Original Article

Vertical Skeletal Pattern influences Alveolar bone Thickness in the Anterior Mandible of Thais

Phuntin Uengkajornkul[1], Korapin Mahatumarat[1], Soontra Panmekiate[2]

[1]Department of Orthodontics, Faculty of Dentistry, Chulalongkorn University, Bangkok

[2]Department of Radiology, Faculty of Dentistry, Chulalongkorn University, Bangkok

Abstract

This study evaluated the alveolar bone thickness (ABT) of the mandibular incisors in Thais with different vertical skeletal patterns. One hundred and thirty-five patients (average age 24.2 years) were divided into three groups according to their vertical skeletal pattern (i.e. skeletal deepbite, skeletal normal bite, and skeletal openbite). The labial and lingual ABTs of the mandibular incisors at 3 mm (cervical level) and 6 mm (mid-root level) apical to the cemento-enamel junction (CEJ) and at the root apices (apical level) were measured from cone-beam computed tomography images. One-way ANOVA was used to determine the differences in ABT between the groups at a 0.05 significance level. There were the differences in ABT between the three groups (p<0.001), with the greatest difference seen between the skeletal deepbite and openbite patients. The skeletal deepbite patients had the significantly thickest labial and lingual alveolar bones of the mandibular incisors followed by the skeletal normal bite and skeletal openbite patients, which were also significantly different from each other, at the lingual mid-root and total apical ABT. In conclusion, considering the alveolar bone as the boundary for tooth movement, greater movement of the mandibular incisors in an antero-posterior direction can be performed in skeletal deepbite patients, while skeletal openbite can undergo the least movement, mainly at the lingual mid-root and root apex levels.

Keywords: Alveolar bone thickness, Cone-beam computed tomography, Mandibular incisors, Vertical skeletal pattern

Received Date: Mar 12, 2019 **Revised Date:** Mar 27, 2019 **Accepted Date:** Apr 26, 2019

Doi: 10.14456/jdat.2019.41

Correspondence to:

Phuntin Uengkajornkul, Department of Orthodontics, Chulalongkorn University 34 Henri-Dunant Rd, Patumwan Bangkok 10330, Thailand. Tel: 0830366276 E-mail: phuntinu@gmail.com

Introduction

To achieve ideal tooth movement, the alveolar bone must adapt consistent with tooth movement, and cortical plate formation must equal the alveolar proper resorption. Hence, successful orthodontic tooth movement must occur within the confines of the alveolar bone. However, the amount of tooth movement that the alveolar bone can adapt to is limited. According to the Envelope of discrepancy model, which indicates the boundary for tooth movement,[1] the mandibular anterior region was the most restricted area for orthodontic tooth movement due to its relatively narrow width. Numerous studies found that deleterious side effects from orthodontic treatment; such as reduced alveolar bone thickness (ABT), bony dehiscences, and perforations of the cortical plate, were related to excessive movement of the mandibular incisors in the labial-lingual direction.[2-5]

Previous studies[6,7] measured the alveolar bone thickness at the anterior mandible to determine the allowable distance for tooth movement. These studies showed a very thin layer of labial and lingual alveolar bone in this area, especially at the upper half of root level. In addition, bony dehiscences and fenestrations at the mandibular incisors were frequently found in non-orthodontic patients.[8] Moreover, the severity of alveolar bone loss after orthodontic treatment was higher in patients who initially had thin alveolar bone.[9]

Vertical facial type is an anatomical factor that associated the alveolar bone thickness in the anterior mandible, especially at the apical level. Skeletal openbite (hyper-divergent) patients had thinner alveolar bone compared with skeletal normal bite (normo-divergent) and skeletal deepbite (hypo-divergent) patients. Some studies indicated that the ABT at the cervical to mid-root level were not different between the three vertical facial types.[10-12] However, Hoang *et al.,*[13] found a difference in ABT at the alveolar crest level between the three vertical skeletal patterns. Although a skeletal openbite is strongly associated with thin alveolar bone, a very thin alveolus was found in every vertical skeletal pattern.[14] However, the association between vertical skeletal type and ABT in a Thai population has not been evaluated.

Cone-beam computed tomography (CBCT) is commonly used for three-dimensional structural examination in orthodontics. The data from CBCT images can solve some problems that are found in conventional lateral cephalometry (a two-dimensional image) such as structural overlapping and magnification error. The anterior mandible is a three-dimensional structure, which consists of four incisors. Therefore, the alveolar bone thickness of each tooth, which could not be exactly measured using conventional lateral cephalometry, can be examined individually with CBCT. Moreover, the accuracy of the dimensional measurements from CBCT images correspond with actual structure sizes, thus clinicians and researchers can get better qualitative and quantitative data from CBCT.[15-16]

The aim of this study was to evaluate the labial and lingual ABT of the mandibular incisors at the cervical to apical levels between groups with different vertical skeletal patterns using CBCT in a Thai population.

Materials and Methods

The study protocol was approved by the Ethics Committee of the Faculty of Dentistry, Chulalongkorn University (HREC-DCU 2018-041). One hundred and thirty-five patients at the Faculty of Dentistry, Chulalongkorn University (65 males and 70 females; age 24.17 ± 5.04 years) whose CBCT images were acquired from August 2013 to April 2018 for maxillary impacted or embedded teeth localization and implant placement treatment planning, were selected using the following inclusion criteria: 1. age 18–30 years-old, 2. no previous orthodontic treatment, 3. full permanent dentition of the mandibular arch without severe rotation or more than 3 mm of mandibular incisor crowding, 4. without oral pathology or periodontal disease of the mandibular arch, and 5. the landmarks used in the study were clearly visible on the CBCT image. The sample size was calculated based on a previous study[13] at a 0.05 significance level and 80 % power using program G* power version 3.1.9.2. This calculation indicated that 28 patients were required per group.

The CBCT images were obtained using a 3DX Accuitomo 170 machine (J. Morita, Kyoto, Japan) with 90 kVp, 5 mA, and 17.5 sec scanning time. The field of view of the CBCT images was 8 x 8 cm with a 0.165 mm voxel size. The patients were divided to three groups (45 patients/group) based on vertical skeletal pattern (skeletal deepbite: 22 males, 23 females, skeletal normal bite: 22 males, 23 females, and skeletal openbite: 21 males, 24 females). The Thai norms for the palatal plane-mandibular plane (PP-MP) angle[17] were used to categorize the patients (skeletal deepbite < 21°, skeletal normal bite = 21°–29°, and skeletal openbite > 29°) (Fig. 1). Furthermore, the Wits appraisal analysis was used to identify the sagittal maxillo-mandibular relationship (Fig. 2).[18]

Infinitt proprietary software v.2 (Infinitt Co., Seoul, Republic of Korea) was used for examining and measuring the CBCT images by a single operator who had been trained and supervised by a board certified oral and maxillofacial radiologist. A 1 mm slice thickness was used for bone thickness measurement. The sagittal slice was set along the long axis of each tooth and aligned perpendicular to the alveolar ridge curvature. The labial and lingual ABTs of the four mandibular incisors were measured perpendicular to the long axis of each tooth from the root surface to the external limit of the mandibular labial and lingual cortical bones at 3 mm (cervical level) and 6 mm (mid-root level) apical to the cemento-enamel junction (CEJ) and at the root apices (apical level) (Fig. 3).

One month after the first measurement, 20 % of the patients were randomly selected. The same operator measured all variables to determine Intra-rater reliability.

Statistical analysis was performed using SPSS v.22.00 (SPSS Inc., Chicago, IL, USA). The significance level was set at 0.05. The Kolomgorov-Smirnov test verified the normal distribution of all variables. The ABTs of the same patient were compared between the left and right teeth and between the central and lateral incisors using the independent *t*-test. The difference between the male and female patients' variables were analyzed using the independent *t*-test. One-way ANOVA and Tukey's post-hoc test were performed to determine the differences in the ABTs of the mandibular incisors between the three vertical skeletal pattern groups.

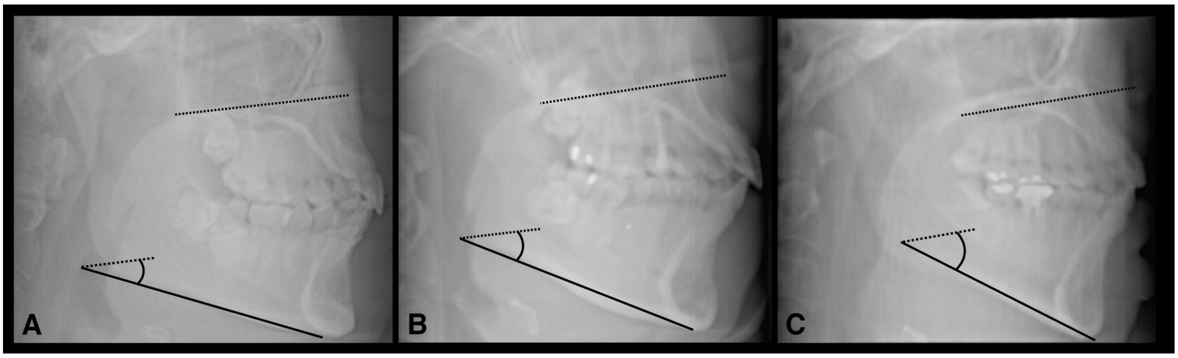

Figure 1 *PP-MP angle measurement in a sagittal maximum intensity projection view of the CBCT image. (A) skeletal deepbite patient, (B) skeletal normal bite patient, and (C) skeletal openbite patient.*

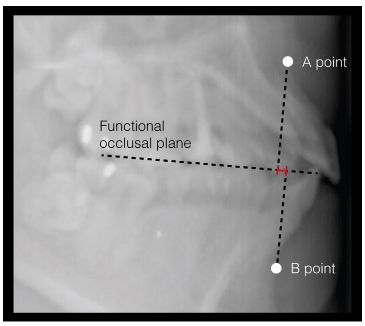

Figure 2 *Wits appraisal analysis, the distance between projecting point A and B in perpendicular lines along the functional occlusal plane, in a sagittal maximum intensity projection view of the CBCT images.*

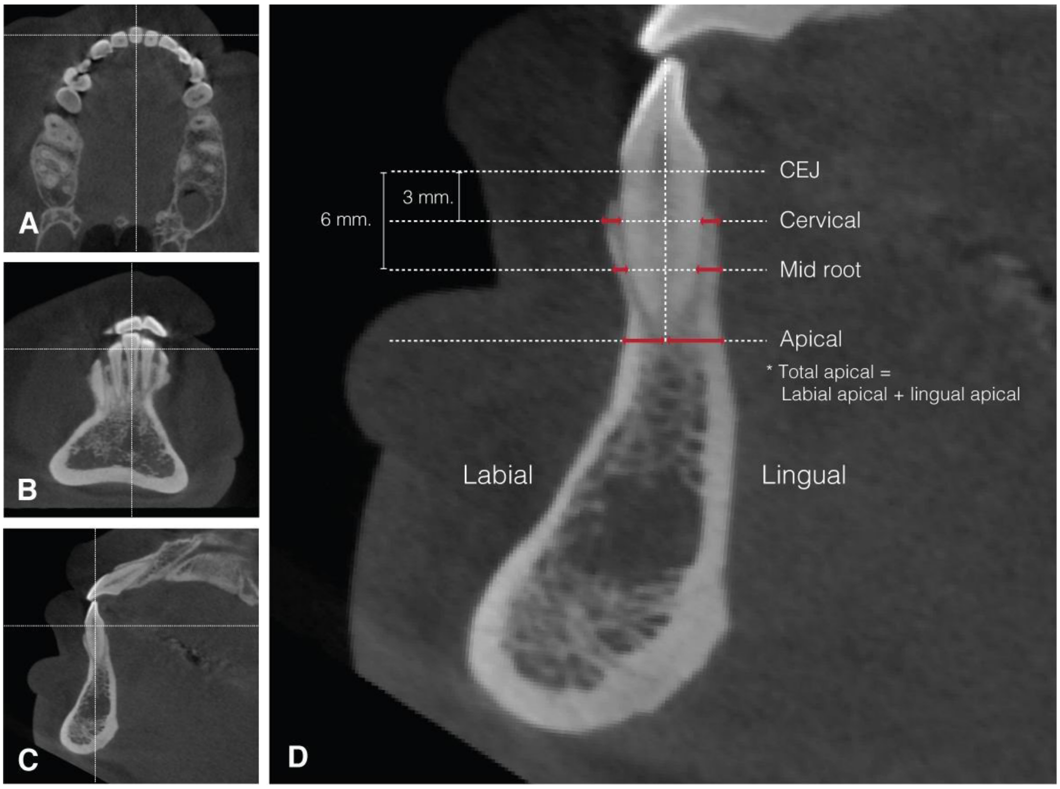

Figure 3 *(A-C) The multiplanar reconstruction used to measure the ABT of the mandibular incisors. (D) Anteroposterior cross-section of the mandibular incisors. Bone thickness was measured perpendicular to the long axis of the tooth.*

Results

An intra-class correlation coefficient (ICC) of 0.87–0.97 was found, indicating excellent intra-rater reliability. There were no the significant differences between the ABTs of the left and right teeth and between male and female patients; thus, the data were combined for further statistical analysis. However, the ABT measurements between the central and lateral mandibular incisors were significantly different. Consequently, the measurements of the central and lateral incisors were analyzed separately.

The descriptive analysis of the patients is shown in Table 1. There were no significant differences in age or sagittal skeletal relationship between the three groups.

The results indicated that at the labial bone, the mean ABT at the cervical to mid-root level was less than 1 mm (Table 2).

There were no significant differences between the mean cervical ABT of the central or lateral incisors between three groups. At the mid-root level of the central incisors, the ABT in the skeletal deepbite group (0.61 ± 0.24 mm.) was significantly higher compared with the skeletal openbite group (0.46 ± 0.21 mm.). The apical alveolar bone of all groups was the thickest area of the labial plate and the mean skeletal deepbite group's ABT was significantly higher compared with the other groups (Table 2).

The lingual alveolar bone was the thinnest at the cervical level and tended to become thicker from the cervical to apical level in every group (Table 3). The mean ABTs in the skeletal deepbite group were significantly higher than those of the other groups, except for the skeletal normal bite group at the lingual cervical ABT of the central incisors and the lingual apical ABT of the central and lateral incisors. The skeletal openbite group's alveolar bone was the significantly thinnest at all levels, however there was no significant difference in lingual cervical ABT between the skeletal openbite and normal bite groups (Table 3).

When the labial and lingual apical ABTs were combined as total apical ABT, the difference between the three groups was significant (Table 4). The skeletal deepbite group demonstrated the thickest total apical alveolar bone (central incisor = 9.06 ± 1.37 mm. and lateral incisor = 9.37 ± 1.22 mm.) followed by the skeletal normal bite (central incisor = 8.07 ± 1.56 mm. and lateral incisor = 8.29 ± 1.53 mm.) and skeletal openbite (central incisor = 6.77 ± 1.47 mm. and lateral incisor = 7.24 ± 1.69 mm.) groups.

Table 1 *Means and standard deviations of age, vertical skeletal pattern, and antero-posterior skeletal pattern.*

Measurement	Overall	Deepbite	Normal bite	Openbite
Age (year)	24.17 ± 5.04	23.82 ± 4.78	25.27 ± 5.49	23.42 ± 4.74
PP-MP angle (°)	25.40 ± 7.10	17.43 ± 3.09	25.48 ± 1.20	33.30 ± 3.37
Wits appraisal(mm.)	-1.45 ± 4.43	-1.32 ± 4.10	-1.42 ± 4.37	-1.31± 4.89

Values were presented as mean ± standard deviation.

PP-MP angle, Angle formed between palatal plane and mandibular plane.

Mean values of age and Wits appraisal were not statistically significant different.

Table 2 *Comparison of the labial alveolar bone thickness between the three vertical skeletal patterns and the multiple comparison test results.*

Measurements (mm.)	Deepbite (D)	Normal bite (N)	Openbite (O)	ANOVA *p*-value	Tukey's tests Significantly different groups
Central incisor					
Labial-cervical (1)	0.86 ± 0.34	0.79 ± 0.34	0.75 ± 0.35	NS	-
Labial-mid root (2)	0.61 ± 0.24	0.52 ± 0.24	0.46 ± 0.21	0.012	D vs O
Labial-apical (3)	4.03 ± 1.21	3.48 ± 1.12	3.11 ± 0.79	< 0.001	D vs N , D vs O
ANOVA *P*-value	< 0.001	< 0.001	< 0.001		
Tukey's tests	1 vs 3	1 vs 3	1 vs 3		
Statiscally different groups	2 vs 3	2 vs 3	2 vs 3		
Lateral incisor					
Labial-cervical (1)	0.92 ± 0.36	0.85 ± 0.42	0.74 ± 0.34	NS	-
Labial-mid root (2)	0.44 ± 0.26	0.37 ± 0.17	0.34 ± 0.16	NS	-
Labial-apical (3)	4.39 ± 1.17	3.71 ± 1.13	3.39 ± 0.89	< 0.001	D vs N , D vs O
ANOVA *P*-value	< 0.001	< 0.001	< 0.001		
Tukey's tests	1 vs 3	1 vs 3	1 vs 3		
Statiscally different groups	2 vs 3	2 vs 3	2 vs 3		

Values were presented as mean ± standard deviation.

Table 3 *Comparison of the lingual alveolar bone thickness between the three vertical skeletal patterns and the multiple comparison test results.*

Measurements (mm.)	Deepbite (D)	Normal bite (N)	Openbite (O)	ANOVA *p*-value	Tukey's tests Significantly different groups
Central incisor					
Lingual-cervical (1)	0.81 ± 0.33	0.74 ± 0.32	0.65 ± 0.25	0.046	D vs O
Lingual-mid root (2)	1.53 ± 0.67	1.21 ± 0.52	0.89 ± 0.49	< 0.001	D vs N, D vs O, N vs O
Lingual-apical (3)	5.03 ± 1.29	4.60 ± 1.14	3.67 ± 1.31	< 0.001	D vs O, N vs O
ANOVA *P*-value	< 0.001	< 0.001	< 0.001		
Tukey's tests	1 vs 2,3	1 vs 3	1 vs 3		
Statiscally different groups	2 vs 3	2 vs 3	2 vs 3		
Lateral incisor					
Labial-cervical (1)	1.04 ± 0.35	0.82 ± 0.36	0.75 ± 0.34	< 0.001	D vs N, D vs O
Labial-mid root (2)	2.05 ± 0.71	1.47 ± 0.57	1.11 ± 0.65	< 0.001	D vs N, D vs O, N vs O
Labial-apical (3)	4.99 ± 1.30	4.58 ± 1.06	3.84 ± 1.39	< 0.001	D vs O, N vs O
ANOVA *P*-value	< 0.001	< 0.001	< 0.001		
Tukey's tests	1 vs 2,3	1 vs 2,3	1 vs 3		
Statiscally different groups	2 vs 3	2 vs 3	2 vs 3		

Values were presented as mean ± standard deviation.

Table 4 *Comparison of the total apical alveolar bone thickness between the three vertical skeletal patterns and the multiple comparison test results.*

Measurements (mm.)	Deepbite (D)	Normal bite (N)	Openbite (O)	ANOVA *p*-value	Tukey's tests Significantly different groups
Central incisor					
total apical	9.06 ± 1.37	8.07 ± 1.56	6.77 ± 1.47	< 0.001	D vs N, D vs O, N vs O
Lateral incisor					
total apical	9.37 ± 1.22	8.29 ± 1.53	7.24 ± 1.69	< 0.001	D vs N, D vs O, N vs O

Values were presented as mean ± standard deviation.

Discussion

The present study evaluated the ABT of the mandibular incisors between different vertical skeletal pattern groups. However, there are other factors related to alveolar bone thickness. A previous study[19] reported that ABT decreases as people age. Moreover, the amount of crowding impacts ABT, patients with mild crowding had thicker alveolar bone compared with those with severe crowding.[20] Hence, the subjects in our study were 18-30 years-old, and had only mild crowding (0-3 mm).

The small field of view (FOV) of the CBCT images (8x8 cm) used in this study did not cover the cranial base region to reduce the radiation dose to the patient.

Therefore, the palatal plane-mandibular plane (PP-MP) angle was used to identify the patients' vertical skeletal pattern rather than the Sella to Nasion-mandibular plane (SN-MP) angle. Petchdachai [17] reported a high correspondence between the PP-MP angle and other parameters, e.g. the Frankfurt horizontal plane and SN-MP angle, which are commonly used to identified the vertical skeletal pattern.

Although the absence of some anatomical landmarks that are used for cephalometric analysis is a disadvantage of using small FOV CBCT images, the small voxel size was an advantage in our study. The small FOV CBCT images provided higher spatial resolution and more clearly display the image details. Because our study investigated the ABT of the mandibular incisors, which is very thin, the small voxel size (0.165 mm) allowed for more accurate measurement compared with a larger size. However objects smaller than the voxel size cannot be identified on CBCT images because of partial volume effect. Therefore, alveolar bone that was thinner than 0.165 mm could not be detected using CBCT. For instance, some teeth that were actually covered by very thin alveolar bone were misdiagnosed as a bony dehiscence or fenestration by CBCT.[21] This limitation of CBCT analysis should be considered when it is used to estimate alveolar bone thickness.

The present study found differences in mandibular incisors' ABT between vertical skeletal pattern patients. Skeletal deepbite patients presented the thickest alveolar bone and skeletal openbite patients had the thinnest alveolus. Similar to previous studies[10-12], the difference in ABT between vertical skeletal relationships was found at the root apex, particularly for total apical ABT.

Although the previous studies[10-12] indicated that the thickness of the alveolar plates at the cervical to mid-root level was not different between vertical skeletal patterns, our study did find differences in ABT at these levels between the three groups. We found that, at the mid-root level of lingual alveolar bone, the skeletal openbite patients' ABT was the thinnest followed by the skeletal normal bite and skeletal deepbite patients. Additionally, at the cervical level, the skeletal openbite patients' lingual alveolar bone was significantly thinner compared with the skeletal deepbite patients at the central incisor and was significantly thinner than that of the skeletal deepbite and normal bite patients at the lateral incisor. These findings were similar to those of Hoang *et al.,*[13] The very thin bony support of the skeletal openbite patients might be a consequence of dentoalveolar compensation, because the teeth and alveolar bone over-erupted to maintain the overbite for the increased vertical skeletal dimension.[22]

Although the differences in ABT at the cervical to mid-root level were significant, our results indicated that the labial plate at the cervical to mid-root level and lingual plate at the cervical level were very thin (0.5–1 mm) in every vertical skeletal relationship. These results confirmed those of previous studies.[6,7,23] Therefore, clinicians should consider the labial alveolar bone thickness at the cervical to mid-root level and lingual alveolar bone at cervical level as less than 1 mm in all patients.

A previous study indicated that the alveolar bone was thicker going from the cervical to apical level.[24] The present study found a the similar pattern for the lingual alveolar bone. However, there was no significant difference in labial ABT between the cervical and mid-root level. Prior studies of postnatal growth of the mandibular symphyseal area[25-26] revealed that the lingual cortex of the anterior mandible, including the dentoalveolar process, underwent periosteal bone deposition during growth, whereas the labial side of the anterior mandible above the protuding chin experienced highly variable periosteal bone resorption, especially at the upper half root level. The difference in the bone remodeling between the labial and lingual cortex might explain why the lingual alveolar bone was thicker going from the cervical to apical level, however, the labial cervical ABT was not significantly different from the labial mid-root ABT.

Thin initial ABT is associated with negative consequences after orthodontic treatment.[2-5,13] To prevent deleterious effects such as alveolar bone loss, bony dehiscence, or fenestration, the pre-treatment alveolar bone thickness of the mandibular incisors should be considered as the boundary of orthodontic tooth movement, particularly in skeletal openbite patients. The type and amount of tooth movement should be initially planned based on the amount of ABT. For instance, when requiring lingual tooth movement, bodily tooth movement or controlled tipping should be selected instead of un-controlled tipping that might move the root apex penetrate the labial plate surface while the crown is moving lingually. Similarly, labial tooth movement should be performed using controlled tipping with a rotation center at the root apex instead of bodily tooth movement. Importantly, clinicians should use a low force for orthodontic tooth movement and carefully monitor the existing labial and lingual alveolar bone of the mandibular incisors throughout the treatment period.

If excessive tooth movement of the mandibular incisors beyond the boundary of the alveolar housing is desired, orthognathic surgery might be an appropriate treatment option.[27] Corticotomy-assisted orthodontic treatment is another option for increasing the amount of mandibular incisor tooth movement. A clinical study[28] reported that after tooth movement was completed, the alveolar bone reduction was less in patients treated with corticotomy alone or combined with bone grafting.

Studies have shown that the sagittal skeletal relationship was also related to the mandibular incisor's alveolar bone dimensions.[10,12] Due to the limited sample size, evaluating the effect of the sagittal skeletal relationship on ABT could not be included in this study. To expand our understanding of the influence of skeletal relationships on ABT of the mandibular incisors ABT, a future CBCT study using a larger sample size should investigate the differences in ABT in patients with all vertical and sagittal skeletal pattern combinations.

Conclusion

There were the differences in mandibular incisor ABT at various areas between the three vertical skeletal patterns. Skeletal deepbite patients had the thickest alveolar bone and those with skeletal openbite had the thinnest, particularly at the lingual mid-root and total apical levels. Thus, skeletal deepbite patients can tolerate more antero-posterior tooth movement in the mandibular incisor area. In contrast, skeletal openbite patients can tolerate limited movement of the mandibular incisor in antero-posterior direction, mainly at root apex level.

References

1. Proffit WR, Fields HW, Sarver DM. Contemporary Orthodontics. 5th ed. St Louis, Mo: Mosby Elsevier; 2012.
2. Sarikaya S, Haydar B, Ciger S, Ariyurek M. Changes in alveolar bone thickness due to retraction of anterior teeth. ***Am J Orthod Dentofacial Orthop*** 2002;122(1):15-26
3. Handelman CS. The anterior alveolus: its importance in limiting orthodontic treatment and its influence on the occurrence of iatrogenic sequalae. ***Angle Orthod*** 1996;66(2):95-109.
4. Wainwright WM. Faciolingual tooth movement: its influence on the root and cortical plate. ***Am J Orthod*** 1973;64(3):278-302.
5. Wehrbein H, Bauer W, Diedrich P. Mandibular incisors, alveolar bone, and symphysis after orthodontic treatment. A retrospective study. ***Am J Orthod Dentofacial Orthop*** 1996;110(3):239-46.
6. Gracco A, Luca L, Bongiorno MC, Siciliani G. Computed tomography evaluation of mandibular incisor bony support in untreated patients. ***Am J Orthod Dentofacial Orthop*** 2010;138(2):179-87.
7. Garib DG, Yatabe MS, Ozawa TO, Silva Filho OG. Alveolar bone morphology under the perspective of the computed tomography: Defining the biological limits of tooth movement. ***Dental Press J Orthod*** 2010;15(5):192-205.
8. 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(1):67-74.
9. Garlock DT, Buschang PH, Araujo EA, Behrents RG, Kim KB. Evaluation of marginal alveolar bone in the anterior mandible with pretreatment and posttreatment computed tomography in nonextraction patients. ***Am J Orthod Dentofacial Orthop*** 2016;149(2):192-201.
10. Baysal A, Ucar FI, Buyuk SK, Ozer T, Uysal T. Alveolar bone thickness and lower incisor position in skeletal Class I and Class II malocclusions assessed with cone-beam computed tomography. ***Korean J Orthod*** 2013;43(3):134-140.
11. Ponraj RR, Korath VA, Nagachandran, Vijayalakshmi D, Parameswaran R, Raman P, *et al.* Relationship of anterior alveolar dimensions with mandibular divergence in Class I malocclusion – A cephalometric study. ***J Clin Diagn Res*** 2016;10(5):29-33.
12. Molina-Berlanga N, Llopis-Perez J, Flores-Mir C, Puigdollers A. Lower incisor dentoalveolar compensation and symphysis dimensions among Class I and III malocclusion patients with different facial vertical skeletal patterns. ***Angle Orthod*** 2013;83(6):948-55.
13. Hoang N, Nelson G, Hatcher D, Oberoi S. Evaluation of mandibular anterior alveolus in different skeletal patterns. ***Progress in Orthodontics*** 2016;17:22.
14. Gama A, Vedovello S, Vedovello-Filho M, Lucato AS, Junior

MS. Evaluation of the alveolar process of mandibular incisor in Class I, II and III individuals with different facial patterns. ***UNOPAR Cient Ciênc Biol Saúde*** 2012;14(2):95-8.

15. Lagravère MO, Carey J, Toogood RW, Major PW. Three-dimensional accuracy of measurements made with software on cone-beam computed tomography images. ***Am J Orthod Dentofacial Orthop*** 2008;134(1):112-6.

16. Timock AM, Cook V, McDonald T, Leo MC, Crowe J, Benninger BL, *et al.* Accuracy and reliability of buccal bone height and thickness measurements from cone-beam computed tomography imaging. ***Am J Orthod Dentofacial Orthop*** 2011;140(5):734-44.

17. Petdachai S. CBCT and Dentistry: Airway volume in normal facial pattern. 1st ed. Bangkok: CU Printing House; 2017.

18. Jacobson A. The "Wits" appraisal of jaw disharmony. ***AM J Orthod*** 1975;67(2):125-38.

19. Koh KK, Tan JS, Nambiar P, Ibrahim N, Mutalik S, Khan Asif M. Age estimation from structural changes of teeth and buccal alveolar bone level. ***J Forensic Leg Med*** 2017;48:15-21.

20. Uysal T, Yagci A, Ozer T, Veli I, Ozturk A. Mandibular anterior bony support and incisor crowding: Is there a relationship? ***Am J Orthod Dentofacial Orthop*** 2012;142(5):645-53.

21. Sun L, Zhang L, Shen G, Wang B, Fang B. Accuracy of cone-beam computed tomography in detecting alveolar bone dehiscences and fenestrations. ***Am J Orthod Dentofacial Orthop*** 2015;147(3):313-23.

22. Anwar N, Fida M. Compensation for vertical dysplasia and its clinical application. ***Eur J Orthod*** 2009;31(5):516-22.

23. Foosiri P, Mahatumarat K, Panmekiate S. Relationship between mandibular symphysis dimensions and mandibular anterior alveolar bone thickness as assessed with cone-beam computed tomography. ***Dental Press J Orthod*** 2018;23(1):54-62.

24. Nauert K, Berg R. Evaluation of labio-lingual bony support of lower incisors in orthodontically untreated adults with the help of computed tomography. ***J Orofac Orthop*** 1999;60(5):321-34.

25. Enlow DH, Haris DB. A study of the postnatal growth of human mandible. ***Am J Orthod*** 1964;50(1):25-50.

26. Kurihara S, Enlow DH, Rangel RD. Remodeling reversals in anterior parts of the human mandible and maxilla. ***Angle Orthod*** 1980 Apr;50(2):98-106.

27. Houston WJ, Edler R. Long-term stability of the lower labial segment relative to the A-POG line. ***EUR J Orthod*** 1990;12(3):302-10.

28. Bhattacharya P, Bhattacharya H, Anjum A, Bhandari R, Agarwal DK, Gupta A, *et al.* Assessment of Corticotomy Facilitated Tooth Movement and Changes in Alveolar Bone Thickness - A CT Scan Study. ***J Clin Diagn Res*** 2014;8(10):26-30.