Journal of Zhejiang University-SCIENCE B (Biomedicine & Biotechnology)
ISSN 1673-1581 (Print); ISSN 1862-1783 (Online)
www.zju.edu.cn/jzus; www.springerlink.com
E-mail: jzus@zju.edu.cn

Association between mandibular posterior alveolar morphology and growth pattern in a Chinese population with normal occlusion*

Min HAN[1], Rong-yang WANG[1], Hong LIU[1], Xiu-juan ZHU[1], Fu-lan WEI[1], Tao LV[1], Na-na WANG[1], Li-hua HU[1], Guo-ju LI[2], Dong-xu LIU[†‡1], Chun-ling WANG[†‡1]

(*[1]Department of Orthodontics, Shandong Provincial Key Laboratory of Oral Biomedicine, Shandong University, Jinan 250012, China*)

(*[2]Department of Radiology, Shandong Provincial Key Laboratory of Oral Biomedicine, Shandong University, Jinan 250012, China*)

[†]E-mail: liudongxu@sdu.edu.cn; wangchl@sdu.edu.cn

Received Apr. 23, 2012; Revision accepted Sept. 27, 2012; Crosschecked Dec. 17, 2012

Abstract: Objective: To investigate the relationship between growth patterns and mandibular posterior tooth-alveolar bone complex morphology in a Chinese population with normal occlusion. Methods: Forty-five patients with normal occlusion (23 males, 22 females) were included in this study. Among these patients, 20 displayed the vertical growth pattern, and 20 had the horizontal growth pattern, while the remaining patients displayed the average growth pattern. All of the patients underwent dental cone beam computed tomography (CBCT), which included the region of the mandibular posterior teeth and the alveolar. A linear regression analysis and a correlation analysis between the facial height index (FHI) and the alveolar bone morphology were performed. Results: The inclination of the molars, the thickness of the cortical bone, and the height of the mandibular bone differed significantly between patients with the horizontal growth pattern and those with the vertical growth pattern ($P<0.05$). Significant positive correlations were found between: the FHI and the inclination of the molars; the FHI and the thickness of the cortical bone; and the FHI and the height of the mandibular bone. Conclusions: The mandibular posterior tooth-alveolar bone complex morphology may be affected by growth patterns.

Key words: Cone beam computed tomography (CBCT), Growth pattern, Alveolar morphology, Normal occlusion
doi:10.1631/jzus.B1200122 **Document code:** A **CLC number:** R783.5

1 Introduction

The tooth-alveolar bone complex, whose main function is to transfer the occlusal force from the tooth to the surrounding bone, is a complicated mechanical structure consisting of mineralized and periodontal soft tissue. The morphology of the tooth-alveolar bone complex is an important factor in orthodontic treatment planning, assessment of treatment progress, and the determination of treatment outcomes (Aasen and Espeland, 2005). The structure of the tooth-alveolar bone complex changes following alterations in loading by forces developed through the dentition and joint as the muscles contract during function (Ingervall and Thilander, 1974; Dechow and Hylander, 2000). Various growth patterns have different biting forces and biological adaptations, and therefore, result in different mandibular tooth-alveolar structures (Dechow and Hylander, 2000).

Numerous investigations have been conducted to assess the relationship between the growth pattern and the tooth-alveolar bone complex (Kasai *et al.*, 1999; Kawamura, 1999; Masumoto *et al.*, 2001; Brown, 2006; Utsuno *et al.*, 2010; Swasty *et al.*,

‡ Corresponding authors

* Project supported by the Shandong Science and Technology Planning Project (Nos. 2010G0020232, 2010HM053, and 2010GSF10269), the Shandong Provincial Natural Science Foundation (No. ZR2012 HM087), the Jinan Science and Technology Planning Project (No. JN201202042), and the Shandong University Project (Nos. 2011JC009 and 2012JC031), China

2011). These studies demonstrated that the evaluation of tooth-alveolar bone can differ according to the observers or their era and social environment, particularly when they are considering subjects' racial characteristics. Anthropometric analysis is important for research into disease and the development of new technologies and therapies. However, there have been no previous studies on the tooth-alveolar bone complex among the Chinese population.

Radiographic cephalometry is arguably one of the most significant diagnostic advancements in orthodontics. However, the information it provides is limited by its two-dimensional (2D) nature, resulting in a lack of perspective, errors in projection and superimposition, imaging artifacts, variations in magnification, information voids, and head position errors (Liang *et al*., 2006; Pohlenz *et al*., 2008). Furthermore, the 2D images fail to represent the complex curving structures of the tooth-alveolar complex. To circumvent these limitations, cone beam computed tomography (CBCT) technology, which gives a realistic representation of a patient's head, has emerged as a comprehensive imaging modality for orthodontics. CBCT offers an undistorted view of the dentition that shows the details of individual dental morphology, as well as the three-dimensional (3D) spatial orientation of the teeth and roots. A cross-sectional view of the tooth-alveolar bone complex generated from CBCT can reveal the dimensions of alveolar bone and the space limitations for intrusion or expansion. The multidimensional nature of imaging and reconstruction of CBCT allows for a comprehensive visualization of the tooth-alveolar bone complex and ensures reliable and anatomically accurate measurements.

Using CBCT, the present study was undertaken to determine whether a correlation exists between the morphology of the mandibular tooth-alveolar complex and growth patterns in a Chinese population with normal occlusion.

2 Materials and methods

2.1 Subjects and CBCT scanning

This research was reviewed and approved by the Research Ethic Committee of Shandong University Dental School. All the subjects were informed and consented to participate in the study. The selection criteria for the subjects included: (1) complete dentition with or without the third molars; (2) Class I molar relationship and normal incisor relationship (over jet: 1.5–3.0 mm; overbite: 1.0–3.5 mm), and crowding was limited within 3.5 mm; (3) no remaining deciduous teeth or obvious periodontal disease (community periodontal index (CPI) <3); (4) all subjects had symmetric mandibles and none were currently receiving orthodontic treatment; (5) subjects were excluded if they had missing teeth, any mandibular surgery, pathology, syndromes, or disease conditions that might affect musculoskeletal function or development (e.g., temporomandibular joint disorder or rheumatoid arthritis).

Forty-five subjects (23 males, 22 females), aged 21 to 41 years, were included in the linear regression and correlation analysis, and 40 of them (20 males, 20 females), aged 23 to 39 years, were subdivided into different growth pattern types according to their Frankfort-mandibular plane angle (FMA) and facial height index (FHI) (Fig. 1a). The measurements for FMA and FHI were obtained from conventional cephalograms. This produced 20 horizontal growth pattern patients (FMA<27°, FHI>65°) and 20 vertical growth pattern patients (FMA>37°, FHI<62°). Five subjects were not included, because they did not belong to a single type according to their FMA and FHI.

Images were obtained using the Galileos CBCT scanner (Sirona, Bensheim, Germany) in Shandong University, China. The scanning parameters were 85 kVp, 21 mA, 14 s per revolution, and 12 in field of view (FOV) (F mode). These settings produced a voxel of 0.38 mm×0.38 mm×0.38 mm. The data were reconstructed into 3D volumes using CBWorks 2.1 software, exported as digital imaging and communications in medicine (DICOM) files, and saved into the AVIA program (Hitachi, Tokyo, Japan). In order to keep the mandibular plane parallel to the floor, all images were reoriented using the "Z" subroutine. The "Z" subroutine was defined as the plane containing the gonion and menton points.

2.2 Measuring parameters

A total of four mandibular cross-sections (P2, V12, M1, and M2) were taken for each subject (Figs. 1b and 1c). The cross-sections were perpendicular to the alveolar arch and defined as follows: P2, the cross-section passing through the center of the

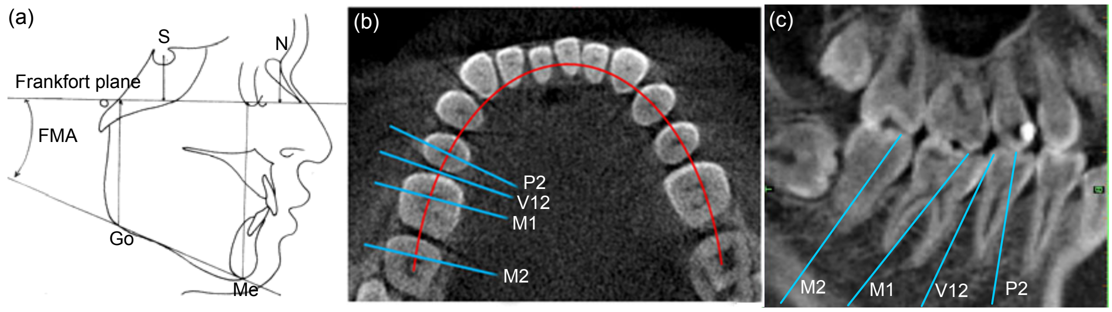

Fig. 1 Identified cephalometric landmarks and sites of cross-sectional sections
(a) Cephalogram. S: sella; N: nasion; Go: gonion; Me: menton; FMA: the angle from the Frankfort plane to Me-Go. Facial height index (FHI) is defined as the sum of distances from S and Go to the Frankfort plane divided by the sum of distances from N and Me to the Frankfort plane. (b) Axial image demonstrating the locations of the sites where the cross-sections were taken. (c) Sagittal image demonstrating the locations where the cross-sections were taken

second premolar; V12, the cross-section passing through the coronal line of the middle of the inter-alveolar septum between the second premolar and the first molar; M1, the cross-section passing through the center of the mesial root of the first molar; M2, the cross-section passing through the center of the mesial root of the second molar.

The images of these sections contained the teeth roots, and displayed the relationship between the roots and bone most clearly, and were therefore clinically beneficial and were chosen by the majority of the researchers.

For each section, several parameters defining the morphology of the tooth-alveolar complex were calculated. The parameters were defined as follows:

1. Inclination of tooth: the angle between the basal line (right and left inferior border of the mandibular section) and the tooth long axis. The long axis of the tooth was defined as the line passing through the mid-point at one-half of the crown width and the mid-point at one-third of the distance from the root apex (Fig. 2a).

2. Inclination of alveolar bone: the angle between the basal line and the line passing through the alveolar ridge crest and the inferior border of the mandible (Fig. 2a).

3. Least thickness of cortical bone: the shortest length of the alveolar bone in the horizontal direction.

4. Average thickness of cortical bone: the mean thickness of 10 points in one fifth of the middle region of the alveolar (Fig. 2b).

5. Average thickness of basal bone: the mean thickness of five sections in the basal region (Fig. 2b).

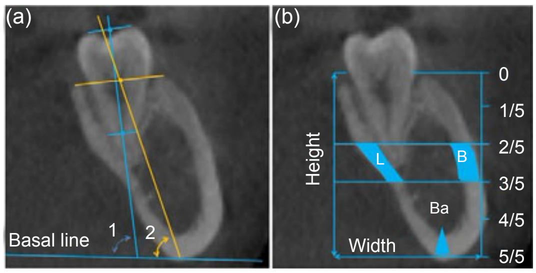

Fig. 2 Definitions of inclination (a) and cortical thickness, height and width (b)
1: tooth inclination; 2: bone inclination; B: buccal; L: lingual; Ba: basal

6. Height of mandibular bone: the vertical length from the alveolar ridge crest to the inferior border of the mandible (Fig. 2b).

7. Width of mandibular bone: the longest length from the buccal side to the lingual side and parallel to the standard plane (Fig. 2b).

2.3 Intra-operator and inter-operator reliabilities

Three doctors performed these measurements independently. The intra-operator error for each operator was obtained by repeating measurements on 16 randomly selected subjects three months after the initial measurements. The average scores of the 16 subjects measured by the three doctors were 0.993, 0.994, and 0.996, which indicated reproducibility using the AVIA software with a single examiner.

Inter-operator errors were evaluated by having operators take measurements on the same subjects. These results were recorded in a spreadsheet and compared with Lin (1989)'s concordance correlation.

Fifteen patients were randomly chosen for inter-operator error measurements. They were divided into three random groups, with five subjects per group. A total of five subjects were measured by Operators 1 and 2, five subjects were measured by Operators 1 and 3, and five subjects were measured by Operators 2 and 3. The mean concordance between Operators 1 and 2 was 0.973. For Operators 2 and 3, the average was 0.981, and for Operators 1 and 3, the average was 0.983. The results demonstrated reproducibility among the operators.

2.4 Statistical analysis

Differences in tooth-alveolar complex morphology between patients with vertical or horizontal growth patterns were analyzed using the Student's *t*-test. Pearson correlation coefficients were calculated to illustrate relationships between the FHI and variables, and linear regression was used to determine forecasting. The relationships analyzed were those between: the FHI and the inclination of molars; the FHI and the average thickness of cortical bone; and the FHI and mandibular height. Analyses were performed using Excel and SAS 9.0.

3 Results

3.1 Molars of the horizontal growth pattern had a greater buccal inclination in the posterior region

Table 1 shows the differences in the inclination of teeth and bone between patients with the horizontal or the vertical growth patterns. There were significant differences in the inclination of the first and second molars ($P<0.05$) between the two groups, but no significant difference in the inclination of the second premolar. Compared with molars of patients with the vertical growth pattern, molars of those with the horizontal growth pattern had a significantly greater buccal inclination in the posterior region. However, there was no statistical difference in the inclination of mandibular bone in the region of the first or second molar or the second premolar.

Table 1 Inclination of posterior teeth and alveolar bone

Measurement		Inclination (°)		P
		Horizontal	Vertical	
Teeth	M2	82.85±4.30	77.86±3.48	0.0232*
	M1	82.69±1.92	80.23±2.10	0.0283*
	P2	85.75±4.56	87.73±4.07	0.0873
Bone	M2	74.20±5.29	72.00±5.33	0.4212
	M1	81.51±2.88	81.31±5.15	0.9250
	P2	84.44±4.89	85.90±5.12	0.5682

Data are expressed as mean±SD (n=20). $^{*}P<0.05$

3.2 Average thickness of the buccal cortical bone was greater in patients with the horizontal growth pattern

Table 2 shows the least thickness of buccal and lingual cortical bone among patients in the horizontal and vertical growth pattern groups. No significant differences were observed. Table 3 shows the average thickness of the cortical bone of the two groups. In the region of the first and second molars, and the buccal side of the second premolar, the average thickness of the cortical bone in patients with the horizontal growth pattern was greater than that in those with the vertical growth pattern ($P<0.05$). There were no statistical differences in the average thickness of the basal bone.

Table 2 Least thickness of cortical bone

Measurement		Least thickness (mm)		P
		Horizontal	Vertical	
Buccal	M2	1.98±0.40	1.94±0.32	0.8066
	M1	2.06±0.24	1.93±0.28	0.3745
	V12	1.11±0.29	1.06±0.18	0.6769
	P2	2.12±0.30	2.07±0.27	0.7721
Lingual	M2	1.30±0.16	1.14±0.17	0.0707
	M1	1.41±0.10	1.48±0.14	0.3432
	V12	1.04±0.37	1.14±0.33	0.5792
	P2	1.75±0.18	1.68±0.40	0.7281

Data are expressed as mean±SD (n=20)

Table 3 Average thickness of cortical bone

Measurement		Average thickness (mm)		P
		Horizontal	Vertical	
Buccal	M2	3.60±0.25	3.08±0.52	0.0221*
	M1	3.03±0.54	2.75±0.55	0.0440*
	V12	2.64±0.52	2.53±0.19	0.3531
	P2	2.73±0.46	2.36±0.39	0.0485*
Lingual	M2	2.25±0.19	1.93±0.33	0.0480*
	M1	2.31±0.31	2.07±0.45	0.0345*
	V12	2.18±0.30	2.13±0.14	0.6763
	P2	2.53±0.55	2.28±0.39	0.3243
Basal	M2	3.51±0.79	3.36±0.28	0.6420
	M1	3.86±0.53	3.56±0.70	0.7385
	V12	4.32±0.34	3.94±0.35	0.4637
	P2	4.43±0.46	4.05±0.89	0.5377

Data are expressed as mean±SD (n=20). $^{*}P<0.05$

3.3 Mandibular posterior alveolar height of patients with the horizontal growth pattern was greater

Fig. 3a shows the mandibular posterior alveolar height of the second premolar, and the first and second molars. The mandibular posterior alveolar height of patients with the horizontal growth pattern was greater than that of those with the vertical growth pattern. The difference was greatest (P<0.001) in the region of the second molar, followed by the region of the first molar (P<0.01), and the region of the second premolar (P<0.05).

3.4 Widths of mandibles of the two groups were equal

Fig. 3b shows the width of the mandibular bone of patients from the horizontal and vertical growth pattern groups. No significant differences were observed.

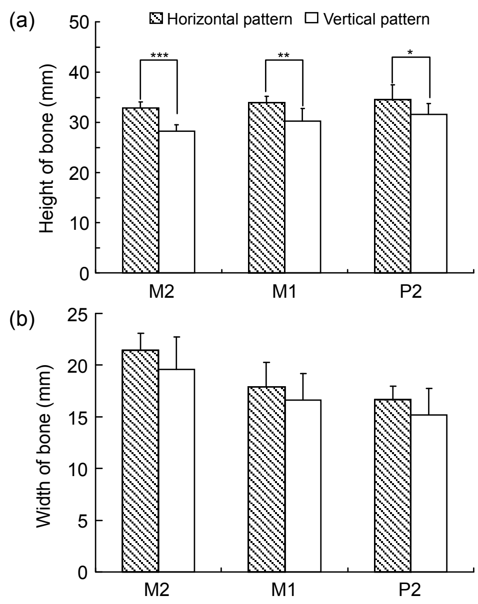

Fig. 3 Height (a) and width (b) of mandibular bone
Data are expressed as mean±SD (n=20). *** P<0.001, ** P<0.01, * P<0.05

3.5 Linear regression analysis and correlation analysis

Significant positive correlations were found between the FHI and the inclination of molars (P<0.05), between the FHI and the average thickness of buccal cortical bone (P<0.01), between the FHI and the average thickness of lingual cortical bone (P<0.01), and between the FHI and mandibular height (P<0.01).

4 Discussion

Compared with molars of patients with the vertical growth pattern, molars of those with the horizontal growth pattern had a significantly greater buccal inclination in the posterior region, similar to the results of Janson *et al*. (2004). Functional hyperactivity of the masticatory system imposes increased stress on the bony structures of the craniofacial complex with possible influences on its structure (Kiliaridis *et al*., 1995). There are three main factors which affect the inclination of the teeth: lingual force (the muscles of the tongue), buccal force (buccinator and masseter), and occlusal force (loading during mastication). The 3D position of the teeth and jaw bone is dependent on the combination of these three forces. Initially, the mandibular molars erupt lingually, and then move buccally due to tongue pressure and masseter function (Janson *et al*., 2004). Finally, the molars reach a balanced position (Masumoto *et al*., 2001). The lower molars are close to the attachment area of the masseter (Ingervall and Thilander, 1974; Tabe, 1976), and therefore are more influenced by the force of the masseter. Subjects with horizontal growth pattern have a stronger masseter (Ingervall and Helkimo, 1978), and it is not surprised that the molars of patients with the horizontal growth pattern have a greater buccal inclination compared to the molars of those with the vertical growth pattern. In clinical orthodontic treatment, it is important to acquire space for patients with crowded teeth. An expansion arch is an efficient method to acquire space if all of the teeth are kept (Motoyoshi *et al*., 2002). Since the molars of patients with the horizontal growth pattern have a greater buccal inclination, the mandibular arch expansion of this group should be limited within a suitable range to guarantee the stability of orthodontic treatment. In contrast, mandibular arch expansion of patients with the vertical growth pattern could be performed within a larger range to acquire space.

In the posterior region, the average thickness of the cortical bone of patients with the horizontal growth pattern was greater than that of those with the vertical growth pattern. Our results were similar to those of Swasty *et al*. (2011), who reported that a long-face group had slightly more narrow cortical bone than others. Subjects with the horizontal growth pattern had a stronger masseter (Ingervall and Helkimo, 1978). These studies suggest that a horizontal growth pattern is seen mostly in individuals with a strong masseter. There were no significant differences in the masseter between males and females (Kiliaridis *et al*., 1995), and we could not predict that a horizontal growth pattern is seen mostly in men. We could expect a thicker bone in individuals with a stronger masseter and a horizontal growth pattern. Recently, the microimplant anchor has become more popular in clinical treatment. Park *et al*. (2006) suggested that the stability of a microimplant is influenced by a number of factors, including cortical bone thickness, oral hygiene, implant site, and inflammation. Miyawaki *et al*. (2003) demonstrated that the cortical bone was thinner in high angle cases compared with low angle cases in the buccal posterior teeth area, which affected the stability of the microimplant anchor. Since the cortical bone thickness influences the stability of the microimplant (Park *et al*., 2006), measurement of the cortical bone thickness helps orthodontists to predict problems and to plan steps in clinical treatments. When the microimplant is used in patients with a horizontal growth pattern, more attention should be given to the direction of the implant, compared with its stability. Alternatively, when it is used in patients with a vertical growth pattern, more attention should be given to the stability of the microimplant.

The mandibular height of patients with the horizontal growth pattern is greater than that of those with the vertical growth pattern. Our results for mandibular height measurements were similar to those of other studies (Brown, 2006; Swasty *et al*., 2011). The difference was greatest in the second molar region, followed by the regions of the first molar and the second premolar. This supports the hypothesis that the height of the mandibular bone is associated with the growth pattern. There is more space for doctors to fix mandible implants in people with the horizontal growth pattern. The range of traction angles generated by implants is larger for those with the horizontal growth pattern.

We found no significant difference in the width of the mandibular bone between the two groups. In contrast, Swasty *et al*. (2011) reported that a long-face group showed a statistically narrower cross-section of the mandible in the upper third region compared with average-face and short-face groups, and that the mandible was wider and taller in males compared with females. Our research defined the bone width as the longest length from the buccal side to the lingual side and parallel to the standard plane, but not the length from the buccal cortical bone to lingual cortical bone, in order to avoid the disturbance caused by the linea mylohyoidea and linea oblique. In the regions of the first and second molars in patients with the horizontal growth pattern, the inclination of teeth was more buccal, while the inclination of the bone and the width of the bone were equivalent when compared to patients with the vertical growth pattern. These results suggest that the distance between the molar root tip and the mandibular edge in patients with the horizontal growth pattern might be smaller than that of those with the vertical growth pattern. Future research should further assess this measurement, as it may guide mandibular arch expansion and torque control.

Significant correlations were found between the FHI and the inclination of molars, between the FHI and the average thickness of cortical bone, and between the FHI and the mandibular height. These results could be used in forecasting the morphology of the mandibular posterior tooth-alveolar bone complex in clinical treatment. The inclination of molars, average thickness of the cortical bone, and the height of the mandibular bone can be obtained only by CBCT (Wang *et al*., 2012) or spiral CT (Guo *et al*., 2011), while the FHI can be obtained using cephalometric film, which is cheaper and easier to acquire in the clinic. The tooth-alveolar complex morphology of patients may be approximated by doctors by assessing the FHI in cephalometric film. Future studies should address additional possible correlations by linear regression and correlation analysis.

In regards to the impact of mesial-distal angulations of the molars on the results obtained, the buccal-lingual sections used for the measurements were parallel to the long axis of the teeth. If the vertical and horizontal growth pattern patients have different mesial-distal angulations of the molars, the accuracy of the bone height measurements would be affected.

However, further work needs to be done to establish whether differences exist and if any differences are significant enough to influence the bone height measurements.

The disadvantage of CBCT is its high radiation dose. Although the radiation dose of a CBCT scan is lower than that of a multi slice CT (MSCT) scan (Ludlow *et al.*, 2006), it is 3–44 times greater than comparable panoramic examination doses, depending on the CBCT device used (Ludlow and Ivanovic, 2008). A further disadvantage of CBCT is its high cost, which makes it unsuitable for regular, daily orthodontic patients.

5 Conclusions

1. The first and second molars of patients with the horizontal growth pattern have a greater buccal inclination compared to those of patients with the vertical growth pattern.

2. The average thickness of the buccal and lingual cortical bone at the first and second molars in patients with the horizontal growth pattern was thicker compared to that of patients with the vertical growth pattern.

3. The bone height at the first and second molars and the second premolar of patients with the horizontal growth pattern was greater than that of those with the vertical growth pattern.

4. There were significant positive correlations between: the FHI and the inclination of the molars; the FHI and the average thickness of cortical bone; and the FHI and mandibular height.

References

Aasen, T.O., Espeland, L., 2005. An approach to maintain orthodontic alignment of lower incisors without the use of retainers. *Eur. J. Orthod.*, **27**(3):209-214. [doi:10.1093/ejo/cji012]

Brown, D.C., 2006. Cross-sectional Mandibular Morphology in High, Average, and Low Angle Subjects. University of California, San Francisco, USA, p.126-127.

Dechow, P.C., Hylander, W.L., 2000. Elastic properties and masticatory bone stress in the macaque mandible. *Am. J. Phys. Anthropol.*, **112**(4):553-574. [doi:10.1002/1096-8644(200008)112:4<553::AID-AJPA9>3.0.CO;2-R]

Guo, Q.Y., Zhang, S.J., Liu, H., Wang, C.L., Wei, F.L., Lv, T., Wang, N.N., Liu, D.X., 2011. Three-dimensional evaluation of upper anterior alveolar bone dehiscence after incisor retraction and intrusion in adult patients with bimaxillary protrusion malocclusion. *J. Zhejiang Univ.-Sci. B (Biomed. & Biotechnol.)*, **12**(12):990-997. [doi:10.1631/jzus.B1100013]

Ingervall, B., Thilander, B., 1974. Relation between facial morphology and activity of masticatory muscles. *J. Oral Rehabil.*, **1**(2):131-147. [doi:10.1111/j.1365-2842.1974.tb00771.x]

Ingervall, B., Helkimo, E., 1978. Masticatory muscle force and facial morphology in man. *Arch. Oral Biol.*, **23**(3):203-206. [doi:10.1016/0003-9969(78)90217-0]

Janson, G., Bombonatti, R., Cruz, K.S., Hassunuma, C.Y., Del Santo, M.J., 2004. Buccolingual inclinations of posterior teeth in subjects with different facial patterns. *Am. J. Orthod. Dentofacial Orthop.*, **125**(3):316-322. [doi:10.1016/j.ajodo.2003.03.010]

Kasai, K., Kawamura, A., Kanazawa, E., 1999. A comparative study of dental arches and mandibular bases in Jomon and modern Japanese using CT scanning. *Orthodontic Waves*, **58**(1):193-198.

Kawamura, A., 1999. Relationship between buccolingual inclination of mandibular molars and dentofacial morphology. *Nihon Univ. J. Oral Sci.*, **25**(3):339-349.

Kiliaridis, S., Johansson, A., Haraldson, T., Omar, R., Carlsson, G.E., 1995. Craniofacial morphology, occlusal traits, and bite force in persons with advanced occlusal tooth wear. *Am. J. Orthod. Dentofacial Orthop.*, **107**(3):286-292. [doi:10.1016/S0889-5406(95)70144-3]

Liang, X., Jacobs, R., Lambrichts, I., 2006. An assessment on spiral CT scan of the superior and inferior genial spinal foramina and canals. *Surg. Radiol. Anat.*, **28**(1):98-104. [doi:10.1007/s00276-005-0055-y]

Lin, L., 1989. A concordance correlation coefficient to evaluate reproducibility. *Biometrics*, **45**(1):255-268. [doi:10.2307/2532051]

Ludlow, J.B., Ivanovic, M., 2008. Comparative dosimetry of dental CBCT devices and 64-slice CT for oral and maxillofacial radiology. *Oral Surg. Oral Med. Oral Pathol. Oral Radiol. Endod.*, **106**(1):106-114. [doi:10.1016/j.tripleo.2008.03.018]

Ludlow, J.B., Davies-Ludlow, L.E., Brooks, S.L., Howerton, W.B., 2006. Dosimetry of 3 CBCT devices for oral and maxillofacial radiology: CB Mercuray, NewTom 3G and i-CAT. *Dentomaxillofac. Radiol.*, **35**(4):219-226. [doi:10.1259/dmfr/14340323]

Masumoto, T., Hayashi, I., Kawamura, A., Tanaka, K., Kasai, K., 2001. Relationships among facial type, buccolingual molar inclination, and cortical bone thickness of the mandible. *Eur. J. Orthod.*, **23**(1):15-23. [doi:10.1093/ejo/23.1.15]

Miyawaki, S., Koyama, I., Inoue, M., Mishima, K., Sugahara, T., Yamamoto, T., 2003. Factors associated with the stability of titanium screws placed in the posterior region for orthodontic anchorage. *Am. J. Orthod. Dentofacial Orthop.*, **124**(4):373-378. [doi:10.1016/S0889-5406(03)00565-1]

Motoyoshi, M., Hirabayshi, M., Shimazaki, T., Namra, S., 2002. An experimental study on mandibular expansion: increases in arch width and perimeter. *Eur. J. Orthod.*, **24**(2):125-130. [doi:10.1093/ejo/24.2.125]

Park, H.S., Jeong, S.H., Kwon, O.W., 2006. Factors affecting the clinical success of screw implants used as orthodontic anchorage. *Am. J. Orthod. Dentofacial Orthop.*, **130**(1): 18-25. [doi:10.1016/j.ajodo.2004.11.032]

Pohlenz, P., Blessmann, M., Blake, F., Gbara, A., Schmelzle, R., Heiland, M., 2008. Major mandibular surgical procedures as an indication for intraoperative imaging. *J. Oral Maxillofac. Surg.*, **66**(2):324-329. [doi:10.1016/j.joms.2007.03.032]

Swasty, D., Lee, J., Huang, J.C., Maki, K., Gansky, S.A., Hatcher, D., Millerg, A.J., 2011. Cross-sectional human mandibular morphology as assessed in vivo by cone-beam computed tomography in patients with different vertical facial dimensions. *Am. J. Orthod. Dentofacial Orthop.*, **139**(4):e377-e389. [doi:10.1016/j.ajodo.2009.10.039]

Tabe, T., 1976. The correlation between the activities in the masseter muscle and the biting force, and the morphology of the orofacial skeleton. *J. Jpn. Orthod. Soc.*, **35**(4): 255-265.

Utsuno, H., Kageyama, T., Uchida, K., Yoshino, M., Miyazawa, H., 2010. Facial soft tissue thickness in Japanese children. *Forensic Sci. Int.*, **199**(1-3):109.e1-109.e6. [doi:10.1016/j.forsciint.2010.02.016]

Wang, R.Y., Han, M., Liu, H., Wang, C.L., Xian, H.H., Zhang, L., Zhang, S.J., Liu, D.X., 2012. Establishment of reference mandibular plane for anterior alveolar morphology evaluation using cone beam computed tomography. *J. Zhejiang Univ.-Sci. B (Biomed. & Biotechnol.)*, **13**(11): 942-947. [doi:10.1631/jzus.B1200052]