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ANATOMIC BASES OF MEDICAL, RADIOLOGICAL AND SURGICAL TECHNIQUES

Morphologic analysis of alveolar bone in maxillary and mandibular incisors on sagittal views

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Abstract

Purpose The aim of this study was to analyze the morphologic features of alveolus in relatively healthy maxillary and mandibular incisors using cone-beam-computed tomography (CBCT).

Methods CBCT images of 318 patients were retrospectively acquired. Alveolar bone in incisive area was divided into: type 1 (thick), type 2 (relatively thick with mono-plate concavity), type 3 (thin with double-plate concavities), and type 4 (vulnerably thin). Alveolus prevalence and widths were analyzed statistically relative to age, gender, and molar relationship.

Results Prevalence of type 1 alveolus was 78.9% in maxillary central incisors, 15.1% in maxillary lateral incisors, 24.1% in mandibular central incisors, and 5.0% in mandibular lateral incisors. Type 2 alveolus was commonly observed in the maxillary lateral incisors (82.2%), mandibular central incisors (66.2%), and mandibular lateral incisors (87.9%). Prevalence of type 3 and 4 alveoli ranged from 0.0 to 9.4%. As for maxillary central incisors, type 1 was the widest both at the alveolar crest (7.77 ± 0.58 mm) and apical area (9.05 ± 1.86 mm), while type 3 had the lowest width at the apical region (4.08 ± 0.51 mm). Among maxillary central incisors, prevalence of type 1 tended to decrease with age. At all maxillary and mandibular incisor sites, alveolus widths were significantly thicker in males than in females. At maxillary lateral incisor and mandibular incisor sites, prevalence of alveolus type was significantly different among three molar relationships.

Conclusion A 4-type classification system was suggested for alveolus morphology in incisive region. Identification of alveolus type might aid in the corresponding treatment.

Keywords Maxillary incisor · Mandibular incisor · Alveolus · Morphology · Cone-beam computed tomography

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Background

The incisive area is an important esthetic zone in oral and maxillofacial region. The lack or malocclusion of teeth in this area has a great impact on patient's chewing, pronunciation, social interaction, and psychology [17]. With the increasing demands for implant restoration and orthodontic treatment in the incisive area, more clinical challenges are faced [7, 22]. In addition to considering the timing of treatment, careful assessments of the alveolar ridge, gingival biotype, periodontal status, and occlusal type are essential for satisfactory stability and esthetic outcomes [15]. Among them, alveolus shape and bone plate thickness are highly important for guaranteed outcomes of implantation and orthodontic treatment [3, 4, 10, 17]. Alveolar bone morphology varies among people and tooth site, and there are currently different classification criteria and measurement methods. However, few studies are found to focus concomitantly on the shape and thickness of alveolus in relatively healthy maxillary and mandibular incisive regions [20, 21]. The purpose of this study was to suggest a new classification system and to analyze the morphologic features of alveolus in relatively healthy maxillary and mandibular incisive regions relative to age, gender, and molar relationship using cone-beam-computed tomography (CBCT).

Materials and methods

Subjects

This study was approved by the institutional review board of our school (PKUSSIRB-201732010). CBCT images of patients who presented at our hospital from July 2015 to August 2016 were retrospectively acquired and evaluated.

Inclusion criteria were as follows: (1) ≥ 15 years old, (2) complete dentition without impacted or congenitally missing anterior teeth, (3) with a complete medical record, (4) high-quality images without motion artifacts.

Exclusion criteria were as follows: (1) presence of moderate or severe periodontal lesions (2) moderately or severely crowded dentition, (3) presence of orthodontic treatment, (4) history of anterior tooth injury, (5) cleft lip and/or palate or maxillofacial tumors.

All CBCT images were obtained by NewTom VGi (NewTom, Verona, Italy), with a field of view of 12 × 8 cm. The NNT Viewer (Version 4.00, NewTom, Verona, Italy) was used to reconstruct the CBCT data. The voxel size was set as 200 µm. The images were observed on a multiplanar reconstruction (MPR) image. All images were assessed, respectively, by two experienced oral radiologists. In the event of a disagreement, the cases were discussed until a consensus was reached.

Evaluation of alveolar morphology

Alveolar bone was observed on median sagittal views set parallel to the long axis of the root of incisors and was divided as:

1. thick type: the alveolar bone was wide and thick, and the thickness of the facial and palatal/lingual bone plates was > 0.5 mm;

2. relatively thick with mono-plate concavity: the alveolar bone was relatively thick, but the unilateral bone plate had obvious concavity with the local bone plate < 0.5 mm;

3. thin with double-plate concavities: the shape of the alveolar bone was relatively thin, and had bilateral concavities; 4. vulnerably thin type: the alveolus was very thin with bilateral bone plates < 0.5 mm.

Moreover, root orientations relative to sagittal views of alveolus were assessed and classified as: (1) buccal type: closer to the buccal cortex; (2) midway type: midway between the buccal and palatal/lingual cortices; (3) palatal/lingual type: closer to the palatal/lingual cortex.

For alveolus type evaluation, intra- and inter-observer agreement was assessed using weighted Cohen kappa test. Ten of the enrolled cases were randomly selected, and evaluation was performed by the two observers separately. These images were evaluated again after 2 weeks. The intra-observer kappa value was calculated as 0.800 and 0.781, respectively, for observer A and B, and the inter-observer kappa value was 0.736.

Measurement of the alveolar width

Buccolingual width was measured at the level of alveolar crest and apical region. (Fig. 1a) Then, ratio of alveolar width was calculated:

Ratio of alveolar width = alveolar width at crest (AWcrest)/alveolar width at apex (AWapex).

All measurements were recorded twice by the same observer at a 2-weeks interval, and the mean of these values was used for analysis.

Statistical analysis

All data were statistically analyzed using SPSS software (version 25.0; IBM, Chicago, IL). alveolus prevalence and alveolar widths were comparatively analyzed relative to age group, gender, and molar relationship. One Way ANOVA was performed among numerical variables, and Pearson Chi-square or fisher's exact test was used among categorical variables. The level of statistical significance was set at $P < 0.05$.

Results

Distribution of alveolus types

With the aid of a statistical estimation of a proper case number, 318 eligible cases were eventually enrolled, which included four age groups: 15–20 years ($n = 96$), 21–30 years ($n = 101$), 31–40 years ($n = 78$), and > 40 years ($n = 43$). They included 86 males and 232 females, with a median age of 27 years (ranging from 15 to 56 years). They consisted of 192 cases of Class I, 58 cases of Class II, and 68 cases of Class III molar relationship (Angel's classification).

Type 1–3 alveoli were observed in maxillary incisors (Figs. 1, 2) and all four types were observed in mandibular incisors (Figs. 3, 4). Prevalence of type 1 and type 2 alveoli were 78.9% and 20.4% in maxillary central incisors, 15.1% and 82.2% in maxillary lateral incisors, 24.1% and 66.2% in mandibular central incisors, and 5.0% and 87.9% in mandibular lateral incisors, respectively. Types 3 and 4 were relatively scarce, ranging from 0.0% to 9.4% (Table 1).

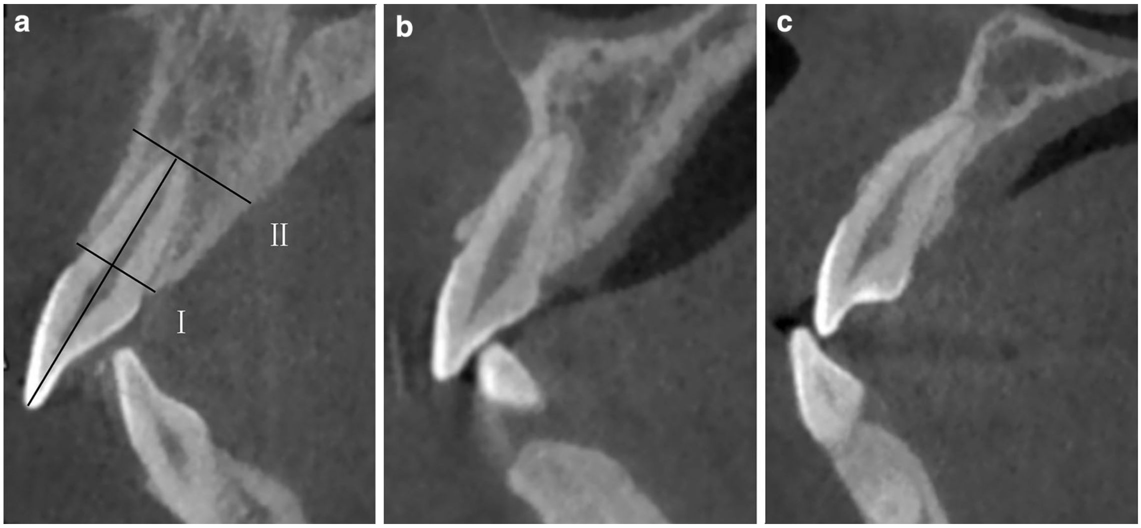
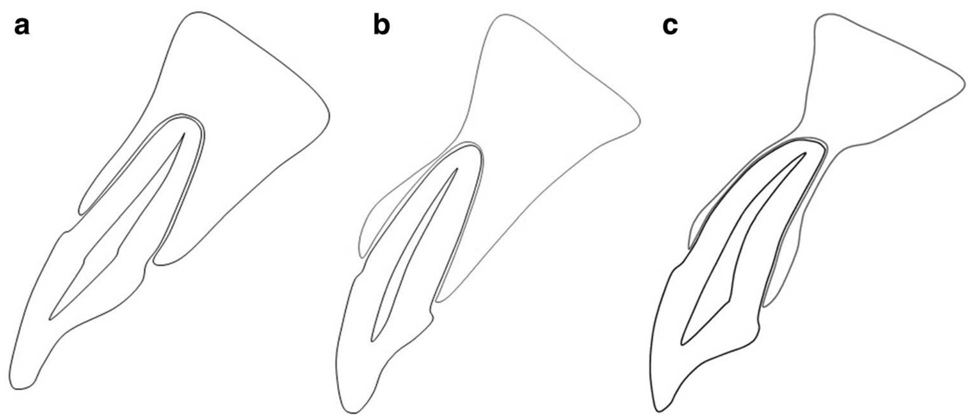


Fig. 1 CBCT images of three alveolus types in maxillary incisors. Note the measurements of alveolar widths at the level of alveolar crest (line I) and apical region (line II). **a**, type 1; **b**,type 2; **c**,type 3

Fig. 2 Schemas of three alveolus types in maxillary incisors. **a**, type 1; **b**,type 2; **c**,type 3



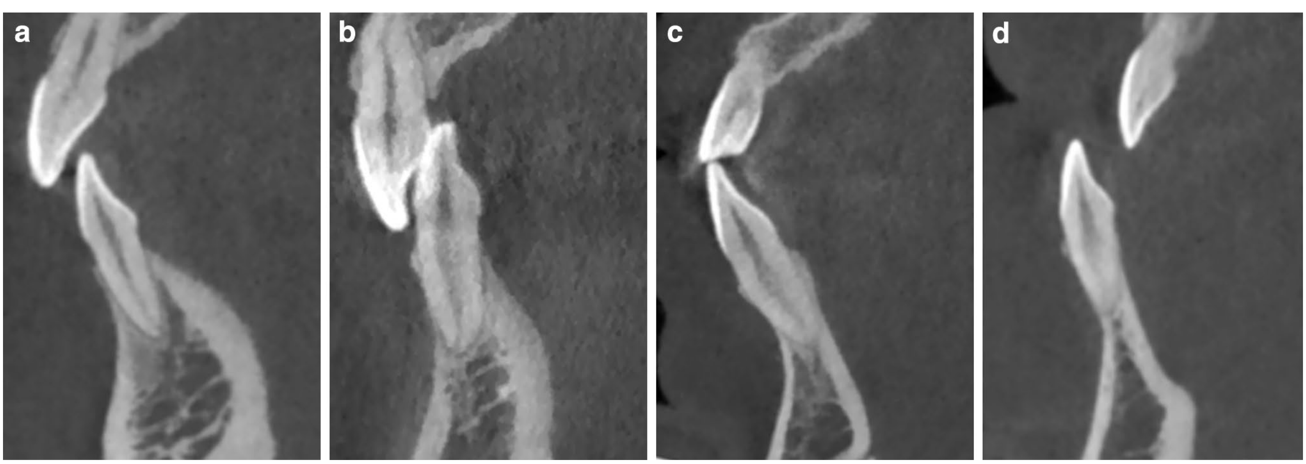


Fig. 3 CBCT images of four alveolus types in mandibular incisors. **a**, type 1; **b**,type 2; **c**,type 3; **d**,type 4

Relationship between alveolus types and root orientations

As for maxillary central incisors, buccal orientations were present in 72.7% of type 1 and 90.8% of type 2 alveolus,

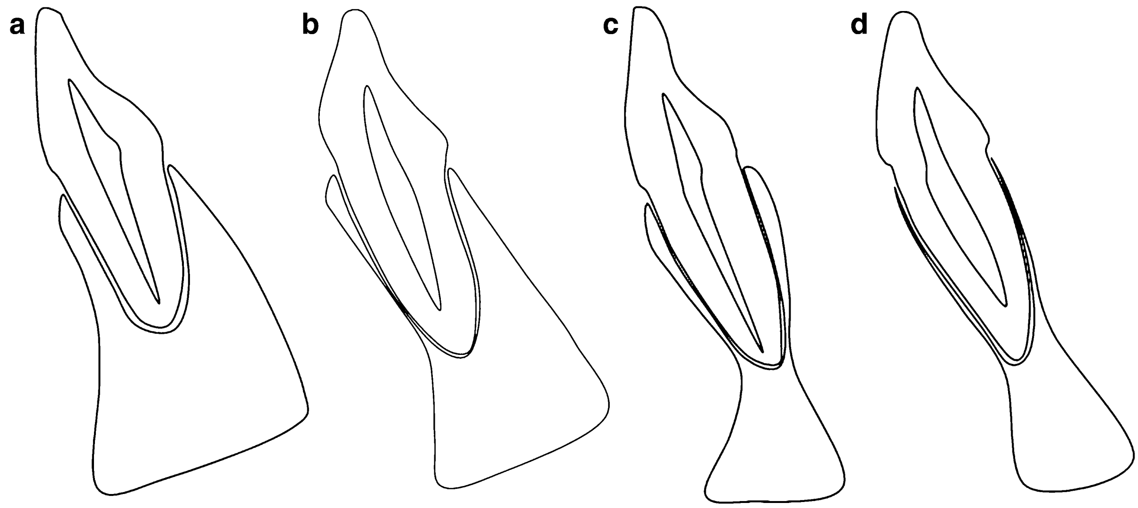


Fig. 4 Schemas of four alveolus types in mandibular incisors. **a**, type 1; **b**, type 2; **c**, type 3; **d**, type 4

Table 1 Relationship between alveolus types and age groups (n, %)

Age group	Type 1	Type 2	Type 3	Type 4	*P* value
Maxillary central incisor					
15–20	153 (79.7)	39 (20.3)	0 (0.0)	–	0.000
21–30	173 (85.6)	29 (14.4)	0 (0.0)	–	
31–40	119 (76.3)	33 (21.2)	4 (2.6)	–	
> 40	57 (66.3)	29 (33.7)	0 (0.0)	–	
Total	502 (78.9)	130 (20.4)	4 (0.6)	–	
Maxillary lateral incisor					
15–20	34 (17.7)	152 (79.2)	6 (3.1)	–	0.829
21–30	26 (12.9)	170 (84.2)	6 (3.0)	–	
31–40	23 (14.7)	129 (82.7)	4 (2.6)	–	
> 40	13 (15.1)	72 (83.7)	1 (1.2)	–	
Total	96 (15.1)	523 (82.2)	17 (2.7)	–	
Mandibular central incisor					
15–20	48 (25.0)	118 (61.5)	8 (4.2)	18 (9.4)	0.003
21–30	56 (27.7)	131 (64.9)	1 (0.5)	14 (6.9)	
31–40	31 (19.9)	108 (69.2)	11 (7.1)	6 (3.8)	
> 40	18 (20.9)	64 (74.4)	4 (4.7)	0 (0.0)	
Total	153 (24.1)	421 (66.2)	24 (3.8)	38 (6.0)	
Mandibular lateral incisor					
15–20	5 (2.6)	161 (83.9)	8 (4.2)	18 (9.4)	0.005
21–30	11 (5.4)	183 (90.6)	4 (2.0)	4 (2.0)	
31–40	11 (7.1)	139 (89.1)	4 (2.6)	2 (1.3)	
> 40	5 (5.8)	76 (88.4)	2 (2.3)	3 (3.5)	
Total	32 (5.0)	559 (87.9)	18 (2.8)	27 (4.2)	

while palatal/lingual type was not found. Besides, buccal orientations were commonly found (77.4%) in maxillary lateral incisors. However, midway orientations were commonly found in mandibular central incisors (75.8%) and mandibular lateral incisors (73.7%).

Widths and ratios of all alveolus types

Among three alveolar types of maxillary central incisors, significant differences were found in AWcrest (type 1: 7.77 ± 0.58 mm, type 2: 7.63 ± 0.64 mm, type 3: 7.68 ± 0.24 mm, $P = 0.048$) and AWapex (type 1: 9.05 ± 1.86 mm, type 2: 8.38 ± 2.09 mm, type 3: 4.08 ± 0.51 mm, $P = 0.000$). Type 1 alveolus were the widest both in the alveolar crest and periapical area, while type 3 had the lowest AWapex. Ratio of alveolar width was < 1 in 75.5% of type 1 and 63.08% of type 2, and was ≥ 1 in all type 3 alveolus.

Among three alveolar types of maxillary lateral incisors, significant difference was not found in AWcrest (type 1: 7.43 ± 0.65 mm, type 2: 7.28 ± 0.68 mm, type 3: 7.33 ± 0.66 mm, $P = 0.156$), but was present in AWapex (type 1: 8.30 ± 1.68 mm, type 2: 7.89 ± 1.85 mm, type 3: 5.59 ± 1.15 mm, $P = 0.000$). In the apical region, type 1 alveolus was the widest and type 3 had the lowest width. Ratio of alveolar width was < 1 in 66.7% of type 1 and 59.5% of type 2, and was ≥ 1 in all type 3 alveolus.

Regarding mandibular incisor sites, type 1 had the widest crest while type 4 had the thinnest crest. And, type 1 was the widest and type 3–4 was the thinnest in the periapical area.

Alveolar widths and ratios in all four incisive regions were demonstrated in Fig. 5 and Table 2.

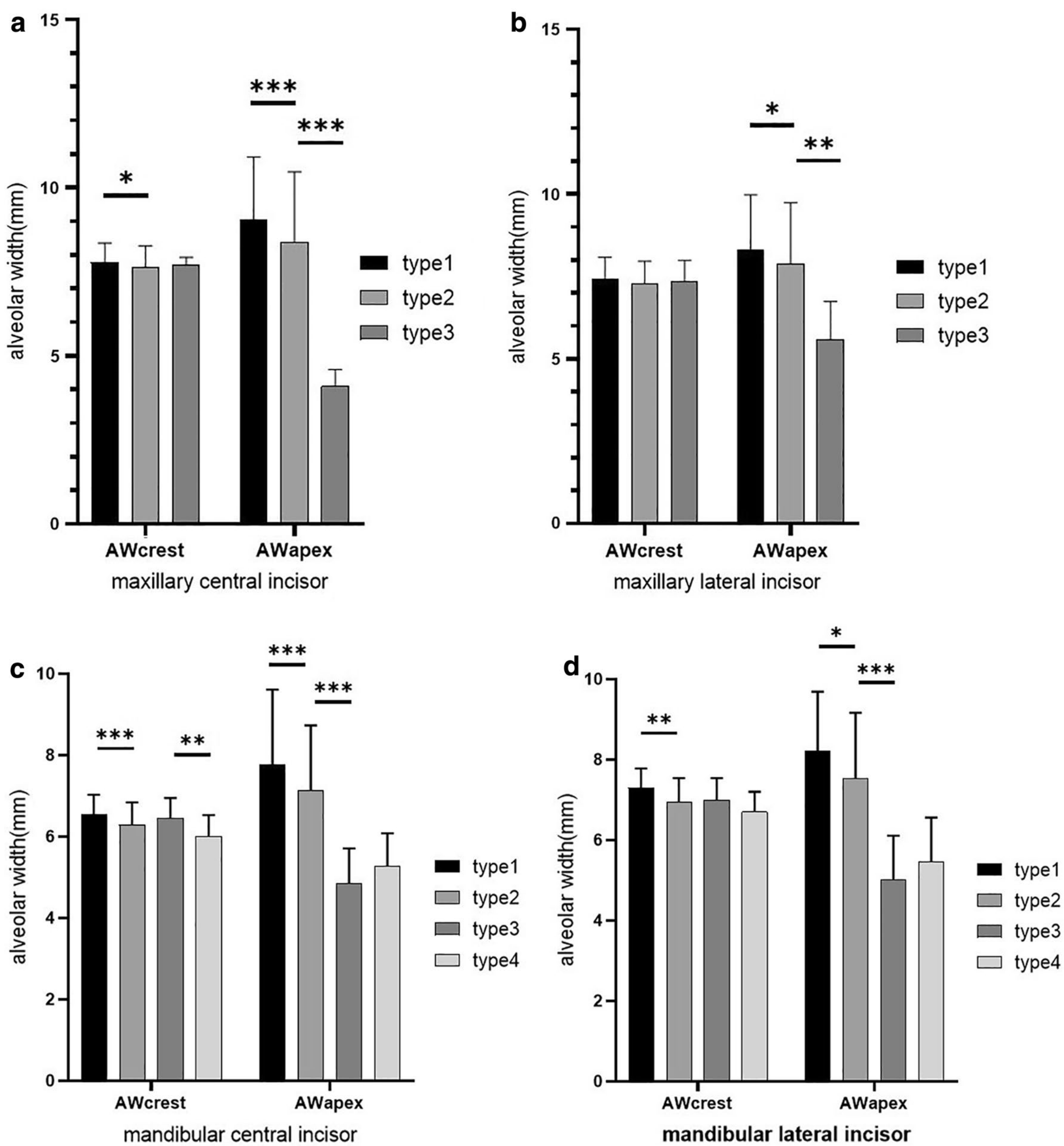


Fig. 5 Bar graphs for widths of all alveolar types. **a**, maxillary central incisors; **b**, maxillary lateral incisors; **c**, mandibular central incisors; **d**, mandibular lateral incisors

Table 2 Ratios of alveolus width (alveolar width at crest/alveolar width at apex)

Ratio of alveolus width	Type 1	Type 2	Type 3	Type 4	Total (%)
Maxillary central incisor					
< 1	379	82	0	–	461 (72.5%)
> 1	123	48	4	–	175 (27.5%)
Maxillary lateral incisor					
< 1	64	311	0	–	375 (59%)
> 1	32	212	17	–	261 (41.0%)
Mandibular central incisor					
< 1	115	287	1	5	408 (64.2%)
> 1	38	134	23	33	228 (35.8%)
Mandibular lateral incisor					
< 1	21	342	1	4	368 (57.9)
> 1	11	217	17	23	268 (42.1%)

Age differences of alveolar types and widths

Among maxillary central incisors, significant differences were found in the distribution of alveolus type ($P = 0.000$). Prevalence of type 1 alveolus tended to decrease with age in the elder three groups (21–30, 31–40 and > 40). Difference was insignificant in maxillary lateral incisors ($P = 0.829$). Moreover, alveolus prevalence was significantly different among age groups in mandibular central ($P = 0.003$) and lateral incisors ($P = 0.005$) (Table 1).

Among maxillary central incisors, two elder groups had thinner alveolar crest than the two younger groups. As for maxillary lateral incisors, AWcrest tended to decrease with age in the three elder groups. Regarding mandibular incisors, two elder groups had thinner AWcrest and AWapex than the two younger groups (Fig. 6).

Gender differences of alveolus types and widths

Type 1 occurred more frequently in males than in females among maxillary lateral incisors (21.5% vs 12.7%,

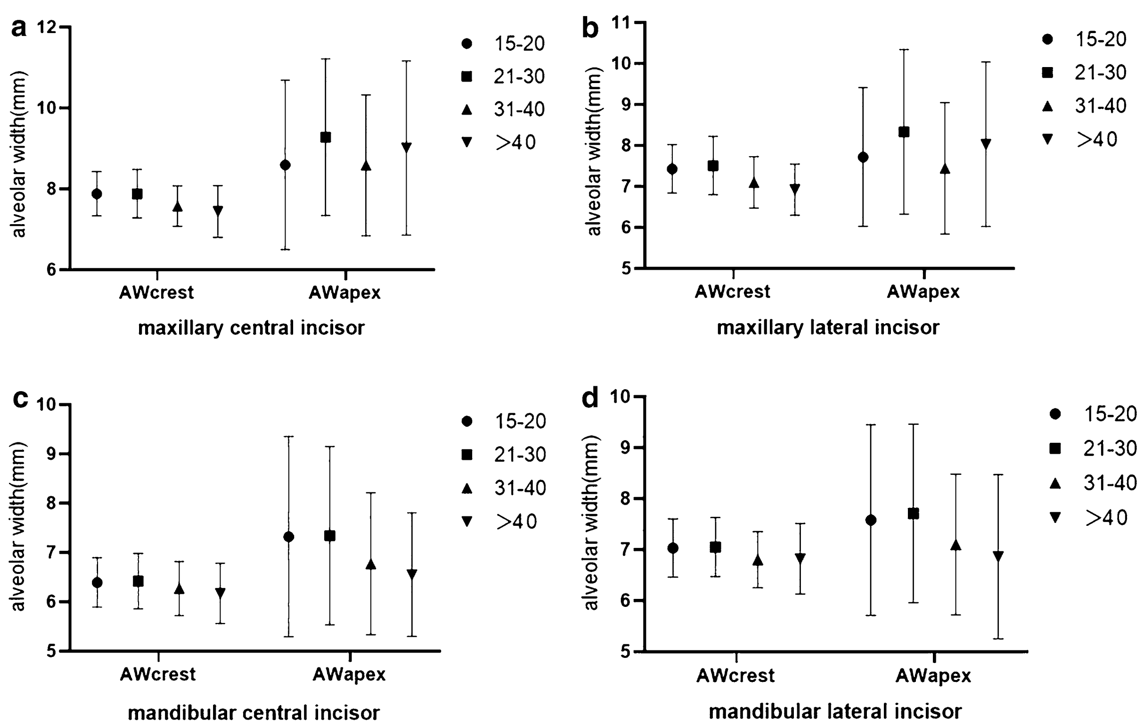


Fig. 6 High–low graphs for age differences of alveolar widths. **a**, maxillary central incisors; **b**, maxillary lateral incisors; **c**, mandibular central incisors; **d**, mandibular lateral incisors

$P=0.004$) and mandibular central incisors (27.3% vs 22.8%, $P=0.026$). Gender difference was insignificant in alveolar type of maxillary central incisors and mandibular lateral incisors (Table 3).

As for all maxillary and mandibular incisor sites, AWcrest and AWapex were significantly thicker in males than in females (Fig. 7).

Relationship between alveolus types and molar relationships

As for the maxillary central incisors, difference was insignificant in the distribution of alveolus type among three molar relationships ($P=0.059$). However, alveolus prevalence was significantly different in the other three incisor sites. Specifically, type 2 occurred more frequently in Class I of maxillary lateral incisors, type 3 occurred more frequently in Class III of mandibular central incisors, and type 1 had a slightly larger proportion in Class II of mandibular lateral incisors. Alveolus prevalence relative to molar relationship was demonstrated in Table 4.

Table 3 Gender differences of alveolus types

Gender	Type 1	Type 2	Type 3	Type 4	*P* value
Maxillary central incisor					
Male	140	30	2	–	0.252
Female	362	100	2	–	
Maxillary lateral incisor					
Male	37	134	1	–	0.004
Female	59	389	16	–	
Mandibular central incisor					
Male	47	102	12	11	0.026
Female	106	319	12	27	
Mandibular lateral incisor					
Male	11	147	4	10	0.461
Female	21	412	14	17	

Discussion

With the development of implant restoration and orthodontic treatment, the necessity of preoperative CBCT evaluation of alveolus is increasing for minimizing the treatment risks and maximizing the aesthetic effects [18, 19]. Classifications and quantitative measurements reflect the three-dimensional morphologic features of alveolar bone. Regarding the classification of alveolar bone morphology in maxillary incisor area, there were different criteria [12, 13, 25]. Zhu et al. [25] used root orientation and bone shape as two main criteria, and proposed anatomical classification of maxillary incisors into five types. In the present study, however, sagittal bone shape was used as the main criterion. Although ≥ 2 mm buccal alveolar plates were needed for maintaining soft tissue retraction, and preventing bone against fenestration and dehiscence, merely ≤ 3% of the population met this criterion [16]. Chappuis et al. [4] defined a facial bone thickness ≤ 1 mm as a thin-walled type, which was proved to have obvious vertical bone absorption. Morton et al. [15] suggested that immediate implantation should be selected for cases with the thickness of bone plate thicker than 1 mm and sufficient bone of the extraction socket base. In the study of Braut et al. [2], the buccal alveolar plates of the maxillary incisors with a thickness of about 0.5–0.6 mm were severely resorbed. Hence, bone plate thickness < 0.5 mm was considered as an important factor for definition of alveolus type 2–4 in the present study. Also, concavity was regarded

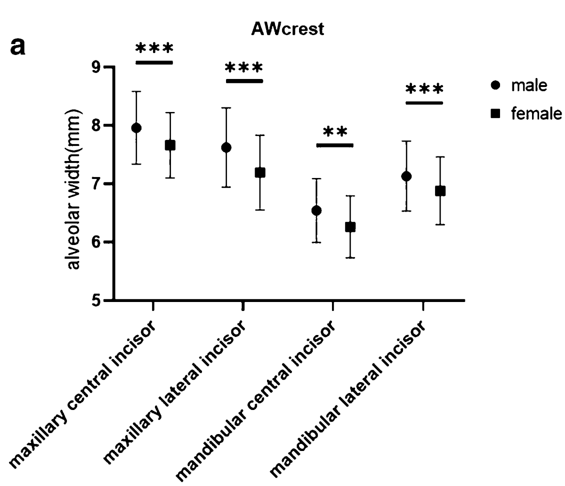


Fig. 7 High-low graphs for gender differences of alveolar widths. **a**.AWcrest; **b**.AWapex

Table 4 Relationship between alveolus types and molar relationships

Angel's classification	Type 1	Type 2	Type 3	Type 4	*P* value
Maxillary central incisor					
Class I	300	82	2	–	0.059
Class II	85	29	2	–	
Class III	117	19	0	–	
Maxillary lateral incisor					
Class I[b]	45	330	9	–	0.012
Class II[a]	22	88	6	–	
Class III[a]	29	105	2	–	
Mandibular central incisor					
Class I[a]	95	255	12	22	0.002
Class II[a]	38	73	3	2	
Class III[b]	20	93	9	14	
Mandibular lateral incisor					
Class I[a]	16	342	10	16	0.008
Class II[b]	14	97	2	3	
Class III[a]	2	120	6	8	

[a,b]Same superscript letters indicate no significant difference

as another criterion for classification (type 2, 3), considering the risks of intraoperative fenestration or necessity of horizontal bone augmentation [11]. Type 1 in the present study was similar to type III and type V suggested by Zhu [25], and type 2 was similar to type II. However, types 3 and 4 were not mentioned in Zhu's report [25]. Furthermore, our study focused on the bone shape of relatively healthy dentition, and the evaluation was closer to the natural morphology of the alveolus. It can be speculated that in most cases, type 1 had sufficient bone for immediate implantation, and type 3–4 alveolar ridges were vulnerable for implantation. In type 2 cases, horizontal bone augmentation or change of implant angulation was often needed [15]. What's more, the risk of bone fenestration and dehiscence in orthodontic procedures could be higher in type 2–4 of this classification [18]. The 4-type classification system, which mainly concerned the bone plate thickness and sagittal shape of relatively healthy dentition, was obviously simple, and could be adopted for both maxillary and mandibular incisive regions.

In the present study, the prevalence of type 1 alveolus was 78.9% in maxillary central incisors. Among maxillary central incisors, type 1 alveolus had the widest AWcrest and AWapex, moreover, Ratio of alveolar width was < 1 in 72.5%. This meant that approximately 3/4 of maxillary central incisors had naturally good basis for implantation [1]. In maxillary lateral incisors, it was reported that increased buccolingual angulation was related to a thinner apical bone plate [6]. Similar results were found in the present study. The prevalence of type 2 alveolus was 82.2%, and ratio of alveolar width was > 1 in 41.0%. This implied that over 40% of maxillary lateral incisors had a thinner alveolar width in the apical region, and special caution should be taken to obviate intraoperative fenestration. The definite mechanisms might be related to differences of tooth development, eruption, occlusal function, and alveolar process remodeling [24].

Classification of mandibular incisive alveolus was relatively rare. The bone plate and buccolingual width were relatively thin, therefore, the risks of the buccal and lingual cortex perforation were increased [21]. Usually, fine-diameter implants were used in mandibular incisors, because buccolingual width was wider than mesiodistal width. Perforation of the lingual cortex may damage the sublingual vessels with serious consequences [9]. Our results showed that in mandibular central incisors, the prevalence of type 2 alveolus was 66.2% and ratio of alveolar width was > 1 in 35.8%. In mandibular lateral incisors, the prevalence of type 2 alveolus was 87.9% and Ratio of alveolus width was > 1 in 42.1%. It was obvious that approximately 40% of mandibular incisors lacked strong bone base in the apical region, which might lead to side effects in orthodontic and implantation procedures [3, 21].

In previous reports, root position and angulation had been used as important classification criteria [12, 13, 25]. Kan et al. [12] classified maxillary anterior alveolus into four classes according to the root positions relative to labial or palatal cortical plate. Yang et al. [23] found that most of the maxillary anterior tooth root of Chinese Han youth was positioned against labial cortical plate, and the labial bone plate was thin and palatal basement was well sufficient. Lau et al. [13] classified the alveolar ridges of maxillary central incisors into three types according to the bone thickness in the mid-root, and into another three types according to root position and angulation. The result showed that 78.8% of the roots were positioned closer to the buccal alveolar surface. In the present study, as for maxillary central incisors, buccal type orientations were present in 72.7% of type 1 and in 90.8% of type 2 ridges, while palatal/lingual type was not found. In addition, labial orientations were present in > 70% of lateral incisors. These findings were consistent with the former reports [23]. What's more, midway type orientations were commonly found in mandibular central (75.8%) and lateral incisors (73.7%). It should be noted that the root orientation was not taken as a classification standard in our classification system, considering that the classification might be more complicated, and central and lateral incisors could not be effectively differentiated.

In previous reports, studies evaluating gender and age differences of alveolar thickness were occasionally found [5, 14, 20]. Uner et al. [20] found that alveolar bone thickness was thicker in men than women and age difference was not evident. Cho et al. [5] did not found significant gender differences in the measurement of alveolar bone crest. Morad et al. [14] reported that male had thicker buccal bone plate in maxillary incisors, but there was no significant gender difference in mandibular incisors. Moreover, they found that middle-aged patients had thicker buccal bone plate than younger and elder groups, and attributed this to buccal bone resorption. In the present study, AWcrest and AWapex were thicker in males than females among all maxillary and mandibular incisors, and type 1 occurred more frequently in males than females among maxillary lateral incisors and mandibular central incisors. Further, the width of mandibular incisive alveolus tended to decrease with age, which was different from the aforementioned. Although the definite reason was still unknown, ageing change might explain the differences [10].

It was reported that even if there was compensation for incisors in skeletal Class I–III, there were no significant differences in the thickness and height of alveolus [3]. Eraydin observed that the mandibular anterior alveolar ridge of the high-angled Class III individuals was thinner [8]. Our measurement showed that, in the maxillary lateral incisor and mandibular incisor sites, the distributions of alveolus type were significantly different among three molar relationships. These results had not yet been reported, and further study was needed for elucidation of the mechanisms.

Conclusion

A 4-type classification system was proposed for alveolus morphology in the incisive region. Type 1 alveolus was thick and sufficient for implant and orthodontic treatment, and was frequently observed in maxillary central incisors. Type 2 alveolus had mono-plate concavity, and was common in the other incisor sites. Type 3–4 alveolus was relatively scarce, and was vulnerable for implantation and orthodontic treatment. As for maxillary central incisors, prevalence of type 1 tended to decrease with age. At all maxillary and mandibular incisor sites, alveolus widths were significantly thicker in males than in females. At maxillary lateral incisor and mandibular incisor sites, prevalence of alveolus type was significantly different among three molar relationships. Identification of these morphologic characteristics might play a significant role in the relevant clinical procedures.

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