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

Communication:

Establishment of reference mandibular plane for anterior alveolar morphology evaluation using cone beam computed tomography*

Rong-yang WANG[§1], Min HAN[1], Hong LIU[1], Chun-ling WANG[1], Hong-hong XIAN[2], Lei ZHANG[3], Shi-jie ZHANG[§3], Dong-xu LIU[†‡1]
([1]*Department of Orthodontics, Shandong Provincial Key Laboratory of Oral Biomedicine, Shandong University, Jinan 250012, China*)
([2]*Department of Stomatology, Qianfoshan Hospital of Shandong Province, Jinan 250014, China*)
([3]*Department of Stomatology, the Second Hospital of Shandong University, Jinan 250033, China*)
[†]E-mail: liudongxu@sdu.edu.cn
Received Feb. 22, 2012; Revision accepted July 29, 2012
Crosschecked Oct. 19, 2012

doi:10.1631/jzus.B1200052
Document code: A **CLC number:** R783.5

To propose a method of establishing the reference mandibular plane (MP), which could be reestablished according to the coordinates of the reference points, and then facilitate the assessment of anterior alveolar morphology using cone beam computed tomography (CBCT), sixty patients with bimaxillary protrusion were randomly selected and CBCT scans were taken. The CBCT scans were transferred to Materialism's interactive medical image control system 10.01 (MIMICS 10.01), and three dimensional models of the entire jaws were constructed. Reference points determining the reference MP were positioned in the coronal, axial, sagittal windows, and the points were exactly located by recording their coordinates in the interfaces of software. The reference MP provided high intra-observer reliability (Pearson's *r* 0.992 to 0.999), and inter-observer reliability (intra-class correlation coefficients (ICCs) 0.996 to 0.999).

Key words: Reference Plane, Cone beam computed tomography, Alveolar morphology

1 Introduction

The position of lower incisors is an important factor in orthodontic treatment planning, as well as in determination of treatment outcome (Aasen and Espeland, 2005). The initial position of lower incisors and morphology of the supporting bone affect not only the choice of therapeutic maneuvers, but also the designation of the ways for incisor movement. It is widely accepted that tooth movement is limited by the alveolar bone (Handelman, 1996; Garib *et al*., 2010), where excessive incisor retraction or incisor root apex moving against the cortical plate may cause bone fenestration, dehiscence, root resorption, and gingival recession (Bimstein *et al*., 1990; Vardimon *et al*., 1998; Simten *et al*., 2002; Guo *et al.*, 2011). Therefore, it is important to evaluate the anterior alveolar morphology before starting orthodontic treatment. However, it was suggested that the evaluation of alveolar morphology might be interpreted differently using different reference landmarks on either two-dimensional (2D) or three-dimensional (3D) cephalometry. Searching for a stable reference is equally important and necessary for cephalometric analysis.

Alveolar bone morphology assessment has been extensively done for conventional 2D cephalometric radiographs. Yet because of the projected magnification and tracing error, it is almost

‡ Corresponding author
§ The two authors contributed equally to this work
* Project supported by the Shandong Science and Technology Planning Project Contract Research (No. 2009GG10002059) of China and the Shandong University Dental School Project Research (Nos. 2011JC009, P2009009, and 2012JC031), China

impossible for cephalometric radiographs to investigate the thickness and the labiolingual inclination of the alveolar bone in the lower central incisor region. Thus, many investigators chose 3D analysis to evaluate mandibular anterior alveolar morphology, especially the latest development of cone beam computed tomography (CBCT) which could help to provide better image resolution, shorten acquisition time, reduce the radiation dose, and lower costs (Maki *et al*., 2003). Although CBCT enables viewing the lower incisors and supporting alveolar bone in multiple-planes without distortion and magnification, problems associated with the difficulties in selecting reference points and the questionable reproducibility still persecute many investigators.

The thickness of the anterior alveolar bone has been investigated using CBCT (Chen *et al*., 2010; Menezes *et al*., 2010; Nowzari *et al*., 2012), yet few studies have assessed the height and inclination of alveolar bone, which might be the result of difficulty in selecting reference lines on 2D sections that generated from 3D CBCT scans. The lower mandibular line (LML) defined as the bisecting line of the right and left tangent lines to the lower border of mandibular angles and the mandibular symphysis (Downs, 1948; Yamada *et al*., 2007), and another line passing through the point menton and tangent to the most superior point in inferior border of the mandibular body (Yu *et al*., 2009), have been used to assess the inclination of the lower incisors and the overlying alveolar bone. Nevertheless, reference planes used in the previous studies were not particularly clarified. Moreover, reproducibility is indispensable for every investigation, and results can vary according to the reference determination. The accurate localization of reference planes is therefore essential for 3D cephalometry.

This study focused on describing a method of establishing the reference mandibular plane (MP), which could be reestablished according to the coordinates of the reference points on 3D models of mandibles. The establishment of 3D reference plane enabled the corresponding 2D reference line to be formed in the sagittal sections of lower central incisors, and then facilitated the investigation of lower anterior alveolar morphology using CBCT.

2 Materials and methods

2.1 Subjects

This study was reviewed and approved by the Research Ethic Committee of Shandong University Dental School. Sixty randomly selected patients were recruited and consented to participate in this investigation. The selection criteria for these subjects were as follows: (1) bimaxillary dentoalveolar protrusion; (2) clinically symmetric; (3) no centric relation/ centric occlusion (CR/CO) discrepancy; (4) A point-Nasion-B point (ANB) angle (range 0° to +5.0°, mean +3.2°); (5) female adults (age ranged 18 to 25 years, mean 22.5 years); (6) no previous orthodontic treatment; (7) reasonably aligned upper and lower incisors without severe crowding; (8) no congenitally missing incisors; (9) acceptable oral hygiene without obvious periodontal disease.

2.2 CBCT acquisition

All the images were acquired using the Galileos CBCT scanner (Sirona, Bensheim, Germany) at the Stomatology Hospital of Shandong University at 85 kV, 7 mA, and 14 s per revolution, which provided resolution accurate enough to 0.15 mm. During image acquisition, patients were required to close their mouth with teeth in maximum intercuspation and the scanning planes were parallel to the Frankfort horizontal plane. The CBCT images were then saved as digital imaging and communications in medicine (DICOM) file.

2.3 Establishment of 3D reference planes

The steps of the method introduced in this article were adjusted for Materialism's interactive medical image control system (MIMICS). After the CBCT scans recorded in DICOM format were transferred to MIMICS 10.01, 3D models of mandibles were constructed based on the threshold from 400 hounsfield units (HU) to 3070 HU. In the interface of MIMICS 10.01, there are four windows, which represented the coronal (x), the axial (y), the sagittal (z) sections, and the 3D models, respectively. One CBCT data from the 60 scans was taken for example in the subsequent image analysis. Table 1 shows the definitions of references used.

Mandibular mid-sagittal plane, which was defined as a plane passing through the center point of the mental process, inner contour of the cortical plate at the labial border of the mandibular symphysis, midpoint between bilateral most medio-inferior points of the open site of the mandibular foramen (Yamada *et al*., 2007), was selected first and the coordinate (z=71.37) was recorded. By using the mid-sagittal window (z=71.37), the cursor was ideally positioned at gnathion (Gn), slight readjustment was done in the axial window (Fig. 1), and then its coordinates (115.73, 13.65, 71.37) were recorded. Subsequently the cursor was placed on the right gonion (RGo) on the right lateral projection of the 3D model preliminarily, and the position of the intersection point could be slightly readjusted in the axial window (Fig. 2). Localization and readjustment of the left gonion (LGo) was done in the same way with the RGo. In the procedures of localization, the coordinates (x, y, z) of RGo and LGo were put down. Finally, the MP plane could be drawn in the axial window by using the "MedCAD-Plane-Draw" routine. In the axial window, point Gn was drawn first according to its coordinates (115.73, 13.65, 71.37). Subsequently, by clicking on the slide bars in the right sides of the coronal, axial, and sagittal windows, the RGo and LGo were readjusted to their previously recorded coordinates separately, and the latter two reference points were drawn successively at the intersection points.

As a result, the reference MP on the 3D model was exactly drawn and the recorded coordinates accurately localized the reference points. The size and color of the reference plane could be readjusted by its attribute.

Based on the establishment of the 3D reference MP, corresponding 2D reference MP line for mandible was formed in the sagittal window (Fig. 3). Evaluation of anterior alveolar morphology in sagittal sections of lower central incisors could be done subsequently.

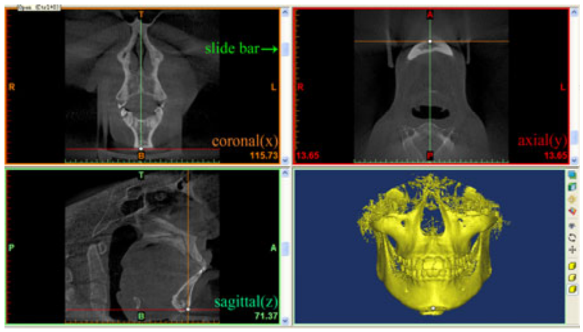

Fig. 1 Localization of gnathion (Gn)
By using the mid-sagittal window (z=71.37), the cursor was ideally positioned at Gn, and slight readjustment could be done in the axial window in order to adjust the coronal position of Gn. Then the coordinates (115.73, 13.65, 71.37) were recorded

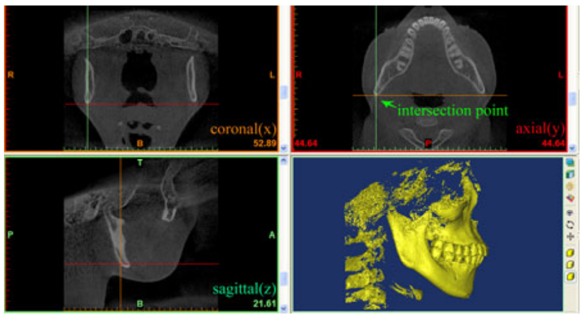

Fig. 2 Localization of the right gonion (RGo)
The cursor was placed on RGo on right lateral projection of the 3D model preliminarily, and the axial position of RGo could be fixed resultantly. Then readjustment of the sagittal and coronal positions of RGo could be done in the axial window. Finally the coordinates (52.89, 44.64, 21.61) were recorded

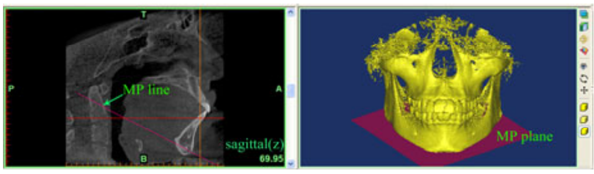

Fig. 3 Effect of reference plane establishment
After that MP plane was drawn on the 3D model, reference MP line was formed in the sagittal section of mandibular central incisor region

Table 1 Definitions of references (reference points and plane) used in this study

Reference	Abbreviation	Definition
Gnathion	Gn	The midpoint between the most anterior and inferior points on the outline of the mandibular symphysis
Gonion	Go	The point on the inferior surface on the mandible that lies midway along the curvature between the ramus and the body. RGo represents the right gonion and LGo represents the left gonion
Mandibular plane	MP	A plane that passes Gn and the both gonions (RGo and LGo)

2.4 Data analysis

The samples of the 60 CBCT scans were analyzed for reliability assessment in this study. Measurements were taken on the mid-sagittal sections of the right mandibular central incisors. The landmarks identified on the mid-sagittal section were: root apex (Ra), incisor crown edge (ICE), labial alveolar ridge crest (LAC), lingual alveolar ridge crest (LIC), the most posterior point of labial alveolar bone (LAP), the most posterior point of lingual alveolar bone (LIP). The variables were defined as follows:

LaH: height of the labial alveolar bone, the shortest distance between LAC and MP.

LiH: height of the lingual alveolar bone, the shortest distance between LIC and MP.

Ra-RP: shortest distance between Ra and MP.

Inc ax/RP: inclination of central incisor, angle between ICE-Ra and MP.

Inc LaC/RP: inclination of labial alveolar bone, angle between LAC-LAP and MP.

Inc LiC/RP: inclination of lingual alveolar bone, angle between LIC-LIP and MP.

To avoid landmark identification errors of the variables, the coordinates (x, y, z) of all landmarks used and the mid-sagittal sections of all lower central incisors were exported into Excel (Microsoft, Redmond, Wash), and saved for the subsequent repeated measurements.

2.5 Statistical analysis and measurement reliability

The reference MPs of all the 60 CBCT scans were reestablished two weeks later by the same observer and another observer separately. The landmarks of all variables and the mid-sagittal sections of the lower central incisors used in the first measurement were selected according to the coordinates recorded before. Repeated measurements were taken subsequently. Thus in the repeated measurements, the parameters were duplicated with the parameters in the first measurement, and the only difference was that, the observers localized the reference points again and the MPs were reestablished.

The statistical analysis was carried out with SPSS (Version 9.0, SPSS, Chicago, USA). The intra-observer reliability for the measurements was determined by calculating Pearson's correlation coefficients (r). Intra-class correlation coefficients (ICCs) were performed to determine the inter-observer reliability. The method error (ME) was calculated according to Dahlberg (1940)'s formula: $s=\sqrt{\sum(d)^2/2n}$ (s for the ME; d for the deviation between the first and second measurements; n for the number of comparisons performed). The maximum ME of linear measurements was 0.34 mm, while for angular measurements was 0.74°.

3 Results

The reliability coefficients of the repeated measurements are displayed in Table 2. Pearson's r (intra-observer reliability) of mandibular linear measurement (MLM) was 0.995, and that of mandibular angular measurement (MAM) was 0.992 (all significant at the 0.01 level two-tailed). The average ICC (inter-observer reliability) was 0.997 for MLM, and 0.996 for MAM.

4 Discussion

The results of this study implied that both the intra-observer and the inter-observer reliabilities were high. Since the landmarks of all variables and the

Table 2 Intra-observer and inter-observer reliabilities (n=60)

Measurement	Pearson's r (intra-observer)	ICC (inter-observer)				
		Average measure (Cronbach's α)	95% confidence interval		F test with true value 0	
			Lower bound	Upper bound	Value	Significance
MLM	0.995**	0.997	0.995	0.999	371.900	0.000
MAM	0.992**	0.996	0.991	0.998	224.661	0.000

ICC: intra-class correlation coefficient; MLM: mandibular linear measurement; MAM: mandibular angular measurement. ** Correlation is significant at the 0.01 level (two-tailed) measuring sections in the repeated measurements were repositioned according to their coordinates recorded in the first measurement, the results indicated that the method of establishing reference MP provided high reliability.

Cephalometric error generally arises from the geometry of radiographic and random errors (Dahlberg, 1940). The random errors involve tracing, landmark identification, and measurements (Chen *et al*., 2004). Landmark-identification errors have been considered the major source of cephalometric error since computer-aided cephalometric analysis has eliminated the mechanical errors in drawing lines between landmarks and in measurements with a protractor (Major *et al*., 1994; Leonardi *et al*., 2008). This type of error is influenced by many factors such as the quality of the radiographic image, the precision of the landmark definition, and the reproducibility of the landmark location.

In 3D cephalometric analysis, another important source of cephalometric error is from the precision and reproducibility of reference planes. Although the application of 3D computed tomography (CT) enables the visualization of facial structures, measurements that assess alveolar morphology still are mainly taken on 2D sections generated from 3D scans. Then problems such as difficulty in selecting reference planes and poor reproducibility occur.

This study presented a method of selecting reference planes for anterior alveolar morphology evaluation. In order to assess the reliability of the reference plane establishment, landmarks of all parameters and the measuring sections were accurately relocalized by their coordinates. On the other hand, if we were to investigate the mandibular anterior alveolar morphology, the reference MP could only be determined by the reference points, which could also be precisely repositioned according to their coordinates in repeated measurements. This can provide high reproducibility of the reference plane and reduce the chance of cephalometric error generated from the reference plane reestablishment.

Reliability of the reference MP establishment described in this article has been assessed. Future well-designed studies that evaluate the accuracy of the reference plane are required.

5 Conclusions

This method of establishing reference MP on 3D models enabled the MP line formed in the 2D sagittal sections for the lower central incisors. The method of reference plane establishment showed high reliability.

Acknowledgements

We wish to thank Yu-qi YUAN (School of Public Health, Shandong University, China) for his assistance.

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]

Bimstein, E., Crevoisier, R.A., King, D.L., 1990. Changes in the morphology of the buccal alveolar bone of protruded permanent mandibular incisors secondary to orthodontic alignment. *Am. J. Orthod. Dentofacial Orthop.*, **97**(5):427-430. [doi:10.1016/0889-5406(90)70115-S]

Chen, C.H., Nakano, H., Liou, E., Maki, K., 2010. A cone beam computer tomographic study of the cortical bone thickness in different class II facial patterns. *Orthodontic Waves*, **69**(4):131-137. [doi:10.1016/j.odw.2010.06.003]

Chen, Y.J., Chen, S.K., Yao, J.C., Chang, H.F., 2004. The effects of differences in landmark identification on the cephalometric measurements in traditional versus digitized cephalometry. *Angle Orthod.*, **74**(2):155-161.

Dahlberg, G., 1940. Statistical methods for medical and biological students. *Public Health*, **54**:92-93. [doi:10.1016/S0033-3506(40)80086-3]

Downs, W.B., 1948. Variation in facial relationships: their significance in treatment and prognosis. *Am. J. Orthod.*, **34**(10):812-840. [doi:10.1016/0002-9416(48)90015-3]

Garib, D.G., Yatabe, M.S., Ozawa, T.O., Filho, O.G.S., 2010. Alveolar bone morphology under the perspective of the computed tomography: defining the biological limits of tooth movement. *Dental Press J. Orthod.*, **15**(5):192-205. [doi:10.1590/S2176-94512010000500023]

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]

Handelman, C.S., 1996. The anterior alveolus: its importance in limiting orthodontic treatment. *Angle Orthod.*, **66**(2):95-110.

Leonardi, R., Annunziata, A., Caltabiano, M., 2008. Landmark identification error in posteroanterior cephalometric radiography. *Angle Orthod.*, **78**(4):761-765. [doi:10.2319/0003-3219(2008)078[0761:LIEIPC]2.0.CO;2]

Major, P.W., Johnson, D.E., Hesse, K.L., Glover, K.E., 1994. Landmark identification error in posterior anterior cephalometrics. *Angle Orthod.*, **64**(6):447-454.

Maki, K., Inou, N., Takanishi, A., Miller, A.J., 2003. Computer-assisted simulation in orthodontic diagnosis and the application of a new cone bean X-ray computed tomography. *Orthod. Craniofac. Res.*, **6**(s1):95-101. [doi:10.1034/j.1600-0544.2003.241.x]

Menezes, C.C., Janson, G., Massaro, C.S., Cambiaghi, L., Garib, D.G., 2010. Reproducibility of bone plate thickness measurements with cone-beam computed tomography using different image acquisition protocols. *Dental Press J. Orthod.*, **15**(5):143-149. [doi:10.1590/S2176-94512010000500017]

Nowzari, H., Molayem, S., Chiu, C.H., Rich, S.K., 2012. Cone beam computed tomographic measurement of maxillary central incisors to determine prevalence of facial alveolar bone width ≥2 mm. *Clin. Implant Dent. Relat. Res.*, **14**(4):595-602. [doi:10.1111/j.1708-8208.2010.00287.x]

Simten, S., Bülent, H., Semra, C., Macit, A., 2002. Changes in alveolar bone thickness due to retraction of anterior teeth. *Am. J. Orthod. Dentofacial Orthop.*, **122**(1):15-26. [doi:10.1067/mod.2002.119804]

Vardimon, A.D., Oren, E., Ben-Bassat, Y., 1998. Cortical bone remodelling/tooth movement ratio during maxillary incisor retraction. *Am. J. Orthod. Dentofacial Orthop.*, **114**(5):520-529. [doi:10.1016/S0889-5406(98)70172-6]

Yamada, C., Kitai, N., Kakimoto, N., Murakami, S., Furukawa, S., Takada, K., 2007. Spatial relationships between the mandibular central incisor and associated alveolar bone in adults with mandibular prognathism. *Angle Orthod.*, **77**(5):766-772. [doi:10.2319/072906-309]

Yu, Q., Pan, V.G., Ji, G.P., Shen, G., 2009. The association between lower incisal inclination and morphology of the supporting alveolar bone—a cone-beam CT study. *Int. J. Oral Sci.*, **1**(4):217-223. [doi:10.4248/IJOS09047]