



## Research article

# Evaluation of alveolar bone morphology of incisors with different sagittal skeletal facial types by cone beam computed tomography: A retrospective study

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## ABSTRACT

**Background:** Safe orthodontic tooth movement should be performed within the alveolar bone. The purpose of this study was to evaluate the morphology of the alveolar bone of incisors.

**Materials and methods:** This retrospective study included pretreatment cone beam computed tomography of 120 patients with malocclusion. Patients were divided into 4 groups (Class I, Class II division 1, Class II division 2 and Class III) according to the subspinale-nasion-supramental (ANB) angle and occlusal relationship. The sagittal root positions, anterior and posterior root-cortical bone angles (AR-CA and PR-CA), root-crown ratios (RCR) and alveolar bone thickness were evaluated.

**Results:** The sagittal root positions were mainly positioned against the labial cortical plate in the maxillary incisors of the Class II division 2 group and engaged by both the labial and palatal cortical plates in the mandibular incisors of the Class III group. The AR-CA was lower than that in the other groups ( $P < 0.01$ ) in the maxillary incisors of the Class II division 2 group, and the AR-CA and PR-CA were lower than those in the other groups ( $P < 0.01$ ) in the mandibular incisors of the Class III group. The alveolar thickness showed no significant difference between the Class II division 1 group and the Class I group ( $P > 0.05$ ), the middle and lower anterior alveolar thickness (LAAT and MAAT) were lower than those in other groups ( $P < 0.01$ ) in the maxillary incisors of the Class II division 2 group, and the alveolar thickness at the measurement sites of the middle and lower line were lower than those in other groups ( $P < 0.01$ ) in the mandibular incisors of the Class III group. The RCR had a moderate positive correlation with the LAAT.

**Conclusion:** Based on several limitations, this study found that maxillary incisor roots were at risk of penetrating the alveolar bone of Class II division 2 patients, and mandibular incisors may have a relatively small range of safe movement on both the labial and lingual sides of Class III patients during orthodontic treatment.

## 1. Introduction

To date, cone beam computed tomography (CBCT) has been the main method of alveolar bone morphology evaluation in oral

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diagnosis. Regarding the accuracy of CBCT in measuring alveolar bone thickness or height, some studies have found that there is no significant difference between CBCT and the physical direct measurement of bone, which is the gold standard reference value [1,2].

In orthodontic tooth movement, the optimal alveolar bone remodeling is that the amount of alveolar bone formation induced by the tension side is consistent with the bone resorption on the pressure side, which is known as “with-the-bone” [3]. Nevertheless, researchers have found iatrogenic adverse effects in receiving different orthodontic treatment techniques, such as alveolar bone thickness reduction, dehiscence and fenestration in the alveolar bone [4,5]. Therefore, it is essential to evaluate alveolar bone morphology before orthodontic treatment during diagnosis.

In the qualitative evaluation of alveolar bone morphology, dehiscence and fenestration are alveolar bone defects with poor boundary conditions [6]. Mandelaris et al. found that approximately 12% of maxillary central incisors had dehiscence or fenestration before orthodontic treatment, although no attachment loss occurred [7]. The ideal root-alveolar relationship is that the root is located in the middle of the alveolar bone. Several studies have classified various changes in the position of the root in the alveolar bone [8,9], in which the sagittal root positions of the maxillary central incisors are more buccal. However, the evaluation of other incisors is lacking.

In the quantitative evaluation of alveolar bone morphology, some studies have evaluated the thickness of alveolar bone. For different sagittal malocclusions, the thickness of alveolar bone in the mandibular incisors in Class II patients was higher than that in Class III patients [10]. Moreover, the thickness of the labial alveolar bone of the maxillary and mandibular incisors in Class III patients was less than 1.0 mm [11]. For different vertical malocclusions, Baysal et al. found that the roots of mandibular incisors were closer to the labial cortex in high-angle patients. It should be noted that the incisor inclination of the two subclasses of Class II patients is comparatively different, and the alveolar bone morphology of the two types should be analyzed separately. Studies have measured the angle between the long axis of the tooth and the alveolar bone [12]. Nevertheless, accurate measurement of the long axis of the alveolar bone is technically difficult. In addition, studies have compared root morphology in patients with different malocclusions, but lack its correlation with alveolar bone morphology [10].

The purpose of this study was to evaluate the sagittal root positions and the morphology of the alveolar bone relative to the roots of the maxillary and mandibular incisors with different sagittal skeletal facial types to provide a reference for the safe range of orthodontic tooth movement.

## 2. Materials and methods

This study was retrospective with CBCT examination performed before the patients underwent routine clinical treatment. This study was a noninvasive examination of patients. The experimental program was approved by the Ethics Committee of the Stomatological Hospital of Fourth Military Medical University (batch number: IRB-REV-2019071) and registered with the China Clinical Trials Registry (registration number ChiCTR2000034222). This study complied with the Helsinki Declaration, and each patient in the project signed a detailed informed consent form.

### 2.1. Study population

Patients were selected between June 2020 and January 2022 from the Department of Orthodontics, Hospital of Stomatology, Fourth Military Medical University. We randomly selected 100 individuals using the random number table method in each type of angle malocclusion (angle class I, angle class II division 1, angle class II division 2 and angle class III), and a total of 400 patients were selected initially. Selection criteria were implemented by an experienced orthodontist and an orthodontic doctoral candidate under the guidance of an authoritative professor following standard operating procedures (SOPs). After applying the inclusion and exclusion criteria as well as the classification criteria of each group, a total of 120 patients were included. The inclusion criteria included the following: 1) Han nationality, aged 18–30 years, with permanent dentition; 2)  $25.1^\circ \leq \text{GoGn-SN} \leq 35.1^\circ$ ; 3) periodontal condition was healthy, including no bleeding on probing, no clinical attachment loss or radiographic alveolar bone resorption, and the maximum probing depth was less than 3 mm; 4) no history of orthodontic treatment; 5) CBCT was taken by the same equipment and the same technician, the images were clear and could be used for orthodontic diagnosis; and 6) voluntary participation in this study and informed consent. The exclusion criteria included the following: 1) history of caries, wear or trauma of incisors; 2) prosthodontic treatment or root canal treatment history of incisors; 3) severe crowding, missing teeth, impacted teeth or supernumerary teeth of incisors; 4) history of the temporomandibular joint disease; and 5) History of maxillofacial surgery involving incisors or history of systemic disease affecting oral and maxillofacial development.

The classification of each group was based on the subspinale-nasion-supramental (ANB) angle and occlusal relationship to exclude the incongruity between the skeletal classification and the angle classification of the malocclusion. 1) Class I group (Angle Class I, skeletal Class I). Inclusion criteria:  $0^\circ \leq \text{ANB} \leq 5^\circ$ , with first molars and canines in normal occlusion, without bimaxillary protrusion or open bite; 2) Class II division 1 group (Angle Class II division 1, skeletal Class II). Inclusion criteria:  $\text{ANB} > 5^\circ$ , with first molars and canines in distal occlusion, with labial inclination of maxillary incisors (at least two maxillary central incisors) and at least  $1^\circ$  deep overjet of anterior teeth; 3) Class II division 2 group (Angle Class II division 2, skeletal Class II). Inclusion criteria:  $\text{ANB} > 5^\circ$ , with first molars and canines in distal occlusion, with a lingual inclination of maxillary incisors (at least two maxillary central incisors) and at least  $1^\circ$  deep overbite of anterior teeth; 4) Class III group (Angle Class III, skeletal Class III). Inclusion criteria:  $\text{ANB} < 0^\circ$ , with first molars and canines in mesial occlusion and reverse overjet and overbite of anterior teeth.

## 2.2. CBCT photography and image processing

The patient was seated and breathing calmly and was scanned with CBCT (LARGEV HiRes3D, Beijing, China). The head was fixed with the orbitale-portion plane parallel to the ground plane, the midsagittal plane was the same as the long axis of the CBCT, and the occlusion was in the intercuspatal position. The shooting parameters were 100 kV voltage, 4 mA current, 16 cm × 15 cm field size, 0.125 mm voxel size, and 15 s scanning time. CBCT data were exported in DICOM format, and three-dimensional image analysis software (Dolphin Imaging 11.0, Chatsworth CA, USA) was used to measure related parameters.

The measured tooth was adjusted to the maximum sagittal slice on the 4-equal slice volume view. The sagittal line (red) and coronal line (green) were adjusted until two lines intersected at the center of the tooth to be measured. In the axial slice, the image was rotated until the sagittal line and the intersection of the labial and palatal/lingual direction of the measured tooth were the longest (Fig. 1A). In the coronal slice, the sagittal line (red) and the axial line (blue) were adjusted until the sagittal line passed through the long axis of the tooth and the axial line passed through the mesial and distal cemento-enamel junction (CEJ) of the measured tooth (Fig. 1B). In the sagittal slice, the coronal line (green) and the axial line (blue) were adjusted to the measured tooth until the coronal line passed the long axis of the tooth (Fig. 1C). The above steps were repeated to adjust each slice in turn to obtain the maximum sagittal slice of the measured tooth (Fig. 1D).

## 2.3. Evaluation of sagittal root positions

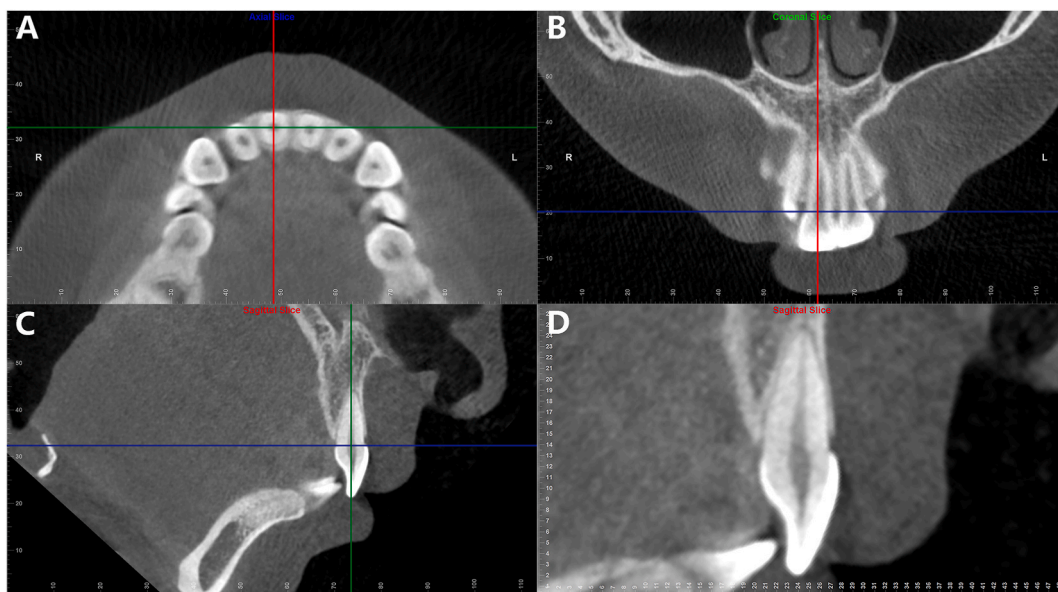
The sagittal root positions were divided into four types according to the relationship between roots and cortical plates [9]. Type I: The root was positioned against the labial cortical plate (Fig. 2A). Type II: The root was centered in the middle of the alveolar housing without engaging either the labial or the palatal cortical plates at the apical third of the root (Fig. 2B). Type III: The root was positioned against the palatal cortical plate (Fig. 2C). Type IV: At least 2/3 of the root was engaged by both the labial and palatal cortical plates (Fig. 2D).

## 2.4. Measurement of alveolar bone morphology

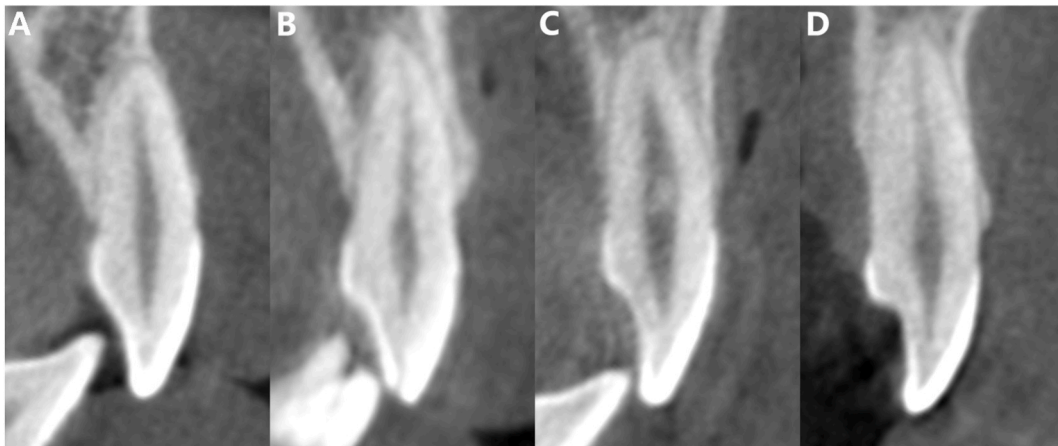
The marked lines and points are shown in Fig. 3. The measurement items are illustrated in Fig. 4 (A-D). For mandibular incisors, each measurement item was the same as the maxillary incisors.

## 2.5. Statistical analysis

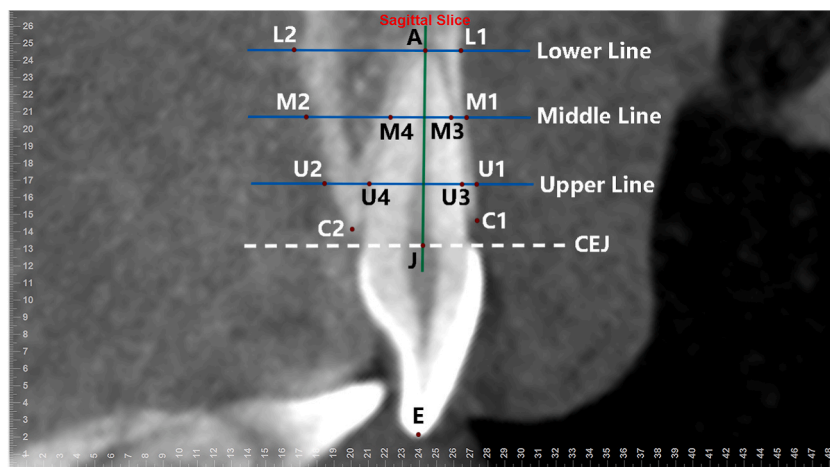
All measurements were measured three times by the same researcher, and the mean value was taken as the measurement result. Another trained physician was invited to perform measurements to evaluate the interobserver reliability. The CBCT of 10 patients was randomly selected and remeasured by the researcher two weeks after the measurement to evaluate the test-retest reliability. The interobserver reliability intraclass correlation coefficient (ICC) was between 0.896 and 0.953, and the test-retest reliability ICC was



**Fig. 1.** Adjustment methods for the measurement plane. (A) Axial slice; (B) Coronal slice; (C) Sagittal slice; (D) Maximum sagittal slice of the measured tooth.



**Fig. 2.** Classification of the sagittal root positions of incisors. (A) Type I; (B) Type II; (C) Type III; (D) Type IV.



**Fig. 3.** Marked lines and points of the tooth and alveolar bone morphology of incisors. A: Root apex; J: Midpoint of the line connecting the labial and lingual CEJ; Connect point A and point J to obtain the long axis of the root, and draw the vertical line of the long axis at the 3-equal points to define the upper line (UL), middle line (ML) and lower line (LL); E: Incisal edge; C1: Apex of the labial alveolar crest; C2: Apex of the palatal/lingual alveolar crest; U1: Intersection of UL and labial cortical bone; U2: Intersection of UL and palatal/lingual cortical bone; U3: Intersection of UL and labial root surface; U4: Intersection of UL and palatal/lingual root surface; M1: Intersection of ML and labial cortical bone; M2: Intersection of ML and palatal/lingual cortical bone; M3: Intersection of ML and labial root surface; M4: Intersection of ML and palatal/lingual root surface; L1: Intersection of LL and labial cortical bone; L2: Intersection of LL and palatal/lingual cortical bone.

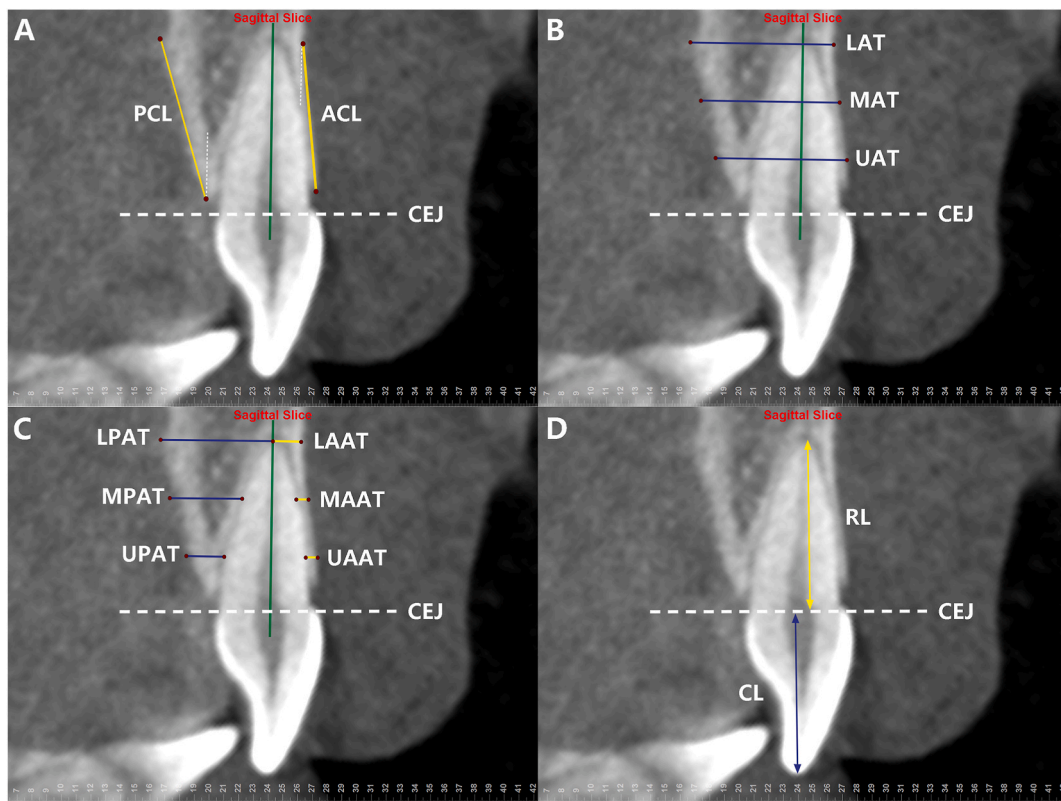
between 0.913 and 0.965, showing high reliability.

The statistical analyses were performed using SPSS 22.0 (IBM, Armonk NY, USA) and GraphPad Prism 8.0 (GraphPad Software, San Diego CA, USA), and the mean and standard deviation ( $\bar{x} \pm s$ ) were used for statistical description. The ICC was performed on teeth of the same type in each half-arch, and the data of each group was between 0.854 and 0.987, indicating high reliability. Therefore, teeth of the same type in each half-arch were combined for analysis. The Shapiro-Wilk test was used to test the characteristics of the normal distribution, and Levene's test was used to test the homogeneity of variance. The data in each group conformed to a normal distribution and had homogeneous variance. One-way ANOVA was used, and the Least significant difference (LSD) test was used for post-hoc comparison between groups with unequal population means. The Pearson correlation coefficient was used for correlation analysis. The *P*-value represents the significant level of the test, and  $P < 0.05$  means the difference is statistically significant.

### 3. Results

#### 3.1. General characteristics

The sample characteristics of each group were as follows. The Class I group included 14 males and 17 females with an age of  $23.2 \pm 2.7$  years. The Class II division 1 group included 15 males and 18 females with an age of  $24.3 \pm 3.5$  years. The Class II division 2 group



**Fig. 4.** Measurement items of alveolar bone morphology of incisors. (A) Measurement of the root-cortical bone angle (R-CA). ACL: anterior cortical bone line, connecting L1 and C1; PCL: posterior cortical bone line, connecting L2 and C2; AR-CA: anterior R-CA, the angle between the extension line of the ACL and AJ connection; PR-CA: posterior R-CA, the angle between the extension line of the PCL and AJ connection. Define the included angle as positive when the opening direction is in the root and negative when the opening direction is in the crown. (B) Measurement of the alveolar bone thickness. UAT: upper alveolar thickness, the distance between U1 and U2; MAT: middle alveolar thickness, the distance between M1 and M2; LAT: lower alveolar thickness, the distance between L1 and L2. (C) Measurement of the anterior and posterior alveolar bone thickness. UAAT: upper anterior alveolar thickness, the distance between U1 and U3; MAAT: middle anterior alveolar thickness, the distance between M1 and M3; LAAT: lower anterior alveolar thickness, the distance between L1 and A; UPAT: upper posterior alveolar thickness, the distance between U2 and U4; MPAT: middle posterior alveolar thickness, the distance between M2 and M4; LPAT: lower posterior alveolar thickness, the distance between L2 and A; (D) Measurement of root-crown ratios. Connect the labial and palatal/lingual CEJ. RL: root length, the distance from A to CEJ; CL: crown length, the distance from E to CEJ; RCR: root-crown ratios, ratios of RL to CL.

**Table 1**

Comparison of the sagittal root positions of incisors in each group.

Tooth	Sagittal root position	I	III1	II2	III
U1	Type I (n, %)	36, 58.1	26, 39.4	59, 98.3	24, 46.2
	Type II (n, %)	25, 40.3	39, 59.1	0, 0.0	24, 46.2
	Type III (n, %)	0, 0.0	1, 1.5	0, 0.0	1, 1.9
	Type IV (n, %)	1, 1.6	0, 0.0	1, 1.7	3, 5.7
U2	Type I (n, %)	38, 61.3	29, 43.9	56, 93.2	27, 51.9
	Type II (n, %)	20, 32.3	32, 48.5	2, 3.4	20, 38.5
	Type III (n, %)	1, 1.6	1, 1.5	1, 1.7	1, 1.9
	Type IV (n, %)	3, 4.8	4, 6.1	1, 1.7	4, 7.7
L1	Type I (n, %)	31, 50.0	36, 54.6	31, 51.6	16, 30.9
	Type II (n, %)	28, 45.2	27, 40.9	21, 35.0	2, 3.8
	Type III (n, %)	1, 1.6	0, 0.0	1, 1.7	2, 3.8
	Type IV (n, %)	2, 3.2	3, 4.5	7, 11.7	32, 61.5
L2	Type I (n, %)	28, 45.2	32, 48.5	30, 50.0	17, 32.7
	Type II (n, %)	32, 51.6	31, 47.0	24, 40.0	3, 5.8
	Type III (n, %)	0, 0.0	0, 0.0	2, 3.3	2, 3.8
	Type IV (n, %)	2, 3.2	3, 4.5	4, 6.7	30, 57.7

Abbreviations: I: Class I group; III1: Class II division 1 group; II2: Class II division 2 group; III: Class III group; U1: maxillary central incisors; U2: maxillary lateral incisors; L1: mandibular central incisors; L2: mandibular lateral incisors.

included 11 males and 19 females with an age of  $23.5 \pm 2.9$  years. The Class III group included 10 males and 16 females with an age of  $23.8 \pm 3.2$  years. There were no significant differences in sex composition ( $P = 0.857$ ) or age ( $P = 0.517$ ) among the four groups, indicating that this study could rule out the possible influence of sex and age composition differences in each group on the results.

### 3.2. Differences in sagittal root positions

The distribution frequency of various types of sagittal root position distributions of incisors in each group is shown in Table 1. The sagittal root positions were principally Type I and Type II in the Class I group and the Class II division 1 group. For maxillary incisors, the distribution frequency of Type I in the Class I group was higher than that of Type II, and the distribution frequency of Type II in the Class II division 1 group was higher than that of Type I. For mandibular incisors, the distribution frequency of Type I was higher than that of Type II in both groups. In the Class II division 2 group, the sagittal root positions of maxillary incisors were principally Type I, and the sagittal root positions of mandibular incisors were mainly Type I and Type II. In the Class III group, the sagittal root positions of maxillary incisors were principally Type I and Type II, and the sagittal root positions of mandibular incisors were principally Type I and Type IV.

### 3.3. Difference in root-cortical bone angle

The AR-CA and PR-CA of incisors in each group were analyzed (Table 2). For maxillary incisors, the AR-CA in the Class II division 2 group was lower than that in the other groups ( $P < 0.01$ ), and the PR-CA was higher than that in the other groups ( $P < 0.01$ ). For mandibular incisors, the AR-CA and PR-CA in the Class III group were lower than that in the other groups ( $P < 0.01$ ). In addition, the PR-CA of mandibular incisors in the Class II division 1 group was lower than that in the Class I group and the Class II division 2 group ( $P < 0.05$ ), and the AR-CA of mandibular lateral incisors was higher than that in the Class I group and the Class II division 2 group ( $P < 0.01$ ).

### 3.4. Differences in alveolar bone thickness

The MAT and LAT of mandibular incisors in the Class III group were lower than those in the other groups ( $P < 0.01$ ), while there was no significant difference in the UAT and MAT of the maxillary incisors in each group. There was no significant difference in the UAT of incisors in each group (Table 3).

The MAAT and LAAT of maxillary incisors in the Class II division 2 group were lower than those in the other groups ( $P < 0.01$ ), while there was no significant difference in the UAAT of the maxillary incisors in each group. In the comparison of the posterior alveolar bone thickness of maxillary incisors, the MPAT and LPAT in the Class II division 2 group were higher than those in the other groups ( $P < 0.01$ ). The MAAT and LAAT of mandibular incisors in the Class III group were lower than those in the other groups ( $P < 0.01$ ), while there was no significant difference in the UAAT of the mandibular incisors in each group. In addition, the LAAT of mandibular central incisors in the Class II division 2 group was lower than those in the Class I group and the Class II division 1 group ( $P < 0.01$ ). The LAAT of mandibular lateral incisors in the Class II division 1 group was higher than that in the Class I group and the Class II division 2 group at the same time ( $P < 0.01$ ). In the comparison of the posterior alveolar bone thickness of mandibular incisors, the MPAT and LPAT of mandibular incisors in the Class III group were lower than those in the other groups ( $P < 0.01$ ), while the LPAT of mandibular lateral incisors in the Class II division 1 group was lower than that in the Class I group ( $P < 0.01$ ). In addition, there was no significant difference in the UPAT in each group (Table 4).

### 3.5. Correlation analysis between root-crown ratios and alveolar bone thickness

As shown in Table 5 and Fig. 5 (A-D), the RCR had a moderate positive correlation with the LAAT of maxillary and mandibular

**Table 2**  
The comparison of R-CA in each group.

Tooth	Variable (°)	I	III	II2	III	P value
U1	AR-CA	$-5.66 \pm 3.07_C$	$-5.74 \pm 4.47_C$	$-14.10 \pm 4.58_{A,B,D}$	$-4.60 \pm 4.59_C$	<0.001**
	PR-CA	$14.46 \pm 4.94_C$	$15.04 \pm 5.25_C$	$27.44 \pm 6.92_{A,B,D}$	$13.97 \pm 4.37_C$	<0.001**
U2	AR-CA	$-5.19 \pm 3.29_C$	$-6.17 \pm 2.67_C$	$-12.78 \pm 3.49_{A,B,D}$	$-5.25 \pm 3.43_C$	<0.001**
	PR-CA	$13.88 \pm 3.91_C$	$14.27 \pm 3.23_C$	$21.77 \pm 6.64_{A,B,D}$	$12.61 \pm 3.53_C$	<0.001**
L1	AR-CA	$1.91 \pm 3.84_D$	$2.23 \pm 4.15_D$	$1.30 \pm 4.38_D$	$-3.89 \pm 3.14_{A,B,C}$	<0.001**
	PR-CA	$9.10 \pm 2.93_{B,D}$	$6.87 \pm 3.01_{A,C,D}$	$9.29 \pm 4.34_{B,D}$	$3.62 \pm 4.79_{A,B,C}$	<0.001**
L2	AR-CA	$-1.29 \pm 3.31_{B,D}$	$1.53 \pm 3.06_{A,C,D}$	$-1.43 \pm 3.24_{B,D}$	$-3.59 \pm 3.52_{A,B,C}$	<0.001**
	PR-CA	$7.01 \pm 3.05_{B,D}$	$5.13 \pm 4.61_{A,C,D}$	$7.12 \pm 4.37_{B,D}$	$2.34 \pm 2.09_{A,B,C}$	<0.001**

Significance: \*\* $P < 0.01$ .

The subscript letters indicate that this group was significantly different from the group represented by the subscript in the post-hoc comparison. Abbreviations: I: Class I group; III: Class II division 1 group; II2: Class II division 2 group; III: Class III group; U1: maxillary central incisors; U2: maxillary lateral incisors; L1: mandibular central incisors; L2: mandibular lateral incisors; AR-CA: anterior root-cortical bone angle; PR-CA: posterior root-cortical bone angle.

**Table 3**  
Comparison of the alveolar bone thickness of incisors in each group.

Tooth	Variable (mm)	I	II1	II2	III	P value
U1	UAT	8.46 ± 0.62	8.69 ± 0.77	8.70 ± 0.68	8.72 ± 0.63	0.423
	MAT	9.07 ± 0.46	9.20 ± 0.80	9.28 ± 0.76	9.03 ± 0.72	0.518
	LAT	9.72 ± 0.69	9.87 ± 0.61	9.89 ± 0.75	9.67 ± 0.75	0.376
U2	UAT	8.36 ± 0.64	7.99 ± 0.61	8.08 ± 0.87	8.01 ± 0.83	0.185
	MAT	8.41 ± 0.72	8.17 ± 0.74	8.27 ± 0.71	8.02 ± 0.67	0.207
	LAT	8.95 ± 0.78	8.71 ± 0.72	8.65 ± 0.81	8.62 ± 0.76	0.333
L1	UAT	6.94 ± 0.58	6.94 ± 0.66	6.82 ± 0.59	6.79 ± 0.67	0.732
	MAT	7.02 ± 0.57 <sub>D</sub>	6.97 ± 0.42 <sub>D</sub>	6.79 ± 0.48 <sub>D</sub>	6.29 ± 0.69 <sub>A,B,C</sub>	<0.001**
	LAT	8.63 ± 0.79 <sub>D</sub>	8.62 ± 0.82 <sub>D</sub>	8.35 ± 0.67 <sub>D</sub>	6.47 ± 0.71 <sub>A,B,C</sub>	<0.001**
L2	UAT	7.45 ± 0.68	7.40 ± 0.62	7.36 ± 0.73	7.31 ± 0.59	0.874
	MAT	7.20 ± 0.56 <sub>D</sub>	7.27 ± 0.68 <sub>D</sub>	7.01 ± 0.57 <sub>D</sub>	6.62 ± 0.43 <sub>A,B,C</sub>	<0.001**
	LAT	8.77 ± 0.78 <sub>D</sub>	8.69 ± 0.83 <sub>D</sub>	8.63 ± 0.80 <sub>D</sub>	6.34 ± 0.67 <sub>A,B,C</sub>	<0.001**

Significance: \*\* $P < 0.01$ .

The subscript letters indicate that this group was significantly different from the group represented by the subscript in the post hoc comparison. Abbreviations: I: Class I group; II1: Class II division 1 group; II2: Class II division 2 group; III: Class III group; U1: maxillary central incisors; U2: maxillary lateral incisors; L1: mandibular central incisors; L2: mandibular lateral incisors; UAT: upper alveolar thickness; MAT: middle alveolar thickness; LAT: lower alveolar thickness.

incisors ( $P < 0.01$ ). In addition, there was no significant correlation between alveolar bone thickness at other sites and RCR.

#### 4. Discussion

There is an increased risk of iatrogenic adverse outcomes when roots move beyond the boundary of the alveolar bone, especially in adult patients [13]. In the present study, we divided the sagittal root positions into four types and evaluated the inclination of the root by measuring the angle between the long axis of the root and the cortical bone line on the labial and palatal sides. We evaluated the alveolar bone thickness to assess the overall range of tooth movement. At the same time, the long axis of the root was divided into three equal parts to evaluate the thickness of the alveolar bone on the labial and lingual sides. The thickness of the alveolar bone at the root neck is associated with the risk of attachment loss due to changes in the alveolar bone. The thickness in the middle of the root is affected by both compensatory and decompensatory tooth movement and is closely related to the risk of fenestration. The limitation of tooth

**Table 4**  
Comparison of the anterior and posterior alveolar bone thickness of incisors in each group.

Tooth	Variable (mm)	I	II1	II2	III	P value	
U1	UAAT	1.16 ± 0.36	1.19 ± 0.28	1.00 ± 0.38	1.17 ± 0.28	0.116	
	MAAT	1.27 ± 0.28 <sub>C</sub>	1.15 ± 0.29 <sub>C</sub>	0.80 ± 0.19 <sub>A,B,D</sub>	1.18 ± 0.26 <sub>C</sub>	<0.001**	
	LAAT	2.45 ± 0.28 <sub>C</sub>	2.34 ± 0.29 <sub>C</sub>	1.01 ± 0.21 <sub>A,B,D</sub>	2.38 ± 0.22 <sub>C</sub>	<0.001**	
	UPAT	1.90 ± 0.58	1.90 ± 0.51 <sub>C</sub>	2.25 ± 0.50 <sub>B,D</sub>	1.94 ± 0.51 <sub>C</sub>	0.046*	
	MPAT	3.87 ± 0.75 <sub>C</sub>	3.65 ± 0.62 <sub>C</sub>	4.46 ± 0.67 <sub>A,B,D</sub>	3.71 ± 0.70 <sub>C</sub>	<0.001**	
	LPAT	7.27 ± 0.65 <sub>C</sub>	7.53 ± 0.59 <sub>C</sub>	8.87 ± 0.71 <sub>A,B,D</sub>	7.22 ± 0.74 <sub>C</sub>	<0.001**	
	U2	UAAT	1.19 ± 0.25	1.09 ± 0.16	1.05 ± 0.21	1.14 ± 0.27	0.102
U2	MAAT	0.76 ± 0.21 <sub>C</sub>	0.73 ± 0.24 <sub>C</sub>	0.55 ± 0.20 <sub>A,B,D</sub>	0.68 ± 0.23 <sub>C</sub>	0.003**	
	LAAT	2.52 ± 0.26 <sub>C</sub>	2.41 ± 0.24 <sub>C</sub>	1.35 ± 0.20 <sub>A,B,D</sub>	2.45 ± 0.19 <sub>C</sub>	<0.001**	
	UPAT	1.70 ± 0.64	1.60 ± 0.43	1.82 ± 0.49	1.57 ± 0.52	0.269	
	MPAT	3.12 ± 0.40 <sub>C</sub>	3.24 ± 0.48 <sub>C</sub>	3.51 ± 0.47 <sub>A,B,D</sub>	3.03 ± 0.55 <sub>C</sub>	0.002**	
	LPAT	6.43 ± 0.66 <sub>C</sub>	6.30 ± 0.71 <sub>C</sub>	7.30 ± 0.74 <sub>A,B,D</sub>	6.16 ± 0.59 <sub>C</sub>	<0.001**	
	L1	UAAT	0.76 ± 0.34	0.77 ± 0.29	0.71 ± 0.28	0.69 ± 0.27	0.718
	MAAT	0.96 ± 0.27 <sub>D</sub>	0.95 ± 0.35 <sub>D</sub>	0.95 ± 0.29 <sub>D</sub>	0.49 ± 0.26 <sub>A,B,C</sub>	<0.001**	
L1	LAAT	3.86 ± 0.26 <sub>C,D</sub>	3.97 ± 0.29 <sub>C,D</sub>	3.69 ± 0.27 <sub>A,B,D</sub>	2.39 ± 0.24 <sub>A,B,C</sub>	<0.001**	
	UPAT	0.88 ± 0.24	0.84 ± 0.29	0.83 ± 0.28	0.81 ± 0.27	0.782	
	MPAT	1.52 ± 0.31 <sub>D</sub>	1.45 ± 0.37 <sub>D</sub>	1.42 ± 0.35 <sub>D</sub>	0.95 ± 0.33 <sub>A,B,C</sub>	<0.001**	
	LPAT	4.76 ± 0.73 <sub>D</sub>	4.65 ± 0.62 <sub>D</sub>	4.66 ± 0.57 <sub>D</sub>	4.07 ± 0.76 <sub>A,B,C</sub>	<0.001**	
	L2	UAAT	0.76 ± 0.22	0.72 ± 0.30	0.79 ± 0.22	0.62 ± 0.26	0.066
	MAAT	0.94 ± 0.24 <sub>D</sub>	0.89 ± 0.28 <sub>D</sub>	0.92 ± 0.26 <sub>D</sub>	0.64 ± 0.20 <sub>A,B,C</sub>	<0.001**	
	LAAT	3.72 ± 0.29 <sub>B,D</sub>	3.97 ± 0.32 <sub>A,C,D</sub>	3.76 ± 0.31 <sub>B,D</sub>	2.67 ± 0.26 <sub>A,B,C</sub>	<0.001**	
L2	UPAT	1.42 ± 0.35	1.40 ± 0.39	1.37 ± 0.31	1.39 ± 0.27	0.951	
	MPAT	1.76 ± 0.36 <sub>D</sub>	1.83 ± 0.37 <sub>D</sub>	1.69 ± 0.33 <sub>D</sub>	1.28 ± 0.29 <sub>A,B,C</sub>	<0.001**	
	LPAT	5.04 ± 0.31 <sub>B,D</sub>	4.72 ± 0.33 <sub>A,D</sub>	4.87 ± 0.37 <sub>D</sub>	3.67 ± 0.29 <sub>A,B,C</sub>	<0.001**	

Significance: \* $P < 0.05$ ; \*\* $P < 0.01$ .

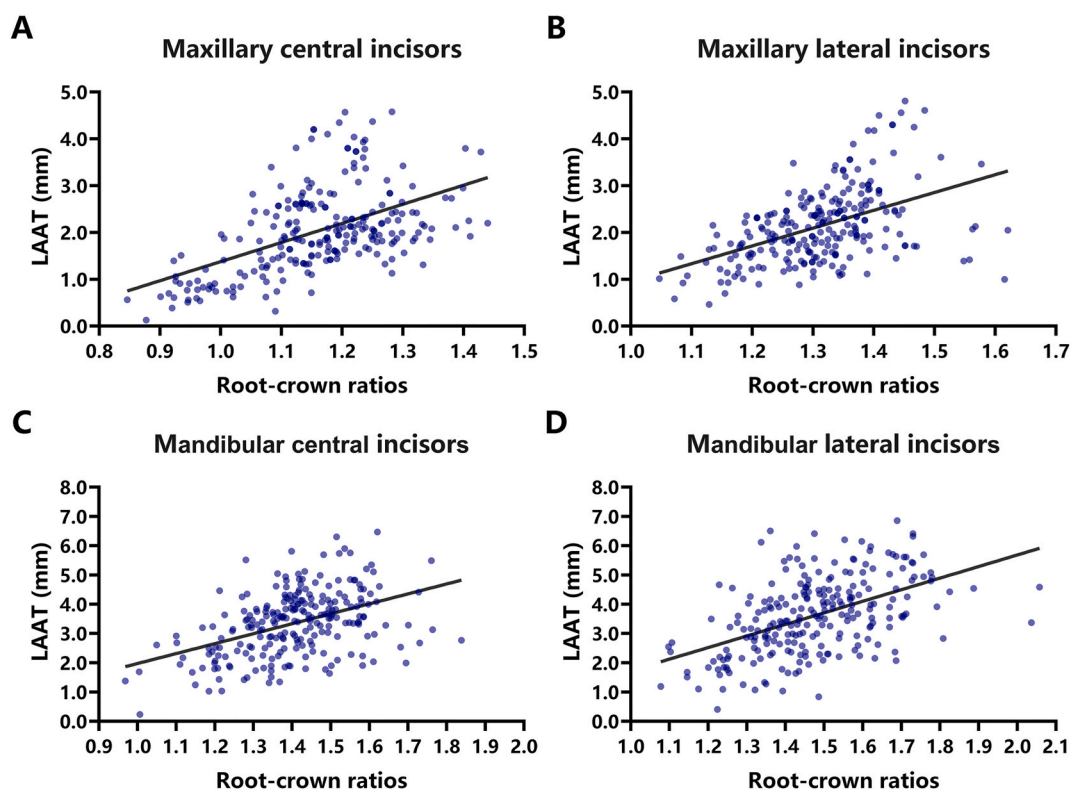
The subscript letters indicate that this group was significantly different from the group represented by the subscript in the post hoc comparison. Abbreviations: I: Class I group; II1: Class II division 1 group; II2: Class II division 2 group; III: Class III group; U1: maxillary central incisors; U2: maxillary lateral incisors; L1: mandibular central incisors; L2: mandibular lateral incisors; UAAT: upper anterior alveolar thickness; MAAT: middle anterior alveolar thickness; LAAT: lower anterior alveolar thickness; UPAT: upper posterior alveolar thickness; MPAT: middle posterior alveolar thickness; LPAT: lower posterior alveolar thickness.

**Table 5**  
Correlation between RCR and anterior and posterior alveolar bone thickness.

Tooth		UAAT	MAAT	LAAT	UPAT	MPAT	LPAT
U1	<i>r</i> (Pearson)	0.124	0.278	0.520	-0.245	-0.108	-0.198
	<i>P</i> value	0.270	0.101	<0.001**	0.128	0.339	0.277
U2	<i>r</i> (Pearson)	0.045	0.174	0.474	-0.179	-0.169	-0.151
	<i>P</i> value	0.695	0.122	<0.001**	0.112	0.134	0.181
L1	<i>r</i> (Pearson)	0.288	0.304	0.445	0.243	0.289	0.200
	<i>P</i> value	0.129	0.106	<0.001**	0.229	0.209	0.173
L2	<i>r</i> (Pearson)	0.018	0.235	0.505	0.104	0.271	0.229
	<i>P</i> value	0.874	0.242	<0.001**	0.335	0.214	0.240

Significance: \*\**P* < 0.01.

Abbreviations: RCR: root-crown ratios; U1: maxillary central incisors; U2: maxillary lateral incisors; L1: mandibular central incisors; L2: mandibular lateral incisors; UAAT: upper anterior alveolar thickness; MAAT: middle anterior alveolar thickness; LAAT: lower anterior alveolar thickness; UPAT: upper posterior alveolar thickness; MPAT: middle posterior alveolar thickness; LPAT: lower posterior alveolar thickness.



**Fig. 5.** Scatter plot of the relationship between RCR and LAAT. (A–D) Scatter plot of the relationship between the RCR and LAAT of the maxillary and mandibular incisors.

movement by the thickness in the apical region is manifested not only in the risk of alveolar bone loss but also in the occurrence of root resorption when the tooth touches or breaks through the cortical bone during tooth movement. Therefore, the correlation between the root-crown ratios and the corresponding alveolar bone thickness of incisors was analyzed to evaluate the safe movement range of teeth, thereby reducing the periodontal risk in orthodontic treatment.

A few sagittal root positions were Type III in maxillary incisors, suggesting that a certain degree of incisor bodily retraction is feasible. At the same time, research has found that most roots of the maxillary incisors were positioned close to the labial cortical bone [14,15], which is consistent with the present study that the proportion of Type II sagittal root positions was not high. At the same time, there was no significant difference in the alveolar bone thickness at each measurement site of the maxillary incisors in each group. Therefore, the limitation of maxillary incisor movement was mainly the position of the teeth relative to the alveolar bone and the difference in the thickness of the alveolar bone on the labial and palatal sides.

Studies have found that the incidence of fenestration in the anterior teeth of Class II patients was higher than that of Class I and Class III patients. In Class II patients, 11.88% had bone fenestration, and 18.51% had bone dehiscence [16]. In the present study, 98.3% of maxillary central incisors and 93.2% of maxillary lateral incisors had Type I sagittal root positions in the Class II division 2 group,



suggesting that such groups have an insufficient labial alveolar bone. At the same time, the AR-CA of the maxillary incisors in this group was the lowest among the patients in each group, and the PR-CA was the highest among all groups, indicating that the root was palatally inclined observably relative to the alveolar bone. In the comparison of alveolar bone thickness, the LAAT of maxillary incisors in the Class II division 2 group was smaller than that in other groups, while the LPAT was higher, indicating that the root is at risk of penetrating the labial alveolar limitation during tooth movement. Other studies also found that when the roots of maxillary central incisors were palatally inclined, the thickness of the labial alveolar bone at the root apex was relatively low [17]. Although restoration to normal labial inclination is the desired treatment goal for Class II division 2 patients, loss of the labial alveolar bone may occur when the ratio of the moment of the couple and the force is not properly controlled; therefore, the center of tooth rotation needs to be adjusted carefully. Considering that the soft tissues of the nose and mentum are well developed in most cases of Class II division 2 patients, the design of incisor movement may not restore the normal inclination completely.

This study found that the R-CA and alveolar bone thickness of the Class II division 1 group were not significantly different from those of the Class I group, indicating that the maxillary incisors of the Class II division 1 group did not show labial inclination relative to the alveolar bone. Nonetheless, the maxillary incisors of Class II division 1 patients mainly showed labial inclination in the analysis of cephalometric measurements. We believe that this is a manifestation of the contradiction between face type and the root-alveolar relationship. When the maxillary anterior teeth are retracted en masse, bone formation in the tension zone is insufficient, and “through-the-bone” tooth movement might appear [18]. The change in the thickness of the alveolar bone caused by the tipping movement of the maxillary anterior teeth is relatively large [19]. It can thus be reasonably assumed that it is a favorable factor for maxillary incisor retraction that the thickness of the alveolar bone on the palatal side is higher than that on the labial side in the Class II division 1 group. In contrast, the risk of root apex breaking through the cortical bone on the labial side is a negative factor. In addition, Lund et al. found that the height of the alveolar bone decreased after tooth retraction with extraction [20]. Therefore, the design of the tipping movement of incisors should take into account the limitation of the labial alveolar bone to ensure safety in the process of retraction of the maxillary incisors.

In this study, the R-CA and alveolar bone thickness of the Class III group were not significantly different from those of the Class I group. Class III patients generally do not extract maxillary premolars during orthodontic camouflage treatment unless the maxillary dentition is severely crowded, in which case the labial tipping movement of the maxillary incisors is generally not limited by the shape of the alveolar bone. When combining orthodontic and orthognathic surgical treatment, extraction of the maxillary premolars is often required for decompensation, and the alveolar bone restriction during retracting maxillary incisors is similar to that of Class II division 1 patients. In addition, the alveolar bone thickness of the maxillary lateral incisors was lower than that of the maxillary central incisors. The maxillary lateral incisors may be palatally displaced in Class II and Class III patients [21]. In this case, when choosing orthodontic camouflage treatment for Class III patients, the bracket of maxillary lateral incisors can be rotated 180° for bonding which is beneficial to the labial movement of the root during the use of the square wire. When Class II division 1 patients plan anterior teeth retraction, reciprocating movement can be avoided by selecting the timing of bonding the brackets.

More than half of the sagittal root positions of mandibular incisors were Type IV in the Class III group, and the MAT and LAT of mandibular incisors were lower than those in other groups, indicating a higher risk of extensive movement. In patients with narrow mandibular incisor alveolar bone, the incidence of fenestration and dehiscence increased to approximately 35% and 50%, respectively [7]. We also found that the AR-CA and PR-CA in the Class III group were lower than those in the other groups, which was related to UAT being lower than LAT in this group. The above suggests that the movable range of the mandibular incisors in Class III patients is very limited, and it is necessary to carefully evaluate whether the lingual retraction of mandibular incisors can be achieved in the orthodontic camouflage treatment plan of Class III patients [22]. In addition, patients receiving orthodontic treatment with lower alveolar bone thickness at the root apex of mandibular incisors were associated with greater facial vertical bone loss [23].

Baysal et al. found that the labial alveolar bone thickness of the mandibular incisors in Class I patients was higher than that in Class II patients, and the root apex of Class II patients was more lingual. Nevertheless, Class II patients were not analyzed separately for the two subclasses [24]. In the present study, the LAAT of the mandibular lateral incisors in the Class II division 1 group was higher than that in the Class I group, and the LPAT was lower. Meanwhile, the AR-CA of mandibular incisors in the Class II division 1 group was higher than that in the Class I group, and the PR-CA was lower, indicating that the mandibular incisors of the Class II division 1 group were labially inclined relative to the alveolar bone, which could provide enough space for the lingual movement of the mandibular incisors. Similarly, the LAAT of mandibular central incisors in the Class II division 2 group was lower than that in the Class I group, which has little restriction on labial tipping movement of mandibular incisors.

A study by Casanova et al. on mandibular central incisors found that root length was positively correlated with alveolar bone thickness, suggesting that root length was the combined effect of individual genotype and local factors, of which alveolar bone limitation was one of the main local factors [25]. In the risk assessment of anterior tooth movement, RCR is an important reference. Lower RCR may lead to complicated treatment planning, in which case root resorption may present a greater challenge to the stability of orthodontic treatment [26,27]. This study found that the RCR had a moderate positive correlation with the LAAT, signifying that the RCR is lower for maxillary incisors in the Class II division 2 group and mandibular incisors in the Class III group, and the risk of root resorption due to apical stress in these teeth needs more attention when torque is applied.

This retrospective study had several limitations. The sex ratio was unbalanced. There were more women (58.3%) than men (41.7%). Although there was no significant difference in the sex composition among the four groups, the unbalanced sex ratio may have biased the measurements. This study did not classify the periodontal biotypes, especially gingival biotypes such as thin gingival type or thick gingival type, which is an interesting and valuable topic worthy of further study. Given that the focus of the study was on average-angle patients in the comparison of different sagittal skeletal facial types, it is not inconceivable that dissimilar evaluations would have arisen if the focus had been on high-angle or low-angle patients. In addition, further studies exploring the amount of

alveolar bone rebuilding in a certain movement of different types of malocclusion would be useful to predict the safe range of roots more accurately.

## 5. Conclusions

The sagittal root positions of maxillary incisors in the Class II division 2 group were mainly Type I. The AR-CA, MAAT, and LAAT of maxillary incisors in the Class II division 2 group were lower than those in other groups, while the mean value of LAAT varied from 1.01 to 1.35 of maxillary incisors, and the PR-CA, MPAT, and LPAT were higher, indicating the risk of penetrating the labial alveolar bone by the root during orthodontic movement. Although the R-CA and alveolar bone thickness of maxillary incisors in the Class II division 1 group were not significantly different from those in the Class I group, controlled tipping movement is essential when retracting the incisors. The sagittal root positions of mandibular incisors in the Class III group were mainly Type IV, and the AR-CA, PR-CA, and alveolar bone thickness at the measurement sites of ML and LL were lower than those in other groups, while the mean value of LAAT varied from 2.39 to 2.67 of maxillary incisors, suggesting that the mandibular incisors have a relatively small range of safe movement on both the labial and lingual sides.

## Author contribution statement

Xu Zhang: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Jie Gao: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Weifu Sun: Conceived and designed the experiments; Performed the experiments.

Haolin Zhang: Analyzed and interpreted the data.

Wen Qin: Contributed reagents, materials, analysis tools or data.

Zuolin Jin: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

## Data availability statement

Data will be made available on request.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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