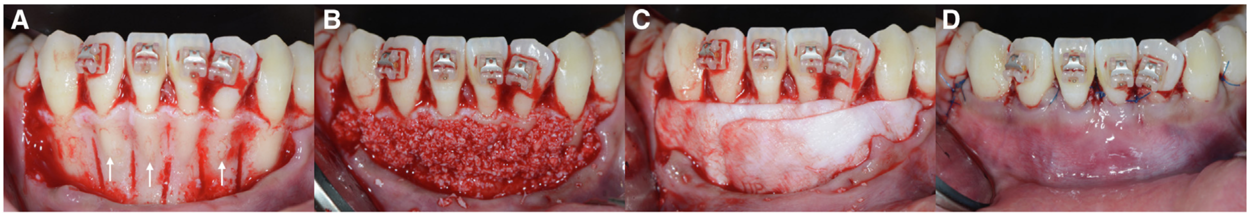

Fig 1. Surgical procedure for augmented corticotomy surgery. **(A)** Full-thickness flaps were elevated, and vertical interproximal cortical bone incisions were created. The arrows indicate the position of the bone fenestration sites. **(B)** Bio-Oss was grafted onto the cortical bone. **(C)** A Bio-Gide collagen membrane was placed to cover the bone grafting area. **(D)** The flaps were coronally repositioned and sutured.

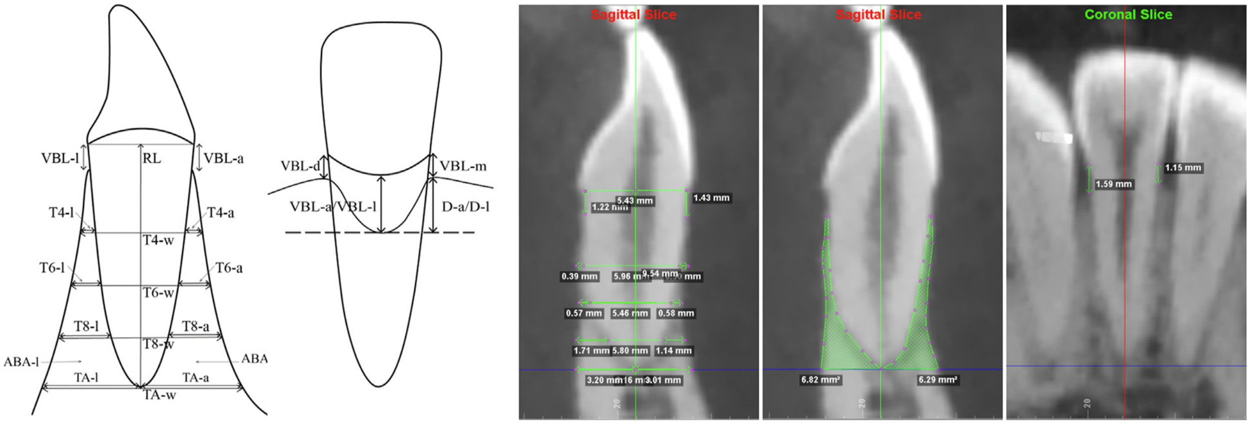

Fig 2. Example and illustration of morphometric measurements of alveolar bone around MCIs. *MCIs,* mandibular central incisors.

where incisors were the widest mesiodistally in the axial view.

The distance between the presurgical and surgical orthodontic treatment of MCIs was measured by the superimposition of CBCT images with a voxel-based method.[24] The midsagittal plane was selected after reorientation,[25] and the SN plane was rotated 7° clockwise as the horizontal coordinate axis. The sagittal and vertical distances were then measured between the incisal edge points at T0 and T1 and the root apex at T0 and T1 (Fig 3).

Cephalometry was performed to evaluate various parameters, including the SNA, SNB, ANB, SN-MP, U1-SN, L1-MP, U1-NA (degrees, millimeters), and

Table II. Definitions of measurements

Measurement type	*Definition*
RL	Root length
Vertical distance	
VBL-a	Distance from the CEJ to the labial alveolar crest parallel to the root long axis on the sagittal slices
VBL-l	Distance from the CEJ to the lingual alveolar crest parallel to the root long axis on the sagittal slices
VBL-m	Distance from the CEJ to the mesial alveolar crest parallel to the root long axis on the coronal slices
VBL-d	Distance from the CEJ to the distal alveolar crest parallel to the root long axis on the coronal slices
VBL-ip	Interproximal vertical bone level, the average of VBL-m and VBL-d
D-a	The distance between the interproximal alveolar crest and the labial alveolar crest parallel to the root long axis
D-l	The distance between the interproximal alveolar crest and the lingual alveolar crest parallel to the root long axis
ABT	
ABT-4a	Labial alveolar bone thickness at the 4 mm level under the CEJ
ABT-4l	Lingual alveolar bone thickness at the 4 mm level under the CEJ
ABT-4w	Whole alveolar bone thickness at the 4 mm level under the CEJ
ABT-6a	Labial alveolar bone thickness at the 6 mm level under the CEJ
ABT-6l	Lingual alveolar bone thickness at the 6 mm level under the CEJ
ABT-6w	Whole alveolar bone thickness at the 6 mm level under the CEJ
ABT-8a	Labial alveolar bone thickness at the 8 mm level under the CEJ
ABT-8l	Lingual alveolar bone thickness at the 8 mm level under the CEJ
ABT-8w	Whole alveolar bone thickness at the 8 mm level under the CEJ
ABT-Aa	Labial alveolar bone thickness at apex level
ABT-Al	Lingual alveolar bone thickness at apex level
ABT-Aw	Whole alveolar bone thickness at apex level
ABA	
ABA-a	Alveolar bone area on labial side
ABA-l	Alveolar bone area on lingual side
ABA-w	Whole alveolar bone area on labial and lingual side

CEJ, cemento-enamel junction.

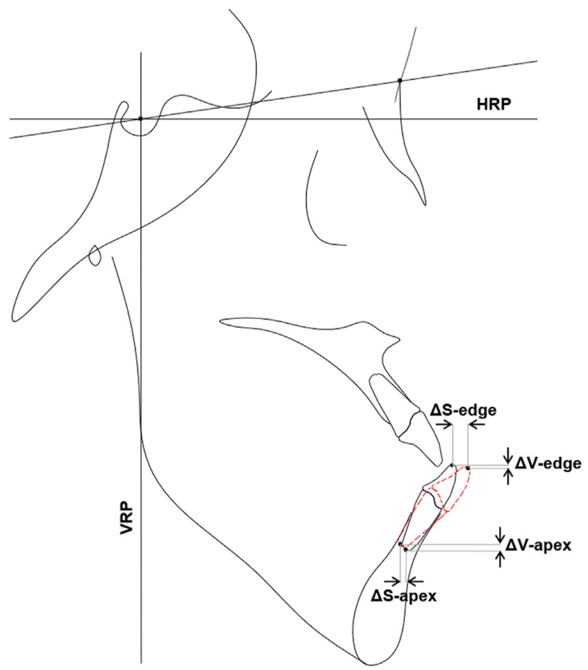

Fig 3. Reference lines and measurements of MCI movement. Reference lines: *SRP,* sagittal reference plane, a horizontal plane angulated 7° clockwise to the sella-nasion plane passing through the sella; *VRP,* vertical reference plane, plane perpendicular to the SRP passing through the sella. Measurement variables: *ΔS-edge,* movement distance of the incisal edge along the sagittal reference plane (SRP); *ΔS-apex,* movement distance of the root apex along the sagittal reference plane (SRP); *ΔV-edge,* movement distance of the incisal edge along the vertical reference plane (VRP); *ΔV-apex,* movement distance of the root apex along the vertical reference plane (VRP). *MCI,* mandibular central incisor.

L1-NB (degrees, millimeters). Lateral cephalograms were reconstructed from CBCT images with Dolphin Imaging software.

The sample size was calculated on the basis of the VBL and ABA reported by Ahn et al.[19] With α and power values set at 0.05 and 80%, respectively, 17 samples per group were needed. We included 18 samples in each group, considering the possibility of loss to follow-up.

Statistical analysis

All data were processed using SPSS (version 20, IBM, Armonk, NY). Differences between the AC and control groups were analyzed using the independent-sample *t* test. A paired *t* test was used to compare changes in all the measurements before and after presurgical orthodontic treatment in the 2 groups. At the same time, Pearson correlation and multiple linear regression analyses were performed to analyze changes in alveolar bone height and thickness during presurgical treatment.

All measurements were conducted twice by the same investigator (H.M.) at an interval of 2 weeks. Bland Altman tests were applied to compare the 2 measurements. In addition, the intraclass correlation coefficient between the 2 measurements was between 0.8 and 1. The average value of the 2 measurements was used for statistical analysis.

RESULTS

There was no significant difference in the movement of MCIs between the 2 groups, as shown in Table III. After decompensatory treatment, the incisal edges of MCIs in both groups moved forward (2.4 mm in the control group and 2.71 mm in the AC group on average), and the apical points moved backward (0.95 mm in the control group and 1.65 mm in the AC group on average). The movement of MCIs controlled tipping, with the center of rotation close to the apex. Vertical changes in the incisor point were not obvious during presurgical treatment. The root apex point moved upward vertically from T0 to T1. In addition, MCIs in both groups were labially proclined by 11.03° to 13.19° without a significant difference.

The RL, whole alveolar bone thickness (ABT-w), and whole alveolar bone area (ABA-w) in the 2 groups were similar at baseline, as shown in Table IV. The RL in the 2 groups decreased by approximately 1 mm after presurgical orthodontic treatment.

The change in ABT-w after presurgical orthodontic treatment (ΔABT-w) was significantly different between the 2 groups. After T1, ABT-w at each level in the control group decreased, whereas ABT-4w and ABT-6w increased, and ABT-8w and ABT-Aw remained unchanged in the AC group. Similarly, the ABA-w of MCIs in the control group decreased significantly after T1, whereas that in the AC group remained unchanged. The difference in ΔABT-w and ΔABA-w between the 2 groups was statistically significant.

The labial ABT at each level was extremely thin before treatment in both groups without a significant difference (Table V). The ABT and ABA on the labial side increased significantly in the AC group but not in the control group. There was a statistically significant difference in the labial ABT and ABA change between the 2 groups.

On the lingual side, there was no significant difference between the 2 groups before treatment. The ABT at each level and ABA decreased in both groups after presurgical treatment, although the average decrease was smaller in the AC group without statistical significance.

Table III. Movement of MCIs during presurgical orthodontic treatment in the control and AC groups

Group	*ΔS-edge*	*ΔS-apex*	*ΔV-edge*	*ΔV-apex*	*ΔL1-MP (°)*
Control	2.40 ± 1.78	−0.95 ± 1.17	−0.20 ± 1.67	−1.58 ± 1.51	11.03 ± 6.50
AC	2.71 ± 1.68	−1.65 ± 0.95	0.38 ± 1.4	−2.18 ± 1.56	13.19 ± 6.18
P value	0.559	0.700	0.144	0.385	0.212

ΔS-edge and ΔS-apex, positive values representing forward movement and negative values representing retraction of the incisal edge and root apex; *ΔV-edge and ΔV-apex*, positive values representing intrusion and negative values representing the extrusion of the incisal edge and root apex; *AC*, augmented corticotomy.

Table IV. Comparison of the RL, ABT-w, and ABA-w of MCIs between the control and AC groups at T0 and T1

	Control				*AC*				*T0 vs T0*	*Δ(T1 − T0) vs Δ(T1 − T0)*
Variables	*T0*	*T1*	*T1 − T0*	P1 *value*	*T0*	*T1*	*T1 − T0*	P2 *value*	P3 *value*	P4 *value*
RL (mm)	10.71 ± 0.89	9.9 ± 0.82	−0.82 ± 0.64	<0.001**	11.27 ± 1.31	10.11 ± 1.45	−1.16 ± 1.06	<0.001**	0.124	0.305
ABT-4w (mm)	6.04 ± 0.58	5.56 ± 0.37	−0.47 ± 0.44	<0.001**	6.24 ± 0.58	6.58 ± 0.51	0.34 ± 0.78	0.068	0.271	<0.001**
ABT-6w (mm)	5.87 ± 0.65	5.26 ± 0.5	−0.6 ± 0.49	<0.001**	5.82 ± 0.72	6.44 ± 0.66	0.62 ± 1.1	0.02*	0.828	<0.001**
ABT-8w (mm)	5.68 ± 0.86	5.25 ± 0.86	−0.43 ± 0.64	0.008**	5.72 ± 1.09	6.15 ± 0.85	0.44 ± 1.38	0.181	0.909	0.016*
ABT-Aw (mm)	6.06 ± 1.3	5.22 ± 0.91	−0.84 ± 0.72	<0.001**	6.2 ± 1.7	5.74 ± 1.14	−0.46 ± 1.73	0.253	0.779	0.32
ABA-w (mm^2)	15.57 ± 9.14	8.97 ± 7.99	−6.60 ± 4.72	<0.001**	15.19 ± 6.74	17.37 ± 5.38	2.18 ± 7.88	0.256	0.883	<0.001**

ABA, alveolar bone area; *ABT,* alveolar bone thickness; *AC,* augmented corticotomy; *P1*, paired-samples *t* test for comparison between T0 and T1 in the control group; *P2*, paired-samples *t* test for comparison between T0 and T1 in the AC group; *P3*, independent-samples *t* test for comparison between the 2 groups at T0; *P4*, independent-samples *t* test for comparison of the change in variables form T0 to T1 between the 2 groups; *RL,* root length.
**P* ≤0.05; ***P* ≤0.01.

The 2 groups showed a significant difference in the labial and lingual vertical bone levels (VBL-a and VBL-l) (Table VI, Fig 4). The VBL-a and VBL-l of the MCIs in the control group increased significantly, which meant that the labial and lingual alveolar bone height decreased significantly. However, in the AC group, the VBL-a decreased significantly, and the VBL-l decreased slightly, which meant that the labial alveolar bone height increased significantly, whereas the lingual alveolar bone height remained the same.

There was no significant difference in the mesial and distal vertical bone levels (VBL-m and VBL-d), so VBL-ip was obtained after averaging the data and used as an indicator for subsequent analyses. Although the VBL-ip increased by 0.3 mm on average in the control group and remained the same in the AC group, there was no significant difference in the ΔVBL-ip between the 2 groups during treatment.

Consistent with the VBL-a and VBL-l, the changes in the D-a and D-l in the 2 groups were significantly different (Fig 5, Table VII). In the control group, there were 2 sites of dehiscence on both the labial and lingual sides at T0. After T1, 8 and 10 additional sites of dehiscence were added on the labial and lingual sides, respectively. The incidence of dehiscence greatly increased to 55.56% (10 out of 18) and 66.67% (12 out of 18) on the labial and lingual sides, respectively. In the AC group, 2 subjects with dehiscence at T0 were cured after presurgical orthodontic treatment assisted by AC. However, 3 subjects had dehiscence on the lingual side at T0 in the AC group, among which 2 were cured at T1, and 1 was left. The incidence of lingual dehiscence was 27.78% at T1 in the AC group because of 4 additional subjects with dehiscence.

In this study, age, sex, ANB, SN-MP, vertical bone level, ABT at T0, and the amount of tooth movement from T0 to T1 were subjected to correlation analysis and stepwise regression analysis to censor variables that affected the change in alveolar bone height and labial ABT, as shown in Table VIII.

As mentioned above, the VBL-a significantly decreased after presurgical orthodontic treatment in the AC group; that is, the labial alveolar bone height increased. The regression analysis showed that the

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Table V. Comparison of the labial and lingual ABT and ABA of MCIs between the control and AC groups during presurgical orthodontic treatment

	Control				AC				T0 vs T0	Δ(T1 − T0) vs Δ(T1 − T0)
Variables	T0	T1	T1 − T0	P1 value	T0	T1	T1 − T0	P2 value	P3 value	P4 value
Labial										
ABT-4a (mm)	0.39 ± 0.3	0.25 ± 0.24	−0.14 ± 0.3	0.05*	0.5 ± 0.27	1.08 ± 0.68	0.58 ± 0.71	0.002**	0.245	0.001**
ABT-6a (mm)	0.49 ± 0.34	0.46 ± 0.42	−0.02 ± 0.43	0.814	0.41 ± 0.2	1.45 ± 0.93	1.03 ± 0.92	0.001**	0.404	0.001**
ABT-8a (mm)	0.78 ± 0.46	1.23 ± 1	0.45 ± 1.01	0.062	0.57 ± 0.27	1.99 ± 1.09	1.42 ± 1.06	0.001**	0.091	0.015*
ABT-Aa (mm)	2.52 ± 0.84	3.41 ± 1.08	0.89 ± 1.11	0.002**	2.18 ± 0.72	3.91 ± 0.96	1.73 ± 1.21	0.001**	0.172	0.046*
ABA-a (mm^2)	5.1 ± 3.34	5.1 ± 3.62	0 ± 3.54	0.998	5.55 ± 3.14	13.87 ± 5.2	8.32 ± 5.91	0.001**	0.849	0.001**
Lingual										
ABT-4l (mm)	0.59 ± 0.32	0.2 ± 0.21	−0.4 ± 0.32	0.001**	0.53 ± 0.36	0.28 ± 0.2	−0.25 ± 0.32	0.002**	0.565	0.118
ABT-6l (mm)	0.83 ± 0.41	0.25 ± 0.33	−0.59 ± 0.39	0.001**	0.76 ± 0.63	0.41 ± 0.32	−0.35 ± 0.57	0.014*	0.648	0.099
ABT-8l (mm)	1.36 ± 0.64	0.55 ± 0.58	−0.82 ± 0.7	0.001**	1.44 ± 1.1	0.66 ± 0.59	−0.78 ± 0.86	0.001*	0.794	0.645
ABT-Al (mm)	3.54 ± 1.07	1.8 ± 1.06	−1.73 ± 1.11	0.001**	4.02 ± 1.78	1.82 ± 0.99	−2.2 ± 1.54	0.001**	0.304	0.398
ABA-l (mm^2)	9.99 ± 6.28	2.79 ± 3.6	−7.2 ± 4.21	0.001**	9.64 ± 5.28	3.5 ± 2.9	−6.14 ± 5.31	0.001**	0.325	0.863

ABA, alveolar bone area; *ABT,* alveolar bone thickness; *AC,* augmented corticotomy; *P1,* paired-samples *t* test for comparison between T0 and T1 in the control group; *P2,* paired-samples *t* test for comparison between T0 and T1 in the AC group; *P3,* independent-samples *t* test for comparison between the 2 groups at T0; *P4,* independent-samples *t* test for comparison of the change in variables form T0 to T1 between the 2 groups.
*$P \leq 0.05$; **$P \leq 0.01$.

Table VI. Comparison of the VBL of MCIs in the control and AC groups before and after presurgical orthodontic treatment

	Control				AC				T0 vs T0	(T1 − T0) vs (T1 − T0)
Variables	T0	T1	T1 − T0	P1 value	T0	T1	T1 − T0	P2 value	P3 value	P4 value
VBL-a (mm)	2.58 ± 1.09	4.66 ± 1.96	2.08 ± 1.85	<0.001**	2.55 ± 0.9	1.34 ± 0.70	−1.21 ± 1.37	0.002**	0.924	<0.001**
VBL-l (mm)	2.31 ± 1.6	5.01 ± 1.82	2.7 ± 1.79	<0.001**	2.25 ± 0.88	2.19 ± 1.05	−0.06 ± 1.33	0.846	0.898	<0.001**
VBL-m (mm)	1.93 ± 0.44	2.24 ± 0.71	0.31 ± 0.37	0.003**	1.91 ± 0.62	2.01 ± 0.49	0.1 ± 0.66	0.538	0.919	0.245
VBL-d (mm)	1.94 ± 0.50	2.26 ± 0.63	0.32 ± 0.31	<0.001**	1.83 ± 0.57	1.95 ± 0.45	0.12 ± 0.63	0.435	0.57	0.23
VBL-ip (mm)	1.93 ± 0.45	2.25 ± 0.65	0.31 ± 0.26	<0.001**	1.87 ± 0.57	1.98 ± 0.44	0.11 ± 0.61	0.462	0.726	0.197
D-a (mm)	2.18 ± 1.00	3.71 ± 1.40	1.53 ± 1.37	<0.001**	2.33 ± 0.98	1.09 ± 0.86	−1.24 ± 1.53	0.004**	0.651	<0.001**
D-1 (mm)	2.26 ± 1.07	4.89 ± 2.14	2.63 ± 1.37	<0.001**	2.75 ± 1.10	2.62 ± 1.12	−0.13 ± 1.52	0.736	0.195	<0.001**

AC, augmented corticotomy; *P1,* paired-samples *t* test for comparison between T0 and T1 in the control group; *P2,* paired-samples *t* test for comparison between T0 and T1 in the AC group; *P3,* independent-samples *t* test for comparison between the 2 groups at T0; *P4,* independent-samples *t* test for comparison of the change in variables form T0 to T1 between the 2 groups; *VBL,* vertical alveolar bone level.
*$P \leq 0.05$; **$P \leq 0.01$.

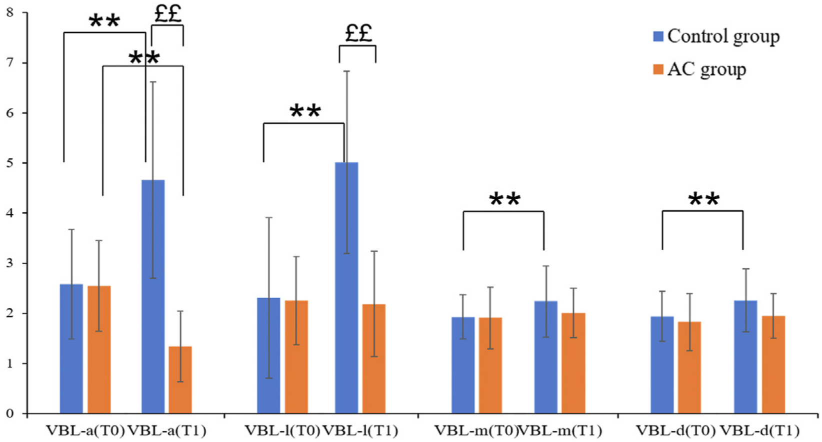

Fig 4. The VBL on different sides of MCIs in the control and AC groups. (**$P \leq 0.01$, paired-samples t test between T0 and T1; ££$P \leq 0.01$, independent-samples t test between control group and AC group.) *AC,* augmented corticotomy; *MCIs,* mandibular central incisors; *VBL,* vertical alveolar bone level.

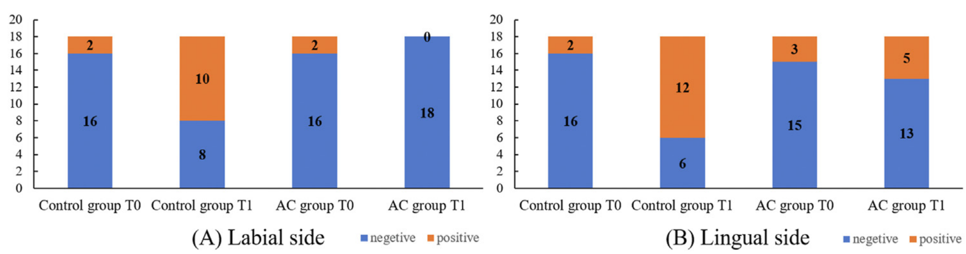

Fig 5. The number of alveolar bone dehiscence of MCIs on the labial side **(A)** and lingual side **(B)**. *MCIs,* mandibular central incisors; *AC,* augmented corticotomy.

Table VII. The number of samples with alveolar bone dehiscence of MCIs in the 2 groups T0 and T1

	Control (n)				*AC (n)*			
Side	*T0*		*T1*		*T0*		*T1*	
Labial	D-a ≤4	16	D-a ≤4	8	D-a ≤4	16	D-a ≤4	16
			D-a >4	8			D-a >4	0
	D-a >4	2	D-a ≤4	0	D-a >4	2	D-a ≤4	2
			D-a >4	2			D-a >4	0
Lingual	D-l ≤4	16	D-l ≤4	6	D-l ≤4	15	D-l ≤4	11
			D-l >4	10			D-l >4	4
	D-l >4	2	D-l ≤4	0	D-l >4	3	D-l ≤4	2
			D-l >4	2			D-l >4	1

AC, augmented corticotomy.

increase in alveolar bone height was influenced by the VBL-a (T0) and ΔV-edge. The lower the labial alveolar bone height at T0 was, the greater the increase in alveolar bone height during treatment in the AC group; this increase was statistically significant. The intrusion of MCIs was conducive to the elevation of the labial alveolar bone height. The lingual alveolar bone height change was also related to the initial VBL at T0.

As for the labial ΔABT, sex was a relevant factor. The ΔABT-4a and ΔABT-6a of MCIs in female patients were approximately 0.5 mm thicker than in male patients after AC and presurgical orthodontic treatment. At the same time, the change in ABT was related to movement in the AC group. Retraction of the root apex and the increase in ΔL1-MP were positively related to the improvement in ABT.

DISCUSSION

Our previous study preliminarily showed the therapeutic effect of AC on insufficient periodontal soft and hard tissues in patients with skeletal Class III malocclusion and reported that the width of the buccal keratinized gingiva and the proportion of thick periodontal biotypes around anterior teeth increased in the AC

Table VIII. Multiple linear regression analysis of the change in the labial ABT and VBL during treatment around MCIs in the AC group

Variables entered	*β*	*Standard deviation*	*Standardized β*	*P values*
ΔVBL-a				
VBL-a (T0)	−1.232	0.276	−0.669	0.001**
ΔV-edge	−0.315	0.138	−0.341	0.04*
ΔVBL-l				
VBL-l (T0)	−0.794	0.274	−0.599	0.011*
ΔABT-4a				
Sex	0.847	0.293	0.524	0.013*
ΔS-apex	−0.364	0.142	−0.466	0.023*
ΔABT-6a				
ΔL1-MP	0.065	0.024	0.494	0.019*
Sex	0.841	0.343	0.453	0.029*
ΔABT-8a				
ΔL1-MP	0.141	0.026	0.825	0.000**

Note. After Pearson correlation tests and multiple stepwise regression tests, equations with *P* values <0.05 were obtained, and the independent variables of interest were screened out.
ABT, alveolar bone thickness; *AC,* augmented corticotomy; *MCIs,* mandibular central incisors; *VBL,* vertical alveolar bone level.
*$P \leq 0.05$; **$P \leq 0.01$.

group.[21] In this study, we further confirmed the ameliorative effect of AC-assisted presurgical orthodontics on different dimensions of alveolar bone and the therapeutic and preventive effects on dehiscence while also analyzing the amount of tooth movement and factors affecting periodontal surgery. This study included a comprehensive set of measurements determined by CBCT, including the amount of tooth movement, ABT-w, and ABA. The results further confirmed the effect of modified AC. In addition, the patients in the AC group in this study were observed for a relatively long period, approximately 15 months after AC surgery.

Compared with previous studies,[17-19] only interproximal longitudinal incisions were created for decortication without a continuous subapical horizontal incision in our study, minimizing trauma and side effects. In addition, both Bio-Oss bone graft materials and Bio-Gide collagen membranes were applied in AC to enhance the guiding effect on periodontal tissue regeneration.[26] The results demonstrated that the modified AC could maintain the whole ABT and increase the amount of labial alveolar bone at different levels. The baseline condition of the alveolar bone morphology was similar in the 2 groups. In the AC group, ABT-4w, ABT-8w, ABT-Aw, and ABA-w remained unchanged, and ABT-6w increased after T1. However, in the control group, ABT-w at each level and ABA-w decreased significantly after T1.

Specifically, the ABT was extremely thin in both groups at T0, especially at the midroot level. After decompensatory orthodontic treatment, the labial thickness of MCIs increased significantly in the AC group but decreased in the control group, whereas the lingual thickness of MCIs decreased in both groups. In this study, AC significantly augmented the amount of labial alveolar bone. However, there was no significant improvement in lingual ABT because AC was applied on the labial side. Although previous studies[18,27] reported that the lingual thickness of the mandibular anterior teeth could remain unchanged or reduced less than that of the control group after presurgical orthodontic treatment, there was insufficient evidence to prove that this was directly related to the labial AC operation. Safe and reliable lingual AC surgery has higher requirements for periodontists and equipment. In the AC group, the increase in ABT was related to sex and tooth movement. The decompensatory tipping movement of MCIs helped to increase the labial ABT. Female patients in the AC group gained 0.5 mm more in terms of ΔABT-4a and ΔABT-6a on average than male patients, which might be related to the fact that estrogen is beneficial for remodeling alveolar bone.[28] The effect of estrogen on AC needs further study in the future.

The change in alveolar bone height was also the focus of this research. In the AC group, the labial alveolar bone height of MCIs increased after presurgical orthodontics, whereas the lingual and interproximal alveolar bone height was maintained. In the control group, the labial, lingual, mesial, and distal alveolar bone heights of MCIs decreased after T1; however, the decrease in the interproximal height in the control group was relatively small, without a significant difference compared with that in the AC group. Hence, our results indicated that AC positively improved the alveolar bone height of anterior teeth during presurgical orthodontic treatment, consistent with previous studies. Giuseppe Coscia et al[18] found that the labial alveolar bone height of incisors did not decrease after AC-assisted accelerated presurgical orthodontics without a control group in their study. Wang Bo et al[27] found that the lingual alveolar bone height of the MCIs decreased in the AC group after presurgical orthodontics, but the decrease was smaller than that in the control group. In a study by Ma Zhigui et al,[29] the height of the labial alveolar bone of the mandibular incisors was significantly increased after AC. Although changes in labial and lingual alveolar bone height after AC vary among different studies, they all illustrated the positive effect of AC on the alveolar bone height. However, the specific mechanism of maintaining lingual alveolar bone height is still difficult to clarify.

More importantly, regression analysis suggested that the increase in alveolar bone height in the AC group was related to the pretreatment status and intrusion

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movement. The lower the labial alveolar bone height at T0, the greater the increase after T1 in the AC group. This increase may be related to maintaining the interproximal alveolar bone height from T0 to T1. Bowers et al[30] suggested that maintaining interproximal alveolar bone height could exhibit improved clinical outcomes and greater chances of complete furcation closure after guided tissue regeneration (GTR). The patients included in this study had a mean age of 21 years and no periodontal disease. Thus, all had VBL-ip within 2 mm without obvious loss pretreatment, which may be why patients in the AC group obtained improved alveolar bone height.

In this study, we also measured the incidence of alveolar bone dehiscence of MCIs in the 2 groups at T0 and T1. Although some studies have questioned the accuracy of CBCT for diagnosing dehiscence, a number of studies[23,31,32] have confirmed the clinical significance and reference value of CBCT for diagnosing dehiscence. However, the incidence of dehiscence in this study was lower than that in the previous studies[7,33] because the diagnostic criteria were different. Yagic et al[7] concluded that a labial alveolar bone height >2 mm could be diagnosed as dehiscence, but the results of our study and many others[9,19] showed that a mean labial alveolar bone height was >2 mm; thus, a higher incidence of bone fracture was obtained using this criterion. In our study, dehiscence was defined as a defect in which the crest of the buccal bone was at least 4 mm apical to the crest of the interproximal bone,[22] which took into account the height of the alveolar bone on the adjacent side. Before treatment, the incidence of bone dehiscence was essentially the same in the 2 groups, with the incidence of labial or lingual dehiscence ranging from 11.11% (2 out of 18) to 16.67% (3 out of 18) (Fig 5). After presurgical treatment, the incidence of bone dehiscence in the control group increased to 55.56% (10 out of 18) and 66.67% (12 out of 18) on the labial and lingual sides, respectively, and decreased to 0% (0 out of 18) on the labial side and 27.78% (5 out of 18) on the lingual side in the AC group. Specifically, in the control group, subjects with dehiscence before treatment showed dehiscence maintenance or deterioration after T1, and many of the subjects without dehiscence before treatment showed dehiscence after T1; in the AC group, all sites of alveolar bone dehiscence on the labial side before treatment were healed after T1 without new patients, and sites of dehiscence on the lingual side were partially healed after T1 with a few new patients. This illustrated that AC-assisted presurgical orthodontics could treat and prevent alveolar bone dehiscence, especially on the labial side.

In addition, previous studies[18,20] believed that AC could help to gain adequate proclination of the mandibular incisors, allowing more favorable surgical outcomes. In the cephalometric measurements of Ahn et al,[19] MCIs proclined 7.51° and 5.31° in the experimental (treated with AC) and control groups, respectively; the incisal edges in the experimental group moved forward 2.35 mm, almost double the change in the control group. They believed that the movement pattern of mandibular incisors in the experimental group differed from that in the control group. In the measurements by CBCT in this study, MCIs proclined 11.03° and 13.19° in the AC and control groups, respectively; the incisal edges moved forward 2.71 mm and 2.4 mm in the AC group and control groups, respectively, both without a significant difference. The amount of tooth movement for presurgical decompensation should be codesigned and decided by the orthodontist and the orthognathic surgeon before treatment. The type of malocclusion and bone-type pretreatment were consistent between the 2 groups in this study, so the target of tooth movement for decompensation was similar. However, substantial alveolar bone resorption occurred in the control group after decompensated tooth movement beyond the limit of alveolar bone remodeling. The AC group augmented the alveolar bone, enabling bone remodeling coordinated with tooth movement. This suggests that orthodontists should be careful in designing the amount of tooth movement for the traditional presurgical orthodontic treatment of skeletal Class III malocclusion and, if necessary, seek adjunctive measures to prevent alveolar bone resorption. Although this study did not explore whether AC-assisted decompensatory treatment can increase the range of tooth movement, it further affirmed the bone augmentation effect of AC, excluding the confounding influence of differences in movement.

Root resorption is related to many factors and is common during orthodontic treatment, with an incidence of 20%-100%.[34] Abbas et al[35] found that the degree of tooth root resorption was 44% higher after corticotomy than after the control treatment; this outcome may have occurred because of the triggering of the regional acceleratory phenomenon reaction by corticotomy and increased inflammatory factor expression. However, Wilcko et al[12] believed that cortical incisions were beneficial for reducing resistance to tooth movement and avoiding root resorption. Moreover, studies by Giuseppe Coscia et al[18] and Wang Bo et al[27] showed no significant root absorption after AC-assisted presurgical orthodontic treatment. In this study, there was no significant difference in the change in RL between the 2 groups after presurgical orthodontic treatment, similar to the result reported by Ahn et al.[19] In summary, the application of

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AC in presurgical orthodontic treatment does not increase the risk of root resorption.

CONCLUSIONS

During presurgical orthodontic treatment, AC-assisted decompensation of MCIs is effective in increasing the alveolar bone height and ABT, enabling bone remodeling coordinated with tooth movement, and is relatively safe without additional root resorption.

AC can be recommended for patients with skeletal Class III malocclusion who require presurgical orthodontic treatment to prevent alveolar bone resorption and improve the alveolar bone morphology.

AUTHOR CREDIT STATEMENT

Huimin Ma contributed to conceptualization, methodology, software, formal analysis, and original manuscript preparation; Hangmiao Lyu contributed to software, validation, and data curation; Li Xu contributed to resources, project administration, and funding acquisition; Jianxia Hou contributed to investigation and resources; Xiaoxia Wang contributed to investigation and resources; Weiran Li contributed to conceptualization, manuscript review and editing, and supervision; and Xiaotong Li contributed to conceptualization, investigation, manuscript review and editing, and funding acquisition.

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