A New Classification System for Alveolar Bone Morphology around Maxillary Incisors in Adult Patients with Maxillary Protrusion

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Objective: *To develop a new alveolar bone morphology classification for maxillary incisors in patients with maxillary protrusion, and to investigate the association of alveolar morphology with skeletal patterns and alveolar bone defects following retraction.*

Methods: *A retrospective study of CBCT scans was performed for 250 patients with maxillary protrusion. The morphology of alveolar bone around maxillary incisors was classified into four types: A1 (upright maxillary incisor in thin alveolar bone), A2 (lingually inclined maxillary incisor in thin alveolar bone), B1 (upright maxillary incisor in thick alveolar bone) and B2 (lingually inclined maxillary incisor in thick alveolar bone). The association of alveolar types with different skeletal patterns and the incidence of post-treatment alveolar bone defects were analysed.*

Results: *For maxillary incisors in patients with maxillary protrusion, A1 was the most common alveolar type (33.4%), followed by A2 (28.5%), B1 (22.1%) and B2 (16.0%). Types B1 (34.4%) and A2 (42.2%) were the most common in maxillary central and lateral incisors, respectively. In high angle patients, A2 and A1 were the most common types for maxillary lateral (49.6%) and central incisors (41.2%), respectively. Additionally, types A1 and A2 were at greater risk of severe lingual dehiscence.*

Conclusion: *This is the first alveolar bone morphology classification for maxillary incisors in patients with maxillary protrusion. The alveolar types exhibited a significant association with skeletal patterns and the incidence of alveolar bone defects after retraction.*

Keywords: *alveolar bone morphology, classification, maxillary incisor*

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For patients with maxillary protrusion, extraction of the maxillary premolars followed by maxillary incisor retraction may improve facial harmony and aesthetics. The sagittal position of the maxillary incisors is considered crucial for treatment planning and facial profile evaluation. There are several methods for determining the ideal sagittal position of the maxillary incisors.[1-3] For example, Andrews[1] proposed six elements of orofacial harmony, and suggested the facial-axis point of the maxillary central incisor should be located at the forehead anterior limit line; however, these methods often neglect the alveolar bone morphology surrounding the maxillary incisors, which limits tooth movement. Exceeding these limits during maxillary incisor retraction can lead to alveolar bone defects, such as labial fenestration and lingual dehiscence, as reported by several studies using CBCT.[4,5] Thus, it is important to evaluate the alveolar bone morphology before initiating orthodontic treatment.

Current classification systems for assessing alveolar bone morphology surrounding the maxillary incisors

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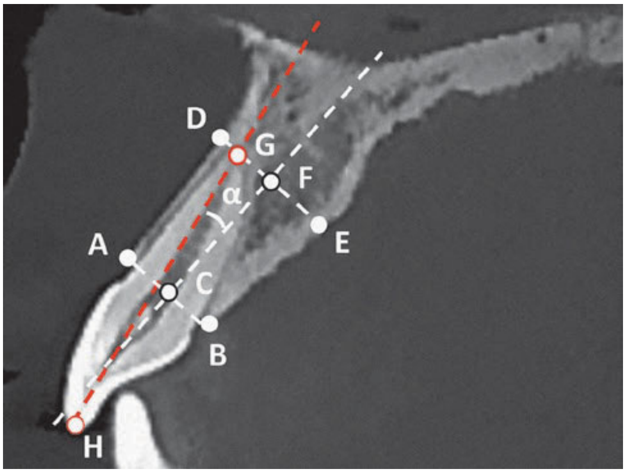

Fig 1 Measurement of alveolar bone thickness (AB, cervical alveolar bone thickness; DE, apical alveolar bone thickness) and maxillary incisor to alveolar bone inclination (angle α, angle between the line HG and the line CF).

are primarily focused on implant treatment. Kan et al[6] and Lau et al[7] classified alveolar bone morphology based on the labial and lingual bone thicknesses and tooth position and angulation for immediate implantation. However, there is a lack of studies regarding the classification of alveolar bone morphology within the context of maxillary incisor retraction in patients with maxillary protrusion.

The present study analysed the maxillary incisor position relative to the corresponding alveolar bone and introduced a new classification system for evaluating alveolar bone morphology in patients with maxillary protrusion. Due to the strong correlation of alveolar bone morphology, including alveolar thickness and tooth inclination, with sagittal and vertical skeletal patterns,[8,9] the present authors further evaluated the distribution of alveolar types across different skeletal patterns and analysed the prevalence of alveolar bone defects following retraction in each alveolar type.

Materials and methods

Participants

This study was approved by the Ethics Committee of Peking University School and Hospital of Stomatology (PKUSSIRB-202168141). Written informed consent was obtained from all participants. The inclusion criteria were age > 18 years, skeletal Class I/II (0° < ANB angle < 8°), maxillary jaw protrusion (SNA angle > 81°),[10] upper lip in front of the E-line (> 1 mm), orthodontic extraction treatment with maxillary incisor retraction (> 3 mm) and available pre- and post-treatment CBCT images. The exclusion criteria were maxillary incisors with obvious crowding (≥ 3 mm), root canal treatment or crowns, moderate to severe root resorption, periodontitis, trauma, tumours, cleft lip and/or palate, systemic disease, smoking and use of medication related to bone metabolism.

A total of 250 patients with maxillary protrusion from the Department of Orthodontics, Peking University School and Hospital of Stomatology were included retrospectively. Three orthodontists (Li WR, Huang YP and Guo RZ) performed the orthodontic treatment using MBT brackets with a 0.022” × 0.028” slot (3M Unitek, Monrovia, CA, USA). Sliding mechanics and one-step retraction were used to retract the maxillary incisors with 0.019” × 0.025” stainless steel. The four maxillary incisors in one patient were analysed separately, resulting in a total of 1,000 maxillary incisors.

CBCT imaging

The CBCT images were generated using a CBCT unit (NewTom VGi, Quantitative Radiology, Verona, Italy) with axial slice thickness 0.25 mm, field of view 16 × 16 cm and scan time 15 s. Raw DICOM data were then imported into Dolphin 3D Imaging software (Dolphin Imaging and Management Solutions, version 11.95 Premium, Chatsworth, CA, USA). The CBCT images of maxillary incisors were orientated by adjusting the axial slice to pass through the cementoenamel junction, with the sagittal slice passing through the long axis of the maxillary incisor (a line connecting the midpoint of the incisal edge and the root apex). The sagittal view of the maxillary incisor acquired in this way was used for further analysis.

Evaluation of alveolar bone morphology

To assess the pre-treatment sagittal root position of maxillary incisors relative to the surrounding alveolar bone, maxillary incisor to alveolar bone inclination and alveolar bone thickness (ABT) at the cervical and apical levels were assessed (Fig 1). The angle between the long axis of the tooth (a line connecting the midpoint of incisal edge and the root apex) and the alveolar bone axis (a line connecting the midpoints of the alveolar bone at the crest and apical levels) was selected as maxillary incisor to alveolar bone inclination.

Alveolar bone defects of the maxillary incisor after retraction, including labial fenestration and lingual dehiscence, were analysed. Labial fenestration was defined as a bone defect involving exposure of the

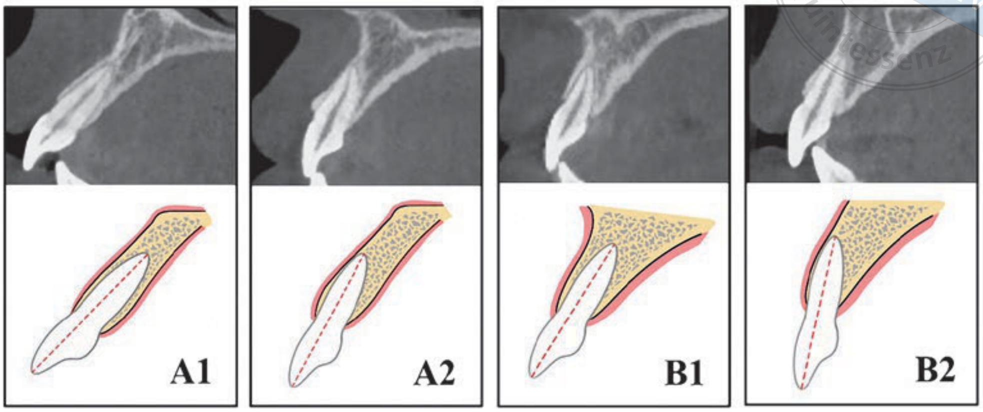

Fig 2 CBCT images and schematic diagrams of four alveolar types (A1, A2, B1 and B2).

labial root surface, lacking a cortical covering, but without involving the alveolar crest.[11] Lingual dehiscence was defined as a defect where the crest of the labial alveolar bone was at least 4 mm apical to that of the interproximal alveolar bone, and was further classified into no or mild, moderate and severe categories (lingual alveolar crest within the cervical, middle and apical thirds of the root, respectively).[12]

New alveolar bone morphology classification

Based on the ABT, alveolar bone morphology of maxillary incisors was initially classified into types A and B, having thin (ABT at apical level less than that at cervical level) and thick alveolar bone (ABT at apical level greater than that at cervical level), respectively. Subtype classification was based on the maxillary incisor to alveolar bone inclination, as reported by Jin et al[13] and Petaibunlue et al.[14] Subtype 1 included maxillary incisors that were upright above the alveolar bone (maxillary incisor to alveolar bone inclination < 20°), whereas subtype 2 included lingually inclined maxillary incisors relative to the alveolar bone (maxillary incisor to alveolar bone inclination ≥ 20°). According to the clinical findings, there were no labially inclined maxillary incisors relative to the alveolar bone (maxillary incisor to alveolar bone inclination < 0°). Altogether, the classification system for alveolar bone morphology of maxillary incisors comprised four alveolar types (A1, A2, B1 and B2) (Fig 2).

Subgroup analysis

To analyse the distribution of the four alveolar types with different sagittal and vertical skeletal patterns, the 250 patients were divided into subgroups according to ANB and SN-MP values. Skeletal Classes I and II were defined as 0° < ANB < 5° and ANB ≥ 5°, respectively. Average, low and high angle skeletal patterns were defined as 28° < SN-MP < 37°, SN-MP ≤ 28° and SN-MP ≥ 37°, respectively. Additionally, the prevalence of post-treatment alveolar bone defects among the four alveolar types was analysed.

Statistical analysis

Twenty patients were randomly selected for reproducibility analysis. The pre-treatment alveolar bone morphology classification and post-treatment alveolar bone defect diagnosis were assessed independently by two examiners (Guo RZ and Qin QY) and repeated after 2 weeks. The intra- and inter-examiner agreements were assessed using a weighted Cohen kappa test. The new classification system showed excellent intra- and inter-examiner agreement (0.962 and 0.974, respectively). For the diagnosis of post-treatment alveolar bone defects, the intra- and inter-examiner agreement was also satisfactory (0.924 and 0.939, respectively). A chi-square test was applied to compare the distribution of alveolar types among groups. Statistical analyses were conducted using SPSS Statistics software (version 26; IBM, Armonk, NY, USA). The level of statistical significance was set at 0.05.

Results

Distribution of alveolar types among maxillary incisors

The basic characteristics of the participants are shown in Table 1. The alveolar bone morphology surrounding the maxillary incisors was predominantly characterised as type A (61.9%), whereas type B accounted for 38.1% (Table 2). Among the four types, A1 (33.4%) was

Table 1 Demographic information of patients included in the study.

Measurements	Mean ± SD
Age (y)	25.30 ± 5.70
Sex (male/female)	29/221
Angle classification (Class I/Class II)	191/59
Vertical overlap (mm)	1.35 ± 1.20
Horizontal overlap (mm)	4.19 ± 1.82
SNA (°)	86.26 ± 2.89
ANB (°)	5.96 ± 2.19
SN-MP (°)	37.00 ± 6.37
U1-SN (°)	110.19 ± 6.40
Nasolabial angle (°)	93.96 ± 10.57

the most common, followed by A2 (28.5%), B1 (22.1%) and B2 (16.0%). The distribution of alveolar types varied significantly between the maxillary central and lateral incisors. Types A1 (33.6%) and B1 (34.4%) were most common around maxillary central incisors, whereas A2 (42.2%) and A1 (33.2%) were most common around maxillary lateral incisors.

Alveolar type distribution in different skeletal patterns

As shown in Table 3, the distribution of the four alveolar types differed significantly between skeletal Class I and Class II patients for both the maxillary central incisor ($P = 0.038$) and lateral incisor subgroups ($P = 0.002$). Skeletal Class II participants had a higher proportion of type 2 alveolar bone (maxillary central incisor 35.3%; maxillary lateral incisor 58.7%) compared to Class I patients (maxillary central incisor 23.2%; maxillary lateral incisor 52.3%). For maxillary lateral incisors, type A1 was more common in skeletal Class I patients (37.3%), whereas type A2 was the most common alveolar type in skeletal Class II patients (46.7%).

Significant differences were also observed in alveolar type distribution among the vertical skeletal patterns ($P < 0.001$ for both maxillary central and lateral incisors). For maxillary central incisors, type B accounted for 56.3%, 78.5% and 44.4% of the average, low and high angle patients, respectively. Regarding the subtypes, B1 was the most common alveolar type in average (41.0%) and low angle (67.9%) patients, whereas A1 was the most common in high angle patients (41.2%). For maxillary lateral incisors, type A was the most common alveolar type in all vertical skeletal patterns. Types A2 (49.6%) and A1 (36.8%) accounted for the majority of high angle patients. Type B was more common in low angle patients (46.4%) compared to average (34.2%) and high angle (13.6%) patients.

Prevalence of alveolar bone defects among alveolar bone morphological types

Following maxillary incisor retraction, the "no or mild lingual dehiscence" category accounted for the majority of type B1 (maxillary central incisor 72.7%; maxillary lateral incisor 61.2%) and B2 cases (maxillary central incisor 62.8%; maxillary lateral incisor 41.9%) (Table 4). Compared to other types, A1 and A2 were at greater risk of severe lingual dehiscence (maxillary central incisor 25.0% and 24.3%; maxillary lateral incisor 31.9% and 40.8%, respectively). Type B1 had the lowest prevalence of labial fenestrations (maxillary central incisor 4.6%; maxillary lateral incisor 14.3%), whereas type B2 in maxillary lateral incisors had the highest prevalence of 27.0%.

Discussion

For patients with maxillary protrusion, maxillary incisor retraction can enhance aesthetics, but it poses a risk of alveolar bone defects. Several CBCT studies have reported a high incidence of alveolar bone defects following maxillary incisor retraction.[15,16] The present authors' previous research demonstrated that the lingual cortical bone was a critical boundary for maxillary incisor retraction, with lingual dehiscence occurring once teeth breached this boundary.[5] Consequently, there is an increasing emphasis on the use of CBCT for evaluating the pre-treatment alveolar bone morphology to minimise the occurrence of alveolar bone defects.[17,18]

Existing classification criteria for alveolar bone morphology of maxillary incisors focus primarily on implant treatment, often taking ABT and tooth position into consideration. Kan et al[6] previously proposed four types of alveolar bone morphology based on the labial and lingual ABT. The present classification system simplified ABT into thin (type A) and thick (type B) types. A previous study reported predominantly thin labial alveolar bone in patients with maxillary protrusion, consistent with the present findings.[19] The labial ABT was thin in both types A and B, whereas the lingual ABT in types A and B was thin and thick, respectively. Due to alveolar bone remodelling, the labial ABT remained relatively stable and the lingual ABT significantly decreased during maxillary incisor retraction. Regarding tooth position, Zhang et al[20] classified it as the root being positioned against the labial cortex, against the lingual cortex or in the centre of the alveolar housing. Orthodontic treatment aims to maintain an upright position of the maxillary incisors within the alveolar bone during retraction. Therefore, the present

Table 2 Distribution of alveolar types among maxillary incisors.

Tooth	Type A1	Type A2	Type B1	Type B2	*P* value
Maxillary incisor	33.4% (334/1,000)	28.5% (285/1,000)	22.1% (221/1,000)	16.0% (160/1,000)	
Maxillary central incisor	33.6% (168/500)	14.8% (74/500)	34.0% (172/500)	17.2% (86/500)	< 0.001
Maxillary lateral incisor	33.2% (166/500)	42.2% (211/500)	9.8% (49/500)	14.8% (74/500)	

Table 3 Distribution of alveolar type in different skeletal patterns.

Skeletal pattern		Maxillary central incisor					Maxillary lateral incisor				
		Type A1	Type A2	Type B1	Type B2	*P* value	Type A1	Type A2	Type B1	Type B2	*P* value
Sagittal skeletal type	Skeletal Class I	34.3% (46/134)	11.9% (16/134)	42.5% (57/134)	11.3% (15/134)	0.038*	37.3% (50/134)	29.9% (40/134)	10.4% (14/134)	22.4% (30/134)	0.002*
	Skeletal Class II	33.3% (122/366)	15.9% (58/366)	31.4% (115/366)	19.4% (71/366)		31.7% (116/366)	46.7% (171/366)	9.6% (35/366)	12.0% (44/366)	
Vertical skeletal type	Average angle	27.0% (60/222)	16.7% (37/222)	41.0% (91/222)	15.3% (34/222)	< 0.001**	30.2% (67/222)	35.6% (79/222)	14.0% (31/222)	20.2% (45/222)	< 0.001**
	Low angle	17.9% (5/28)	3.6% (1/28)	67.9% (19/28)	10.6% (3/28)		25.0% (7/28)	28.6% (8/28)	25.0% (7/28)	21.4% (6/28)	
	High angle	41.2% (103/250)	14.4% (36/250)	24.8% (62/250)	19.6% (49/250)		36.8% (92/250)	49.6% (124/250)	4.4% (11/250)	9.2% (23/250)	

$^*P < 0.05$, $^{**}P < 0.001$.

Table 4 Prevalence of alveolar bone defects among alveolar bone morphological types.

Alveolar type		No or mild lingual dehiscence	Moderate lingual dehiscence	Severe lingual dehiscence	Labial fenestration	*P* value
Maxillary central incisor	Type A1	48.8% (82/168)	13.7% (23/168)	25.0% (42/168)	12.5% (21/168)	< 0.001
	Type A2	32.4% (24/74)	31.1% (23/74)	24.3% (18/74)	12.2% (9/74)	
	Type B1	72.7% (125/172)	16.9% (29/172)	5.8% (10/172)	4.6% (8/172)	
	Type B2	62.8% (54/86)	12.8% (11/86)	12.8% (11/86)	11.6% (10/86)	
Maxillary lateral incisor	Type A1	27.1% (45/166)	19.3% (32/166)	31.9% (53/166)	21.7% (36/166)	< 0.001
	Type A2	21.8% (46/211)	19.4% (41/211)	40.8% (86/211)	18.0% (38/211)	
	Type B1	61.2% (30/49)	18.4% (9/49)	6.1% (3/49)	14.3% (7/49)	
	Type B2	41.9% (31/74)	17.6% (13/74)	13.5% (10/74)	27.0% (20/74)	

authors first used the alveolar bone axis as a reference and classified the alveolar bone into two subtypes, i.e., upright maxillary incisors (subtype 1) and lingually inclined maxillary incisors (subtype 2), based on the angle between the long axis of the tooth and the alveolar bone axis. To the best of the present authors' knowledge, this is the first classification system for alveolar bone morphology around maxillary incisors in patients with maxillary protrusion.

According to the present authors' new classification system, significant differences in alveolar bone morphology were observed between maxillary central and lateral incisors. Studies have reported that maxillary lateral incisors typically exhibit narrower alveolar bone widths compared with maxillary central incisors, particularly in the apical region, consistent with the present findings.[20,21] The prevalence of type A was 48.4% in maxillary central incisors and 75.4% in maxillary lateral incisors. Jin et al[13] reported that maxillary central incisors were positioned upright within the alveolar bone in 74.67% of men and 84.66% of women. The present results indicated that types B1 and A1 were more common in maxillary central incisors, whereas type A2 was more common in maxillary lateral incisors. Aside from the thinner alveolar bone, maxillary lateral incisors also exhibited a lingual inclination relative to the alveolar bone axis.

Differences in alveolar bone morphology among different skeletal patterns have been reported. Dalaie et al[8] reported that high angle individuals often presented with thinner alveolar bone around maxillary central incisors. Similarly, Son et al[22] demonstrated that Class II malocclusions with a high angle and normal maxillary incisor inclination were a risk factor for lingual bone loss. In line with these findings, the present study demonstrated that type A was more common in high angle patients, whereas type B was more common in those with average and low angle patterns. In high angle patients, A1 and A2 were the most common types in the maxillary central and lateral incisors, respectively. Regarding the sagittal skeletal patterns, Class II patients had a higher proportion of type 2 alveolar bone compared to Class I patients because of the compensatory lingual inclination of maxillary incisors in Class II patients. Thus, the vertical skeletal pattern primarily influenced the ABT, whereas the sagittal skeletal pattern influenced the maxillary incisor position.

The incidences of alveolar bone defects, including lingual dehiscence and labial fenestration, among the four types were further evaluated. Compared to maxillary incisors with type B alveolar bone, those with type A bone were at a greater risk of lingual dehiscence following retraction. In particular, the incidence rates of severe lingual dehiscence in maxillary lateral incisors with type A1 and A2 bone were 31.9% and 40.8%, respectively. Sheng et al[4] demonstrated that the apex to labiolingual ABT before orthodontic treatment was inversely related with the risk of bone defect occurrence. Hence, excessive retraction of maxillary incisors with type A bone should be performed cautiously. Labial fenestration is another common alveolar bone defect during maxillary incisor retraction. The present authors found that the incidence of labial fenestration in maxillary lateral incisors was higher than that in maxillary central incisors. In addition, labial fenestration was more common in maxillary incisors with subtype 2 compared to those with subtype 1. Subtype 2 often requires torque control in maxillary incisors to mitigate the risk of labial fenestration during long-distance retraction. Thus, a clear association was present between the original alveolar bone morphology and the occurrence of alveolar bone defects after treatment. It is therefore essential to evaluate the initial condition of the alveolar bone using CBCT scans before proceeding with orthodontic treatment. This classification system could enhance the predictability of alveolar bone defects following maxillary incisor retraction and facilitate clinical decision-making.

Several considerations require emphasis during the application of this classification. The retraction distance of maxillary incisors was not considered. Hence, the reported predictability of alveolar bone defects following maxillary incisor retraction was preliminary. Additionally, there were no cases of labial bone dehiscence or lingual bone fenestrations in this study. Consequently, these defects could not be analysed. In these 250 patients, there were no cases with labially inclined maxillary incisors relative to the alveolar bone. Further studies with larger sample sizes are needed to verify the present results and improve the classification. Meanwhile, analysis of the association between the classification system and other factors, such as age and sex, will also be performed in further studies.

Conclusion

A new classification of alveolar bone morphology around maxillary incisors for patients with maxillary protrusion was proposed in this study. A1 was the most frequently observed type, with A1 and B1 being common in maxillary central incisors, and A2 being more common in maxillary lateral incisors. The alveolar type surrounding the maxillary incisors was significantly associated with the skeletal patterns. Type A was the main alveolar type in high angle patients, whereas type B was more common in average and low angle patients. Skeletal Class II patients had a higher proportion of subtype 2 compared to skeletal Class I patients. Pre-treatment alveolar type was significantly associated with the occurrence of alveolar bone defects after treatment. Maxillary incisors with type A bone, particularly lateral incisors with type A2 bone, had a higher risk of lingual dehiscence following retraction.

Conflicts of interest

The authors declare no conflicts of interest related to this study.

Author contribution

Dr Qian Yi QIN contributed to the data analysis and manuscript draft; Drs Yun Fei ZHENG, Yi Ping HUANG, and Yi Fan LIN contributed to the CBCT data collection and statistical analysis; Dr Run Zhi GUO contributed to the study design and manuscript draft; Dr Wei Ran LI contributed to the study conception and manuscript revision.

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References

1. Andrews WA. AP relationship of the maxillary central incisors to the forehead in adult white females. Angle Orthod 2008;78:662–669.
2. Cao L, Zhang K, Bai D, Jing Y, Tian Y, Guo Y. Effect of maxillary incisor labiolingual inclination and anteroposterior position on smiling profile esthetics. Angle Orthod 2011;81:121–129.

3. Naini FB, Manouchehri S, Al-Bitar ZB, Gill DS, Garagiola U, Wertheim D. The maxillary incisor labial face tangent: Clinical evaluation of maxillary incisor inclination in profile smiling view and idealized aesthetics. Maxillofac Plast Reconstr Surg 2019;41:31.
4. Sheng Y, Guo HM, Bai YX, Li S. Dehiscence and fenestration in anterior teeth : Comparison before and after orthodontic treatment. J Orofac Orthop 2020;81:1–9.
5. Guo R, Li L, Lin Y, et al. Long-term bone remodeling of maxillary anterior teeth with post-treatment alveolar bone defect in adult patients with maxillary protrusion: A prospective follow-up study. Prog Orthod 2023;24:36.
6. Kan JY, Roe P, Rungcharassaeng K, et al. Classification of sagittal root position in relation to the anterior maxillary osseous housing for immediate implant placement: A cone beam computed tomography study. Int J Oral Maxillofac Implants 2011;26:873–876.
7. Lau SL, Chow J, Li W, Chow LK. Classification of maxillary central incisors-implications for immediate implant in the esthetic zone. J Oral Maxillofac Surg 2011;69:142–153.
8. Dalaie K, Hajimiresmail YS, Safi Y, Baghban AA, Behnaz M, Rafsanjan KT. Correlation of alveolar bone thickness and central incisor inclination in skeletal Class I and II malocclusions with different vertical skeletal patterns: A CBCT study. Am J Orthod Dentofacial Orthop 2023;164:537–544.
9. Yagci A, Veli I, Uysal T, Ucar FI, Ozer T, Enhos S. Dehiscence and fenestration in skeletal Class I, II, and III malocclusions assessed with cone-beam computed tomography. Angle Orthod 2012;82:67–74.
10. El H, Palomo JM. An airway study of different maxillary and mandibular sagittal positions. Eur J Orthod 2013;35:262–270.
11. Evangelista K, Vasconcelos Kde F, Bumann A, Hirsch E, Nitka M, Silva MA. Dehiscence and fenestration in patients with Class I and Class II division 1 malocclusion assessed with cone-beam computed tomography. Am J Orthod Dentofacial Orthop 2010;138:133.e1–e7.
12. Davies RM, Downer MC, Hull PS, Lennon MA. Alveolar defects in human skulls. J Clin Periodontol 1974;1:107–111.
13. Jin L, Bishuang P, Yulan X, Chengze W, Gang W, Jing L. The influence of angulation of maxillary anterior teeth on treatment design of dental implants [in Chinese]. Hua Xi Kou Qiang Yi Xue Za Zhi 2016;34:611–616.
14. Petaibunlue S, Serichetaphongse P, Pimkhaokham A. Influence of the anterior arch shape and root position on root angulation in the maxillary esthetic area. Imaging Sci Dent 2019;49:123–130.
15. Ahn HW, Moon SC, Baek SH. Morphometric evaluation of changes in the alveolar bone and roots of the maxillary anterior teeth before and after en masse retraction using cone-beam computed tomography. Angle Orthod 2013;83:212–221.
16. Yang CYM, Atsawasuwan P, Viana G, et al. Cone-beam computed tomography assessment of maxillary anterior alveolar bone remodelling in extraction and non-extraction orthodontic cases using stable extra-alveolar reference. Orthod Craniofac Res 2023;26:265–276.
17. Leung CC, Palomo L, Griffith R, Hans MG. Accuracy and reliability of cone-beam computed tomography for measuring alveolar bone height and detecting bony dehiscences and fenestrations. Am J Orthod Dentofacial Orthop 2010;137: S109–S119.
18. Kapila SD, Nervina JM. CBCT in orthodontics: assessment of treatment outcomes and indications for its use. Dentomaxillofac Radiol 2015;44:20140282.
19. Tsigarida A, Toscano J, de Brito Bezerra B, et al. Buccal bone thickness of maxillary anterior teeth: A systematic review and meta-analysis. J Clin Periodontol 2020;47:1326–1343.
20. Zhang LQ, Zhao YN, Zhang YQ, Zhang Y, Liu DG. Morphologic analysis of alveolar bone in maxillary and mandibular incisors on sagittal views. Surg Radiol Anat 2021;43:1009–1018.
21. Zhang W, Skrypczak A, Weltman R. Anterior maxilla alveolar ridge dimension and morphology measurement by cone beam computerized tomography (CBCT) for immediate implant treatment planning. BMC Oral Health 2015;15:65.
22. Son EJ, Kim SJ, Hong C, et al. A study on the morphologic change of palatal alveolar bone shape after intrusion and retraction of maxillary incisors. Sci Rep 2020;10:14454.