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Morphometric evaluation of the alveolar bone around central incisors during surgical orthodontic treatment of high-angle skeletal class III malocclusion

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Abstract

Objectives: To evaluate morphometric characteristics of alveolar bone around the incisors of high-angle skeletal class III patients receiving surgical orthodontic treatment.

Setting and Sample Population: Thirty high-angle skeletal class III patients (mean age, 20.94 ± 3.25 years) underwent cone-beam computed tomography before treatment (T0), after pre-surgical orthodontic treatment (T1) and after treatment (T2).

Materials and Methods: The vertical bone level (VBL), alveolar bone thickness (ABT), alveolar bone area (ABA) and position of upper and lower central incisors (UCIs and LCIs) were evaluated. The ABT included five levels (4, 6, 8 mm from the cemento-enamel junction, midroot and root apex level). One-way repeated measures ANOVA with Bonferroni's multiple-comparison test and matched *t* test was performed to compare variables.

Results: Before treatment, the average labial ABT was approximately 1 mm in UCIs and 0.38 ~ 0.79 mm in LCIs, and the VBL of the LCIs was over 2 mm. After treatment, the VBL increased by 2.19 ± 1.96 mm (P < .001) on the lingual side of UCIs and 2.78 ± 2.29 mm and 3.09 ± 2.52 mm on the labial and lingual sides of LCIs, respectively (all P < .001). ABT at every level decreased significantly, decreasing by 1.66 ± 1.93 mm at the 8 mm level of UCIs and 1.06 ± 1.01 mm at the apex of LCIs (P < .001). The lingual ABA of UCIs and LCIs decreased by over 50% (P < .001).

Conclusions: In high-angle skeletal class III patients, the condition of alveolar bone around UCIs and LCIs was extremely poor before treatment. Further alveolar bone resorption occurred during surgical orthodontic treatment. More attention should be paid to the movement of anterior teeth in cases of severe alveolar bone loss.

KEYWORDS

alveolar bone around central incisors, skeletal class III malocclusion, surgical orthodontic treatment

1 | INTRODUCTION

Remodelling of alveolar bone around teeth is one of the basic considerations for orthodontic tooth movement. The traditional view on the biological basis of orthodontic tooth movement was that 'alveolar bone traces tooth movement', which meant that the amount of bone remodelling and tooth movement was equal and that, consequently, the thickness of alveolar bone was stable.[1] However, recent studies have shown that alveolar bone does not trace tooth movement and that orthodontic tooth movement leads to alveolar bone loss.[2-5] Handelman et al[6] reported that the alveolar bone boundary is the limit of tooth movement during orthodontic treatment. Orthodontic tooth movement should not exceed this range. Otherwise, alveolar bone loss and root absorption may occur.

Alveolar bone is an important supporting structure that affects the occlusal function of teeth.[7] Loss of alveolar bone, particularly alveolar bone height, is relevant to attachment level loss, gingival recession, fenestration and other periodontal destruction.[8,9] Clinically, these periodontal problems occur more frequently in skeletal class III patients,[10] especially high-angle patients. The prevalence of this problem affects the oral function, tooth preservation and oral aesthetics of these patients after treatment.

Pre-surgical orthodontic treatment in skeletal class III patients provides adequate retraction of upper incisors and proclination of lower incisors to ensure appropriate jaw movement during orthognathic surgery. During these treatments, if the teeth move beyond the alveolar bone boundary, this will cause bone resorption. Kim et al[5] studied the alveolar bone of class III patients after pre-surgical decompensation treatment and found more vertical bone loss in lower incisors than in upper incisors. However, they did not observe the alveolar bone morphology around incisors before and after treatment. Lee et al[11] selected 25 skeletal class III patients and found that during pre-surgical orthodontic treatment, the alveolar bone thickness (ABT) and height on both labial and lingual sides around mandibular incisors were decreased. However, they did not mention upper incisors. Previous studies were rarely designed to measure the area of alveolar bone, the measurement of which was more comprehensive than line measurement.

Therefore, the purpose of this study was to evaluate the morphological characteristics of alveolar bone around the UCIs and LCIs of skeletal class III malocclusion patients during surgical orthodontic treatment.

2 | MATERIALS AND METHODS

This study was approved by the Biomedical Ethics Committee of Peking University School and Hospital of Stomatology (PKUSSIRB-201522060). Thirty skeletal class III patients (15 men, 15 women; mean age, 20.94 ± 3.25 years) who required surgical orthodontic treatment at the Orthodontic Department of Peking University School and Hospital of Stomatology were enrolled in this study. Inclusion criteria for subjects were as follows: age > 18 years, skeletal and dental class III malocclusion (ANB < 0°, overjet < 0 mm), high angle (SN-MP > 37.7°), mild crowding in the anterior arch (<4 mm), absence of severe facial asymmetry (<4 mm of chin point deviation from the facial midline) and no periodontitis. Exclusion criteria were missing or malformed teeth in the anterior arch, past orthodontic or orthognathic treatment, endodontic therapy or prostheses of the central incisors, craniofacial syndromes and cleft lip or palate.

First of all, all recruited patients were referred to one periodontal specialist for periodontal examination and treatment, including oral hygiene instruction, scaling and root planning if indicated. Regular professional care was carried out every 3 months to make each subject meet and maintain clinical periodontal health status as follows: good oral hygiene (plaque score ≤ 20%), sites with bleeding on probing (BOP) < 10% with probing pocket depths ≤ 3 mm. The average time of pre-surgical and post-surgical orthodontic treatment was 25.42 ± 5.02 months and 10.36 ± 4.79 months. Pre-surgical and post-surgical orthodontic treatment was performed by a single orthodontist with straight-wire fixed appliance. The arch-wire sequence involved 0.014-, 0.016-, 0.018- and 0.018 × 0.025-inch nickel-titanium wires followed by a 0.018 × 0.025-inch stainless-steel wire before orthognathic surgery and debonding. Pre-surgical orthodontic treatment involved extraction of the bilateral maxillary first premolars and closing of the extraction space with sliding mechanics. All subjects underwent bimaxillary jaw surgery (Le-Fort I maxillary advancement and mandibular setback sagittal split ramus osteotomy) with rigid internal fixation by one orthognathic surgeon.

The minimum sample size of 30 subjects was calculated using Power Analysis and Sample Size software (version 15.0; NCSS) with a significance level of 0.05 and a statistical power of 80%.

Cone-beam computed tomography (CBCT) scans and lateral cephalograms were obtained before treatment (T0), after pre-surgical orthodontic treatment (T1) and after treatment (T2). CBCT images were recorded using NewTom VG (Aperio Services, Italy) with full scan mode (15 × 12 cm field of view, 110 kV, 2.05 mA, 3.6-second exposure). The axial thickness was 0.3 mm, and voxels were isotopic. CBCT data and lateral cephalograms were imported into Dolphin Imaging software (Version 11.8, Dolphin Imaging and Management Solutions).

Upper central incisors (UCIs) and lower central incisors (LCIs) on the right side were selected. Sagittal slices of CBCT were measured where incisors were the widest labio-lingually in the axial view, and images were oriented along the long axis of the root, as presented in Figure 1. In this study, the long axis of the root was the line from the midpoint of the cemento-enamel junction (CEJ) to the apical point because severe adult skeletal class III malocclusion exhibited a smaller crown–root angle compared with skeletal class I malocclusion.[12] Specific measurement marking points, reference planes and measurement variables are shown in Figure 1. Measurements included the vertical bone level (VBL), alveolar bone thickness (ABT), alveolar bone area (ABA) and root length (RL). The ABT was measured at five levels (4, 6, 8 mm from the CEJ, midroot and root apex level). Morphometric measurements of alveolar bone used in this study were modified from the report by Lee et al[11]

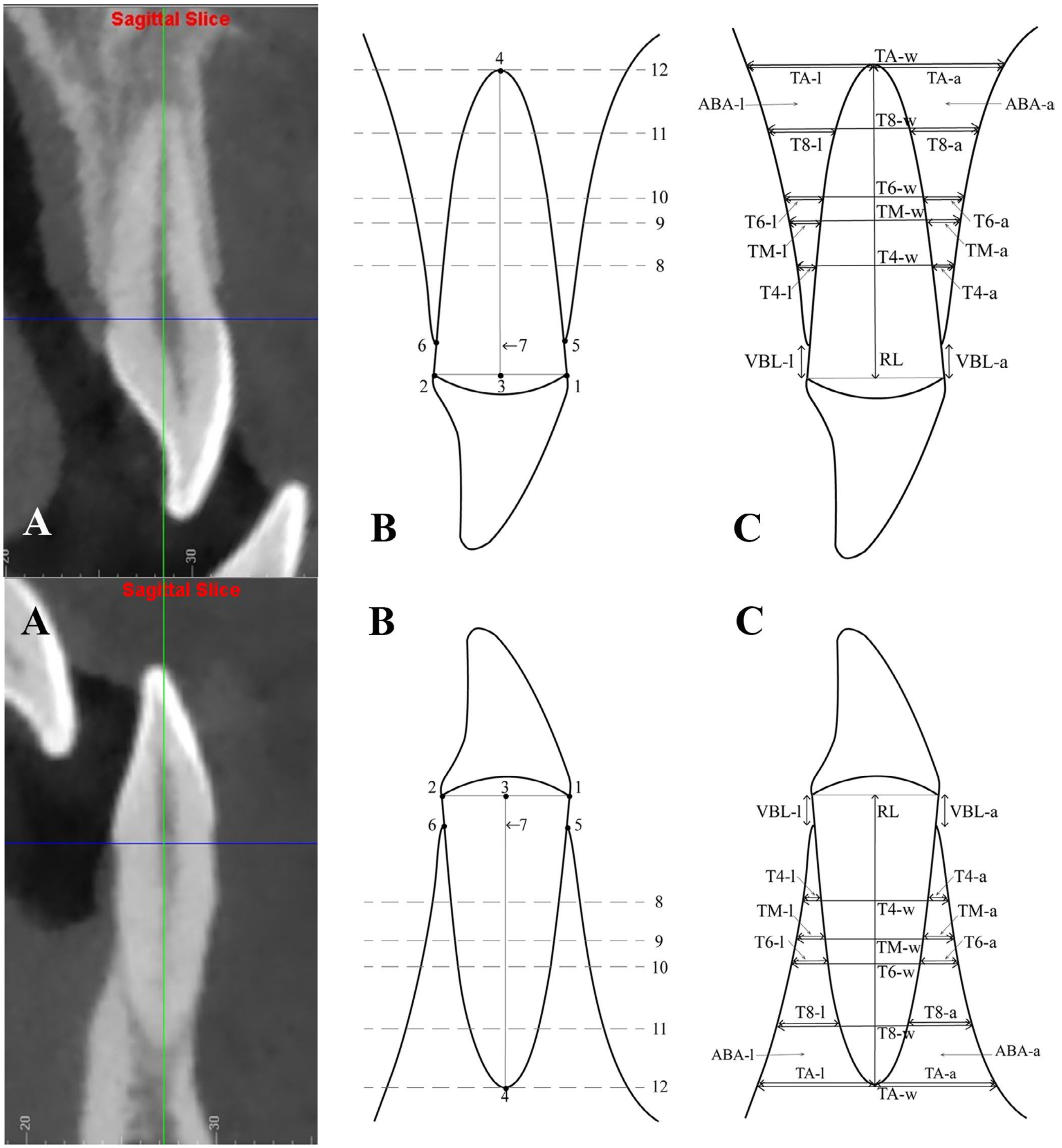

FIGURE 1 Example and illustrations of morphometric measurements of the alveolar bone around the UCIs and LCIs in skeletal class III patients. A, example of cone-beam computed tomography (CBCT) images of the right upper and lower central incisors, orientated by the root long axis. B, Reference points and lines: 1 and 2, cemento-enamel junction (CEJ) points; 3, midpoint of the CEJ; 4, root apex; 5 and 6, alveolar crest points; 7, root long axis, a line from points 3 to 4; 8, 10 and 11, intersecting line perpendicular to the root long axis at 4, 6 and 8 mm apical to the midpoint of the CEJ; 9, intersecting line perpendicular to the root long axis at the middle of the root length; 12, intersecting line perpendicular to the root long axis at the root apex. C, Measurement variables: RL, root length (distance from points 3 and 4); VBL-a and VBL-l, vertical bone level on the labial and lingual sides, (distance from the CEJ to the alveolar crest parallel to the root long axis); T4-a, T4-l and T4-w, labial, lingual and whole thickness at 4mm apical to the CEJ; T6-a, T6-l and T6-w, labial, lingual and whole thickness at 6mm apical to the CEJ; T8-a, T8-l and T8-w, labial, lingual and whole thickness at 8mm apical to the CEJ; TM-a, TM-l and TM-w, labial, lingual and whole thickness at the midroot; TA-a, TA-l and TA-w, labial, lingual and whole thickness at the apex

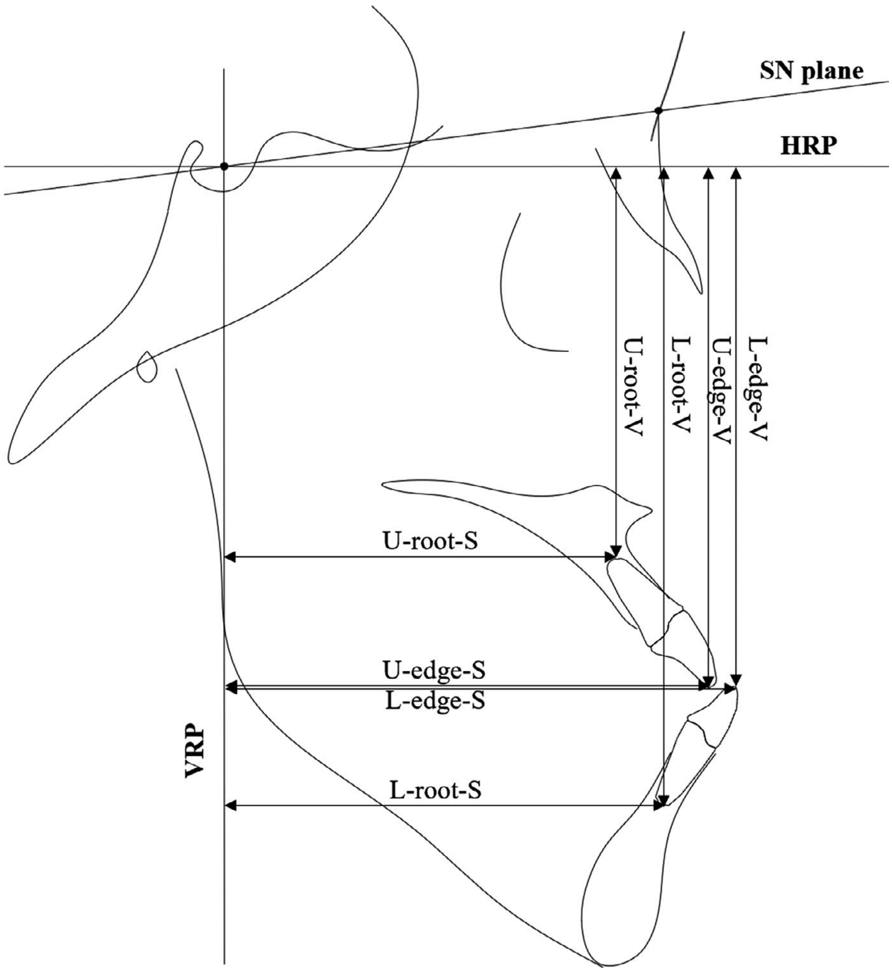

FIGURE 2 Reference lines, and variables of position measurements of the UCIs and LCIs in skeletal class III patients. Reference lines: HRP, horizontal reference plane: a horizontal plane at an angle 7° clockwise to the Sella-Nasion plane passing through Sella; VRP, vertical reference plane: plane perpendicular to the HRP passing through Sella. Measurement variables: U-edge-S, sagittal distance from the vertical reference plane (VRP) to the incisal edge of the UCI; U-edge-V, vertical distance from the HRP to the incisal edge of the UCI; U-root-S, sagittal distance from the VRP to the root apex of the UCI; U-root-V, vertical distance from the HRP to the root apex of the UCI; L-edge-S, sagittal distance from the VRP to the incisal edge of the LCI; L-edge-V, vertical distance from the HRP to the incisal edge of the LCI; L-root-S, sagittal distance from the VRP to the root apex of the LCI; L-root-V, vertical distance from the HRP to the root apex of the LCI

The positions of the incisal edge and root apex of UCIs and LCIs were measured in midsagittal slices at the T0 and T1 stages (Figure 2). The orientation method of CBCT referred to the study of Kim et al[13] Distances from the incisal edge and root apex of UCIs and LCIs to the horizontal reference plane (HRP) and vertical reference plane (VRP) were measured.[4]

Cephalometric measurement items included SNA, SNB, ANB, SN-MP, U1-SN and L1-MP.

2.1 | Statistical analysis

All measurements were conducted twice by the same investigator with an interval of 2 weeks. The intraclass correlation (ICC) between the two measurements was between 0.8 and 1. The average value of the two measurements was used for statistical analysis.

One-way repeated measures ANOVA was performed to compare morphometric measurements and RL at T0, T1 and T2 using SPSS (IBM SPSS Statistics 20). Multiple comparisons were performed using the Bonferroni test with repeated measures analysis. A matched *t* test was used to compare changes in the positions of UCIs and LCIs between T0 and T1.

3 | RESULTS

3.1 | Orthognathic surgical treatment improved the facial aesthetics of patients

Before treatment (T0), the results of cephalometric measurements were as follows: SNA, 77.48 ± 3.21°; SNB, 82.13 ± 3.23°; ANB, −4.67 ± 2.49°; SN-MP, 42.93 ± 4.27°; U1-SN, 108.52 ± 7.27°; L1-MP, 75.75 ± 8.68°. UCIs were inclined labially, and LCIs were inclined lingually.

The cephalometric measurements at T1 were as follows: SNA, 77.21 ± 2.9°; SNB, 82.12 ± 3.53°; ANB, −4.89 ± 2.50°; SN-MP, 42.91 ± 5.07°; U1-SN, 105.48 ± 5.44°; L1-MP, 85.86 ± 7.37°. After pre-surgical orthodontic treatment, U1-SN (°) and U1-NA (°) decreased, and L1-MP (°) increased.

The cephalometric measurements at T2 were as follows: SNA, 80.97 ± 3.80°; SNB, 79.45 ± 3.60°; ANB, 1.51 ± 1.89°; SN-MP, 41.89 ± 4.67°; U1-SN, 106.13 ± 7.34°; L1-MP, 84.37 ± 7.32°. After orthognathic surgery, SNA and ANB increased, and SNB decreased, which harmonized the facial profile of subjects. No significant change was noted in SN-MP (°) among the three time points.

3.2 | Movement of UCIs and LCIs during pre-surgical orthodontic treatment

After pre-surgical orthodontic treatment, the incisal edge and apex of UCIs were retracted 3.92mm and 1.44mm, respectively ($P < .01$) (Table 1). The amount of incisal edge retraction was more than twice that of apical retraction. UCIs moved in a controlled tipping manner. The incisal edge of the LCIs was protruded by 3.16 mm. The apex of the LCIs did not move significantly in the sagittal direction.

3.3 | Alveolar bone morphology of UCIs

The VBLs on both the labial and lingual sides of the UCIs were within 2mm before treatment, while the labial ABTs were very thin, with all measuring approximately 1mm at different reference levels (Table 2).

The VBL of the UCIs increased significantly after treatment, especially on the lingual side, which meant that the vertical alveolar bone height decreased. The VBL-l at the T2 stage was 3.55 ± 1.95 mm, increasing by 2.19 ± 1.96 mm.

There was no significant change in the labial ABT after treatment, while the lingual ABT decreased significantly at each level. The whole ABT decreased at all referential levels after treatment. ABA-l decreased by 16.27 ± 9.72 mm^2 ($P < .01$), which was more than half of the value at T0.

3.4 | Alveolar bone morphology of the LCIs

The VBLs on both the labial and lingual sides of LCIs were over 2 mm before treatment: the VBL-a and VBL-l of the LCIs were 2.72 ± 1.65 mm and 2.51 ± 1.82 mm, respectively (Table 3). The labial alveolar bone was already very thin, and the average T4-a, T6-a, TM-a and T8-a of the LCIs were 0.38, 0.40, 0.37 and 0.79 mm, respectively.

After treatment, the vertical alveolar bone loss on the labial and lingual sides was 2.78 ± 2.29 mm and 3.09 ± 2.52 mm from T0 to T2, respectively. The VBL-a increased by 1.57 ± 1.89 mm from T0 to T1 ($P < .01$) and by 1.21 ± 1.83 mm from T1 to T2 ($P < .01$). The VBL-l increased by 2.82 ± 2.32 mm from T0 to T1 ($P < .01$), and it was preserved from T1 to T2. Although the VBL-a of both UCIs and LCIs increased significantly after treatment, that of LCIs showed a greater increase than that of UCIs.

The labial ABT of LCIs remained thin during treatment. However, the lingual ABT at all levels decreased significantly after treatment, dropping to 0.09 ± 0.2 mm at T4-l, 0.23 ± 0.41 mm at T6-l, 0.18 ± 0.27 mm at TM-l, and 0.46 ± 0.72 mm at T8-l. The ABA-l was 10.1 ± 6.54 mm^2 at the T0 stage but decreased to 2.99 ± 4.29 mm^2 at the T2 stage, which meant a 7.11 ± 5.16 mm^2 alveolar bone area loss on the lingual side. Similarly, the whole alveolar bone around the lower incisors did not maintain the same thickness during tooth movement and decreased significantly at each level.

3.5 | RL of UCIs and LCIs

The results showed that the root length (RL) of both UCIs and LCIs decreased during treatment (both $P < .01$) (Table 4). The RL of UCIs and LCIs decreased by 1.24 ± 1.16 mm and 1.05 ± 0.68 mm from T0 to T2, respectively. VBL% increased significantly after treatment, especially in the LCIs. After treatment, the average VBL-a% and VBL-l% of the UCIs were 22.4% and 38.28%, respectively; the average VBL-a% and VBL-l% of LCIs were 56.89% and 57.52%, respectively.

TABLE 1 Position of the UCIs and LCIs of skeletal class III patients at T0 and T1 (mean ± SD)

Variables		T0	T1	⊿T1-T0	*P*
UCI	U-edge-S (mm)	70.43 ± 5.72	66.51 ± 5.63	−3.92 ± 1.78	.000**
	U-edge-V (mm)	76.14 ± 3.72	77.26 ± 3.54	1.12 ± 1.63	.012*
	U-root-S (mm)	57.75 ± 5.54	56.31 ± 6.00	−1.44 ± 1.63	.002**
	U-root-V (mm)	57.17 ± 4.04	57.84 ± 3.79	0.67 ± 1.14	.027*
LCI	L-edge-S (mm)	71.44 ± 7.72	74.61 ± 8.45	3.16 ± 1.97	.000**
	L-edge-V (mm)	77.16 ± 5.07	78.06 ± 4.49	0.89 ± 1.82	.07
	L-root-S (mm)	64.79 ± 8.09	64.42 ± 9.03	−0.37 ± 2.05	.485
	L-root-V (mm)	96.76 ± 4.02	95.55 ± 3.95	−1.22 ± 1.6	.011*

Abbreviations: LCI, lower central incisor; L-edge-S, sagittal distance from the VRP to the incisal edge of the LCI; L-edge-V, vertical distance from the HRP to the incisal edge of the LCI; L-root-S, sagittal distance from the VRP to the root apex of the LCI; L-root-V, vertical distance from the HRP to the root apex of the LCI; *P*, a matched *t* test was performed to compare the differences between the changes in central incisors during pre-surgical orthodontic treatment; T0, before treatment; T1, after pre-surgical orthodontic treatment; UCI, upper central incisor; U-edge-S, sagittal distance from the vertical reference plane (VRP) to the incisal edge of the UCI; U-edge-V, vertical distance from the horizontal reference plane (HRP) to incisal edge of the UCI; U-root-S, sagittal distance from the VRP to the root apex of the UCI; U-root-V, vertical distance from the HRP to the root apex of the UCI.

*$P \le .05$;

**$P \le .01$.

TABLE 2 Alveolar bone morphology of the UCIs of skeletal class III patients at T0, T1 and T2 (mean ± SD)

Variables	T0	T1	T2	*P*	Multiple Comparisons	⊿T1-T0	⊿T2-T1	⊿T2-T0
VBL-a (mm)	1.67 ± 0.54	1.86 ± 0.67	2.10 ± 0.70	.000**	T0, T1 < T2	0.19 ± 0.50	0.23 ± 0.40	0.43 ± 0.42
VBL-l (mm)	1.36 ± 0.49	3.48 ± 2.16	3.55 ± 1.95	.000**	T0 < T1, T2	2.12 ± 2.03	0.07 ± 1.93	2.19 ± 1.96
T4-a (mm)	1.04 ± 0.22	1.21 ± 0.35	1.01 ± 0.38	.107	–	0.17 ± 0.41	−0.21 ± 0.52	−0.03 ± 0.46
T4-l (mm)	1.76 ± 0.59	0.63 ± 0.65	0.74 ± 0.74	.000**	T0 > T1, T2	−1.13 ± 0.63	0.11 ± 0.79	−1.02 ± 0.86
T4-w (mm)	8.17 ± 0.75	7.31 ± 0.75	7.21 ± 0.87	.000**	T0 > T1, T2	−0.82 ± 0.48	−0.42 ± 1.6	−1.24 ± 1.61
T6-a (mm)	1.1 ± 0.27	1.27 ± 0.58	0.98 ± 0.52	.068	–	0.17 ± 0.65	−0.29 ± 0.65	−0.09 ± 0.51
T6-l (mm)	2.54 ± 0.71	1.34 ± 1.04	1.08 ± 0.94	.000**	T0 > T1, T2	−1.2 ± 0.75	−0.25 ± 0.91	−1.5 ± 0.87
T6-w (mm)	8.37 ± 0.93	7.21 ± 1.01	6.87 ± 0.92	.000**	T0 > T1, T2	-1.16 ± 0.76	−0.33 ± 0.75	−1.55 ± 0.75
T8-a (mm)	1.33 ± 0.53	1.42 ± 0.65	1.54 ± 0.95	.488	–	0.09 ± 0.75	0.03 ± 0.87	0.12 ± 0.93
T8-l (mm)	3.29 ± 0.98	2.18 ± 1.3	1.89 ± 1.11	.000**	T0 > T1, T2	−1.1 ± 1.12	−0.39 ± 1.11	−1.49 ± 1.14
T8-w (mm)	8.59 ± 1.25	7.52 ± 1.11	7.32 ± 1.23	.000**	T0 > T1, T2	−1.07 ± 1.1	-0.59 ± 1.79	-1.66 ± 1.93
TM-a (mm)	0.99 ± 0.23	1.11 ± 0.43	0.84 ± 0.42	.012*	T1 > T2	0.12 ± 0.46	-0.26 ± 0.39	-0.14 ± 0.46
TM-l (mm)	2.26 ± 0.77	0.82 ± 0.89	0.70 ± 0.78	.000**	T0 > T1, T2	−1.44 ± 0.85	−0.11 ± 0.53	−1.56 ± 0.79
TM-w (mm)	8.31 ± 0.99	7.32 ± 0.82	6.94 ± 0.88	.000**	T0 > T1 > T2	−0.98 ± 0.74	−0.37 ± 0.39	−1.36 ± 0.74
TA-a (mm)	2.57 ± 0.93	3.18 ± 1.23	3.28 ± 1.42	.003**	T0 < T1, T2	0.60 ± 1.05	0.1 ± 1.07	0.70 ± 1.19
TA-l (mm)	6.20 ± 1.56	4.91 ± 1.83	4.17 ± 1.86	.000**	T0 > T1 > T2	−1.28 ± 1.63	−0.74 ± 1.44	−2.03 ± 1.73
TA-w (mm)	8.79 ± 1.99	8.10 ± 1.87	7.43 ± 1.98	.000**	T0 > T1 > T2	−0.69 ± 1.33	−0.67 ± 1.01	−1.36 ± 1.32
ABA-a (mm^2)	9.5 ± 3.93	9.47 ± 4.79	8.26 ± 5.59	.144	–	−0.03 ± 4.1	−1.21 ± 3.21	−1.24 ± 3.63
ABA-l (mm^2)	26.51 ± 10.75	12.46 ± 9.6	10.24 ± 8.98	.000**	T0 > T1, T2	−14.05 ± 9.73	−2.23 ± 5.14	−16.27 ± 9.72

Abbreviations: multiple-comparison Bonferroni test with repeated measures analysis; *P*, a one-way repeated measures analysis was performed for comparisons among T0, T1 and T2; T0, before treatment; T1, after pre-surgical orthodontic treatment; T2, after treatment; T4-a, T4-l and T4-w, labial, lingual and whole thickness at 4mm apical to the CEJ; T6-a, T6-l and T6-w, labial, lingual and whole thickness at 6mm apical to the CEJ; T8-a, T8-l and T8-w, labial, lingual and whole thickness at 8mm apical to the CEJ; TA-a, TA-l and TA-w, labial, lingual and whole thickness at the apex; TM-a, TM-l and TM-w, labial, lingual and whole thickness at the midroot; VBL-a and VBL-l, vertical bone level on the labial and lingual sides, (distance from the CEJ to the alveolar crest parallel to the root long axis).

*$P \le .05$;

**$P \le .01$.

4 | DISCUSSION

This study observed the pattern of morphological changes in the alveolar bone around UCIs and LCIs in patients with high-angle skeletal class III during pre- and post-surgical orthodontic treatment. For these subjects, the alveolar bone in the original state is an important factor to consider. The results showed that the condition of the alveolar bone around the central incisors was poor before treatment. Braut considered an ABT of less than 1mm to indicate 'extremely thin alveolar bone'.[14] In this study, the average ABT of LCIs before treatment was less than 1 mm, which indicated 'extremely thin'. The VBL, meaning the distance from the alveolar crest to the CEJ, in normal occlusion was <2 mm.[15] However, in this study, the VBL of LCIs was 2.72 ± 1.65 mm and 2.51 ± 1.82 mm on the labial and lingual side before treatment. Handelman et al[6] found that the ABT around the incisors of patients with class III malocclusion was less than that of patients with class I malocclusion. In addition, the researchers reported that the ABT in high-angle groups was less than that in low-angle and average-angle groups. Chung et al[16] reported that the alveolar bone height and thickness of patients with skeletal class III high-angle occlusion were significantly smaller than those with skeletal class III average-angle occlusion and normal occlusion. The alveolar bone around incisors becomes thinner with the discrepant growth of jaws and the developmental compensation of teeth.

Although the condition of subjects before treatment was poor, there was still further absorption during treatment. Contrary to the traditional view that 'alveolar bone traces tooth movement', several scholars have concluded that because the amount of bone resorption is more than that of bone apposition, orthodontic tooth movement could lead to loss of alveolar bone.[2-5,17,18] In addition, alveolar bone that is thinner before treatment is more likely to be absorbed during treatment.[19] Kim et al[5] found that after pre-surgical orthodontic treatment in patients with skeletal class III malocclusion, the alveolar bone around the maxillary and mandibular anterior teeth decreased considerably, particularly around the mandibular anterior teeth. In a study by Lee et al,[11] the alveolar bone height and thickness around the lower incisors of skeletal class III patients decreased significantly after surgical orthodontic treatment. In this study, a significant decrease was noted in the alveolar bone height, thickness and area of UCIs and LCIs: the VBL-a% of UCIs increased by 25.4%;

TABLE 3 Alveolar bone morphology of the LCIs of skeletal class III patients at T0, T1 and T2 (mean ± SD)

Variables	T0	T1	T2	*P*	Multiple Comparisons	⊿T1-T0	⊿T2-T1	⊿T2-T0
VBL-a (mm)	2.72 ± 1.65	4.28 ± 2.43	5.5 ± 2.34	.000**	T0 < T1 < T2	1.57 ± 1.89	1.21 ± 1.83	2.78 ± 2.29
VBL-l (mm)	2.51 ± 1.82	5.31 ± 2.44	5.60 ± 2.51	.000**	T0 < T1, T2	2.82 ± 2.32	0.28 ± 1.62	3.09 ± 2.52
T4-a (mm)	0.38 ± 0.28	0.24 ± 0.23	0.23 ± 0.31	.173	–	−0.17 ± 0.3	0.01 ± 0.3	−0.16 ± 0.39
T4-l (mm)	0.61 ± 0.44	0.18 ± 0.2	0.09 ± 0.2	.000**	T0 > T1 > T2	−0.42 ± 0.41	−0.07 ± 0.15	−0.5 ± 0.4
T4-w (mm)	6.04 ± 0.6	5.58 ± 0.38	5.52 ± 0.34	.000**	T0 > T1, T2	−1.3 ± 1.99	0.55 ± 2.26	−0.75 ± 1.1
T6-a (mm)	0.4 ± 0.25	0.42 ± 0.47	0.36 ± 0.48	.755	–	0.02 ± 0.43	−0.06 ± 0.36	−0.04 ± 0.52
T6-l (mm)	0.85 ± 0.6	0.25 ± 0.39	0.23 ± 0.41	.000**	T0 > T1, T2	−0.6 ± 0.47	−0.01 ± 0.35	−0.61 ± 0.58
T6-w (mm)	5.85 ± 0.83	5.33 ± 0.63	5.21 ± 0.7	.000**	T0 > T1, T2	−0.51 ± 0.5	−0.12 ± 0.51	−0.6 ± 0.7
T8-a (mm)	0.79 ± 0.57	1.32 ± 1.05	1.21 ± 1.17	.045*	T0 < T1	0.53 ± 0.95	−0.11 ± 0.69	0.41 ± 1.04
T8-l (mm)	1.44 ± 0.84	0.57 ± 0.72	0.46 ± 0.72	.000**	T0 > T1, T2	−0.88 ± 0.7	−0.1 ± 0.34	−0.98 ± 0.72
T8-w (mm)	5.98 ± 1.08	5.49 ± 1.15	5.29 ± 1.28	.02*	T0 > T1, T2	−0.44 ± 0.66	−0.19 ± 0.68	−0.64 ± 0.83
TM-a (mm)	0.37 ± 0.29	0.28 ± 0.41	0.17 ± 0.31	.002**	T0, T1 > T2	−0.10 ± 0.23	−0.11 ± 0.22	−0.20 ± 0.28
TM-l (mm)	0.72 ± 0.69	0.21 ± 0.35	0.18 ± 0.27	.000**	T0 > T1, T2	−0.60 ± 0.56	−0.03 ± 0.20	−0.54 ± 0.57
TM-w (mm)	6.02 ± 1.12	5.41 ± 0.81	5.21 ± 0.64	.000**	T0 > T1, T2	−0.49 ± 0.47	−0.20 ± 0.40	−0.82 ± 0.86
TA-a (mm)	2.55 ± 0.96	3.45 ± 1.40	3.15 ± 1.48	.002**	T0 < T1	1.01 ± 1.25	−0.31 ± 0.73	0.60 ± 1.37
TA-l (mm)	3.63 ± 1.11	1.91 ± 1.00	1.97 ± 1.15	.000**	T0 > T1, T2	−1.72 ± 1.18	0.06 ± 0.65	−1.66 ± 1.24
TA-w (mm)	6.19 ± 1.56	5.35 ± 1.59	5.13 ± 1.67	.000**	T0 > T1, T2	−0.84 ± 0.70	−0.22 ± 0.52	−1.06 ± 1.01
ABA-a (mm^2)	5.04 ± 3.98	5.57 ± 5.71	4.04 ± 4.69	.105	–	0.52 ± 3.69	−1.53 ± 2.29	−1.01 ± 4.06
ABA-l (mm^2)	10.1 ± 6.54	2.67 ± 3.69	2.99 ± 4.29	.000**	T0 > T1, T2	−7.42 ± 3.97	0.32 ± 2.98	−7.11 ± 5.16

Abbreviations: multiple-comparison Bonferroni test with repeated measures analysis; T0, before treatment; T1, after pre-surgical orthodontic treatment; T2, after treatment. *P*, a one-way repeated measures analysis was performed for comparisons among T0, T1 and T2; T4-a, T4-l and T4-w, labial, lingual and whole thickness at 4 mm apical to the CEJ; T6-a, T6-l and T6-w, labial, lingual and whole thickness at 6mm apical to the CEJ; T8-a, T8-l and T8-w, labial, lingual and whole thickness at 8mm apical to the CEJ; TA-a, TA-l and TA-w, labial, lingual and whole thickness at the apex; TM-a, TM-l and TM-w, labial, lingual and whole thickness at the midroot; VBL-a and VBL-l, vertical bone level on the labial and lingual side, (distance from the CEJ to the alveolar crest parallel to the root long axis).

*$P \le .05$;

**$P \le .01$.

the VBL-a% and VBL-l% of LCIs increased by 31.25% and 34.19%, respectively; the lingual and whole ABT significantly decreased at each level and the lingual ABA decreased more than 50%. After surgical orthodontic treatment, the alveolar bone around the central incisors was extremely thin, especially in the LCIs. Thus, orthodontists should pay special attention to severe anterior alveolar bone loss during surgical orthodontic treatment.

Root resorption is one of the most frequent complications in the orthodontic process.[20,21] Levander et at. defined root absorption of <2 mm as minor absorption.[22] In a previous study, Janson reported that there was no root resorption in 2.25%, slight resorption in 42.56% and moderate resorption in 53.37% of analysed teeth.[23] Another study revealed that the mean root resorption of maxillary and mandibular central incisors was approximately 1 mm, which did not have any serious clinical significance.[24]

Pre-surgical orthodontic treatment of skeletal class III malocclusion requires retraction of upper incisors and the uprighting of lower incisors.[25] Differences in alveolar bone changes between UCIs and LCIs might be related to opposite movement directions. In a study by Ahn, the ABA on the lingual side significantly decreased at each level after retraction of the upper incisors.[4] Samples in this study were treated by extraction of bilateral maxillary first premolars with strong anchorage and UCIs moved in a controlled tipping manner. Therefore, a significant decrease in lingual ABT in UCIs was observed. For mandibular incisors, a previous study reported that proclination of mandibular incisors contributed to the development of dehiscence and gingival recession.[26] The significant protrusion of the incisal edge and vertical alveolar bone height loss of LCIs in this study proved this. Thus, the decrease in alveolar bone height on the labial side of LCIs was greater than that of UCIs. The amount of decompensation of the LCIs was positively correlated with the amount of mandibular setback during surgery.[27] The outcome of surgical correction was limited by inadequate pre-surgical incisor decompensation.[25] However, adequate decompensation might cause anterior teeth to exceed the alveolar bone housing, leading to more severe alveolar bone loss and other unacceptable side effects.

In this study, patients underwent orthognathic surgery and post-surgical orthodontic treatment from T1 to T2, with an average of 10.36 ± 4.79 months. Although alveolar bone loss and tooth movement mainly occurred during pre-surgical orthodontic treatment, the labial alveolar bone height and RL still decreased significantly during post-surgical orthodontic treatment, and the ABT did not recover.

TABLE 4 RL and VBL% of the UCIs and LCIs of skeletal class III patients at T0, T1 and T2 (mean ± SD)

Teeth	Variables	T0	T1	T2	P	Multiple Comparisons	⊿T1-T0	⊿T2-T1	⊿T2-T0
UCIs	RL (mm)	11.2 ± 1.89	10.23 ± 2.06	9.95 ± 2.13	.000**	T0 > T1 > T2	−0.96 ± 0.88	−0.28 ± 0.5	−1.24 ± 1.16
	VBL-a% (%)	15.16 ± 4.95	19.08 ± 8.03	22.4 ± 9.80	.000**	T0 < T1 < T2	3.92 ± 1.11	3.32 ± 0.99	7.24 ± 1.26
	VBL-l% (%)	12.88 ± 7.16	36.41 ± 23.45	38.28 ± 22.73	.000**	T0 < T1, T2	23.53 ± 4.17	1.87 ± 3.99	25.4 ± 4.31
LCIs	RL (mm)	10.92 ± 1.03	10.2 ± 1.07	9.87 ± 1.03	.000**	T0 > T1 > T2	−0.72 ± 0.62	−0.33 ± 0.39	−1.05 ± 0.68
	VBL-a% (%)	25.64 ± 16.96	42.42 ± 24.15	56.89 ± 25	.000**	T0 < T1 < T2	16.78 ± 3.57	14.47 ± 3.57	31.25 ± 4.59
	VBL-l% (%)	23.33 ± 16.91	53.26 ± 25.81	57.52 ± 27.25	.000**	T0 < T1, T2	29.93 ± 4.92	4.26 ± 3.09	34.19 ± 5.31

Abbreviations: LCI, lower central incisor;multiple-comparison Bonferroni test with repeated measures analysis; P, a one-way repeated measures analysis was performed for comparisons among T0, T1 and T2; RL, root length; T0, before treatment; T1, after pre-surgical orthodontic treatment; T2, after treatment. UCI, upper central incisor; VBL-a%, ratio of the vertical bone level on the labial side to the root length, VBL-a/RL × 100; VBL-l%, ratio of the vertical bone level on the lingual side to the root length, VBL-l/RL × 100.

*$P \leq .05$;

**$P \leq .01$.

In skeletal class III malocclusion, the alveolar bone around incisors is originally or developmentally thinner than normal occlusion, and extremely thin alveolar bone is prone to additional loss during orthodontic treatment. Therefore, orthodontists need to fully measure the morphology of the anterior alveolar bone before treatment and determine a safe treatment plan for each individual patient to find a balance between the health of the alveolar bone and the outcome of orthognathic surgery. The periodontally accelerated osteogenic orthodontics (PAOO) technique proposed by Wilcko[28,29] has the additional advantage of increased bone width when bone grafting is performed. In recent years, different versions of improved PAOO with bone grafting/augmentation have been used for skeletal class III patients and have achieved positive results.[30-32] Some scholars doubt the accuracy and reliability of CBCT. Most studies[33-35] have shown that there is no significant difference between CBCT measurement and physical measurement, although the alveolar bone height and thickness measured by CBCT tends to be smaller. Patcas et al[36] concluded that it is difficult to accurately measure the boundary of thin alveolar bone with CBCT. Within the range of informed consent and ethical acceptance of patients, CBCT with smaller voxels can be performed to improve the accuracy of measurement.

5 | CONCLUSIONS

In high-angle skeletal class III patients, the condition of alveolar bone around UCIs and LCIs was extremely poor before treatment. Further alveolar bone resorption occurred during surgical orthodontic treatment. Therefore, more attention should be paid to the movement of anterior teeth in cases of severe alveolar bone loss.

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AUTHOR CONTRIBUTIONS

Huimin Ma contributed to the collection of samples, acquisition and analysis of data and drafted the manuscript. Weiran Li contributed to the interpretation of data and critically revised the manuscript. Li Xu contributed to the design of the study, and collection of samples. Jianxia Hou contributed to the design of the study, and collection of samples. Xiaoxia Wang contributed to the collection of samples, and orthognathic surgery of patients in this study. Shuai Ding contributed to the collection of samples, and acquisition of data. Hangmiao Lv contributed to the acquisition and analysis of data. Xiaotong Li contributed to the design of the study, orthodontic treatment of patients in this study, interpretation of data and critically revised the manuscript.

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