Original Article

Evaluation of root resorption in the lower incisors after orthodontic treatment of skeletal Class III malocclusion by three-dimensional volumetric measurement with cone-beam computed tomography

Junjie Chen[a]; Ruoyu Ning[b]

ABSTRACT

Objectives: To investigate the volumetric changes of the lower incisor roots in skeletal Class III orthodontic patients with anterior crossbite after premolar extraction therapy.

Materials and Methods: Thirty-six adults, aged 18–28 years, had four-premolar extraction treatment. Pre- and posttreatment cone-beam computed tomography (CBCT) images were used to assess the thickness and height of alveolar bone, root volume, and length. A paired *t*-test was used to detect changes in root volume and length before and after treatment. Pearson's correlation analysis was applied to estimate the correlation between root volume and dentoskeletal morphology.

Results: Both the central and lateral incisors had intrusion and tipping movement after treatment. Compared with pretreatment data, root length decreased significantly. The lingual root volume of root cervical, apical third, and the labial root volume of the root apical third decreased significantly ($P < .05$), among which the percentage of tooth loss at the tip volume was the highest. The pretreatment height of the alveolar ridge crest, thickness of the alveolar bone, and type of incisor movement were related to the volume and length loss.

Conclusions: Volume and length loss in the apical third of the lower incisor roots in skeletal Class III patients treated with a Class III bicuspid extraction pattern is common. The pretreatment height of the alveolar ridge crest, thickness of the alveolar bone, and type of tooth movement are related to the loss. (*Angle Orthod.* 2023;93:320–327.)

KEY WORDS: Root resorption; Extraction treatment; Alveolar bone

INTRODUCTION

An anterior crossbite combined with a moderately to severely crowded dentition is often resolved by premolar extraction therapy. During treatment, the lower incisors would be retracted with strong anchorage to correct the anterior crossbite. Since Ketcham[1] first reported root resorption in orthodontic treatment in 1927, many studies have suggested that root resorption is one of the common complications of orthodontic treatment. Functional remodeling of the periodontium is the basis for tooth movement during orthodontic treatment, but improper force will cause severe pathological root resorption. Modern orthodontics advocates the concept of "healthy orthodontics," that is, achieving the esthetic, functional, and stable goals on the basis of health, of which periodontal tissue and root are important indicators.[2] Several factors are associated with root resorption, including duration of treatment,[3] type and magnitude of force,[4] amount of tooth movement and other factors.[5] The root resorption caused by orthodontic treatment cannot be completely avoided, but it is of great significance to grasp the controllable factors and minimize the degree of root resorption as much as possible.

Although root resorption after orthodontic treatment can be observed as root shortening in the apical regions on two-dimensional x-ray images, it is difficult

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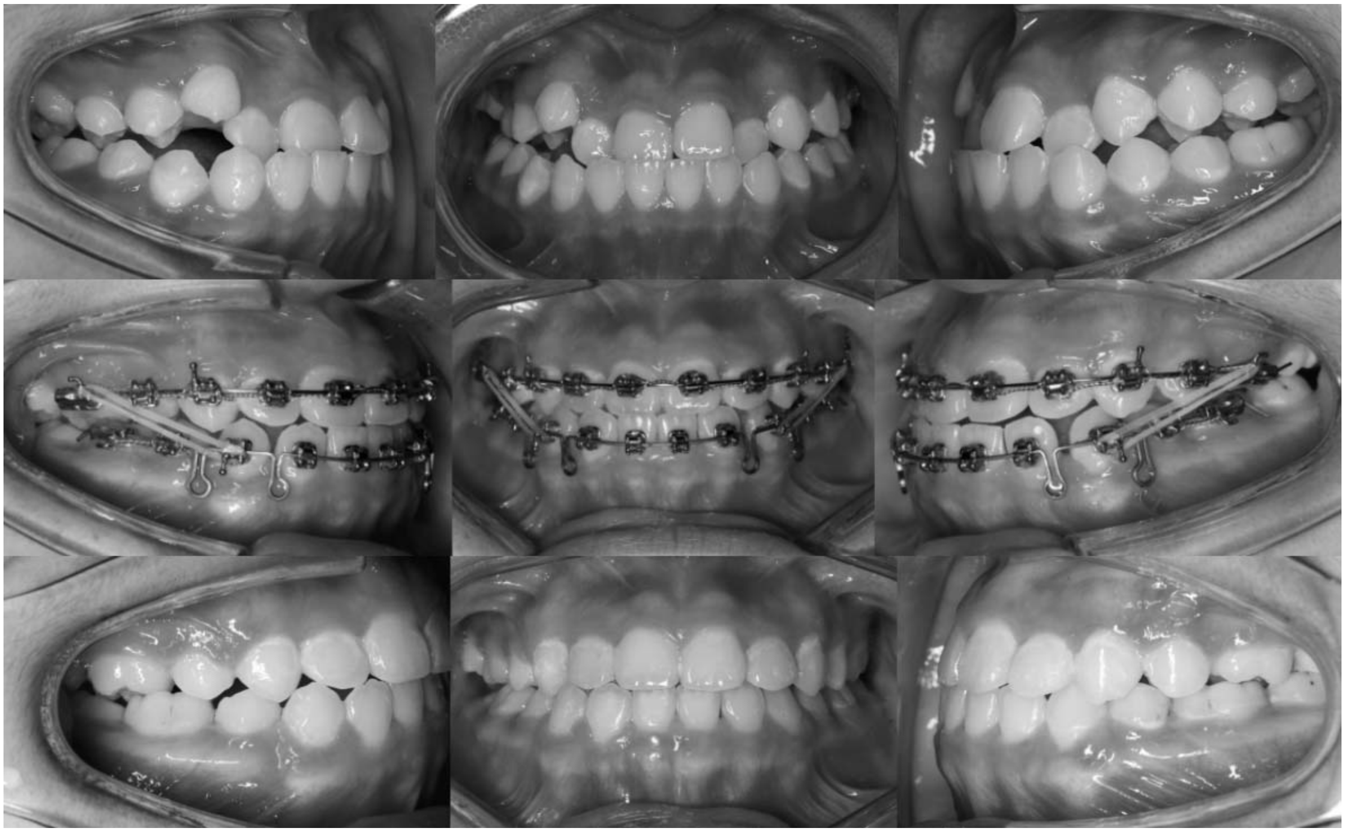

Figure 1. Treatment using double T-loop.

to analyze quantitatively. Cone-beam computed tomography (CBCT) images are obtained quickly, have the advantages of convenient image processing, and are associated with a low radiation dose compared with conventional tomography. CBCT three-dimensional reconstruction technology was used for this study, which aimed to compare the volume and length of the root before and after orthodontic treatment in patients with premolar extractions and to explore retrospectively the possible underlying correlations between the root resorption and dentoskeletal morphology, providing references for clinical practitioners.

MATERIALS AND METHODS

Participants

This retrospective study selected 18- to 28-year-old skeletal Class III adults with anterior crossbite and premolar extractions as the experimental subjects. The research was performed based on the measurements from 20 men and 16 women who started orthodontic treatment between October 2019 and July 2022 at the Xiangya Stomatological Hospital of Central South University. Subjects were selected according to the following criteria: (1) orthodontic treatment with four-premolar extraction, including lower first premolars; (2) Class III skeletal pattern, ANB: −5° to 0° or Wits: −6 mm to −1 mm; (3) permanent dentition, with no defect of dentition before orthodontic treatment; (4) no craniofacial anomalies, syndromes, severe asymmetries, clefts, or severe periodontal disease; and (5) no systemic disease or clinical history. This study was approved by the Medical Ethics Committee of Xiangya Stomatological Hospital of Central South University. Written informed consent was obtained from all participants.

Study Design

All patients had fixed orthodontic treatment with extraction of four premolars (second premolars of the upper arch and first premolars of the lower arch) with moderate to maximum anchorage with or without screw implantation. With the double closing T-loop technique, 80 g intrusive and retractive force was applied to the four incisors.[6] In addition to tooth alignment, the extraction space was mostly used for lower incisor retraction and was mainly used for mesial movement of molars in the upper arch to achieve a Class I molar relationship, normal overjet, and overbite (Figure 1). The average total treatment time was 28.5 ± 4.3 months. Patient data before and after treatment are shown in Table 1. All treatment was performed by

Table 1. Patient Characteristics Before and After Treatment

Variable	T_0	T_1
Mandibular crowding, mm	4.8 ± 2.2	0
U1-SN, °	107.6 ± 4.5	106.9 ± 3.3
L1-MP, °	90.5 ± 3.8	89.6 ± 3.2
Overbite, mm	−2.3 ± 1.7	2.1 ± 0.9
Overjet, mm	4.0 ± 1.2	2.1 ± 0.3
Molar relationship, No.		
Class I	4	36
Class II	0	0
Class III	32	0

one clinician, and the assessment after treatment was done by another evaluator who was blinded to the treatment protocol and the history of each subject.

Data Acquisition

Data including pre- (T_0) and posttreatment (T_1) CBCT images (acquired by New Tom 5G CBCT scanner, QR system, Verona, Italy, with exposure settings of 110 kV, 12-inch field of view, and 5.4-second exposure time) of all patients were accessed with the same position and posture following the guidelines of the machine. All were calibrated and obtained by the same observer.

Root Volume

Measurement of root volume was carried out in Mimics 21.0 software (IBM, Armonk, NY). The 3D reconstruction of the target incisors was performed by setting three orthogonal sections: sagittal, coronal, and cross sections (Figure 2). For a better analysis and understanding of the changes in volume, the root was further divided into six segments. The intersection of the tooth long axis and the cemento-enamel junction (CEJ) was used as the point “root neck,” and the connection between this point and the root apex was divided into three equal parts, defined as the neck part, middle part, and apical part of root. The measurements of root volume are shown in Figure 3 and Table 2. Percentage of tooth loss (%) = (pretreatment root volume/length − posttreatment root volume/length)/pretreatment root volume/length × 100%.

Root Length and Alveolar Bone Morphology

Landmarks of CBCT for root length and alveolar bone morphology were designated on the 2D surface in Dolphin Imaging 11.8 software (Figure 3 and Table 2). Head positions were standardized in the CBCT according to the horizontal plane and the sagittal plane. The horizontal plane was positioned passing through the superior border of the external acoustic meatus and the inferior border of the infraorbital margin of both sides. The sagittal plane was positioned passing

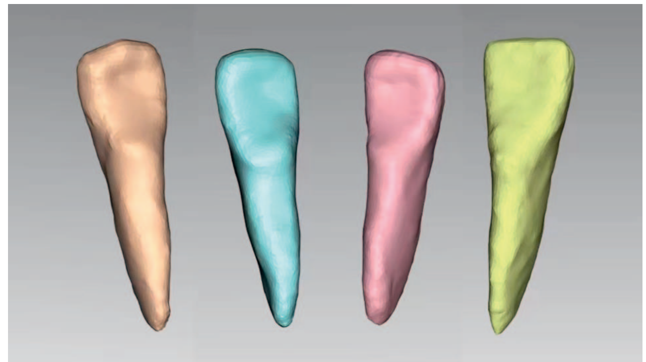

Figure 2. Three-dimensional reconstruction of the target incisors.

through the anterior nasal spine, the internasal suture, and glabella.

Tooth Movement

Dolphin imaging voxel overlap was used to overlap the CBCT images of T_0 and T_1. Voxel overlap was performed with the chin, the mandibular body, and the basal bone of the lower incisors as the main overlapping areas. Sagittal and vertical tooth movement amount and torque changes were measured. Detailed definitions of each measurement are shown in Figure 4 and Table 2.

Statistical Analysis

All quantifications were digitized and duplicated twice by the investigator Dr Ning, with a 1-week time interval. All data were analyzed using IBM SPSS Statistics 21 software. Kolmogorov-Smirnov analysis and Fanchazzi analysis were used for the homogeneity of variance test and normal distribution, and statistical

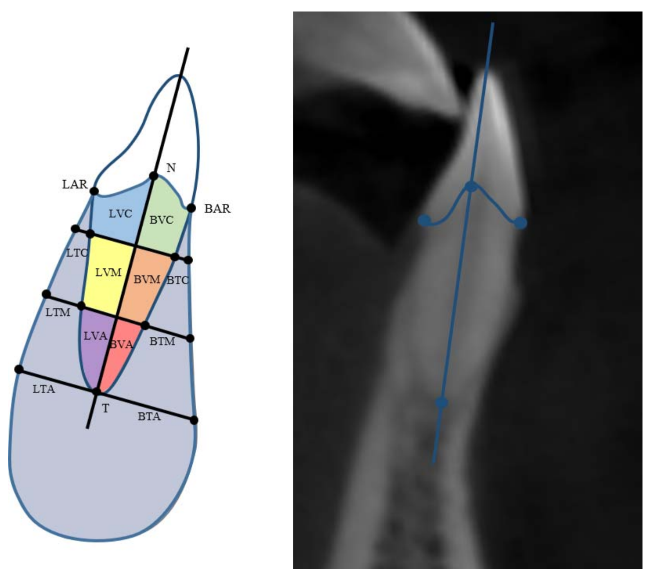

Figure 3. Measurements of root volume and length.

Table 2. Detailed Definitions of Each Measurement

Measurement	Definition
MP-L1, °	Angle between the MP plane and long axis of L1
V/S-cusp change, mm	Vertical/sagittal distance moved of the incisor cusp Cusp movement to the gingival side was denoted as (+) value, and jaw side was denoted as (−) value
V/S-root change, mm	Vertical/sagittal distance moved of the root apex Apical movement to the labial side was denoted as (−) value, and lingual side was denoted as (+) value
BAR, mm	Height of labial alveolar ridge crest; BAR: labial alveolar ridge point
LAR, mm	Height of lingual alveolar ridge crest; LAR: lingual alveolar ridge point
NT, mm	Root length: the distance between RT and RN
BTC, mm	Thickness of labial/buccal alveolar bone at the root cervical third
BTM, mm	Thickness of labial/buccal alveolar bone at the root middle third
BTA, mm	Thickness of labial/buccal alveolar bone at the root apical third
LTC, mm	Thickness of lingual alveolar bone at the root cervical third
LTM, mm	Thickness of lingual alveolar bone at the root middle third
LTA, mm	Thickness of lingual alveolar bone at the root apical third
BVC, mm^3	Labial/buccal root volume of the root cervical third
BVM, mm^3	Labial/buccal root volume of the root middle third
BVA, mm^3	Labial/buccal root volume of the root apical third
LVC, mm^3	Lingual root volume of the root cervical third
LVM, mm^3	Lingual root volume of the root middle third
LVA, mm^3	Lingual root volume of the root apical third

significance was established at $\alpha = .05$. A paired *t*-test was used to test the root volume and length for significant differences between T_0 and T_1. Pearson's correlation analysis was applied to evaluate the correlation between variables of the root and dentoskeletal morphology at $P < .05$. An intraclass correlation coefficient (ICC) was used to determine the intraobserver reliability of the measurements through reliability analysis in SPSS. Reliability was divided into three categories: poor (ICC $<$ .40), fair to good (.40 $\leq$ ICC $\leq$ .75), and excellent (ICC $>$ .75).[7]

RESULTS

Kolmogorov-Smirnov analysis and Fanchazzi analysis, all with $P > .05$, showed that each set of data conformed to the homogeneity of variance test and normal distribution. The retrospective power was from .801 to .879, calculated by PASS software. The intraobserver reliability of some measurements (ICCs) ranged from .690 (fair to good) to .862 (excellent).

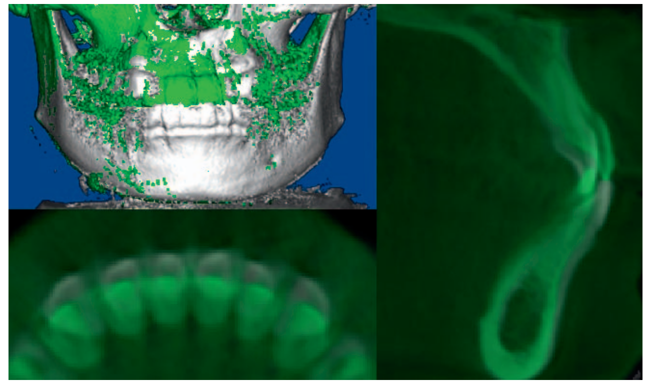

Figure 4. Measurements of tooth movement in Dolphin software.

Comparison of Root Volume and Length Between T_0 and T_1

The characteristics of change for the root length and volume of the central and lateral incisors were consistent (Table 3). Compared with pretreatment data, root length decreased significantly. The lingual root volume of the root cervical third, apical third, and labial root volume of the apical third decreased significantly, among which the percentage of tooth loss at the tip: buccal volume at the apical third (BVA) (24.57% $\pm$ 5.87%) and lingual volume at the apical third (LVA) (26.53% $\pm$ 6.91%), were the highest.

Parameters and Their Changes of the Mandibular Incisors

At the end of treatment, both the central and lateral incisor torque decreased (Table 4). Intrusive movement occurred at both root tips and roots. The amounts of retraction of the tooth cusps were 4.56 $\pm$ 1.35 mm in the central incisor and 3.70 $\pm$ 1.02 mm in the lateral incisor; the retraction amounts at the root tip were 1.37 $\pm$ 0.28 mm in the central incisor and 1.23 $\pm$ 0.67 mm in the lateral incisor. This indicated that the central and lateral incisor retraction was more retroclination than bodily translation.

Correlation Between Root Volume and Dentoskeletal Morphology

Root length loss was related to torque change, sagittal movement of the incisor cusp, sagittal (S-root) and vertical (V-root) movement of the root, pretreatment thickness of the buccal alveolar bone at the root middle (BTM) and apical third (BTA), and pretreatment height of the alveolar ridge crest at the lingual and buccal (LAR, BAR, respectively; Table 5). Volume losses of the buccal root at the apical third (BVA),

Table 3. Comparison of Root Volume and Length Between Pre- and Posttreatment

Measurement	T_0 Mean ± SD	T_1 Mean ± SD	Percentage of Tooth Loss, % Mean ± SD	P
Central incisors				
NT, mm	13.08 ± 1.45	11.13 ± 1.37	14.87 ± 7.60	.034*
BVC, mm³	80.13 ± 20.05	78.46 ± 19.33	2.08 ± 1.14	.525
BVM, mm³	42.90 ± 11.68	41.23 ± 10.55	3.87 ± 2.20	.879
BVA, mm³	19.94 ± 5.18	15.04 ± 4.03	24.57 ± 5.87	.003*
LVC, mm³	75.52 ± 16.09	70.99 ± 15.75	7.64 ± 2.50	.014*
LVM, mm³	40.60 ± 10.97	39.17 ± 10.21	3.08 ± 1.23	.299
LVA, mm³	18.24 ± 3.56	13.40 ± 3.69	26.53 ± 6.91	.002*
Lateral incisors				
NT, mm	12.56 ± 1.56	10.64 ± 1.48	15.28 ± 7.20	.021*
BVC, mm³	65.89 ± 16.31	64.53 ± 15.87	2.06 ± 1.25	.476
BVM, mm³	36.13 ± 9.27	35.70 ± 9.79	1.19 ± 0.84	.760
BVA, mm³	16.82 ± 4.73	13.24 ± 3.61	21.28 ± 6.73	.001*
LVC, mm³	58.07 ± 15.85	53.43 ± 15.42	8.15 ± 1.40	.002*
LVM, mm³	35.82 ± 9.02	34.68 ± 8.97	3.59 ± 2.37	.175
LVA, mm³	17.73 ± 4.80	12.29 ± 3.60	27.07 ± 7.88	.001*

* $P < .05$.

lingual root at the cervical third (LVC), and apical third (LVA) were related to torque change, distance of tooth movement, and pretreatment LAR, BAR.

DISCUSSION

CBCT

Root resorption is a common complication in orthodontics affecting treatment satisfaction, which is an issue of importance to the orthodontist and patient. Root resorption caused by orthodontic tooth movement was observed as root shortening in the apical regions on 2D x-ray images.[8] However, the tooth moves because the root is under pressure, which causes the alveolar bone to resorb, and the corresponding side of the root may also undergo resorption. When root morphology changes occur on the side, 3d root resorption cannot be simply reflected by root length shortening. It was reported that the volume loss measured by CBCT was smaller than the length loss measured by 2D x-ray.[9] CBCT can measure root length quantitatively and greatly improve accuracy.[10] At present, CBCT 3D reconstruction technology has been used to measure the root volume loss of the upper teeth during rapid maxillary expansion,[11–13] during maxillary anterior tooth retraction in skeletal Class I,[14] and during leveling and aligning in severe crowding.[15,16] In this study, CBCT three-dimensional reconstruction technology was used to measure the root length and volume loss as well as the movement of the mandibular incisors during orthodontic treatment. The conclusion that could not be obtained by the length change was reflected by the volume loss, and the factors affecting resorption of the root were explored.

Table 4. Measures of Mandibular Incisor Movements During Treatment

Measurement	Central Incisors Mean ± SD	Central Incisors Range	Lateral Incisors Mean ± SD	Lateral Incisors Range
Inclination change (MP-L1, °	−8.24 ± 5.15	−15.21 to 0.73	−7.30 ± 5.52	−14.58 to 1.03
V-cusp change, mm	2.87 ± 0.79	0.17 to 3.45	2.91 ± 0.88	0.63 to 2.96
S-cusp change, mm	4.56 ± 1.35	3.10 to 5.98	3.70 ± 1.02	2.86 to 5.74
V- root change, mm	0.61 ± 0.14	0 to 1.68	0.54 ± 0.31	0.4 to 1.59
S-root change, mm	1.37 ± 0.28	0.57 to 2.79	1.23 ± 0.67	0.17 to 3.12
T_0 BAR, mm	1.24 ± 0.30	0 to 2.04	0.86 ± 0.25	0 to 1.95
T_0 LAR, mm	1.49 ± 0.53	0 to 1.83	1.24 ± 0.39	0 to 1.76
T_0 BTC, mm	0.85 ± 0.44	0.12 to 1.55	0.72 ± 0.40	0.15 to 1.48
T_0 BTM, mm	1.88 ± 1.10	0.51 to 2.76	1.65 ± 0.83	0.64 to 2.95
T_0 BTA, mm	3.32 ± 1.73	1.34 to 4.09	2.84 ± 1.27	1.52 to 3.63
T_0 LTC, mm	0.71 ± 0.49	0.15 to 1.68	0.86 ± 0.42	0.10 to 1.77
T_0 LTM, mm	1.41 ± 1.08	0.92 to 3.16	1.54 ± 1.15	0.84 to 3.05
T_0 LTA, mm	2.08 ± 1.45	1.20 to 3.88	2.31 ± 1.60	1.30 to 3.61

* $P < .05$.

Table 5. Correlation Between Root Volume and Dentoskeletal Morphology

Variable	Root Length	BVA	LVC	LVA
MP-L1 change	.023*	.015*	.001*	.001*
V-cusp change	.565	.002*	.330	.001*
S-cusp change	.004*	.298	.003*	.463
V- root change	.001*	.019*	.482	.030*
S-root change	.001*	.001*	.687	.001*
T_0 BAR	.006*	.004*	.003*	.010*
T_0 LAR	.007*	.008*	.001*	.008*
T_0 BTC	.608	.750	.498	.406
T_0 BTM	.542	.664	.460	.318
T_0 BTA	.397	.027*	.512	.011*
T_0 LTC	.345	.878	.001*	.197
T_0 LTM	.018*	.167	.644	.248
T_0 LTA	.001*	.001*	.410	.002*

* $P < .05$.

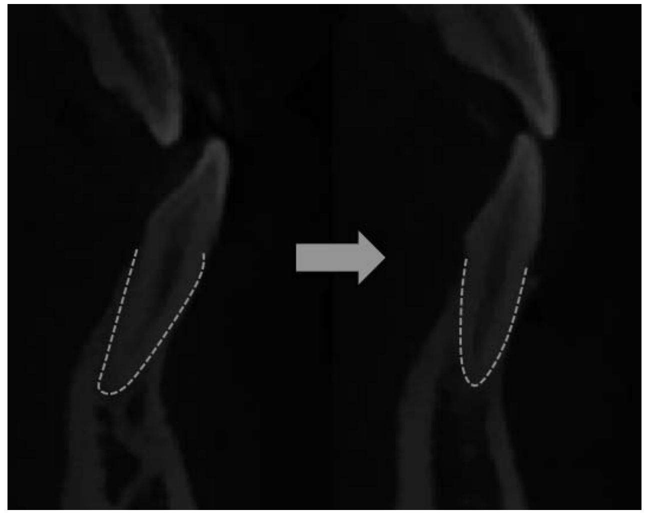

Figure 5. Example of a resorbed root before and after treatment.

Volume Change and the Influential Factors

Patients with skeletal Class III have special anatomic features: the alveolar bone thickness of the lower anterior teeth is narrower than normal.[17,18] This feature limits the movement range of the incisors and causes the roots to easily touch the alveolar bone cortex, which may lead to more root resorption than those with sufficient alveolar bone mass. In the current study, to protect the alveolar bone and roots in the lower anterior region, the double loop, longer than a single loop and exerting a lighter force, was used to apply gentle force to minimize bone fenestration and root resorption as much as possible. However, root resorption was unavoidable, and an example of a resorbed root before and after treatment is shown in Figure 5.

At present, there are few segmented measurement studies on the change of root volume in skeletal Class III patients after orthodontic treatment. In this study, the 3D root volume was divided into six parts, and the resorption characteristics of each part were further refined. The results showed that lingual root volume of the root cervical third, apical third, and labial root volume of the root apical third decreased significantly, among which the percentage of tooth loss at the apical volume was the highest. Pearson's correlation analysis in the study also showed that the pretreatment height of the alveolar ridge crest, thickness of alveolar bone, incisor torque change, and type of tooth movement were related to the volume and length loss.

The torque of central and lateral incisors decreased in this study. The retraction amount of the incisor cusp was larger than the retraction amount of the root apex, which indicated that the incisors mainly underwent tipping movement. In addition, intrusion occurred at both root tips and tooth cusps. All the data indicated the way the teeth move is one of the factors that cause root resorption. In the process of closing extraction space, the retraction and intrusion pressure on anterior teeth easily lead to root resorption[19] due to compression of the root apex and periodontium.[20] Root apices experience obvious force and move a large distance, finally resulting in obvious root apex resorption.[21,22] Although the amount of intrusion did not necessarily correlate with volume loss,[23] the relationship between the movement of apices and their resorption was confirmed in previous studies.[24,25] The reason for the excessive resorption on the lingual surfaces was that the force was applied to the tooth in the lingual direction. Simultaneously, compression occurred on the lingual surfaces of the root, while tension occurred on the labial surfaces. Root resorption may occur during the elimination of the hyalinization tissue on the compressed side.[26]

The thickness of alveolar bone and the distance between the root and the alveolar bone cortex are also influencing factors that cause root resorption. Studies have found that contact between the upper incisors and the incisive canal, or with the labial bone cortex during tooth movement, was more likely to cause severe root resorption. The closer the incisors were to the palatal bone cortex, the more likely it was to have root resorption.[27] The current study showed that pretreatment thickness of labial alveolar bone at the root apex and the thickness of the lingual alveolar bone at the root apical and middle third, were associated with the loss of tooth length and volume. The thin lingual and labial alveolar bone at the apical area and the large amount of movement of the apex (sometimes moving labially) made the roots more likely to contact with the bone cortex, which eventually led to obvious resorption of the root apices.

The height of the retreatment alveolar ridge crest affected the root volume and length. It was reported that patients with periodontitis may have severe external root resorption during orthodontic treatment.[28,29] Because patients with marginal bone loss had less bony support, stress distribution may vary from normal tissue, leading to different extent of root resorption. Heavy forces induce more root resorption than light forces do, especially for patients with marginal bone loss.[30–32] The favorable force for those with normal bone support will be too high for periodontitis patients. For patients with marginal bone loss, 10 g of intrusive force was recommended.[6] In the current study, 80 g was applied, and that may account for the results of root resorption and length loss of periodontitis patients in this study.

CONCLUSIONS

- Significant volume and length loss in the apical third of the lower incisor roots in skeletal Class III patients treated with a Class III premolar extraction pattern is common.
- The height of the pretreatment alveolar ridge crest, thickness of the pretreatment alveolar bone, and type of tooth movement are related to the root resorption observed.

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