ACTA ODONTOLOGICA SCANDINAVICA
2018, VOL. 76, NO. 4, 287–293
https://doi.org/10.1080/00016357.2017.1420227

ORIGINAL ARTICLE

Morphometric analysis for evaluating the relation between incisal guidance angle, occlusal plane angle, and functional temporomandibular joint shape variation

Seulgi Han[a], Sang Min Shin[b], Yong-Seok Choi[c], So Yeun Kim[d], Ching-Chang Ko[e] and Yong-Il Kim[a,f]

[a]Departmet of Orthodontics, Dental Research Institute, Pusan National University Dental Hospital, Yangsan, Korea; [b]Departmet of Management Information Systems, Dong-A University, Busan, Korea; [c]Departmet of Statistics, Pusan National University, Kumjeong-ku, Korea; [d]Departmet of Prosthodontics, Pusan National University Hospital, Busan, Korea; [e]Departmet of Orthodontics, School of Dentistry, University of North Carolina at Chapel Hill, Chapel Hill, NC, USA; [f]Institute of translational dental science, School of Dentistry, Pusan National University, Yangsan, Korea

ABSTRACT

Objective: The correlations between morphology of the temporomandibular joint structure, the anterior guidance angle, and occlusal plane were investigated.
Materials and methods: A cone beam computed tomography analysis was performed in 158 patients (86 women and 72 men). 3D software was employed to obtain the coordinates of the shape of the incisal guidance angle, occlusal guidance angle, articular fossa, and mandibular condyle. Generalized Procrustes analysis including principal components analysis (PCA) were performed and produced principal components (PCs) scores of each shape and their centroid size (CS).
Results: A significant Pearson correlation coefficient of 0.3451 ($p < .001$) was observed between the incisal guidance angle and occlusal plane. The CS also showed a correlation with the incisal guidance angle, but not with the occlusal plane angle. The PCA results revealed that there were no significant correlations between the temporomandibular joint structure (TMJ) shape (fossa and condyle) and the incisal guidance angle.
Conclusions: Incisor guidance angle and occlusal plane angle were correlated. In addition, there was a correlation between CS and incisal guidance angle. In the PCA, It can be concluded that the size is more related to the incisor guidance angle than the morphological factors of the constituent components of the TMJ.

ARTICLE HISTORY
Received 24 August 2017
Revised 1 December 2017
Accepted 18 December 2017

KEYWORDS
Morphometrics; TMJ shape; guidance angle; occlusal plane

Introduction

It is well known that there is a significant correlation between the morphology of the temporomandibular joint structure (TMJ) and the functional loading from chewing forces [1,2]. Several studies have already reported that the mandible and the TMJ have different shapes in persons with diverse dentofacial morphologies and various malocclusions [3,4].

Among influencing factors to occlusion, the articular eminence inclination completes about 90–94% of its growth by the age of 20 years [3]. Previous studies have reported that morphological changes may occur in the eminence structure with aging, which result in the flattening of the eminence on the long term [4,5]. In contrast, other studies have reported no correlation between age and the eminence anatomy both in relation to height and inclination [6,7]. Another study was conducted on the structures that consist of TMJ as well [8]. However, the results are still not clear.

The relationship between sex and the TMJ has been previously discussed in many studies. It has been reported that there is no significant difference in the roof thickness of the articular fossa between men and women [9–11]. Moreover, men have larger joint spaces than women, which could be possibly explained by a greater soft tissue thickness [12–15]. The overall size of the condyle has been reported to be significantly larger in men that women [16]. These studies have addressed the relationship between sex and the size of the TMJ structure. However, to our knowledge, no study has so far investigated the correlation between sex and the morphology of the TMJ.

The mandibular movement is controlled by anterior controlling factors such as the anterior guidance, and posterior controlling factors such as the condylar guidance. The posterior controlling factor is significantly affected by inclinations of articular eminence. Indeed, it determines the condylar guidance angle and the path of the mandibular condyle in accordance with the antero-medial-inferior movement when mandibular functional movement occurs. Although there is a relationship between anterior controlling factor (incisal guidance) and posterior controlling factor (TMJ structure) [17], the quantitative analysis is still insufficient.

Therefore, the purpose of this study was to investigate the correlation between the morphology of the TMJ and the

CONTACT Yong-Il Kim kimyongil@pusan.ac.kr Department of Orthodontics, Institute of translational dental sciences, School of Dentistry, Pusan National University, 3-3, Beomeori, Mulgeum, Yangsan, 662-770 Korea

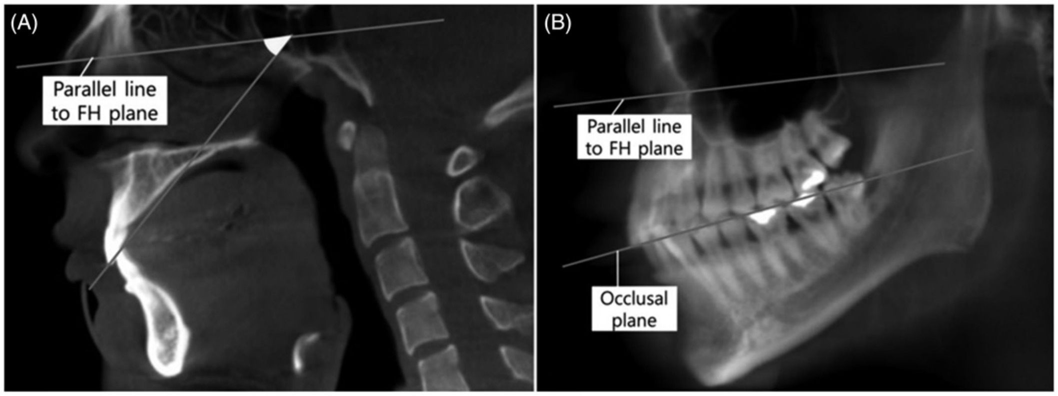

Figure 1. Incisal guidance angle (A) and occlusal plane angle (B).

anterior guidance angle and occlusal plane according to age and sex, using the statistical shape analysis [18,19].

Materials and methods

Samples

The measurements were performed on cone beam computed tomography (CBCT) records of 158 patients (72 men, 86 women), with a mean age of 27.5 ± 9.40 (women: 25.70 ± 9.36, men: 28.62 ± 9.41), who were treated at Pusan National University Dental Hospital between January 2010 and December 2015. The CBCTs were obtained for several clinical purposes (impacted tooth, extraction of third molar, dental implantation and other clinical examination). Images of TMJ, incisors, and occlusal plane were analysed in order to evaluate the incisor guidance angle, occlusal plane angle, condylar guidance angle, and the shape of the TMJ structure. Exclusion criteria included patients who had a TMJ disorder or a history of facial trauma or collapsed posterior occlusion due to missing teeth. The study was approved from institutional review board of Pusan National University Dental Hospital (PNUDH-2016-035).

Image analysis from CBCT data

The data were obtained from CBCT (Zenith3D, Vatech Co., Seoul, Korea). OnDemand3D (Cybermed Co., Seoul, Korea) was used to obtain the coordinates of the shape of the incisal guidance angle, occlusal guidance angle, articular fossa, and mandibular condyle. In order to obtain an even image quality, they were captured under the same conditions (windowing level and width for 1000 and 3000, respectively).

In the present study, the following two reference planes were used. The Frankfort horizontal (FH) reference plane, extending from the left Orbitale to both Porion points, was used as the horizontal plane, and the midsagittal reference (MSR) plane, which is perpendicular to FH and simultaneously passing Nasion and Basion, was used as a vertical reference plane.

For measuring the incisal guidance angle, the analysed image was obtained from an 8.0-mm thick ray-cast image, based on the midsagittal reference plane. Coordinates of the maxillary and mandibular central incisal edge were obtained. The angle formed with the line connecting the maxillary central incisal edge and the mandibular central incisal edge and the FH plane was calculated (Figure 1(A)).

For measuring the occlusal plane angle, 20.0-mm-thick ray-cast sagittal images were adjusted simultaneously to the present maxillary central incisal and the distobuccal cusp of the maxillary first molar. The maxillary central incisal edge and the distobuccal cusp of maxillary first molar were measured for occlusal plane angle. The angle formed between the occlusal plane and the FH plane was measured (Figure 1(B)).

For statistical shape analysis of the articular fossa and the mandibular condyle, 10.0-mm-thick ray-cast images of the TMJ were used. The coordinates of the TMJ structure were described as followed:

1. To obtain the coordinates from the articular fossa, the superior contact point of the articular fossa with a line parallel to the FH plane was set to landmark Fs. The inferior contact point of the anterior wall of the articular fossa with a line parallel to the FH plane was set to landmark Fa1. The points dividing between Fa1 and Fs into three equal parts were set to semi-landmark Fa2 and Fa3 from the front. To evaluate the morphology of the posterior wall of the articular fossa, three points were measured. The contact point of the line parallel to the FH plane passing inferior point of external auditory meatus with the posterior wall was set to landmark Fp3. The points dividing between Fs and Fp3 into three equal parts were set to semi-landmark Fp1 and Fp2 from the front. The morphology of the articular fossa was calculated from the landmarks (Figure 2(A)).
2. To obtain the coordinates from the mandibular condyle, the superior contact point of the mandibular condyle with a line parallel to the FH plane was set to landmark Cs. The contact point of the line parallel to the FH plane passing the inferior point of the external auditory meatus with the anterior wall of the mandibular condyle was set to landmark Ca1. The points dividing between Ca1 and Cs into three equal parts were set to semi-landmark Ca2 and Ca3 from the front. To evaluate the morphology of the posterior wall of the mandibular condyle, three points were measured. The contact point of the line parallel to the FH plane passing the inferior point of the external auditory meatus with the posterior

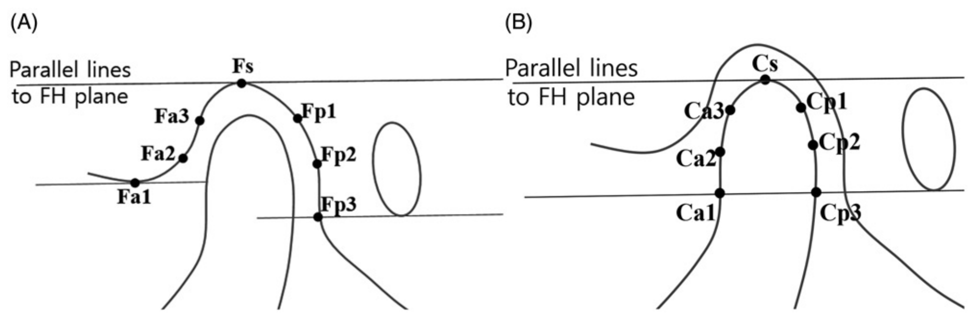

Figure 2. Landmarks of the articular fossa (A) and mandibular condyle (B).

wall of mandibular condyle was set to landmark Cp3. The points dividing between Cs and Cp3 into three equal parts were set to semi-landmark Cp1 and Cp2 from the front. The morphology of the mandibular condyle was calculated from the landmarks (Figure 2(B)).

All the landmarks' coordinates were used for statistical shape analysis. Generalized procrustes analysis (GPA) including Procrustes superimposition and principal components analysis (PCA) were performed and produced principal components (PCs) scores of each shape and their centroid size (CS) [18]. All measurements were carried out by a single investigator (SGH).

Statistical analysis

To evaluate the correlation between age, incisal guidance angle, and occlusal plane angle, Pearson correlation analysis was performed. PC score and CS of each shape as well as the correlation of the incisal guidance angle and occlusal plane angle were estimated using Pearson correlation coefficients ($p < .05$). To evaluate intra-examiner reliability, we repeatedly obtained the landmarks of 15 randomly selected samples at two-week intervals. Intra-examiner agreement was evaluated using intra-class correlation coefficient (ICC). ICC was high (0.980, range; 0.964–0.996). The language R (Vienna, Austria) was used for statistical computation.

Results

Changes of the incisal guidance angle and occlusal plane angle according to age

There were no significant correlations between the incisal guidance angle and age in all groups ($p > .05$). Similarly, there were no significant correlations between the occlusal plane angle and age ($p > .05$).

Correlation between the incisal guidance angle and the occlusal plane angle

The correlation between the incisal guidance angle and the occlusal plane resulted in a significant Pearson correlation coefficient of 0.3451 ($p < .001$). In addition, the correlation of the incisal guidance angle and the occlusal plane angle of women and men resulted in a Pearson correlation coefficient of 0.2060 ($p > .05$) and 0.4817 ($p < .001$), respectively.

Table 1. Correlation analysis between centroid sizes and incisal guidance angle.

	Incisal guidance angle					
	Overall		Women		Men	
		p value		*p* value		*p* value
Fossa	−.1780	.0470	−.2277	.0599	−.1133	.4059
Condyle	−.1941	.0301	−.1050	.3904	−.2754	.0399

Correlation analysis between the TMJ shapes (fossa and condyle) and the incisal guidance angle and occlusal plane angle using statistical shape analysis

Centroid size

There were statistically significant but weak correlations: The correlation coefficients between CSs of TMJ shapes and the incisal guidance angle (women/men) were −0.1780 (−0.2277/−0.1133), and −0.1941 (−0.1050/−0.2754) with the fossa, and condyle, respectively. However, there were no significant correlations with the occlusal plane angle (Table 1).

Principal components analysis (PCA)

Principal components analysis results confirmed that meaningful PCs (women/men) were 3 (3/2), and 2 (2/2) at the fossa, and condyle, respectively (Table 2). Only PC3 of the fossa shape (overall mean and both men and women) was significantly correlated with the occlusal plane angle ($p < .05$). However, there were no significant correlations between PCs and the incisal guidance angle. The mean fossa and condyle shape (middle) and the effect of the first three PCs are shown in Figures 3 and 4. Mean shapes were warped by applying to each PC an amount equal to three-standard deviations (SDs) both in negative (left) and positive (right) directions.

Discussion

In the correlation between the occlusal plane angle and age, it has been reported that the occlusal plane maintains a constant angle to the SN plane, palatal plane, and mandibular plane in a growth study of children aged between three months and eight years [20,21]. And the posterior part of the

Table 2. Meaningful principal components (PCs) from principal components analysis.

	Fossa			Condyle		
	Overall	Women	Men	Overall	Women	Men
PC1	46.03	39.95	53.32	57.01	58.25	57.83
PC2	22.21	25.82	18.27	16.89	17.67	15.52
PC3	9.07	10.57	8.33	10.50	8.71	10.71
PC4	6.73	7.11	4.37	4.13	3.89	3.89
PC5	4.62	6.38	3.68	3.22	3.05	3.05
PC6	3.73	3.09	3.24	2.08	2.41	2.41
PC7	2.63	2.61	2.57	1.76	2.12	2.12
PC8	1.78	1.60	1.86	1.45	1.16	1.16
PC9	1.31	1.39	1.31	1.30	1.12	1.12
PC10	1.13	0.99	1.02	0.86	0.90	0.90
PC11	0.72	0.46	0.92	0.75	0.68	0.68
PC12	0.00	0.00	0.00	0.00	0.00	0.00
PC13	0.00	0.00	0.00	0.00	0.00	0.00
PC14	0.00	0.00	0.00	0.00	0.00	0.00

occlusal plane moves more downwardly than the anterior part in children aged 8–17 years, due to a delayed growth. They also reported in that study that along with growth, the occlusal plane becomes less inclined and more parallel [22]. In this study, there was no correlation between age and the occlusal plane angle. This may be because the study was conducted on patients (14–40 years) excluding young children who undergo rapid changes. Therefore, the incisor guidance angle or occlusal plane angle becomes a characteristic of the individual after the completion of growth, and no major changes may further occur unless rapid changes happen.

From the result, there was a correlation between the incisor guidance angle and the occlusal plane angle. This interaction was reflected in the mandibular movement because

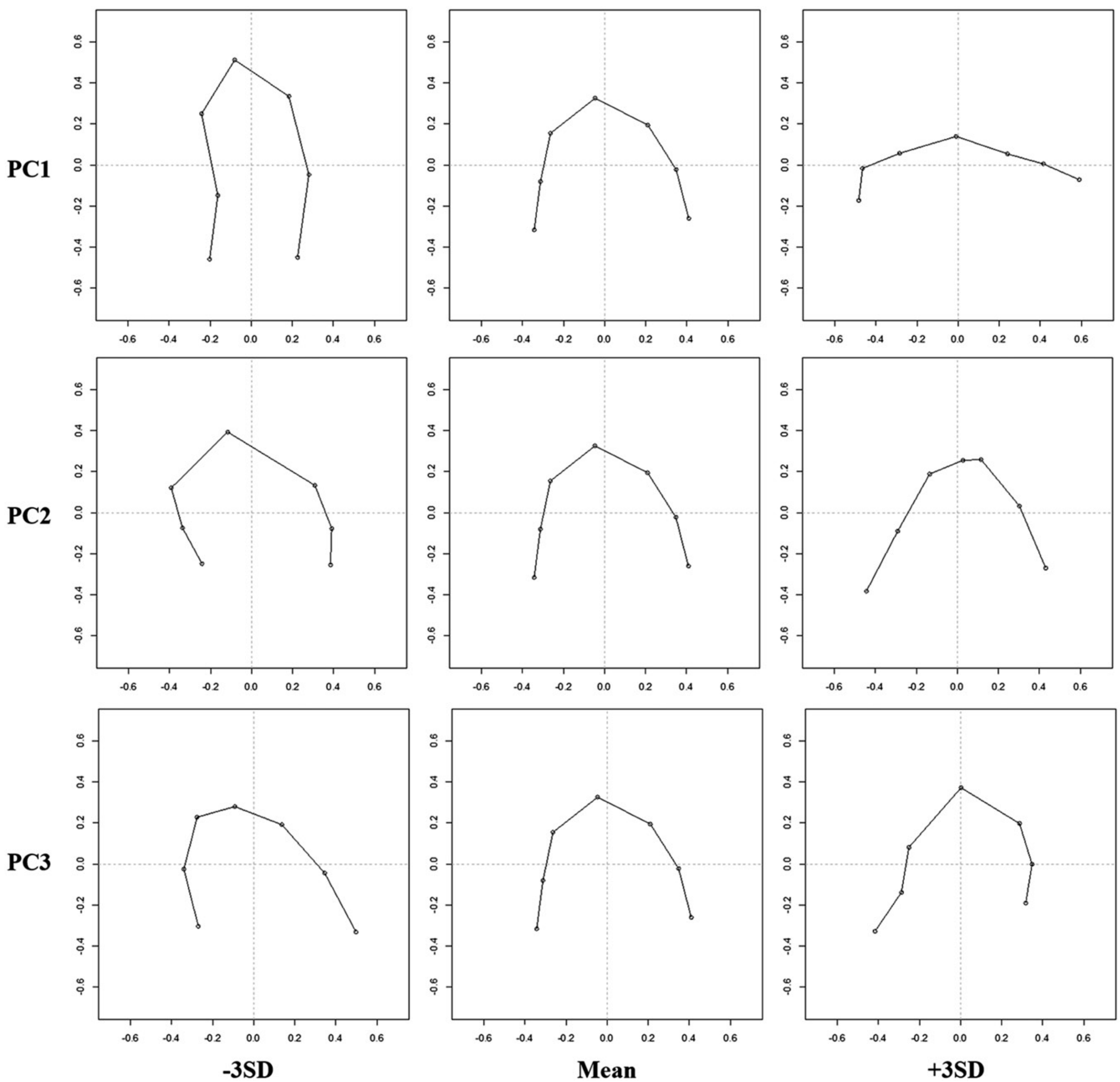

Figure 3. The mean condyle shape (middle) and effect of the first three PCs is shown. Mean shapes were warped by applying each principal component (PC) by amount equal to three standard deviations (SDs) in negative (left) and positive (right) directions.

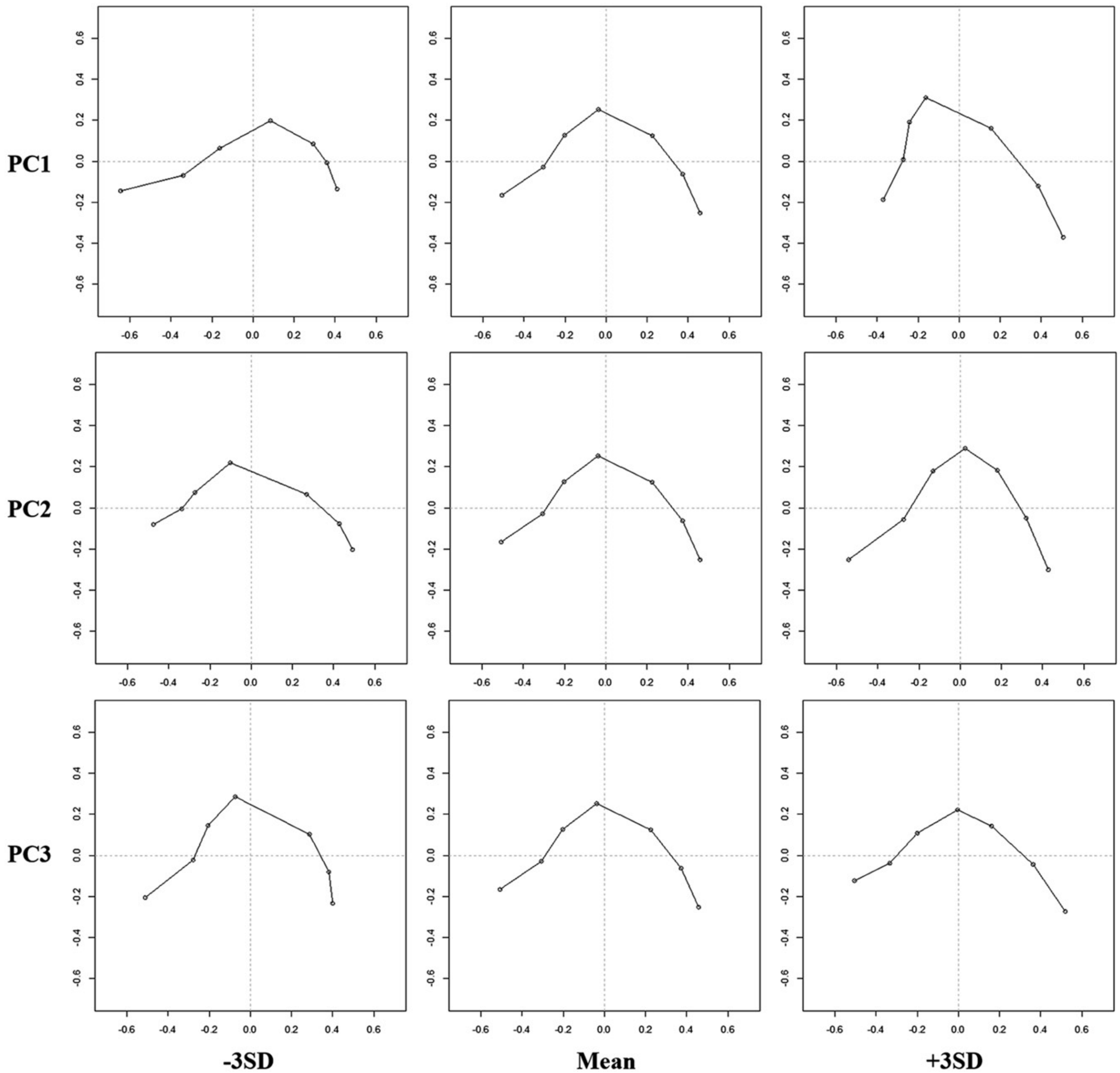

Figure 4. The mean fossa shape (middle) and effect of the first three PCs is shown. Mean shapes were warped by applying each principal component (PC) by amount equal to three standard deviations (SDs) in negative (left) and positive (right) directions.

the chewing activity is affected by both incisor guidance angle and occlusal plane. Occlusal plane is a functional plane that formed in consequence of tooth and alveolar bone growth and development [23,24]. The complex of intrinsic genetic factors and extrinsic environmental factors are reflected in the occlusal plane by interaction of jaw, muscle and teeth [25,26]. Thus, it has a great clinical importance to analyse an adaptation of tooth and alveolar bone to a craniofacial structure and its dysplasia through occlusal plane [27]. Therefore, it is clinically meaningful to observe the incisal guidance and occlusal plane angle, which was adapted from the facial growth.

Dawson insisted that these interactions (TMJ, anterior guidance, and occlusal surfaces) determine the position of individual teeth and form the shape of the TMJ [28]. The shape of TMJ can be affected by the occlusion as its result. Our results revealed a correlation between the CS and incisal guidance angle. There were weak, but statistically significant correlations between the CSs of condyle, fossa and incisal guidance angle. In the Hanau quint, the incisal guidance has an inverse correlation with the condylar inclination as well [29]. According to Dawson et al. [30], the anterior guidance is associated with the motion of the early condylar movement and may be linked to the size and path of the condyle and fossa. However, there was no significant correlation between CS and occlusal plane angle in our present study.

Principal components analysis is a statistical technique that extracts the PC that concisely “expresses” patterns of distributed types of many variables as a linear combination of the original variables [18]. The purpose of PCA is to provide a simple and understandable description of the complex structure between variables that correlate with each other while minimizing the loss of information. The first PC describes the variation of the data, the subsequent PCs describe the remaining information in the data, and the size decreases gradually. In general, the number of PCs in PCA is defined as PCs with a cumulative proportion of 70% [18]. In this study, PCs that were significant in PCA are defined as PCs with more than 70% characteristics.

In the present study, only PC3 of the fossa had a significant relationship with the occlusal plane angle. The remaining PCs showed no significant correlation with the occlusal plane angle or the incisor guidance angle. PCA analysis of the fossa showed 46.0% contribution rate of PC1 and 68.24% cumulative explanation rate for PC2, but PC3 contribution rate was low. Therefore, even though PC3 has a significant relationship with the occlusal plane angle, our PCA data could not demonstrate a significant relationship between the shape of the fossa and the occlusal plane, considering the definition of PCs. In the fossa, and condyle, PCs and occlusal plane angles or incisal guidance angles are not related to PCs. It can be concluded that the shape variation of fossa and condyle is not related to the occlusal plane angle and incisal guidance angle. Because the shape of the fossa and condyle is related to the condylar guidance angle [31,32], there should be a relationship between the occlusal plane angle and the incisor guidance angle. Previously, CS was suggested to be correlated with the incisor guidance angle. In other words, it can be concluded that the size is more related to the incisor guidance angle than the morphological factors of the constituent components of the TMJ.

In this study, CBCT on homogeneous position such as centric relation was not taken because this was retrospective study. It could include inaccuracies due to head positioning. However, the CBCT scans were made with the patient sitting in an upright position, Frankfort horizontal (FH) plane parallel to the floor and teeth in maximum intercuspation. And we focused on the relationship between incisal guidance angle or occlusal plane angle and fossa–condyle shapes at a specific static position. It is meaningful though it did not implement under identical position. In the further study, it would be better to control the patients' posture to determine the relationship between incisal guidance angle and occlusal plane angle and fossa–condyle shapes. In this study, we measured the TMJ shape, incisor guidance angle, and occlusal plane angle in a static state. Further research is needed to consider the dynamic aspects. In addition, 3-dimensional TMJ shape was obtained by using CBCT, but three dimensional TMJ and occlusal plane were projected in two dimensions. Therefore, it was difficult to reflect the exact TMJ shape. Further research is needed to improve these factors.

Conclusions

Incisor guidance angle and occlusal plane angle were correlated. And there were weak correlations between CS and incisal guidance angle. It can be concluded that the size is more related to the incisor guidance angle than the morphological factors of the constituent components of the TMJ. It could be concluded that the shape variation of the fossa and condyle was not related to the occlusal plane angle and incisal guidance angle.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This study was supported by clinical research grant from Pusan National University Dental Hospital.

References

[1] Jiang H, Li C, Wang Z, et al. Assessment of osseous morphology of temporomandibular joint in asymptomatic participants with chewing-side preference. J Oral Rehabil. 2015;42:105–112.
[2] Tanne K, Tanaka E, Sakuda M. Stress distributions in the TMJ during clenching in patients with vertical discrepancies of the craniofacial complex. J Orofoc Pain. 1995;9:153–160.
[3] Katsavrias EG, Dibbets JM. The growth of articular eminence height during craniofacial growth period. Cranio. 2001;19:13–20.
[4] Sülün T, Cemgil T, Duc JM, et al. Morphology of the mandibular fossa and inclination of the articular eminence in patients with internal derangement and in symptom-free volunteers. Oral Sur Oral Med Oral Pathol Oral Radiol Endod. 2001;92:98–107.
[5] Kurita H, Ohtsuka A, Kobayashi H, et al. Flattening of the articular eminence correlates with progressive internal derangement of the temporomandibular joint. Dentomaxillofac Radiol. 2000;29:277–279.
[6] Sümbüllü MA, Cağlayan F, Akgül HM, et al. Radiological examination of the articular eminence morphology using cone beam CT. Dentomaxillofac Radiol. 2012;41:234–240.
[7] Jasinevicius TR, Pyle MA, Lalumandier JA, et al. Asymmetry of the articular eminence in dentate and partially edentulous populations. Cranio. 2006;24:85–94.
[8] İlguy D, İlguy M, Fisekcioglu E, et al. Articular eminence inclination, height, and condyle morphology on cone beam computed tomography. Scientific World J. 2014;13:761714.
[9] Honda K, Kawashima S, Kashima M, et al. Relationship between sex, age, and the minimum thickness of the roof of the glenoid fossa in normal temporomandibular joints. Clin Anat. 2005;18:23–26.
[10] Ejima K, Schulze D, Stippig A, et al. Relationship between the thickness of the roof of glenoid fossa, condyle morphology and remaining teeth in asymptomatic European patients based on cone beam CT data sets. Dentomaxillofac Radiol. 2013;42:90929410.
[11] Kijima N, Honda K, Kuroki Y, et al. Relationship between patient characteristics, mandibular head morphology and thickness of the roof of the glenoid fossa in symptomatic temporomandibular joints. Dentomaxillofac Radiol. 2014;36:249014.
[12] Ikeda K, Kawamura A. Assessment of optimal condylar position with limited cone-beam computed tomography. Am J Orthod Dentofacial Orthop. 2009;135:495–501.
[13] Dalili Z, Khaki N, Kia SJ, et al. Assessing joint space and condylar position in the people with normal function of temporomandibular joint with cone-beam computed tomography. Dent Res J. 2012;9:607–612.
[14] Kinniburgh RD, Major PW, Nebbe B, et al. Osseous morphology and spatial relationships of the temporomandibular joint: comparisons of normal and anterior disc positions. Angle Orthod. 2000;70:70–80.
[15] Al-koshab M, Nambiar P, John J. Assessment of condyle and glenoid fossa morphology using CBCT in South-East Asians. PLoS One. 2015;10:e0121682.

[16] Tadej G, Engstrom C, Borrman H, et al. Mandibular condyle morphology in relation to malocclusions in children. Angle Orthod. 1989;59:187–194.

[17] Trapozzano VR. Laws of articulation. J Prosthet Dent. 1963; 13:34–44.

[18] Dryden IL, Mardia KV. Statistical shape analysis. Chichester (UK): John Wiley & Sons; 1998.

[19] Katsavrias EG, Halazonetis DJ. Condyle and fossa shape in class II and class III skeletal patterns: a morphometric tomographic study. Am J Orthod Dentofac Orthop. 2005;128:337–346.

[20] Broadbent BH. A new X-ray technique and its application to orthodontia: the introduction of cephalometric radiography. Angle Orthod. 1931;1:45–57.

[21] Brodie AG. On the growth pattern of the human head from the third to the eighth year of life. Am J Anat. 1941;68:209–262.

[22] Lee SY, Chang YI. A study on the occlusal plane inclination in lateral cephalograph. Korean J Orthod. 1991;21:367–397.

[23] Enlow DH. A morphogenetic analysis of facial growth. Am J Orthod. 1966;52:283–299.

[24] Enlow DH, Kuroda T, Lewis AB. Intrinsic craniofacial compensations. Angle Orthod. 1971;41:271–285.

[25] Harvold EP. The role of function in the etiology and treatment of malocclusion. Am J Orthod. 1968;54:888–898.

[26] Harvold EP, Hierici G, Vargervic K. Experiments on the development of dental malocclusions. Am J Orthod. 1972;61:38–44.

[27] Moyers RE. Handbook of orthodontics. 4th ed. Chicago, London & Boca Raton: Year Book Medical Publishers Inc.; 1988. p. 247–301.

[28] Dawson PE. Evaluation, diagnosis, and treatment of occlusal problems. Baltimore: Mosby; 1989.

[29] Schuyler CH. The function and importance of incisal guidance in oral rehabilitation. 1963. J Prosthet Dent. 2001;86:219–232.

[30] Dawson PE. Evaluation, diagnosis, and treatment of occlusal problems. Baltimore (USA): Mosby; 1989.

[31] Mohl ND, Zarb GA, Carlsson GE, et al. A textbook of occlusion. Chicago: Quintessence 1988; p. 139–140

[32] Zarb GA, Bolender CL. Prosthodontic treatment for edentulous patients: complete dentures and implant-supported prostheses. 12th ed. St Louis: Mosby; 2004. p. 294.