Mandibular condyle and fossa morphology according to vertical and sagittal skeletal patterns : a cone beam computed tomography study

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Mandibular condyle and fossa morphology according to vertical and sagittal skeletal patterns : a cone beam computed tomography study

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Anatomy of the temporomandibular joint (TMJ) is diagnostic and prognostic indicators of clinical conditions and TMJ-related examination before orthodontic treatment is essential. However, influence of dentofacial skeletal pattern on the joint morphology has not been completely understood. To compare the TMJ structures in the diverse skeletal patterns, it is necessary to obtain the combined classifications of skeletal type according to the vertical and sagittal patterns. The purpose of this study was to compare morphology of TMJ structures according to vertical and sagittal skeletal patterns using CBCT and to understand interactive effects of diverse skeletal patterns on the joint morphology.

This retrospective study included 131 subjects who had no TMJ symptom and had taken lateral cephalogram and CBCT. The subjects were divided into 3 sagittal groups of Class I (n = 43), II (n = 42), and III (n = 46) by ANB angle. They were also divided into 3 vertical groups of hypodivergent (n = 37), normodivergent (n = 47), and hyperdivergent (n = 47) by Sella-Nasion and mandibular plane (SN-MP) angle. We measured condylar volume, condylar size (width, length, and height), fossa size (length and height), and condyle-to-fossa joint space. All measurements were analyzed by one-way ANOVA and interactive skeletal effects on the measurements were analyzed by two-way ANOVA. The results were listed below:

1. There were significant differences among three sagittal groups for condylar width, condylar height, and fossa height: the Class III group showed higher values of condylar width, condylar height, and fossa height than the Class II group ($P < 0.05$).

2. Condylar volume, condylar width, fossa length and height, and superior joint space were significantly different according to the vertical skeletal patterns: mean condylar volume and superior joint space in the hyperdivergent group were significantly smaller than the other two vertical groups ($P < 0.05$), and fossa length and height were significantly larger in the hyperdivergent group than in the other groups ($P < 0.05$). Condylar width in the hypodivergent group was significantly larger than in the hyperdivergent group ($P < 0.05$).
3. There were interactive effects of sagittal and vertical skeletal patterns on condylar width, posterior joint space, and fossa length ($P < 0.05$). In condylar width, the hyperdivergent group showed significantly lower value than the other vertical groups, and the Class II group was the lowest among sagittal groups. The Interaction of the hyperdivergent and the Class II skeletal patterns makes condylar width smaller, definitely. Posterior joint space showed no main effects of the sagittal and vertical skeletal patterns, but their interaction were statistically effective ($p < 0.05$), not clinically. Fossa length was significantly larger in the hyperdivergent group than in the other groups, and the Class III tendency amplified that vertical effect.

TMJ morphology differed according to diverse skeletal patterns. Vertical skeletal patterns were more influential on the condyle and fossa morphologies than sagittal skeletal patterns. The condylar width and fossa length were affected by both vertical and sagittal skeletal patterns.

Key words: Temporomandibular Joint; Mandibular Condyle; Cone-Beam Computed Tomography; sagittal skeletal pattern; vertical skeletal pattern

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I. Introduction

In dental practice, temporomandibular joints (TMJ) are anatomic structures that cannot be overlooked. The mandibular condyle is a part of TMJ structure and its shape and volume have been considered to play an important role in the stability of long-term treatment results in prosthodontic, orthodontic, and orthognathic patients (Krisjane et al., 2007; Tecco et al., 2010). Dental practitioners need to consider morphology and position of the condyle in treatment planning stage, because treatment results can influence the condylar morphology and position in reverse.

The amount of CR-CO discrepancy at the level of the condyle is known to be correlated with the probability of patients having temporomandibular disorders (TMDs) before, during and/or after orthodontic or prosthetic treatment (Costea et al., 2016). TMJ with persisting disc displacement that is the most important sign of TMD could make the mandibular condyle small, moreover, the size of the condyle was maintained even after symptoms and signs of TMJ disorders were resolved or reduced (Hasegawa et al., 2011; Kurita et al., 2006). That is, the position and size of the mandibular condyle are closely related to the probability of TMD. The morphology of TMJ is diagnostic and prognostic indicators of clinical conditions and TMJ-related studies need to be performed before initiation of orthodontic treatment (Al-Riyami et al., 2009; Mupparapu et al., 2011; Saccucci et al., 2012b). Therefore, measurements of the TMJ structure consisted of the mandibular condyle, fossa, and joint spaces could be useful in predicting or estimating for temporomandibular disorders (TMDs), which could eventually contribute to long-term stability of prosthodontics, orthodontic and orthognathic therapies

(Katsavrias, 2006; Krisjane et al., 2009; Saccucci et al., 2012b).

In patients' diverse dentofacial morphologies, the condyle and the fossa may differ in shape and their interrelations because the mandible and the fossa can be loaded differently (Katsavrias and Halazonetis, 2005; Krisjane et al., 2009). At the stage of orthodontic diagnosis, particularly when facial morphology including facial asymmetry is evaluated, not only the condylar size but also the size of the glenoid fossa should be considered comprehensively (Kim et al., 2016). However, influences of dentofacial skeletal pattern on joint morphology have not been completely understood. Sagittal skeletal pattern could influence the condylar volume: patients having skeletal Class III malocclusion showed large condylar volume while those having skeletal Class II malocclusion showed small volume (Krisjane et al., 2009; Saccucci et al., 2012a). Vertical skeletal pattern also demonstrated significant relationships with the condyle: patients having hyperdivergent skeletal pattern tend to have smaller and more superiorly positioned condyles than those having hypodivergent skeletal pattern (Park et al., 2015).

It is more accurate to identify facial type as multi-dimensional combination because interrelation of the sagittal and vertical relationship is responsible for various facial types (Kim et al., 2005). However, previous studies barely considered sagittal and vertical skeletal patterns together. To compare the TMJ structures in the diverse skeletal patterns, it is necessary to obtain the combined classifications of the skeletal type according to the vertical and sagittal characteristics.

Several methods, such as conventional radiography, magnetic resonance images (MRI), and computed tomography (CT), have been introduced to examine the TMJ structure (Katsavrias, 2006; Krisjane et al., 2009; Yamada et al., 2004). Cone-beam computed tomography (CBCT) has recently been used in several studies for measurements of bony structure due to its high-resolution images with minimal distortion and less radiation dosage compared to conventional CT (Petersson, 2010; Sumbullu et al., 2012). Three-dimensional (3D) CBCT images enable to measure volume and lengths in multiple planes, which can contribute to make an accurate diagnosis and bring out predictable treatment outcomes (Tecco et al., 2010). Therefore, the purpose of this study was to evaluate the following null hypothesis: there are no differences of morphology of the TMJ structures according to vertical and sagittal skeletal patterns. This study further investigated diagnostic and prognostic indicators of the TMJ structures.

II. Materials and Methods

1. Subjects

This retrospective study included 131 subjects having no TMJ symptom (48 men, 83 women; mean age 23.5 years; range 18.0–39.6 years). They were selected from 449 patients who had visited to Yonsei university dental hospital between January 2012 and June 2016 and had taken lateral cephalogram and CBCT including the TMJ structure. The subjects had taken CBCT for the following reasons: orthodontic diagnosis for orthognathic surgery; presence of impacted tooth; and evaluation of available amount of the alveolar bone for orthodontic tooth movement. The inclusion criteria were no signs and symptoms of TMD (conditions enough to initiate orthodontic or orthognathic treatments); availability of lateral cephalogram and CBCT images; and age over 18 years. The exclusion criteria were history of orthodontic or orthognathic treatments; congenital skeletal deformity; and facial asymmetry with more than 4 mm of menton deviation (Nur et al., 2016).

Based on cephalometric analysis, the subjects were classified according to vertical and sagittal skeletal relationships. ANB angle was used to divide them into Class I ($1^{o} <$ ANB $< 4^{o}$), Class II (ANB $> 4^{o}$), and Class III (ANB $< 1^{o}$) groups (Kim et al., 2011); Sella-Nasion to mandibular plane (SN-MP) angle was used to divide the subjects into hypodivergent (SN-MP $< 30^{o}$), normodivergent ($30^{o} <$ SN-MP $< 38^{o}$), and hyperdivergent (SN-MP $> 38^{o}$) groups (Kim et al., 2014). Finally, the subjects were divided into nine subgroups (Table 1). This study was approved by OO Hospital Institutional Review Board (No. 2-2016-0001). Because of the retrospective nature of this study, the institutional review board waived the requirement for written informed patient consent.

Table 1. Demographic features of the study subjects

		Hypodivergent (n = 37)	Normodivergent (n = 47)	Hyperdivergent (n = 47)	P value†
Age (years)	**Class I (n = 43)**	25.61 ± 5.16 (n = 11; M9 F2)	20.97 ± 3.34 (n = 16; M5 F11)	23.93 ± 4.67 (n = 16; M3 F13)	0.93
	Class II (n = 42)	27.59 ± 8.26 (n = 11; M4 F7)	23.44 ± 5.91 (n = 15; M5 F10)	23.02 ± 5.95 (n = 16; M4 F12)	0.08
	Class III (n = 46)	20.87 ± 3.92 (n = 15; M8 F7)	24.27 ± 5.12 (n = 16; M4 F12)	20.78 ± 2.72 (n = 15; M6 F9)	0.08
	P value*	0.17	0.68	0.40	
ANB (°)	**Class I**	2.46 ± 0.82	2.85 ± 0.95	2.44 ± 0.91	0.44
	Class II	5.70 ± 1.20	5.64 ± 0.97	6.78 ± 1.55	0.08
	Class III	-1.84 ± 3.32	-2.49 ± 2.75	-2.01 ± 1.38	0.79
	P value*	0.00*	0.00*	0.00*	
SN-MP (°)	**Class I**	26.12 ± 7.06	34.16 ± 2.15	43.65 ± 3.74	0.00†
	Class II	25.42 ± 2.35	35.25 ± 2.00	44.45 ± 3.37	0.00†
	Class III	26.66 ± 2.18	34.30 ± 2.15	42.05 ± 2.62	0.00†
	P value*	0.87	0.33	0.16	

Values are presented as mean ± standard deviation. M, male; F, female; ANB, A point-nasion-B point; SN-MP, Sella-nasion to mandibular plane angle.
P value* indicates ANOVA results for comparisons among three sagittal groups, while P value† indicates ANOVA results for comparisons among three vertical groups.
*$P<0.05$

2. Measurements

Three-dimensional images were acquired with a CBCT device (Alphard VEGA, ASAHI Roentgen IND, Kyoto, Japan) set at 5.0–8.0 mA and 80 kV, and images were captured for 17s, with a 0.30-mm voxel size. The field of view was 154 X 154 mm^2. Images were transformed to DICOM format and reconstructed and analyzed with OnDemand software (Cybermed Co., Seoul, Korea). The CBCT images were reoriented with the Frankfort horizontal (FH) plane parallel to the ground. Thereafter, the midsagittal reference plane (MSP), which was perpendicular to FH plane and passed through nasion, was automatically set.

To measure size of the mandibular condyle and glenoid fossa, one coronal section and one sagittal section where the cortical lines of the condyle and glenoid fossa were clearly noticed and the most prominent condylar points are noted in those sections were obtained. Twelve anatomic landmarks (Cd-med, Cd-lat, Cd-ant, Cd-post, Cd-sup, Sig-inf, Sig-post, Fs-ant, Fs-post, Fs-sup, At-inf, and Am-inf) were defined and identified (Table 2).

Table 2. Definition of the landmarks used in this study

Landmark		Abbreviation	Definition
Condyle	Superior	Cd-sup	The most superior point of the condylar head in the axial and sagittal planes
	Medial	Cd-med	The most mesial point of the condylar head in the coronal plane
	Lateral	Cd-lat	The most lateral point of the condylar head in the coronal plane
	Anterior	Cd-ant	The most anterior point of the condylar head within a 5-mm radius from Cd-sup in the sagittal plane
	Posterior	Cd-post	The most posterior point of the condylar head within a 5-mm radius from Cd-sup in the sagittal plane
Sigmoidal	Inferior	Sig-inf	The most inferior point of the sigmoid notch
	Posterior	Sig-post	Perpendicular point from the Sig-inf to the tangent line of the ramal posterior surface in the sagittal plane
Fossa	Superior	Fs-sup	The point having the shortest distance from Cd-sup to the superior wall of the glenoid fossa
	Anterior	Fs-ant	The point having the shortest distance from Cd-ant to the anterior wall of the glenoid fossa
	Posterior	Fs-post	The point having the shortest distance from Cd-post to the posterior wall of the glenoid fossa
Articular tubercle		At-inf	The most inferior point of the articular tubercle
Auditory meatus		Am-inf	The most inferior point of the auditory meatus

The study was designed to analyze condylar volume, condylar size (width, length, and height), fossa size (length and height), and condyle-to-fossa joint spaces at the anterior, superior, and posterior condylar poles. The measurements were performed on both sides, and the mean values were used. The measurements in this study were listed in Table 3.

Table 3. Definition of the measurements in this study

Measurement		Definition
Condyle	Volume	Volume of separated condyle between the line across the most superior condylar point and the tangent line to the Sig-inf., which is parallel to the FH plane
	Width	The widest distance between Cd-med. and Cd-lat. in selected coronal section
	Length	The longest distance between Cd-ant. and Cd-post. in selected sagittal section
	Height	A perpendicular distance from Cd-sup. to the line between Sig-inf. and Sig-post. in selected sagittal section
Fossa	Length	A distance from At-inf. to a point that the line connecting At-inf. and Am-inf. meets to the posterior wall of the glenoid fossa in selected sagittal section
	Height	A perpendicular distance from Fs-sup. to the line connecting At-inf. and Am-inf. in selected sagittal section
Joint space	Superior	The shortest distance from Cd-sup. to the corresponding glenoid fossa
	Anterior	The shortest distance from Cd-ant. to the corresponding glenoid fossa
	Posterior	The shortest distance from Cd-post. to the corresponding glenoid fossa

For measurement of the condylar volume, the condylar structure was separated from mandible and volumetric assessment was done (Al-koshab et al., 2015) (Figure 1).

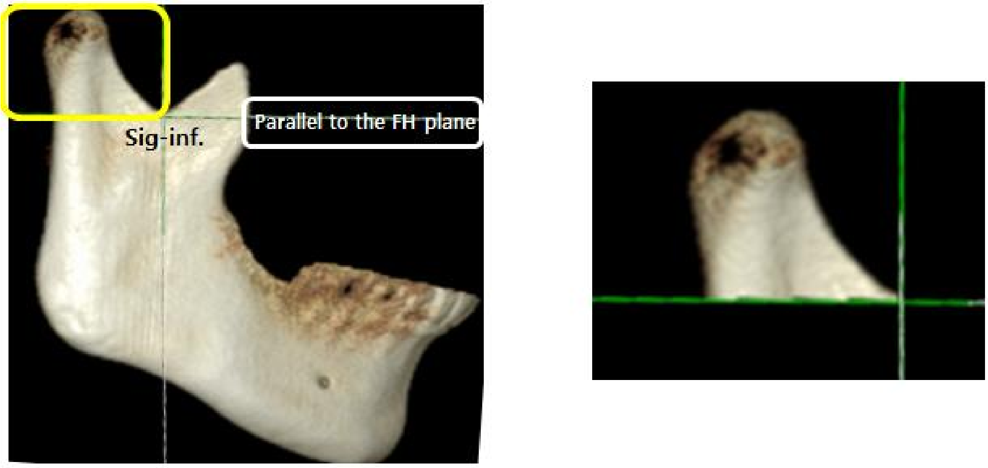

Figure 1. Condylar volume measurement

The Cd-sup was first selected where the opaque area are appearing at first on the axial view, while scrolling the images from the top of the glenoid fossa to the sigmoid notch, then it was confirmed on the sagittal view as the most superior point of the mandibular condyle (Saccucci et al., 2012b). Condylar width was measured in a coronal section (Table 3, Figure 2). In the sagittal section, we could measure the condylar length and height (Al-koshab et al., 2015; Hilgers et al., 2005) (Table 3, Figure 3).

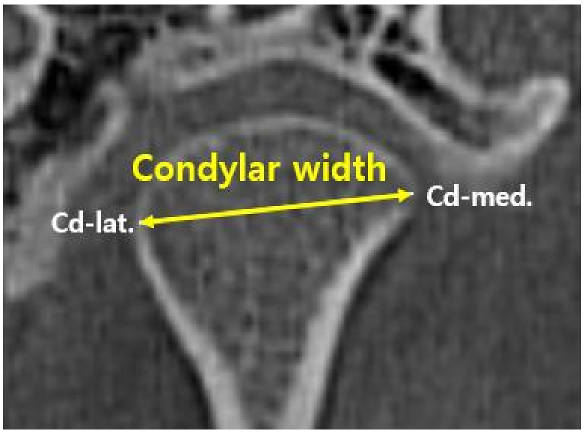

Figure 2. Condylar width (coronal section)

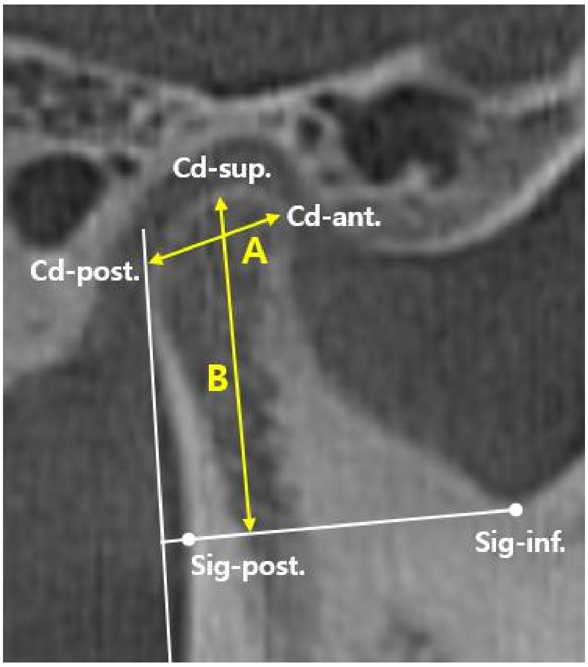

Figure 3. Condylar length (A) and height (B) (sagittal section)

Then, the fossa length and height were measured in this section, too (Krisjane et al., 2009) (Table 3, Figure 4). Lastly, condyle-to-fossa joint spaces were measured at three points in the selected sagittal section (Park et al., 2015) (Table 3, Figure 5).

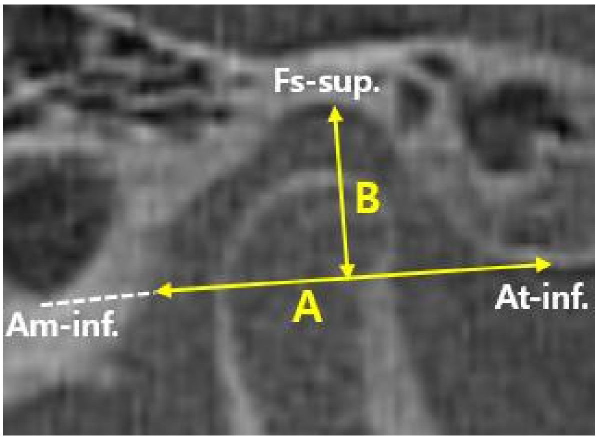

Figure 4. Fossa length (A) and height (B) (sagittal section)

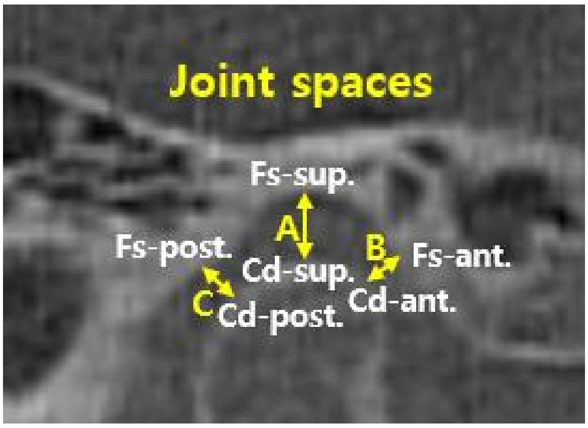

Figure 5. Joint spaces (sagittal section) A, superior joint space; B, anterior joint space; C, posterior joint space

3. Statistical analysis

One examiner performed all measurements. To evaluate intra-examiner reliability, the same examiner re-analyzed 20 randomly selected subjects within a 2-week interval.

One-way ANOVA and Scheffe post-hoc test were used to compare Class I, II, and III groups according to sagittal skeletal patterns. The same tests were performed to compare hypodivergent, normodivergent, and hyperdivergent groups according to vertical skeletal patterns. The 9 subgroups were compared by two-way ANOVA and Bonferroni post-hoc test to evaluate the interaction between the sagittal and vertical skeletal pattern. All measurements were analyzed by using the IBM SPSS Statistics software (version 23.0; IBM Corp., Armonk, NY, USA).

III. Results

Intra-class correlation coefficients of 0.995 were achieved. Therefore, reproducibility of the evaluation method was acceptable.

There were significant differences among three sagittal groups for condylar width, condylar height, and fossa height ($P < 0.05$; Table 4): Class III group showed larger values of condylar width, condylar height, and fossa height than Class II group ($P < 0.05$; Table 4).

Table 4. Overall comparison of measurements according to sagittal skeletal patterns

		Class I (N = 43)	Class II (N = 42)	Class III (N = 46)	P value
Condylar volume (mm^3)		1086.83 ± 287.72	1096.23 ± 283.26	1083.99 ± 271.81	0.978
Condyle	**Width (mm)**	16.09 ± 3.60 [ab]	15.35 ± 3.14[a]	17.10 ± 2.71[b]	0.037*
	Length (mm)	7.51 ± 1.18	7.62 ± 1.34	7.38 ± 1.03	0.629
	Height (mm)	23.23 ± 3.97 [ab]	21.92 ± 2.94[a]	25.16 ± 3.93[b]	0.000*
Fossa	**Length (mm)**	20.32 ± 2.20	20.33 ± 1.98	20.67 ± 2.00	0.666
	Height (mm)	9.29 ± 1.72 [ab]	8.69 ± 1.51[a]	9.71 ± 1.43[b]	0.011*
Joint space	**Superior (mm)**	3.03 ± 0.83	2.86 ± 0.88	2.89 ± 0.76	0.598
	Anterior (mm)	2.64 ± 0.59	2.86 ± 0.70	2.67 ± 0.83	0.305
	Posterior (mm)	2.63 ± 0.78	2.51 ± 0.90	2.53 ± 0.73	0.765

Values are presented as mean ± standard deviation.
The same letters indicate there were no statistically significant differences.
P value indicates one-way ANOVA results for comparisons among three sagittal groups.
*$P < 0.05$

According to the vertical skeletal patterns, condylar volume, condylar width, fossa height and length, and superior joint space showed significant differences among three vertical groups ($P < 0.01$; Table 5): condylar volume and superior joint space in the hyperdivergent group were significantly smaller than the other two vertical groups, whereas fossa height and length were significantly higher in hyperdivergent group than in the other groups. Condylar width was significantly different between two groups: hypodivergent group had wider condylar head than hyperdivergent group ($P < 0.01$; Table 5).

Table 5. Overall comparison of measurements according to vertical skeletal patterns

		Hypodivergent (N = 37)	Normodivergent (N = 47)	Hyperdivergent (N = 47)	P value
Condylar volume (mm^3)		1152.39 ± 275.11[a]	1191.28 ± 279.20[a]	936.39 ± 211.67[b]	0.000***
Condyle	Width (mm)	17.61 ± 2.95[a]	16.07 ± 2.75[ab]	15.23 ± 3.51[b]	0.003**
	Length (mm)	7.60 ± 1.23	7.71 ± 1.23	7.21 ± 1.05	0.104
	Height (mm)	23.12 ± 3.26	24.20 ± 4.12	23.07 ± 4.02	0.292
Fossa	Length (mm)	20.10 ± 2.12[a]	19.98 ± 1.73[a]	21.19 ± 2.12[b]	0.007**
	Height (mm)	8.51 ± 1.17[a]	8.97 ± 1.61[a]	10.10 ± 1.51[b]	0.000***
Joint space	Superior (mm)	3.27 ± 0.82[a]	3.02 ± 0.85[a]	2.57 ± 0.65[b]	0.000***
	Anterior (mm)	2.70 ± 0.61	2.69 ± 0.68	2.77 ± 0.83	0.861
	Posterior (mm)	2.41 ± 0.65	2.69 ± 0.90	2.53 ± 0.80	0.280

Values are presented as mean ± standard deviation.
The same letters indicate there were no statistically significant differences.
P value indicates one-way ANOVA results for comparisons among three vertical groups.
**P < 0.01; ***P < 0.001

Two-way ANOVA tests among 9 subgroups showed that there were no statistically significant interactions between the sagittal and vertical skeletal patterns on the condylar parameters and joint spaces ($P > 0.05$). However, there were statistically significant interactions between sagittal and vertical skeletal patterns on fossa length and height (Table 6). In fossa length, Class III-hyperdivergent subgroup showed the highest value and skeletal Class III-hypodivergent subgroup showed the lowest value ($P < 0.05$, Figure 6). In fossa height, skeletal Class I-hyperdivergent subgroup was the highest rank, and skeletal Class II-normodivergent subgroup was the lowest one ($P < 0.01$, Figure 6).

The 9 subgroups were restructured into the 4 subgroups by the results of one-way ANOVA, separating the most prominent group from another groups. Hyperdivegent group from other vertical groups and Class II or Class III groups from other sagittal groups were separated in this process. Two-way ANOVA among 4 subgroups showed different results compared with two-way ANOVA among 9 subgroups. There were no interactive effects of vertical and sagittal groups in fossa height ($P > 0.05$), because the main effects of sagittal and vertical skeletal patterns were correlated with the interactive effects. Fossa length, however, still showed interactive effects by two-way ANOVA among 4 subgroups ($P<0.05$) (Figure 7).

By two-way ANOVA among 4 subgroups, condylar width ($P < 0.01$) and posterior joint space ($P < 0.05$) were identified additionally that had affected by interactive actions of two skeletal patterns (Figure 8). Condylar width was affected by each sagittal or vertical skeletal pattern, and interaction of both skeletal patterns. The interactive effect was confirmed by two-way ANOVA among 4 subgroups composed of Class II group, other sagittal groups, hyperdivergent group, and other vertical groups. Posterior joint space was also affected by interactive actions of two skeletal patterns and this was confirmed by two-way ANOVA among 4 subgroups composed of Class III group, other sagittal groups, hyperdivergent group, and other vertical groups. However, there was no main effect of sagittal or vertical skeletal pattern on posterior joint space.

Table 6. Fossa length and fossa height of 9 subgroups by two-way ANOVA

		Class I (N = 43)	Class II (N = 42)	Class III (N = 46)	P value
Fossa length (mm)	Hypodivergent (N = 37)	20.80 ± 2.84[a]	19.83 ± 1.17[a]	19.78 ± 2.06[a]	NS
	Normodivergent (N = 47)	19.90 ± 2.03[a]	20.18 ± 2.01[a]	19.87 ± 1.12[a]	NS
	Hyperdivergent (N = 47)	20.42 ± 1.93[a]	20.82 ± 2.36[ab]	22.41 ± 1.53[b]	*
	P value	NS	NS	*	0.045**
Fossa height (mm)	Hypodivergent (N = 37)	8.63 ± 1.36[a]	8.45 ± 1.52[ac]	8.47 ± 0.73[a]	NS
	Normodivergent (N = 47)	8.32 ± 1.44[a]	8.31 ± 1.37[ac]	10.24 ± 1.23[b]	*
	Hyperdivergent (N = 47)	10.71 ± 1.20[d]	9.23 ± 1.56[ac]	10.38 ± 1.40[bcd]	*
	P value	*	NS	*	0.002**

Values are presented as mean ± standard deviation.
The same letters indicate there were no statistically significant differences.
P value** indicate statistically significant interactions between sagittal and vertical skeletal patterns by two-way ANOVA.

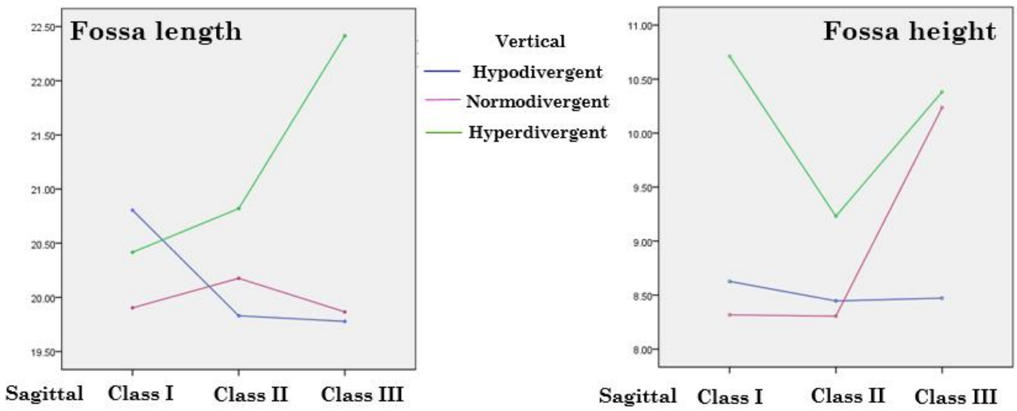

Figure 6. Fossa length and fossa height of 9 subgroups

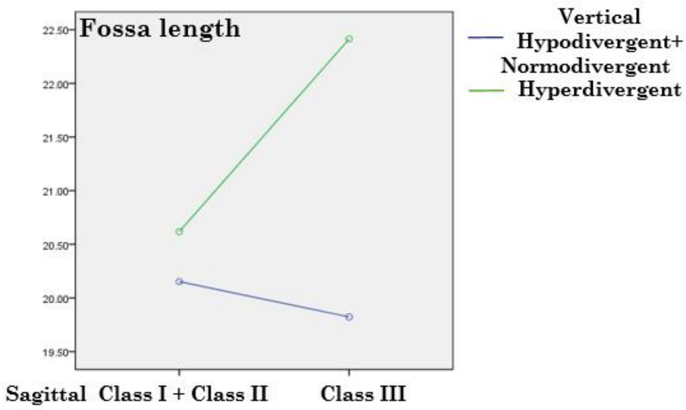

Figure 7. Fossa length of 4 subgroups

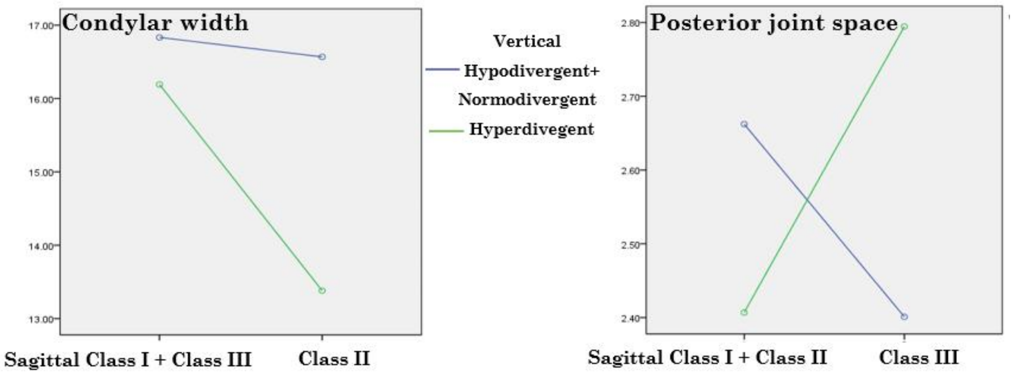

Figure 8. Condylar width and posterior joint space of 4 groups

IV. Discussion

This study was designed to compare the morphology of TMJ structures and the spatial relationships between condyle and fossa according to vertical and sagittal skeletal patterns. In this study, Class III group showed higher values of condylar width, condylar height, and fossa height than Class II group. Condylar volume, condylar width and superior joint space in Hyperdivergent group were significantly smaller than Hypodivergent group, while fossa length and height were significantly larger in Hyperdivergent group than Hypodivergent group. In addition, there were statistically significant interactions between vertical and sagittal skeletal patterns in condylar width, fossa length, and posterior joint space. Therefore, the null hypothesis of this study was rejected.

Condylar width has showed both main effects and interactive effects of sagittal and vertical skeletal patterns. Condylar width was the smallest in Class II-hyperdivergent patients. That is, the combination of Class II sagittal pattern and hyperdivergent vertical pattern makes condylar width much smaller than other subgroups. In fossa length, the results of two-way ANOVA showed that skeletal Class III-hyperdivergent group have the longest antero-posterior fossa and skeletal Class III-hypodivergent group have the shortest one among 9 subgroups. That implied vertical skeletal pattern have a stronger effect on the fossa length than sagittal skeletal pattern. Hyperdivergent skeletal pattern contributed to make fossa length longer than other vertical patterns and Class III pattern makes this tendency stronger. Katsavrias and Halazonetis (2005) and Krisjane et al. (2009) reported that skeletal Class III group had a wider glenoid fossa antero-posteriorly when comparing with Class II group, which was partly going in line with our study. Posterior joint space was affected by interactive action of vertical and sagittal skeletal patterns, while there was no main effect of each one. According to the result, Class III-hyperdivergent group have the most anteriorly-positioned condyles. However, the difference between the highest and the lowest groups seems clinically insignificant.

Sagittal and vertical skeletal combination could influence condyle and fossa morphology: for example, skeletal Class II-hyperdivergent pattern could make condylar width smaller and skeletal Class III-hyperdivergent pattern made fossa length longer. Large condyles provide stable support for occlusal changes and they are considered to be more resistant to displacement because the fossa and condyle are well-fitted; conversely, small condyles provide unreliable support for occlusal changes, are easily displaced because they make a stable fitting of components difficult (Arnett and Gunson, 2004;

Krisjane et al., 2009). Thus, before initiating the treatments that might change the patients' occlusion, practitioner should pay more attention to the condylar condition of patients who have skeletal patterns that could make small condyle or large fossa.

Regaarding fossa height, skeletal Class III-hyperdivergent combination showed the largest fossa height. Class III group and Hyperdivergent group also had the larger value than other groups in each sagittal and vertical comparison, respectively. In previous study, fossa height was considered to correlate with the facial form, especially lower face. Rectangular facial form with low mandibular angle and prognathism tend to have marked fossa height and eminence inclination (Ingervall, 1974). The controversies in relationship of skeletal pattern and fossa height could be explained by differences in imaging techniques, methods of measurements, and other differences between the populations (Paknahad et al., 2016). Fossa height is associated with anterior mandibular movement and the significant differences in fossa height according to diverse skeletal patterns imply the differences of mandibular functional efficiency (Cohlmia et al., 1996).

Measurements of condylar parameters have been reported in association with the several malocclusions (Krisjane et al., 2009; Park et al., 2015; Saccucci et al., 2012a; Saccucci et al., 2012b; Tecco et al., 2010). In this study, Class III group showed larger values of condylar width and height than Class II group. These results support Krisjane et al. (2009) that skeletal Class III group who has longer condyle underwent excessive vertical development of mandibular ramus during growth. According to the vertical skeletal patterns, condylar volume, width and superior joint space were significantly small in Hyperdivergent group than Hypodivergent group (Table 5). Another condylar parameters also have tendencies that Hyperdivergent group have lower values than Normodivergent and Hypodivergent groups. Park et al. (2015) reported that the small superior joint space in Hyperdivergent group indicate that the hyperdivergent skeletal group have superiorly positioned condyles. Also, Burke et al. (1998) found preadolescent patients with hyperdivergent tendency exhibit reduced superior joint space. Though it still remains undetermined that the relationship of condylar growth and structural adaptations, reduced superior joint spaces may induce decreased condylar growth. Balance between condylar growth and the dentoalveolar processes could make normal occlusion and stable facial structures (Bjork and Skieller, 1972; Peltola et al., 1995). Therefore, decreased condylar growth may allow increased development of anterior face and the result would be an imbalance in anterior and posterior face heights, decreased ramus height, clockwise rotation of the mandible and increased vertical development (Burke et al., 1998).

There were previous studies that analyze condylar and fossa morphology in relation to either sagittal skeletal pattern, or vertical skeletal pattern. However, interactive effects of two skeletal patterns on TMJ structure had been rarely discussed. A patient's facial form and malocclusion could be explained more exactly by considering sagittal and vertical skeletal patterns together. The present study showed interactive effects of sagittal and vertical skeletal patterns on condylar width and fossa length, with clinical significance. In particular, vertical skeletal patterns of patients are more influential on their condyle and fossa morphologies than sagittal skeletal patterns.

There were limitations in this study. The articular disc could not be evaluated because only CBCT images were measured. Therefore, there might be a possibility of asymptomatic patients with internal derangement could have been included in this study. To exclude TMD patients with disc displacement, the information obtained from additional diagnostic tools, such as magnetic resonance imaging might be needed in further study. The sagittal and vertical skeletal patterns of subjects were measured and the transverse skeletal condition which might affect to the malocclusion pattern was not considered in this study. Thus, transverse skeletal pattern as well as sagittal and vertical skeletal patterns might be considered in the next study. There were insufficient subjects due to the limitation of the retrospective study. This limitation could be overcome by a well-organized prospective study; accumulating more pre-orthodontic patients who have to be taken lateral cephalogram and CBCT. For the ethical reasons, taking CBCT was limited to prescribed patients for the treatment purposes.

V. Conclusion

From this study, the following conclusions can be drawn:

1. TMJ morphology differed according to diverse skeletal patterns; there were significant differences among three sagittal groups for condylar width, condylar height, and fossa height; while condylar volume, condylar width, fossa height and length, and superior joint space showed significant differences among three vertical groups.
2. Vertical skeletal patterns were more influential on the condyle and fossa morphologies than sagittal skeletal patterns.
3. The condylar width and fossa length were affected by interactions of vertical and sagittal skeletal patterns.

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국 문 요 약

수직적, 시상적 골격 형태에 따른 과두와 측두와의 형태에 대한 Cone-beam CT 연구

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측두하악관절(TMJ)의 해부학적 구조는 관절의 임상적인 상태에 대한 진단적 도구, 또는 치료 예후에 대한 지표라고 할 수 있으므로 교정 치료가 시작되기 전 TMJ 관련 검사를 꼭 시행해야 한다. 그러나 치열안면골격의 유형이 측두하악관절에 미치는 영향에 대해서는 완전하게 의견 일치가 되고 있지 않다. 다양한 골격 형태에 따른 TMJ 구조물의 비교를 위해서는 수직 방향과 시상 방향의 골격 유형을 조합한 분류가 필요하다. Cone-beam computed tomography (CBCT)에 의해 얻어진 3차원 영상을 통해 TMJ 구조물을 여러 각도의 평면으로 볼 수 있을 뿐만 아니라 부피의 측정도 가능해졌다. 이를 통해 더 정확하게 진단하게 되고 치료 결과도 더 믿을 만 해졌다. 이번 연구의

목적은 CBCT를 이용해 수직적, 시상적 골격 유형에 따른 TMJ 구조물의 형태학적 차이를 확인하는 것이며, 또한 골격 형태의 상호작용이 관절의 형태에 미치는 영향에 대해 알아보고자 한다.

TMJ에 이상이 없으면서 lateral cephalogram과 CBCT를 모두 촬영한 교정 전 환자 131명을 선택하였다. 환자들은 ANB angle 값을 통해 skeletal Class I (n = 43), Class II (n = 42), Class III (n = 46) 군으로 분류되었고, 또한 Sella–Nasion 선과 mandibular plane 사이의 각도 (SN–MP angle)를 통해 hypodivergent (n = 37), normodivergent (n = 47), hyperdivergent (n = 47) 군으로 분류되었다. 이 수직적, 시상적 골격 형태를 조합하여 총 9개의 subgroup 으로 분류되었다. 이번 연구에서는 하악 과두의 부피, 과두 과두의 크기(너비, 길이, 높이), 측두와의 크기(길이와 높이), 그리고 전방, 상방, 후방 관절사이공간의 거리를 측정하였다. 모든 측정 결과는 one–way ANOVA와 Scheffe 사후검정법을 통해 각각의 골격 형태에 따른 계측 항목의 유의차를 확인하였고, 골격 형태 간의 상호작용은 two–way ANOVA와 Bonferroni 사후검정법을 통해 분석하였다.

결과는 다음과 같다.

1. 시상적 골격 형태에 따른 세 개의 군 간에는 과두의 너비, 과두의 높이, 그리고 측두와의 높이에서 유의한 차이가 있었다: Class III 군에서 Class II 군에 비해 이 세 항목의 평균값이 더 크게 나타났다 ($P < 0.05$).

2. 수직적 골격 형태에 따른 세 개의 군 간에는 과두의 부피, 과두의 너비, 측두와의 길이, 측두와의 높이, 그리고 상방 관절사이공간에서 유의한 차이가 있었다: 평균 과두 부피와 상방 관절사이공간은 hyperdivergent 군이 다른 두 군에 비해 더 큰 작은 값을 보였다 ($P < 0.05$). 과두의 길이와 높이는 hyperdivergent 군이 다른 군에 비해 더 큰 값을 보였다 ($P < 0.05$). 과두의 너비는 hypodivergent 군이 hyperdivergent 군에 비해 유의하게 큰 값을 나타내었다 ($P < 0.05$).
3. 시상적 골격과 수직적 골격 형태가 상호작용을 나타내는 항목에는 과두의 너비, 측두와의 길이, 그리고 후방 관절사이공간이 있었다 ($P < 0.05$). 과두의 너비는 hyper- divergent 군이 다른 수직 분류군들에 비해, Class II 군이 다른 시상적 분류군들에 비해 유의하게 작은 값을 보이며, hyperdivergent 이면서 Class II 일 때 과두의 너비가 확연하게 작아지는 상호작용 효과를 보였다. 측두와의 길이는 hyperdivergent 군이 유의하게 큰데, Class III로 갈수록 그 경향이 심화되었다.

   후방 관절사이공간은 시상적, 수직적 골격 형태 각각의 영향을 받지는 않으면서 상호작용은 유효한 것으로 나타났지만 ($P < 0.05$), 그 최대값과 최소값의 차이가 임상적으로 무시할 만한 차이였다.

환자의 시상적, 수직적 골격 형태는 각각 측두하악관절의 형태에 영향을 미쳐서 골격 형태에 따라 과두와 측두와의 크기가 다양하였다. 환자의 수직

적 골격 형태는 시상적 골격 형태에 비해 하악 과두와 측두와의 형태에 더 큰 영향을 주었다. 특히, 과두의 너비와 측두와의 길이는 골격 형태의 상호작용에 영향을 받는 것을 알 수 있었다.

핵심되는 말: 측두하악관절; 하악 과두; Cone-Beam Computed Tomography;
시상적 골격 유형, 수직적 골격 유형