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Morphological analysis of the temporomandibular joint in patients with malocclusion using three-dimensional models

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Studying the morphology of the temporomandibular joint (TMJ) in Class II malocclusion is important for understanding the relevant interrelationship between form and function. The present study was conducted with the aim of understanding malocclusion-induced TMJ variations by measuring and comparing major morphological parameters of the TMJ between Class II malocclusion and normal occlusion. The skull was reconstructed into a 3D model to measure the horizontal condylar angle (HCA), coronal condylar angle (CCA), and coronal condylar width (CCW). As for the differences in TMJ morphology depending on the occlusion type, significant differences were observed in the left and right HCA and CCA, but not in the CCW among males and females. With regard to differences between sexes in the TMJ morphology, there were significant differences between male and female subjects in the normal occlusion group in the left and right CCWs. In contrast, no statistically significant differences between sexes were observed in the HCA or CCA. In the Class II malocclusion group, significant differences were observed between male and female subjects in all morphological parameters of the TMJ. Since the variations in condylar morphology are difficult to discern by visual inspection only, we constructed a 3D model of the condyle using Mimics software. These findings provide a deeper insight into TMJ morphology and imply that the shape of the condyle in Class II malocclusion may lead to arthralgia, TMJ disc perforation, or TMJ dysfunction. The results of this study are expected to serve as fundamental data for utilization in future studies.

Keywords: 3D measurement, malocclusion, TMJ, Mimics

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Introduction

Class II (division I) malocclusion is a complex disorder with a multifactorial etiology involving dental, skeletal, and functional asymmetries[1]. Studying the morphology of the TMJ (temporomandibular joint) in Class II malocclusion is therefore important for understanding the relevant interrelationship between form and function[2]. A correlation between TMJ morphology and the occlusal force has recently been reported[3], which suggests that the masticatory loading associated with variations in mandibular morphology can affect the form and function of Class II malocclusion. The present study was conducted with the aim of understanding malocclusion induced TMJ variations by measuring and comparing major morphological parameters of the TMJ between Class II malocclusion and normal occlusion.

TMD (temporomandibular joint disorder), which is characterized by TMJ dysfunction and pain, is known to be two to three times more prevalent among women than among men. This suggests that there are sex dependent morphological differences in the TMJ[4]. Tadej *et al.* found that the TMJ is significantly larger in male than female orthodontic patients[5]. In contrast, Honda *et al.* observed no significant sex related differences[6]. This lack of consensus among researchers regarding sex differences in TMJ morphology indicates the need for further research[7].

The overlapping of adjacent structures makes it challenging to use plain x-rays to evaluate TMJ morphology, whereas computed tomography can facilitate clear TMJ analyses. In particular, CBCT (cone-beam computed tomography) is widely used for dental imaging due to its advantage of allowing measurements on a micrometer scale[8-10]. A 3D (three-dimensional) model with the same anatomical dimensions can be reconstructed from 2D (two-dimensional) projection images using CBCT[7], thus allowing reliable linear measurements of the TMJ such as of its width, length, height, and angles[11].

In this study we compared Class II malocclusion and normal occlusion with the aim of identifying variations in the TMJ, and tested intergroup differences. We achieved this by reconstructing CBCT data of the subjects in 3D models and comparing TMJ morphological measurements.

Material and Methods

Samples

This study was approved by the Institutional Review Board of Dankook University Dental Hospital (DUDH IRB 2015-12-022). CBCT data were obtained for 20 Class II malocclusion patients and 20 normal occlusion patients admitted to the orthodontics divisions in the Department of Oral and Maxillofacial Radiology at Dankook University. An orthodontist selected patients with malocclusion based on the following criteria: no missing teeth (i.e., all 28 teeth were present), no systemic diseases, and no history of orthodontic treatment or occlusion correction. The included patients had a mean age of 22.9 years, and they were classified into the following two groups (Table 1):

Normal occlusion. ANB (subspinale point-nasion-supramentale point) angles between 1° and 4° and a normal anterior–posterior relationship of the maxillary posterior teeth.

Class II malocclusion. ANB angles larger than

Table 1. Study group classification by sex, age, ANB, and vertical pattern

Anteroposterior Skeletal Relationship	Sex	N	Age(SD)	ANB angle	First molars position
Normal occlusion	Male	10	21.7(1.94)	1~ 4°	most common
	Female	10	24.4(6.48)		
Class II	Male	10	23.4(4.67)	>4°	posterior positioning of mandible to maxilla
	Female	10	22.1(2.42)		

4°, and maxillary protraction or mandibular retraction with the mandibular first molar located in the posterior region.

3D modeling

The resolution of the CBCT scans of the patients was 512 pixels by 512 pixels. Scans comprising 290th, no systemic obtained in the DICOM (Digital Imaging and Communications in Medicine) format using a CBCT scanner (Alphard 3030, Asahi, Kyoto, Japan). The DICOM files were imported into Mimics software (version 20.0, Materialise, Leuven, Belgium) for constructing 3D models of the skull.

Morphological analysis of the TMJ

For the 3D model measurements, the DICOM files were imported into Mimics software and the skull was reconstructed into a 3D model to measure the HCA, CCA and CCW defined as follows (Fig. 1):

HCA. The angle between the line between the most anterior points of the bilateral auricles and the long axis of the condyle.

CCA. The angle between the FH (Frankfort horizontal) plane and the long axis of the condyle.

CCW. The length of a line passing through the most lateral point of the condyle, corresponding to a segment parallel to the FH plane.

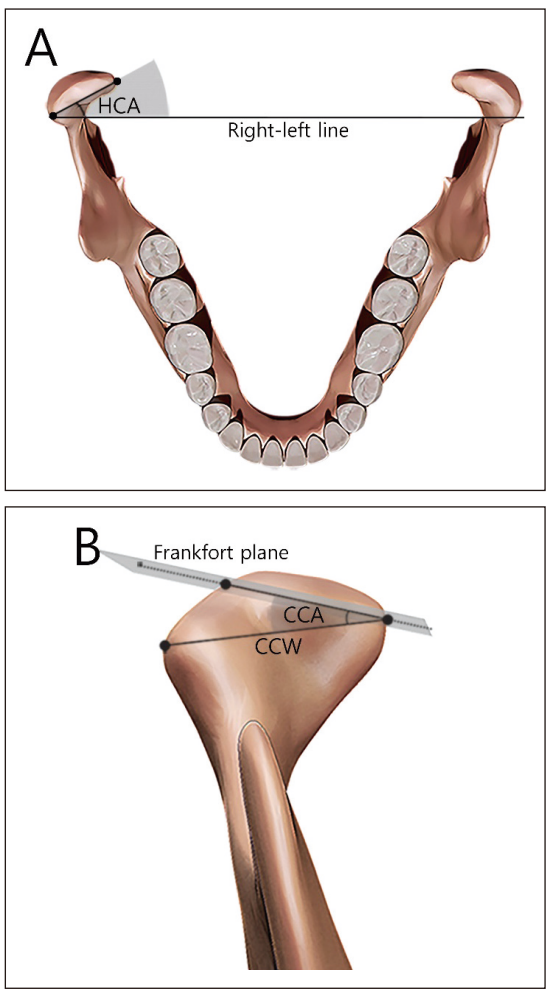

Figure 1. Measurement of TMJ in 3D models. (A) Horizontal view. (B) Coronal view.

Statistical analysis

The data collected in this study were analyzed using the Statistical Package for the Social Sciences (version 20.0, SPSS, IBM, USA). We then applied the independent t-test to identify sex dependent morphological differences and to compare TMJ related differences between the Class II malocclusion and normal occlusion groups.

Results

With regard to sex differences in TMJ morphology, there were significant differences between male and female subjects in the normal occlusion group in the left and right CCWs: 22.21±1.89 vs. 19.01±2.03 mm (mean±SD) ($p = 0.002$) and 22.51±1.34 vs. 19.28±1.89 mm ($p < 0.001$), respectively. In contrast, no statistically significant sex differences were observed in the HCA or CCA. In the Class II malocclusion group, significant differences were observed between male and female subjects in all morphological parameters of the TMJ, as follows: (i) left and right HCAs of 23.56±1.46 vs. 21.64±1.65 mm ($p = 0.013$) and 23.28±1.00 vs. 21.44±1.97 mm ($p = 0.017$), respectively; (ii) left and right CCAs of 40.46±1.14 vs. 38.07±2.40 mm ($p = 0.011$) and 40.93±2.05 vs. 37.99±3.75 mm ($p = 0.044$), respectively; and (iii) left and right CCWs of 20.92±2.39 vs. 17.93±3.43 mm ($p = 0.037$) and 20.90±2.24 vs. 18.31±2.86 mm ($p < 0.001$), respectively. As for differences in TMJ morphology depending on the occlusion type, significant differences were observed in the left and right HCA and CCA (all $p < 0.001$) but not in the CCW among males, and similarly in the left and right HCA (both $p < 0.001$) and left and right CCA ($p < 0.001$ and $p = 0.002$, respectively) but not in the CCW among females (Table 2).

Discussion

Skeletal Class II malocclusion maxillary prognathism (protrusion of the upper jaw) or mandibular retrognathism (inadequate growth of the lower jaw)[12]. These etiological factors suggest that a TMJ affected by Class II malocclusion can exhibit functional and biomechanical disorders, with symptoms that include frequent headaches, condyle clicking, and pain during jaw movement. Henrikson *et al.* reported that TMD occurred more frequently in Class II malocclusion than in normal occlusion[13]. Huang *et al.* considered that attention should be paid to the mandibular condyle (an important component of the TMJ) during treatment planning to ensure the long-term stability after orthodontic treatment[1]. We therefore compared TMJ morphological differences between Class II malocclusion and normal occlusion groups, by measuring HCA, CCA and CCW as TMJ morphological parameters. HCA and CCA are associated with degenerative joint disease and disc displacement and CCW is associated with the occlusion type and occlusal force[14,15].

The comparisons of TMJ morphology between the Class II malocclusion and normal occlusion groups revealed that the left and right HCA and CCA were significantly larger in the Class II malocclusion group than in the normal occlusion group, irrespective of sex. This is presumably due to the position of the mandible in retrognathism involving underdevelopment of the lower jaw or larger occlusal forces

Table 2. Morphometric analysis of TMJ

Morphologic Parameters		Male	Female	t	p
L.HCA	Normal occlusion	14.63(1.53)	15.19(2.40)	-0.617	0.545
	Class II	23.56(1.46)	21.64(1.65)	2.753	0.013*
	t	-13.328	-7.016		
	p	<0.001**	<0.001**		
L.CCA	Normal occlusion	31.64(2.74)	30.92(4.29)	0.446	0.661
	Class II	40.46(1.14)	38.07(2.40)	2.843	0.011*
	t	-9.410	-4.597		
	p	<0.001**	<0.001**		
L.CCW	Normal occlusion	22.21(1.89)	19.01(2.03)	3.653	0.002*
	Class II	20.92(2.39)	17.93(3.43)	2.257	0.037*
	t	1.340	0.853		
	p	0.197	0.405		
R.HCA	Normal occlusion	14.56(1.71)	14.57(1.82)	-0.009	0.993
	Class II	23.28(1.00)	21.44(1.97)	2.652	0.017*
	t	-13.916	-8.086		
	p	<0.001**	<0.001**		
R.CCA	Normal occlusion	32.64(3.38)	31.78(3.96)	0.552	0.608
	Class II	40.93(2.05)	37.99(3.75)	2.170	0.044*
	t	-6.635	-3.599		
	p	<0.001**	0.002*		
R.CCW	Normal occlusion	22.51(1.34)	19.28(1.89)	4.405	<0.001**
	Class II	20.90(2.24)	18.31(2.86)	2.258	0.037*
	t	1.939	0.897		
	p	0.068	0.381		

Mean (SD), *p-value were obtained by independent sample t-test($p < 0.05$), ** p-value were obtained by independent sample t-test($p < 0.001$)

during mastication acting in Class II malocclusion compared with normal occlusion[16,17]. Comparison of the TMJ morphology between males and females revealed that CCW was significantly larger among males in the normal occlusion group while HCA, CCA and CCW were significantly larger among males in the Class II malocclusion group. These findings are consistent with Tadej *et al*[5]. reporting that the condyle is generally larger in males than in females[5,7]. It is also assumed that the smaller CCW in female Class II malocclusion patients influenced their HCA and CCA values.

Variations in condylar morphology are difficult to discern by visual inspection only, so we construct-

ed a 3D model of the condyle using Mimics software. The values measured in a 3D model will then not be affected by image distortion, which can yield more accurate results compared with conventional simple 2D CBCT linear measurements. Zhang *et al.* compared joint space measurements made using 2D CBCT and 3D modeling, and found that the latter method was more accurate and effective[15]. Some researchers have been making considerable efforts in establishing 3D measurement standards for the TMJ, but this remains a great challenge due to the lack of data obtained using consistent measurement criteria and methods[15]. This situation prompted the present study to provide TMJ morphological reference data using a 3D measurement method.

This study has verified the presence of differences in TMJ morphology depending on sex and occlusion type (normal malocclusion vs. Class II occlusion). These findings provide a deeper insight into TMJ morphology and imply that the shape of the condyle in Class II malocclusion may lead to arthralgia, TMJ disc perforation, or TMJ dysfunction. The results of this study are expected to serve as basic data for utilization in future studies.

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한글초록

3차원 모델을 이용한 부정교합 환자의 턱관절 형태학적 분석

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Class II TMJ의 형태학적 연구는 형태와 기능 사이의 상호 연관성을 이해하는데 중요하다. 이에 본 연구는 부정교합에 의한 TMJ의 변이를 이해하기 위해 Class II와 정상교합자의 TMJ의 형태학적 매개변수를 계측하여 비교하였다. 3D모델에서 대상자의 HCA, CCA, CCW을 계측하여 TMJ 형태를 분석했다. 부정교합 유형에 따른 TMJ의 차이를 살펴본 결과, 남성과 여성 모두 좌 우측 HCA와 CCA에서 모두 유의한 결과가 나타났다. 반면 CCW는 통계적으로 유의한 차이가 없었다. 성별에 따른 TMJ의 차이를 확인해 본 결과, 정상교합자의 CCW에서 좌 우측에서 모두 유의한 결과가 나타났다. 반면 HCA, CCA는 통계적으로 유의한 차이가 없었다. Class II의 경우 HCA, CCA, CCW에서 좌측과 우측에서 모두 유의한 결과가 나타났다. 본 연구에서는 상의 왜곡 없이 실측치를 얻을 수 있는 Mimics software를 이용하여, 육안으로 관찰하기 어려운 condyle의 형태를 3D모델로 재구성하여 분석하였다. 이 결과는 TMJ 형태에 대한 더 깊은 통찰력을 제공하며, Class II의 condyle은 관절통, 디스크 천공 또는 TMJ 기능장애로도 이어질 수 있다는 것을 암시한다. 또한 향후 연구가 계획될 수 있는 기준 데이터도 제공할 것이다.

주제어: 3D 측정, 부정교합, 턱관절, Mimics