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# Horizontal impact of extensive incisor retraction on alveolar bone

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## Abstract

**Objective** To explore the horizontal impact of extensive incisor retraction on alveolar bone and to investigate the relationship of changes in alveolar bone thickness (ΔBT) with horizontal retraction distance of the incisal edge (HRD) and horizontal retraction distance of alveolar ridge crest (HRD′) in orthodontic treatment.

**Materials and methods** This retrospective study included 84 patients who underwent orthodontic extraction treatment, involving extensive incisor retraction (≥ 3 mm). Pre-treatment (T0) and post-treatment (T1) cone-beam computed tomography (CBCT) data were collected. The samples were divided into adult (> 18 years) and adolescent (≤ 18 years) groups. Changes in the horizontal alveolar bone thickness in the incisor region, as well as changes in HRD and HRD′, were measured at T0 and T1. Data were statistically analyzed using SPSS 27.0, utilizing paired and independent samples t-tests.

**Results** After extensive retraction, both upper and lower central incisors exhibited increased buccal alveolar bone thickness, while lingual and total alveolar bone thicknesses decreased. The horizontal plane near the root apice exhibited overall thickening of the alveolar bone. The tooth roots consistently remained upright within the alveolar bone, maintaining a stable relative position. The magnitude of ΔBT was smaller compared to the changes in HRD and HRD′.

**Conclusion** Alveolar bone thickness decreased during extensive retraction, especially near the alveolar crest, with less noticeable variations closer to the tooth root apices. The stable positioning of incisors within the alveolar bone indicates that the alveolar bone changes were primarily morphological, and suggests that partial tooth movement resulted from bone deformation. (Registration Number: ChiCTR2000034288; Approval Date: 01/07/2020)


**Keywords** Bone resorption, Alveolar morphology, Incisor retraction, CBCT

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## Introduction

Lip protrusion is commonly observed among individuals of Asian descent, and its treatment primarily involves extracting four premolars and retracting the anterior teeth. There are two prevailing theories regarding bone remodeling during orthodontic tooth movement: tooth movement 'with the bone' and tooth movement 'through the bone.' The former posits that the alveolar bone aligns with the direction of tooth movement, maintaining a consistent width. Under compression, resorption occurs on the pressure side of the alveolar bone, while new bone formation occurs on the tension side [1–3]. In the case of tooth movement 'through the bone,' an imbalance exists between bone resorption and apposition. In this situation, the tooth breaches the bone boundary, partially extending beyond its limits. The morphology of periodontal tissues, differences in bone density, the inclination and position of teeth, and the direction and magnitude of orthodontic force may determine the type of bone reaction. A systematic review found that the extent of bone loss is influenced not only by the degree of incisor displacement but also by changes in their inclination. As cellular activity slows with advancing age, the degree of bone loss tends to be significantly more pronounced in adults than in adolescents [4]. Several studies investigating periodontal conditions after orthodontic intervention have drawn attention to the potential iatrogenic consequences, including alveolar bone loss, dehiscence, fenestration, and gingival recession, particularly in cases involving excessive retraction of the anterior teeth [5]. Additionally, the target position of anterior teeth is constrained by the craniofacial hard tissues. Therefore, understanding the anatomical factors limiting tooth movement is crucial to mitigate potential harm to roots and alveolar bone during orthodontic treatment [6–8].

Adequate alveolar bone thickness is essential for supporting normal periodontal tissues and is a critical prerequisite for positive outcomes in various dental procedures, including orthodontic treatment, apical surgery, and implant procedures [9–12]. Previous studies have investigated changes in alveolar bone thickness before and after orthodontic treatment, consistently revealing that significant incisor retraction leads to a reduction in both the alveolar bone height and width in the maxillary and mandibular anterior regions, with a more pronounced decrease on the lingual side [13–18]. Generally, bone resorption tends to exceed bone deposition, with a positive correlation between the overall amount of bone resorption and the distance of tooth movement, indicating that greater retraction results in greater alveolar bone resorption [19, 20]. Despite these findings, there is currently a lack of consensus on the processes involved in alveolar bone formation during tooth movement and whether alveolar bone resorption strictly follows the direction and extent of tooth movement.

Since the early 21st century, cone-beam computed tomography (CBCT) has seen increased utilization in craniofacial morphology analysis due to advantages, such as a low radiation dose and high resolution. Consequently, CBCT has become a widely used method for both qualitative and quantitative evaluation of alveolar bone status [21, 22]. Previous research has indicated that CBCT measurements exhibit no significant differences compared to direct measurements, considered the gold standard for bone height and thickness. Moreover, CBCT measurements are more accurate than traditional two-dimensional radiographs. By precisely assessing alveolar bone thickness and height across multiple dimensions and planes, CBCT data can aid orthodontists in determining the limitations of tooth movement before treatment and serve as a valuable monitoring tool during treatment [23–25].

Building on this foundation, we designed this experiment using CBCT data collected before and after treatment to investigate horizontal alveolar bone changes following extensive incisor retraction. This study explored the relationship between alveolar bone changes and the resorption-deposition mechanism.

## Materials and methods

This retrospective analysis was approved by the PKUSS Ethics Committee (Approval Number: PKUSSIRB-202054049; Approval Date: 17/04/2020) and was registered in the Chinese Clinical Trial Registry (Registration Number: ChiCTR2000034288; Approval Date: 01/07/2020). Patients undergoing orthodontic treatment and X-ray imaging were provided with a thorough explanation of the protocol for using their radiographic data in scientific research. An informed consent form was obtained from each patient or their legal guardian, authorizing this use.

The study included 84 participants, comprising 58 adults and 26 adolescents, who underwent orthodontic treatment involving the extraction of four premolars and extensive retraction of incisors ($\geq 3$ mm). The age range was 11–38 years, with a mean age of $21.77 \pm 7.21$ years. The inclusion criteria were patients with a dental midline deviation of $< 3$ mm who underwent orthodontic treatment, involving the extraction of four premolars and extensive incisor retraction ($\geq 3$ mm). The exclusion criteria were the absent or supernumerary incisors, a history of incisor trauma, nasopalatine canal lesions, and congenital anomalies or craniofacial syndromes. Sample size calculation was performed based on pre-experiment data (20 cases), with a mean alveolar bone thickness of $1.16 \pm 0.67$ mm before treatment and $0.93 \pm 0.84$ mm after treatment. The calculation, using a paired t-test with a power of 0.8 and alpha of 0.05, indicated that a total of 84 subjects was required to detect clinically meaningful changes with sufficient statistical power. Pre-treatment (T1) CBCT scans were taken before the initiation of orthodontic treatment, and post-treatment (T2) scans were conducted after treatment completion (post-debonding), with an average interval of 40.65 ± 10.67 months between T1 and T2.

CBCT images were obtained using the same machine (NewTom, Verona, Italy) with exposure settings of 110 kV, 0.07 mA, and a 153.6-mm field of view (FOV). After acquisition, raw data were converted into the Digital Imaging and Communications in Medicine (DICOM) format and reconstructed with a voxel size of 0.3 mm [3]. The DICOM data were then saved in a personal computer for analysis using the Dolphin software (version 11.8, Leuven, Belgium).

It is important to note that voxel size does not simply correspond to clinical resolution. Smaller voxels do not always yield higher resolution, as they capture fewer light quanta, reducing data per voxel. Due to variations in tissue and beam interactions, neighboring voxels may be unevenly affected, resulting in reduced contrast and increased noise. Thus, smaller voxels do not guarantee better resolution or measurement accuracy [26]. CBCT settings must balance voxel size and noise to optimize imaging resolution and measurement accuracy. Studies show that CBCT with a voxel size under 0.3 $mm^3$ is sufficient for accurate alveolar bone measurements [27–30]. Therefore, a voxel size of 0.3 $mm^3$ was chosen for this study.

Root length (RL) was defined as the perpendicular distance from LIA (the root apex of the lower central incisor) to the cementoenamel junction (CEJ) plane (Fig. 1a). On the longitudinal axis of the tooth, planes perpendicular to the CEJ were established at distances of 3 mm, 6 mm, and 9 mm, denoted as L1, L2, and L3, respectively (Fig. 1b). Vectors were drawn on the horizontal cross-sections of L1, L2, and L3, intersecting the labial bone plate and the labial outer wall of the tooth root at points BT1, BT2, and BT3, respectively. Similarly, vectors intersecting the lingual bone plate and the lingual outer wall of the tooth root were denoted as points LT1, LT2, and LT3, respectively (Fig. 1c).

CBCT images captured before and after treatment were superimposed, with subsequent measurements taken for the horizontal retraction distance of the incisal edge of the central incisor (HRD) and the horizontal retraction distance of the alveolar ridge crest (HRD') (Fig. 2). For maxillary measurements, maxillary superimposition was performed automatically based on selected stable regions [31]. The pre- and post-treatment DICOM data were imported into Dolphin software. Bilateral frontozygomatic sutures and the superior margin of the right infraorbital foramen were manually identified. Initial superimposition was achieved by utilizing the automatic superimposition function. In the median sagittal section of the multi-planar reconstruction (MPR) mode, voxel-based superimposition was performed by selecting the sella turcica and adjacent anatomical structures [32, 33]. For mandibular measurements, mandibular superimposition was performed using voxel-based stable region superimposition [34]. To perform automatic voxel superimposition using the basal bone of the mandibular body, extending from the external part of the symphysis to the first molar [34].

Two trained examiners conducted measurements following established protocols. The intraclass correlation coefficient (ICC) was 0.90, indicating high reliability. Averaged measurements were analyzed for the sake of accuracy and comprehensiveness.

## Results

### Root resorption after extensive incisor retraction

Both maxillary and mandibular incisors underwent apical resorption following orthodontic treatment with anterior tooth retraction, but maxillary incisors exhibited greater apical resorption compared to mandibular incisors. Apical resorption occurred more frequently among adults than in adolescents, but the difference was not statistically significant. Consequently, the data listed in Table 1 represents ungrouped data.

Table 1 illustrates that maxillary incisor 11 experienced an average length reduction of 1.33 mm, corresponding to a decrease of −11.00% relative to the total root length. Similarly, maxillary incisor 21 showed an average length reduction of 1.50 mm, equivalent to −12.23% of the total root length. The mandibular incisor 41 exhibited an average length reduction of 1.06 mm, i.e., −9.38% of the total root length, while tooth 31 exhibited an average reduction in length of 1.01 mm, equivalent to −9.14% of the total root length.

### Changes in horizontal alveolar bone thickness

Table 2 presents the changes in the alveolar bone around the maxillary central incisors. Following extensive incisor retraction, the labial alveolar bone thickened at L1 and L2, while the lingual alveolar bone thinned, resulting in a decrease in total alveolar bone thickness. The labial alveolar bone also thickened at L3, with no statistically significant differences observed in the changes in lingual and total alveolar bone thicknesses.

Table 3 presents the alveolar bone changes around the mandibular central incisors. At L1, there was no significant change in labial alveolar bone thickness, while the lingual and total alveolar bone thicknesses decreased. At L2, labial alveolar bone thickened, while the lingual and total alveolar bone thicknesses decreased. At L3, labial

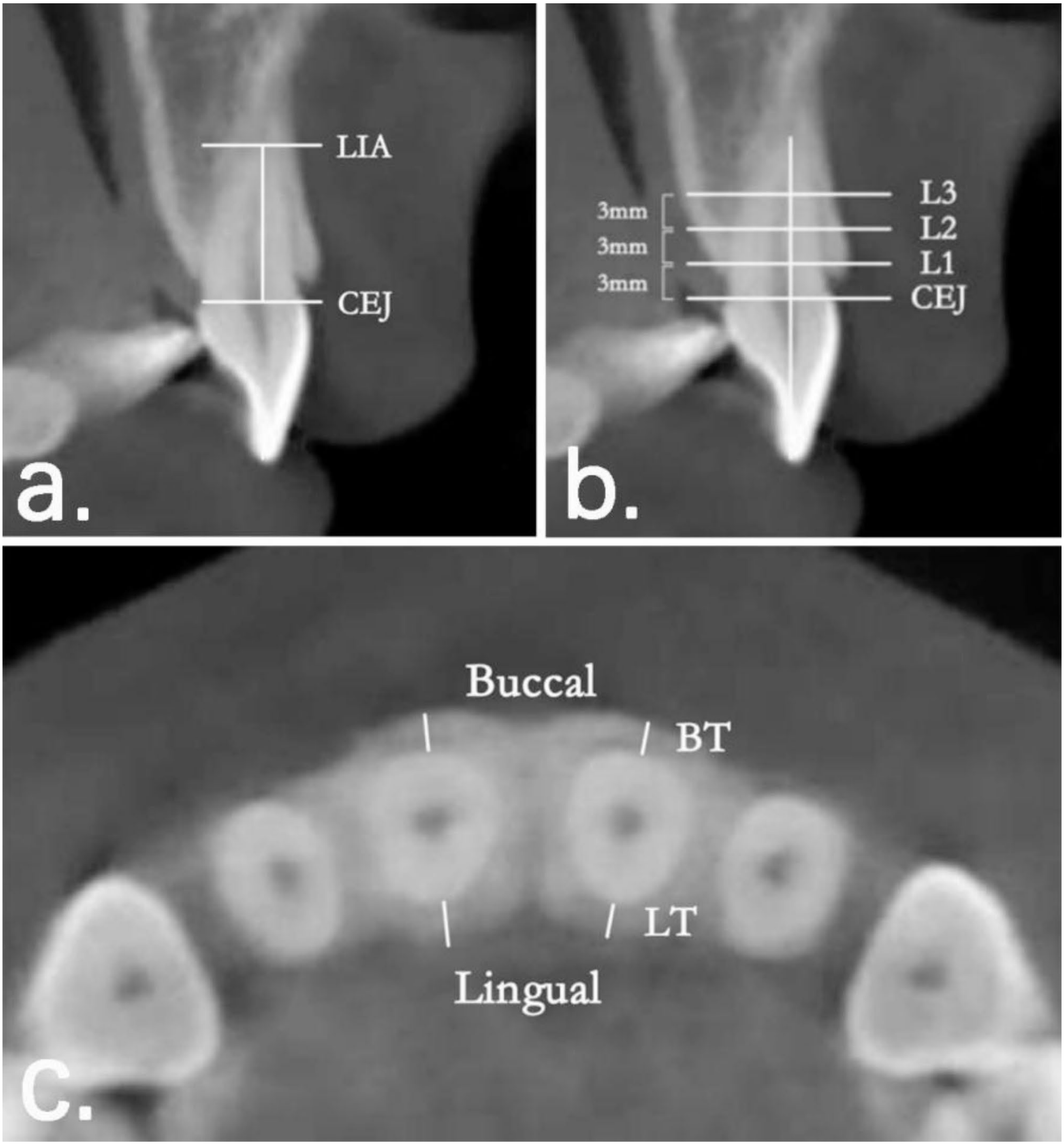


**Fig. 1** Alveolar bone thickness. (**a**) Root length (RL). (**b**) Along the tooth's longitudinal axis, planes perpendicular to the cementoenamel junction (CEJ) were established at distances of 3 mm, 6 mm, and 9 mm, designated as L1, L2, and L3, respectively. These planes (L1, L2, and L3) are perpendicular to the long axis of the incisors and parallel to the CEJ plane. (**c**) Vectors were drawn on the horizontal cross-sections of L1, L2, and L3, intersecting the labial bone plate and the labial outer wall of the tooth root at BT (BT1, BT2, BT3, respectively). Similarly, vectors intersecting the lingual bone plate and the lingual outer wall of the tooth root were denoted as points LT1, LT2, and LT3, respectively

alveolar bone thickness increased and lingual alveolar bone thickness decreased, with an overall thickening of total alveolar bone thickness.

Figure 3 illustrates the horizontal changes in the alveolar bone of maxillary and mandibular central incisors following extensive retraction in orthodontic treatment. A plus sign indicates alveolar bone thickening on that side, while a minus sign indicates alveolar bone narrowing. The plus or minus signs within the circle on the far

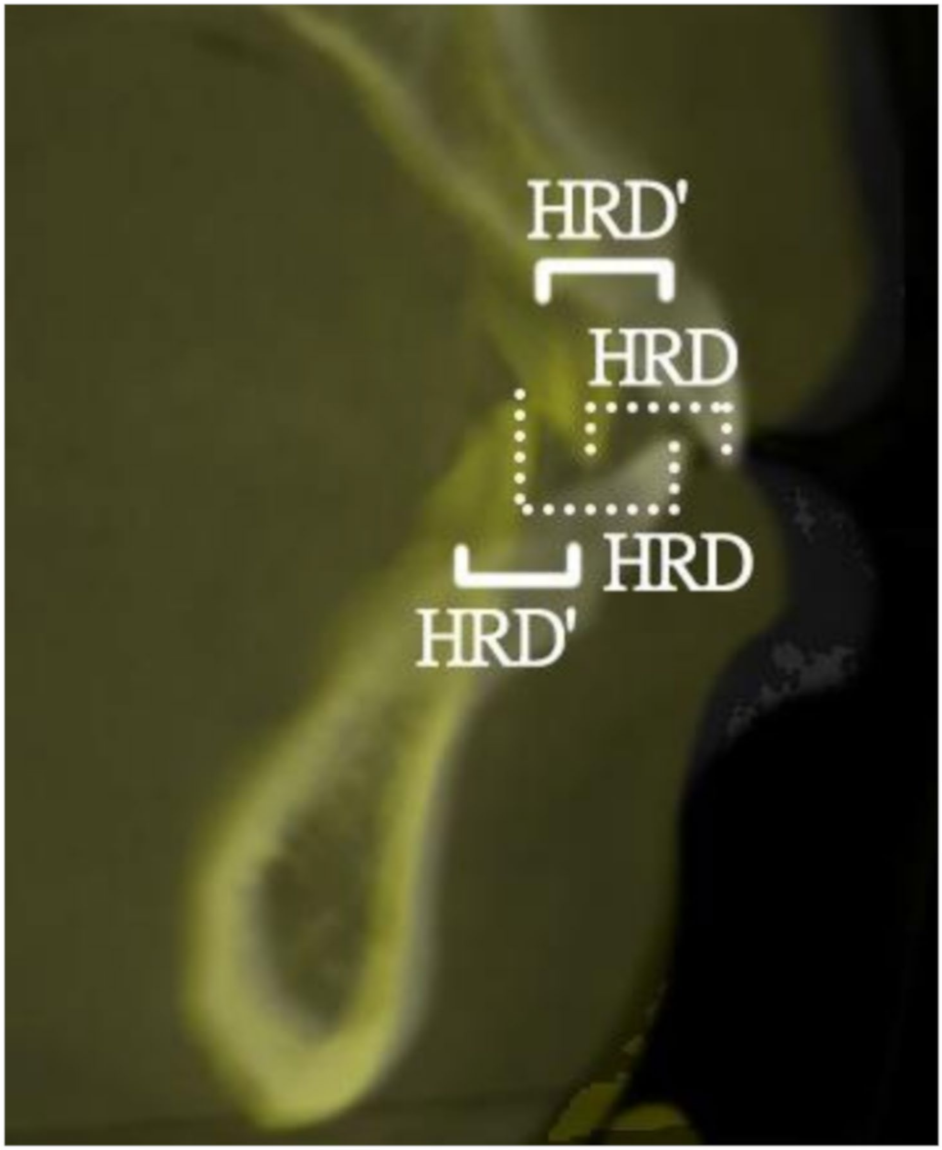


**Fig. 2** HRD: horizontal retraction distance of the incisal edge of the central incisor
HRD': horizontal retraction distance of alveolar ridge crest

**Table 1** Root length (RL) before and after treatment

| | ΔRL | Pre-RL | Post-RL | *P* value |
|---|---|---|---|---|
| 11 (*n* = 76) | −1.33 ± 1.05 | 12.14 ± 1.50 | 10.83 ± 1.70 | < 0.001** |
| 21 (*n* = 76) | −1.50 ± 1.14 | 12.23 ± 1.47 | 10.73 ± 1.82 | < 0.001** |
| 41 (*n* = 57) | −1.06 ± 0.91 | 11.18 ± 1.31 | 10.17 ± 1.21 | < 0.001** |
| 31 (*n* = 57) | −1.01 ± 0.82 | 11.23 ± 1.23 | 10.24 ± 1.17 | < 0.001** |

left indicate whether the total amount of alveolar bone in that horizontal plane has increased or decreased.

### HRD and HRD'

HRD' was defined as the mean value of the lowest point of the alveolar ridge crest in the mid-sagittal section of the upper central incisors and the mean value of the highest point of the alveolar ridge crest in the mid-sagittal section of the lower central incisors. Table 4 illustrates the HRD and HRD' values for the adult and adolescent groups. No statistically significant differences were observed in the HRD and HRD' values between the maxilla and mandible in the two groups, so we combined the data from both groups for presentation.

In the maxilla, the HRD of the upper central incisors was significantly greater than HRD'. In the mandible, there was no significant difference in the HRD and HRD' for lower central incisors between the two groups. However, in the adult group, HRD of the lower central incisors was significantly greater than the HRD'.

**Table 2** Labial, lingual, and total alveolar bone thicknesses for the maxillary central incisor in three horizontal planes

| | | 11 | | | | 21 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | ΔBT | Pre | Post | *P* value | ΔBT | Pre | Post | *P* value |
| L1 | B | 0.27 ± 0.62 | 1.00 ± 0.46 (*n* = 76) | 1.27 ± 0.66 (*n* = 76) | < 0.001** | 0.35 ± 0.73 | 0.92 ± 0.43 (*n* = 76) | 1.27 ± 0.78 (*n* = 76) | < 0.001** |
| | L | −0.81 ± 0.79 | 1.35 ± 0.63 (*n* = 76) | 0.54 ± 0.63 (*n* = 76) | < 0.001** | −0.68 ± 0.76 | 1.27 ± 0.62 (*n* = 76) | 0.59 ± 0.68 (*n* = 76) | < 0.001** |
| | T | −0.54 ± 1.02 | 2.35 ± 0.83 (*n* = 76) | 1.81 ± 0.91 (*n* = 76) | < 0.001** | −0.33 ± 0.92 | 2.19 ± 0.82 (*n* = 76) | 1.86 ± 0.96 (*n* = 76) | 0.002** |
| L2 | B | 0.25 ± 0.66 | 1.16 ± 0.43 (*n* = 76) | 1.41 ± 0.72 (*n* = 75) | 0.001** | 0.40 ± 0.88 | 1.08 ± 0.42 (*n* = 76) | 1.47 ± 0.95 (*n* = 75) | < 0.001** |
| | L | −0.94 ± 1.18 | 2.38 ± 0.74 (*n* = 76) | 1.41 ± 1.08 (*n* = 75) | < 0.001** | −0.72 ± 1.35 | 2.29 ± 0.69 (*n* = 76) | 1.57 ± 1.21 (*n* = 75) | < 0.001** |
| | T | −0.68 ± 1.00 | 3.54 ± 0.89 (*n* = 77) | 2.83 ± 1.07 (*n* = 75) | < 0.001** | −0.32 ± 1.08 | 3.38 ± 0.83 (*n* = 77) | 3.04 ± 1.17 (*n* = 75) | 0.011* |
| L3 | B | 0.39 ± 1.07 | 1.03 ± 0.57 (*n* = 74) | 1.43 ± 1.08 (*n* = 67) | 0.004** | 0.42 ± 1.17 | 1.02 ± 0.61 (*n* = 73) | 1.50 ± 1.12 (*n* = 65) | 0.006** |
| | L | −0.19 ± 1.66 | 3.25 ± 1.02 (*n* = 74) | 3.04 ± 1.58 (*n* = 67) | 0.349 | −0.10 ± 2.01 | 3.39 ± 1.10 (*n* = 73) | 3.19 ± 1.81 (*n* = 65) | 0.696 |
| | T | 0.20 ± 1.39 | 4.28 ± 1.08 (*n* = 74) | 4.48 ± 1.51 (*n* = 67) | 0.244 | 0.32 ± 1.61 | 4.41 ± 1.17 (*n* = 73) | 4.69 ± 1.53 (*n* = 65) | 0.119 |

**Table 3** Labial, lingual, and total alveolar bone thicknesses for the mandibular central incisor in three horizontal planes

| | | 41 | | | | 31 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | ΔBT | Pre | Post | *P* value | ΔBT | Pre | Post | *P* value |
| L1 | B | 0.02 ± 0.69 | 0.72 ± 0.50 (*n* = 57) | 0.74 ± 0.70 (*n* = 58) | 0.789 | −0.11 ± 1.42 | 0.77 ± 1.27 (*n* = 57) | 0.66 ± 0.57 (*n* = 58) | 0.571 |
| | L | −0.45 ± 0.57 | 0.52 ± 0.49 (*n* = 57) | 0.06 ± 0.25 (*n* = 58) | < 0.001** | −0.57 ± 0.58 | 0.59 ± 0.57 (*n* = 57) | 0.02 ± 0.09 (*n* = 58) | < 0.001** |
| | T | −0.43 ± 0.87 | 1.24 ± 0.65 (*n* = 57) | 0.81 ± 0.77 (*n* = 58) | < 0.001** | −0.68 ± 1.61 | 1.36 ± 1.48 (*n* = 57) | 0.68 ± 0.57 (*n* = 58) | 0.002** |
| L2 | B | 0.49 ± 0.89 | 0.67 ± 0.48 (*n* = 57) | 1.16 ± 0.87 (*n* = 58) | < 0.001** | 0.64 ± 0.85 | 0.54 ± 0.44 (*n* = 57) | 1.19 ± 0.84 (*n* = 58) | < 0.001** |
| | L | −0.92 ± 0.73 | 1.13 ± 0.69 (*n* = 57) | 0.22 ± 0.47 (*n* = 58) | < 0.001** | −1.01 ± 0.69 | 1.18 ± 0.68 (*n* = 57) | 0.16 ± 0.33 (*n* = 58) | < 0.001** |
| | T | −0.42 ± 1.03 | 1.80 ± 0.75 (*n* = 57) | 1.38 ± 0.97 (*n* = 58) | 0.003** | −0.37 ± 1.03 | 1.72 ± 0.80 (*n* = 57) | 1.35 ± 0.94 (*n* = 58) | 0.009** |
| L3 | B | 1.16 ± 1.28 | 1.10 ± 0.66 (*n* = 56) | 2.25 ± 1.39 (*n* = 48) | < 0.001** | 1.45 ± 1.24 | 1.08 ± 0.63 (*n* = 55) | 2.53 ± 1.32 (*n* = 49) | < 0.001** |
| | L | −0.71 ± 1.04 | 1.66 ± 0.86 (*n* = 56) | 0.88 ± 0.96 (*n* = 48) | < 0.001** | −0.83 ± 1.07 | 1.54 ± 0.84 (*n* = 55) | 0.70 ± 0.95 (*n* = 49) | < 0.001** |
| | T | 0.46 ± 1.24 | 2.76 ± 1.07 (*n* = 56) | 3.13 ± 1.45 (*n* = 48) | 0.013* | 0.63 ± 1.41 | 2.62 ± 1.06 (*n* = 55) | 3.23 ± 1.49 (*n* = 49) | 0.003** |

## Discussion

In orthodontic treatment, tooth movement involves the application of orthodontic force on the alveolar bone through the periodontal ligament (PDL). Throughout this process, the periodontal ligament and alveolar bone undergo remodeling and reorganization. The side of the alveolar bone subjected to orthodontic force undergoes resorption, while the tension side undergoes new bone formation [1–3]. Theoretically, coordinated formation and resorption should maintain the structural characteristics and size of the alveolar bone during tooth movement and the alveolar bone thickness should remain constant during the tooth retraction process. However, several studies have demonstrated a significant change in alveolar bone thickness after extensive retraction compared to pre-treatment [35–40].

Bone resorption in orthodontics presents potential treatment risks, including gingival recession, bone fenestration, dehiscence, and loose teeth. Because of the relatively thin labial alveolar bone covering the anterior region, changes in the anterior alveolar bone require special attention. The average thickness of the labial alveolar bone in maxillary anterior teeth ranges from 0.4 mm to 1.9 mm, while for mandibular anterior teeth, it varies between 0.4 mm and 3.7 mm. Additionally, lingual alveolar bone thickness for mandibular anterior teeth ranges from 0.4 mm to 5.4 mm [37]. Therefore, orthodontists closely monitor changes in the alveolar bone after extensive retraction of incisors in orthodontic treatment. However, there is currently no consensus on how the alveolar bone undergoes remodeling during tooth movement and whether bone resorption always follows the direction and extent of tooth displacement.

In a CBCT study of patients undergoing orthodontic treatment with the extraction of maxillary first premolars, Ahn [4] demonstrated a significant reduction in both the height and thickness of the alveolar bone on the palatal side of maxillary incisors after orthodontic treatment, accompanied by significant external root resorption. Sarikaya [36] also reported a significant reduction in palatal alveolar bone thickness following the retraction of maxillary incisors. Meanwhile, Yodthong [38] reported

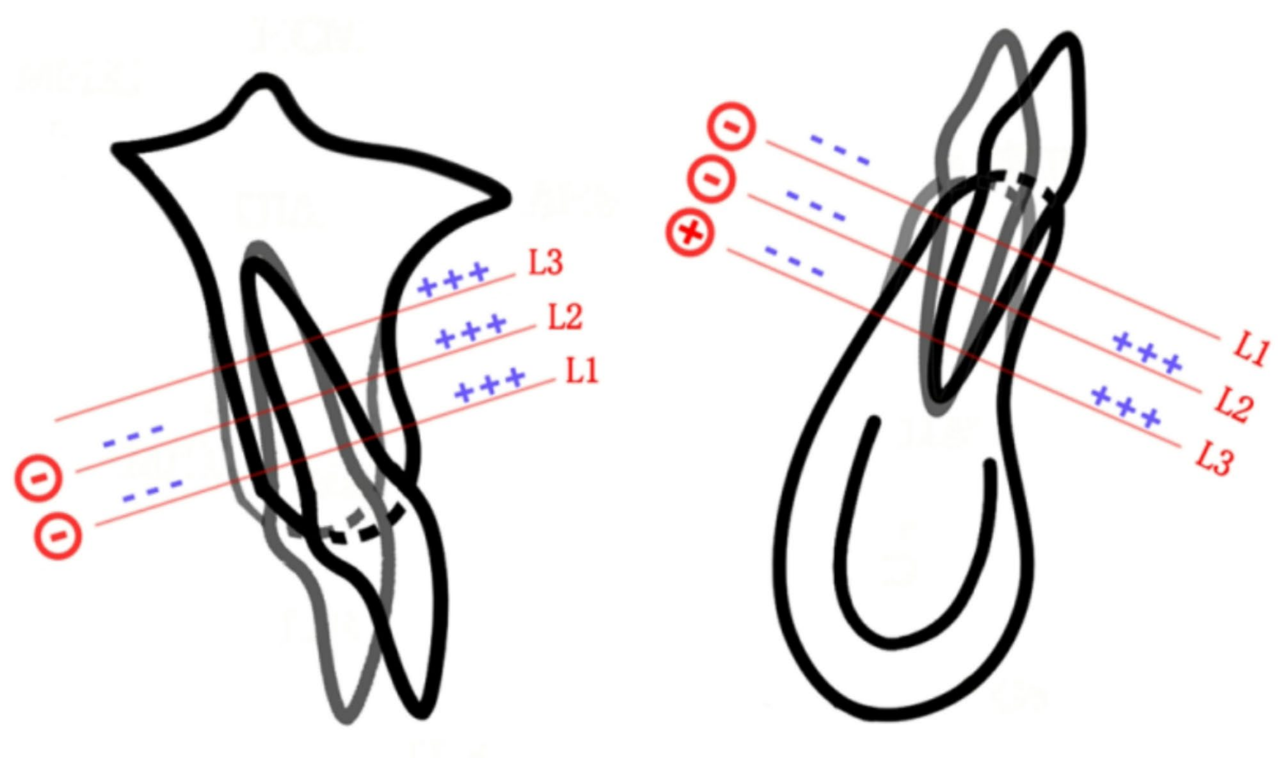


**Fig. 3** Schematic representation of horizontal alveolar bone changes in three horizontal planes following orthodontic treatment with extensive upper and lower incisor retraction

**Table 4** Horizontal changes in the alveolar ridge crest(HRD′) and incisal edge(HRD)

| | HRD′ | HRD |
|---|---|---|
| U1 (*n* = 76) | 3.36 ± 1.67 | 5.89 ± 1.86 |
| L1 (*n* = 57) | 3.81 ± 1.47 | 4.51 ± 1.28 |

an increase in buccal alveolar bone thickness at the cervical region following maxillary incisor retraction. In contrast, Oliveira [39] found no significant change in the overall buccal and palatal alveolar bone thickness after anterior tooth retraction. Guo [40] suggested that palatal alveolar bone becomes thinner while buccal alveolar bone thickens after anterior tooth retraction, but post-treatment, buccal alveolar bone returns to its original thickness. A study by Nayak Krishna [41] yielded similar results, demonstrating reduced palatal alveolar bone thickness after anterior tooth retraction, with a more pronounced effect in the cervical and mid-root regions compared to the apical region. Considering the inclination movement during anterior tooth retraction, the maximum stress is exerted near the alveolar crest of the incisors, leading to more severe bone resorption.

Our CBCT analysis revealed that, in cases involving extensive incisor retraction during extraction orthodontics, palatal alveolar bone resorption is the primary manifestation of bone remodeling, with greater resorption occurring horizontally near the alveolar crest. Meanwhile, observable buccal bone formation is constrained throughout the retraction process. It is worth noting that, regardless of the horizontal planes at L1, L2, and L3 levels, the magnitude of alveolar bone thickness variation was only 1/6 to 1/10 of HRD and HRD′. This indicates the stability of incisor position relative to the alveolar bone. During extensive incisor retraction, the bone remodeling mechanism may not be easily explained by a singular theory of bone resorption-deposition. Building upon this foundational understanding, further research and exploration will contribute to a more comprehensive understanding of bone remodeling. Moreover, additional research is required to optimize orthodontic treatment, aiming to minimize bone resorption and promote bone formation.

A study by De Angelis [42] suggested that orthodontic force induces torsional deformation of the alveolar bone through the piezoelectric effect. Baumrind [43] observed a ten-fold difference between the distance of crown movement and PDL width changes during tooth movement, attributing this phenomenon to bone deformation. This offers valuable insights into the bone remodeling process. While orthodontic treatment often focuses on adjusting tooth positions, our understanding of the microscopic structural changes in the alveolar bone accompanying these adjustments remains inadequate, and require further research.

In addition to alveolar bone alterations, external root resorption is another common iatrogenic consequence of orthodontic treatment, particularly affecting the upper anterior teeth [44, 45]. Kaley [46] suggested that the contact between the root and the cortical bone plays a pivotal role in causing root resorption. Additionally, Horiuchi [47] reported that the approximation of the apex to the palatal cortical plate, resulting from incisor retraction, is a critical factor contributing to root resorption. Furthermore, insufficient maxillary width during tooth movement has been identified as a potential risk factor for root resorption. Existing studies have proposed that central incisors are notably susceptible to the effects of external root resorption [48]. This study revealed that root resorption is prevalent in both maxillary and mandibular central incisors. The extent of external root resorption induced by extensive retraction was lower in the adolescent group compared to the adult group. This discrepancy may be attributed to the developmental potential of the alveolar bone and tooth roots during adolescence. It also suggests a need for greater attention to the risk of external root resorption during extensive incisor retraction in adults.

Building on these results, this study provides valuable insights for orthodontic clinical practice. In cases involving extensive incisor retraction, special attention should be given to the resorption of the palatal alveolar bone, particularly near the alveolar crest, as it may lead to risks such as gingival recession, fenestration, and even tooth mobility. It was also found that labial alveolar bone formation is limited during incisor retraction. Therefore, orthodontists must closely monitor the periodontal condition in patients with thin labial alveolar bone to prevent adverse outcomes. Furthermore, this study highlights the importance of individual factors. Adolescents typically have stronger alveolar bone remodeling capacity and greater tooth root development potential, allowing them to better withstand the stresses associated with extensive incisor retraction. In contrast, adults may experience more pronounced bone and root resorption. Therefore, orthodontists should adjust treatment strategies based on these individual differences, potentially using lighter forces or limiting the extent of incisor retraction in adult patients to reduce the occurrence of adverse outcomes during treatment.

It is important to consider the limitations of this study. Patients being treated by different orthodontists with diverse treatment plans could potentially have influenced the research outcomes. While having a single orthodontist could enhance consistency, it might also limit representativeness. Including more patients treated by different orthodontists makes it easier to detect general trends. To mitigate the impact of diverse treatment protocols on our results, all patients in this study underwent a standardized approach: fixed-appliance treatment involving the extraction of two premolars in the upper and/or lower arches, coupled with at least 3 mm of incisor retraction. Previous studies have shown that CBCT is limited by its spatial resolution, resulting in lower accuracy for measuring alveolar bone with a thickness below 1 mm. Therefore, the results of this study are intended for qualitative reference [49, 50]. While this study did not specifically investigate the impact of different incisor retraction types (tipping or bodily movement) on alveolar bone remodeling, it is worth noting that a previous study [51] observed an increase in labial bone thickness at the root apex, along with an overall increase in total bone thickness, in the controlled tipping group. In contrast, no significant changes were observed in the bodily movement group. These findings suggest that the type of incisor retraction may influence bone remodeling outcomes, which could be an important consideration for future research.

Exploring the molecular mechanisms underlying alveolar bone deformation is a key future goal. A deeper understanding of molecular-level alveolar bone remodeling mechanisms is required to develop accurate orthodontic plans, providing patients with precise healthcare services.

## Conclusions

- The risk of root resorption during extensive retraction, particularly in adults, requires careful attention.
- Horizontal alveolar bone thickness decreases during extensive retraction, especially near the alveolar crest, with less noticeable variations in thickness closer to the tooth root apices.
- Incisor positions within the alveolar bone remain stable during extensive retraction, indicating the morphological nature of the observed alveolar bone changes.

**Abbreviations**

| | |
|---|---|
| ΔBT | Changes in alveolar bone thickness |
| CBCT | Cone-beam computed tomography |
| CEJ | Cementoenamel junction |
| HRD' | Horizontal retraction distance of alveolar ridge crest |
| HRD | Horizontal retraction distance of the incisal edge |
| ICC | Intraclass correlation coefficient |
| LIA | The root apex of the lower central incisor |
| PDL | Periodontal ligament |
| RL | Root length |
| T0 | Pre-treatment |
| T1 | Post-treatment |

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### Author contributions
WH Lu and YF Zhang contributed to the conceptualization of the work, performed all the analyses, and wrote the first draft of the manuscript. WH Lu, YF Zhang, XM Liu and TY Xin contributed to data collection and constructive discussion. B Han, S Chen and XY Zhang contribute to supervision and revision of the manuscript. All authors have read and approved the final manuscript.

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### Data availability
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

## Declarations

### Ethical approval
This retrospective analysis was approved by the PKUSS Ethics Committee (Approval Number: PKUSSIRB-202054049; Approval Date: 17/04/2020) and was registered in the Chinese Clinical Trial Registry (Registration Number: ChiCTR2000034288; Approval Date: 01/07/2020).

### Human ethics and consent to participate
This study was conducted in accordance with the principles of the Helsinki Declaration. Informed consent to participate was obtained from all participants. For participants under the age of 16, informed consent was obtained from their parents or legal guardians.

### Consent for publication
Not applicable.

### Competing interests
The authors declare no competing interests.

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