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Evaluation of Articular Eminence Morphology in Patients with Spontaneous Temporomandibular Joint Dislocation using CBCT

조선대학교 대학원

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CBCT를 이용한 측두하악관절 탈구환자의
관절융기 형태의 평가

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이 논문을 치의학 박사학위신청 논문으로 제출함.

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김지후의 박사학위 논문을
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초록

CBCT를 이용한 측두하악관절 탈구환자의 관절융기 형태의 평가

김 지 후
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연구목적: 본 연구는 Cone Beam Computed Tomography (CBCT)를 사용하여 측두하악관절 탈구환자의 관절융기의 형태를 분석하고 평가하여 탈구의 소인 및 치료에 대한 이해를 넓혀보고자 하였다.

연구대상 및 연구방법: 탈구로 진단된 만 14세부터 83세의 31명 (남성 10명, 여성 21명) 탈구환자와 만 15세부터 86세의 32명 (남성 16명, 여성 16명) 대조군을 대상으로 하였다. 총 63명 (남자 26명, 여자 37명)을 대상으로 총 126개의 측두하악관절에 대해 CBCT를 이용하여 연구를 수행하였다. 관절융기의 높이, 너비, 후방경사도는 Parasagittal plane에서 계측하였다. 후방경사도의 측정은 "Top-roof line angle (TR angle)" 방법과 "Best-fit line angle (BF angle)" 방법을 사용하였다. 계측 후, 탈구환자의 좌측과 우측의 관절융기를 각각 따로 구분하여 대조군과 비교하였고, 양측 관절융기를 비교할 때는 양측의 평균값을 사용하였다. 또한, 관절융기를 성별, 연령에 따라 비교하였으며, 편측성 탈구환자의 양쪽 관절융기를 서로 비교하고 양측성 탈구환자와 대조군을 비교하였다.

결과: 탈구는 남자 (32.3%)보다 여자 (67.7%)에서 빈번하고, 탈구환자의 평균 연령은 34.9 ± 18.5 세이고, 남자는 26.6 ± 9.8세, 여자는 38.9 ± 20.3세이다.

탈구환자는 대조군보다 우측 관절융기와 양측 관절융기 평균값에서 TR angle이 더 완만했고, 좌측과 우측 관절융기 모두 대조군보다 너비가 더 넓었다 ($p<0.05$). 탈구환자에서 남자가 여자보다 관절융기의 높이가 더 높고 통계적으로 유의미한 차이가 있었다 ($p<0.05$). 대조군에서 남자는 여자보다 관절융기의 높이가 더 높고, TR angle 및 BF angle이 더 가팔랐다 ($p<0.05$). 탈구는 20대 (38.7%)에서 가장 빈번하였고, 탈구환자의 왼쪽 관절융기와 양쪽 관절융기 평균값에서 너비는 연령이 증가함에 따라 감소하였다 ($p<0.05$). 편측 탈구환자에서 탈구가 일어난 부위가 탈구가 일어나지 않은 부위보다 관절융기의 너비는 좁고, TR angle 및 BF angle이 가팔랐다 ($p<0.05$). 양측성 탈구환자에서는, 좌측과 우측 관절융기의 너비가 대조군보다 넓었고, 양측 관절융기의 TR angle 평균값이 대조군보다 더 완만했다 ($p<0.05$).

결론: 편측성 탈구환자는 탈구가 일어나는 부위가 탈구가 일어나지 않는 부위에 비해 관절융기의 후방경사도가 더 가파르고 너비는 더 좁았다. 그러나 양측성 탈구환자는 대조군보다, 양측 관절융기 모두 너비가 더 넓고, 양측 관절융기의 후방경사도의 평균값은 더 완만하였다. 이처럼, 탈구의 소인을 밝혔고 임상에서 해부학적 요인을 고려하여 진단 및 수조작술 등의 치료를 시행할 때 적용해볼 수 있다.

주제어: 관절 융기, 콘빔 컴퓨터 단층 촬영, 탈구

I. Introduction

The mandibular condyle articulates with the squamous portion of the temporal bone at the base of the skull. Anterior to the mandibular fossa is a convex osseous prominence called articular eminence (AE). The degree of convexity of AE varies widely, however the slope of this surface is critical as it determines the path of the mandibular condyle and the degree of rotation of the articular disc to the condyle when the mandible moves forward [1,2].

A dislocation occurs in a joint prone to subluxation, but subluxation is an anatomical feature of a joint and is not pathological. Subluxation is most common in AEs with a short, steep posterior slope and a long, flat anterior slope. The anterior slope is often higher than the apex of the AE. Occasionally, the mandibular condyle slides anteriorly to the AE beyond the maximal opening limitation and cannot return to the rest position (closed position), and this is called a spontaneous dislocation or open lock [1]. Dislocations can be further categorized into partial (subluxation) or complete (dislocation), bilateral or unilateral, and chronic (or acute) persistent or chronic recurrent [3]. Dislocations can occur in several directions, the most common of which is anterior dislocation. Anterior dislocations usually occur after the normal sequence of muscle activity when the mouth is open wide and then closed [3,4]. Other types of dislocations such as medial, lateral, posterior, and superior (when the condyle goes up into the middle cranial fossa) are rare and are mostly associated with trauma [3,4,5].

The most common clinical symptoms of dislocation are drooling and difficulty in speaking, moving the lips, and closing the mouth. Acute dislocation is usually painful in the preauricular area, but such pain is rarely found in chronic recurrent dislocation. In a unilateral dislocation, the mandible may be deflected to the opposite side, and a depression of the preauricular area can be observed with an empty feeling upon palpation on the joint space. The patient may also appear anxious [1,6].

Temporomandibular joint (TMJ) dislocation is due to an imbalance of neuromuscular function or structural defects. Changes in neuromuscular function are caused by relaxation of the articular disk and capsule ligaments, long-lasting internal derangement, and spasm of the lateral pterygoid muscle. Structural defects are accompanied by arthritic changes in TMJ, which include flattening of the mandibular condyle, narrowing of the joint space, and shortening of AE. Morphological changes of the mandibular fossa, zygomatic arch, and squamotympanic fissure may also take place. [3,5,7]. Changes in age and dentition also play an important role in dislocation [3,4,7,8]. Other causes include hyperfunction of TMJ, which may happen while opening the mouth wide during yawning, laughing, vomiting, and receiving treatments such as extraction of the third molar, endotracheal intubation, and endoscopy [3,5]. Genetic defects in collagen synthesis, such as orofacial dystonia, Ehlers-Danlos syndrome, and Marfan syndrome, are also considered causative [3,6].

Chronic recurrent dislocation, which is often found with the habit of opening the mouth wide, is usually spontaneous and self-limiting depending on the morphology of the TMJ and the degree of change in adjacent structures. Dislocations are common in patients with features such as high AE, hypoplastic AE, narrow mandibular fossa, flaccid joint capsule, collagen disorders, small mandibular condyle, hypermobility syndrome, oromandibular dystonia, and neuroleptic drug use [4]. Chronic and repeated dislocation may stretch the ligaments and potentially induce some degree of disc displacement [1,9]. Dislocation is also usually associated with a posterior slope of the AE at the position of the maximal opening [6].

However, not all patients with dislocation possess a steep AE slope. There have been many studies on the treatment of dislocation [7,8,10] or the relationship between the morphology of AE and disc displacement [11–20], but almost no studies have been found on the relationship between the morphology of AE and dislocation except for the study of Adir et al. [21]. In their study [21], the morphology of AE did not affect the anterior dislocation of the TMJ. Therefore, this study aimed to broaden our understanding of the predisposing factor and treatment of dislocation by analyzing and evaluating the AE morphology of the TMJ in subjects with and without dislocation using cone beam computed tomography (CBCT).

II. Materials and Methods

1. Study subjects

The data were collected from the medical records of patients that visited Chosun University Dental Hospital in Gwangju, Korea, between February 1, 2012, and August 31, 2021. The subjects of the study were 31 patients, who were diagnosed with dislocation and whose CBCT images were available. There were 10 males and 21 females, ranging from 14 to 83 years (Table 2).

To compare with the dislocation group, 32 patients (16 males, 16 females, ages 15 to 86) with available CBCT images and no history of dislocation were chosen at random for a control group. Patients with a history of temporomandibular disorder (TMD) with opening limitation or pain, osteoarthritis of the TMJ on radiographic imaging, orthodontic treatment, craniofacial abnormalities, fractures of the oral and maxillofacial region, and any systemic diseases that could cause dental or skeletal changes were excluded from the control group (Table 2).

In this study, a total of 126 joints were investigated from the 63 patients (26 males, 37 females). The study was approved by the Institutional Review Board of Chosun University Dental Hospital (CUDHIRB-2103-001).

2. Study methods

The CBCT machines used for the 3D imaging of the TMJ were CB Mercuray (Hitachi corp., Tokyo, Japan), Viso G7 (Planmeca corp., Sweden), and CS9300 3D (Carestream Health Inc., Rochester, NY, USA. The following exposure parameters were used: 85-120 kV tube potential, 4-10mA tube current, and 0.2-0.3mm voxel size.

OnDemand3D (Cybermed Co., Seoul, Korea) was used as the software for analyzing CT images of the TMJ area as it allows section, rotation, and reconstruction of 3D images. Images were reconstructed based on each subject's individual angle of AE. To make a measurement slice, the Frankfort Horizontal plane (FH plane) was selected as a horizontal reference plane, and the image was rotated so that the FH plane and the axial plane aligned (Fig. 1). Paracoronal images were then reconstructed parallel to the line connecting the outermost and innermost points of the mandibular fossa in the axial plane. Considering the widest part of the oval-shaped mandibular fossa, the outermost point was set at the posterior edge of the lateral part of the AE in the axial plane, and the innermost point was set at the point where the sphenoidal spine of the sphenoid bone and the petrotympanic fissure meet in the axial plane. Parasagittal images were reconstructed in a plane perpendicular to the center of the mandibular fossa in the paracoronal plane. The height, the width, and the posterior slope of the AE were then measured in this parasagittal image (Fig 2).

The height of the articular eminence (EH) was measured as the vertical distance from the deepest point of the mandibular fossa to the line passing through the horizontal reference plane and the lowest point of the AE [15,16,22,23]. The width of the articular eminence (EW) was measured as the horizontal distance from the lowest point of the AE to the line descending vertically from the deepest point of the mandibular fossa, which should be parallel to the FH plane [22]. The inclination of the AE is the angle formed by the posterior part of the AE and the horizontal reference plane, and this angle was measured by two methods. The first method was to use the "Top-roof line angle (TR angle)", which is the angle between the horizontal reference plane and the line connecting the lowest point of the AE and the deepest point of the mandibular fossa. The second was to use the "Best-fit line angle (BF angle)", which is the angle between the horizontal reference plane and the tangent line drawn at the posterior slope of the AE (Fig. 3). The length was measured with a precision of 1/10 mm, and the slope was measured with a precision of 1/10 degree. All measurements were taken three times by a single observer, and the average of the measurements was used for statistical analyses. The Intraclass correlation coefficient (ICC) was used to verify intra-observer reproducibility (Table 1).

In this study, the AE on the left side (AEL) and AE on the right side (AER) of the subjects with dislocation were separately considered and compared with the control group. At this time, when comparing the AEL of the dislocation group with the control group, the total average value of the AEL of the left unilateral dislocation subjects and bilateral dislocation subjects were used. Also, when comparing the AER of the dislocation group with the control group, the total average value of the AER of the right unilateral dislocation subjects and bilateral dislocation subjects were used. When comparing AE on the both sides (AEB) of the dislocation group with the control group, the average value of both sides was used. Additionally, AEs were also analyzed according to gender and age. When comparing AE according to gender in the dislocation group, the average value of AEB was used including the area where dislocation did not occur. When analyzing the relationship of articular eminence according to age, groups were divided into age groups with 10 years interval, with the exception of 70s and 80s group, which were merged together as there was no subjects in 70s. AEB of the subjects with unilateral dislocation were compared to one another, AEs of the subjects with bilateral dislocation, and AEs of the control group.

3. Statistical analysis

IBM SPSS Statistics ver. 26.0 (IBM Co., Armonk, NY, USA) was used to perform statistical analysis. All quantitative variables were expressed as mean ± standard deviation. The normality of the distribution was confirmed by the Kolmogorov-Smirnov test, and the homogeneity of the variance was confirmed by the Levene test. An independent t-test was used for group comparison, and Pearson correlation analysis was used to examine the relationship between groups. A p-value less than 0.05 was considered statistically significant.

Fig. 1. The image rotated to coincide with the Frankfort horizontal plane and the axial plane.

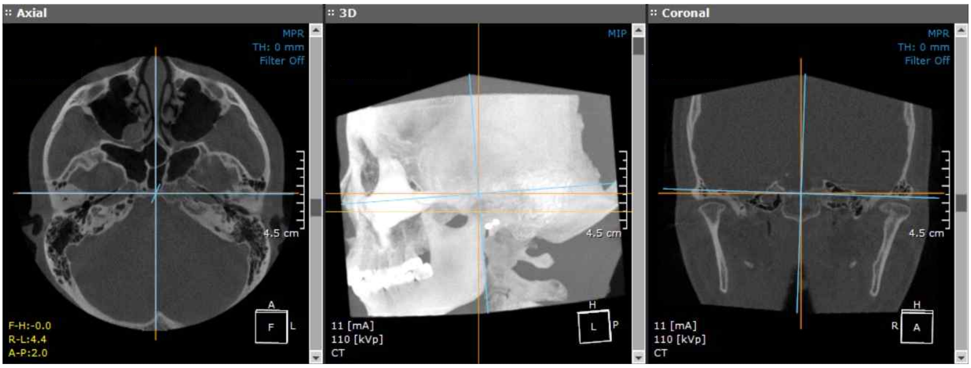


Fig. 2. Axial imaging reconstruction.

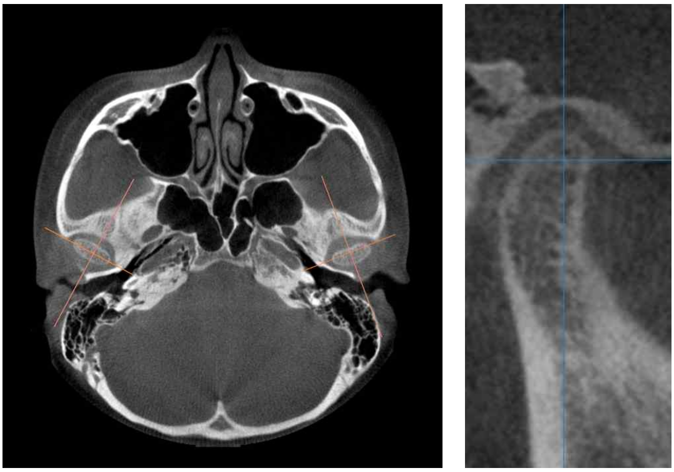
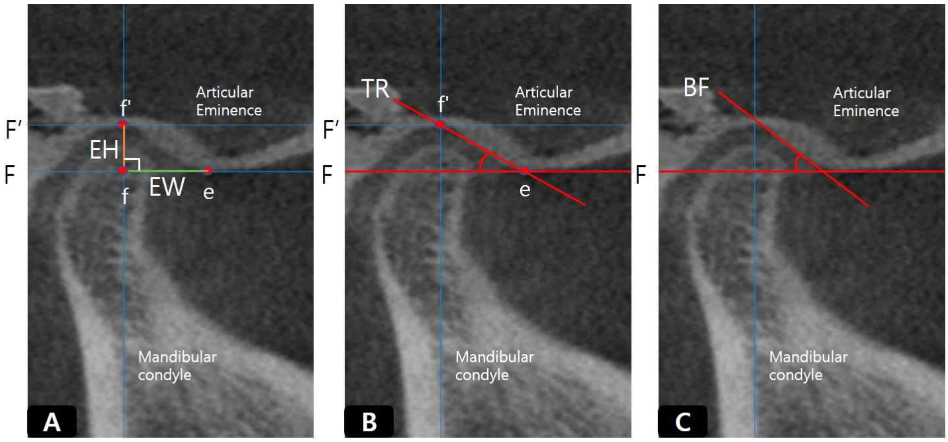


Fig. 3. Measurements for the morphology of the articular eminence. (A) EH (eminence height), the distance between point f' and f. EW (eminence width), the distance between point f and e. (B) TR (top-roof line angle), the angle formed by a straight line passing through the deepest point of the mandibular fossa (f') and the lowest point of the articular eminence (e) with the FH plane. (C) BF (best-fit line angle), the angle between the tangent to the posterior inclination of the articular eminence and the FH plane.



Point f', highest point of the mandibular fossa.
Point e, lowest point of the articular eminence.
Point f, point that meets when descending vertically from the deepest point of the mandibular fossa in the FH plane passing through the lowest point of the articular eminence
Plane F, Frankfort Horizontal plane
Plane F', parallel line to the Frankfort Horizontal plane, passing point f'

III. Results

The height, the width, and the posterior inclination of the AE measured three times in repetition by the observer showed remarkable reproducibility (ICC > 0.9) (Table 1).

1. Proportion and the average age of males and females in the dislocation and control groups.

The dislocation group consisted of 10 male and 21 female subjects, and it was found that dislocation was more frequent in females (67.7%) than males (32.3%). Their ages ranged from 14 to 83 years old, and the average age was 34.9 ± 18.5 years, with males having an average age of 26.6 ± 9.8 years and females having 38.9 ± 20.3 years. The control group consisted of 16 male and 16 female subjects, and their ages ranged from 15 to 86 years old. The average age was 42.6 ± 20.3 years, with 42.8 ± 20.6 years for males and 42.4 ± 19.9 years for females (Table 2).

2. Morphology of articular eminence in the dislocation and control groups.

Compared with the control group, the dislocation group had a wider width in the AEL and AER ($p<0.05$), and the TR angle was smoother in the AER and in the average of AEB ($p<0.05$) (Table 3).

3. Morphology of articular eminence in the dislocation and control groups according to gender.

In the dislocation group, the height of AE was higher in males than in females with a statistically significant difference ($p<0.05$). In the control group, the height of AE was higher in males than in females, and the TR angle and BF angle was steeper with a statistically significant difference ($p<0.05$) (Table 4).

4. Morphology of articular eminence in the dislocation and control groups according to age.

Dislocations were most frequent in the 20s (38.7%), and the width of AEL and the average of AEB decreased with age in dislocation group ($p<0.05$). In the control group, there was no statistically significant difference in height, width, and posterior slope of the AEL, AER and the average of AEB according to age ($p>0.05$) (Table 5).

5. Morphology of articular eminence at the dislocated side and the unaffected side in patients with unilateral dislocation.

When comparing AEB in subjects with unilateral dislocation, the width of the AE was narrower, and the TR angle and BF angle was steeper at the site of dislocation ($p<0.05$) (Table 6).

6. Morphology of articular eminence in patients with bilateral dislocation and in the control group.

In subjects with bilateral dislocation, the AEL and the AER were wider, and the TR angle of the average of AEB was smoother compared to the control group ($p<0.05$) (Table 7).

Table 1. Intraclass correlation coefficient (ICC).

		ICC	
		Dislocation group (N=31)	Control group (N=32)
EH (mm)	AEL	0.986	0.980
	AER	0.991	0.983
EW (mm)	AEL	0.987	0.976
	AER	0.971	0.985
TR (°)	AEL	0.994	0.990
	AER	0.992	0.993
BF (°)	AEL	0.998	0.997
	AER	0.997	0.998

N, number; EH, eminence height; EW, eminence width; TR, Top-roof line angle; BF, Best-fit line angle; AEL, articular eminence on the left side; AER, articular eminence on the right side.

Table 2. Demographic characteristics of the subjects.

<table>
<tr><th rowspan="2" colspan="2">Characteristic</th><th colspan="3">Group</th></tr>
<tr><th colspan="2">Dislocation (N=31)</th><th>Control (N=32)</th></tr>
<tr><td rowspan="4">Sex</td><td>Male</td><td colspan="2">10 (32.3%)</td><td>16 (50%)</td></tr>
<tr><td>Female</td><td colspan="2">21 (67.7%)</td><td>16 (50%)</td></tr>
<tr><td rowspan="2">Total</td><td rowspan="2">31</td><td>Unilateral 25</td><td rowspan="2">32</td></tr>
<tr><td>Bilateral 6</td></tr>
<tr><td rowspan="3">Average age (y)</td><td>Male</td><td colspan="2">26.6 ± 9.8</td><td>42.8 ± 20.6</td></tr>
<tr><td>Female</td><td colspan="2">38.9 ± 20.3</td><td>42.4 ± 19.9</td></tr>
<tr><td>Total</td><td colspan="2">34.9 ± 18.5</td><td>42.6 ± 20.3</td></tr>
</table>

n, number; y, year.

Values are presented as number(%) or mean ± standard deviation.

Table 3. Morphology of articular eminence in the dislocation and control groups.

	AEL [E] (N=23)**	AEL [C] (N=32)	AER [E] (N=14)***	AER [C] (N=32)	AEB [E] (N=6)	AEB [C] (N=32)
EH (mm)	8.0 ± 1.7	7.7 ± 1.3	7.9 ± 1.7	7.8 ± 1.3	8.6 ± 1.7	7.7 ± 1.1
p-value	0.430		0.816		0.167	
EW (mm)	9.3 ± 2.3	8.1 ± 1.5	10.3 ± 2.0	8.3 ± 1.9	11.1 ± 1.9	8.2 ± 1.4
p-value	0.018*		0.002*		0.000*	
TR (°)	41.4 ± 9.1	44.1 ± 6.5	37.6 ± 6.3	43.5 ± 7.1	38.2 ± 6.7	43.8 ± 5.7
p-value	0.205		0.011*		0.044*	
BF (°)	60.6 ± 15.2	57.9 ± 9.9	48.9 ± 10.3	55.9 ± 11.0	54.1 ± 8.5	56.9 ± 8.8
p-value	0.416		0.051		0.486	

AEL, articular eminence on the left side; AER, articular eminence on the right side; AEB, articular eminence on the both sides; E, experimental group; C, control group; N, number; EH, eminence height; EW, eminence width; TR, Top-roof line angle; BF, Best-fit line angle.

Values are presented as mean ± standard deviation.

p-values were obtained by the independent t-test.

*$p<0.05$

**AEL of left unilateral dislocation subjects + AEL of bilateral dislocation subjects

***AER of right unilateral dislocation subjects + AER of bilateral dislocation subjects

Table 4. Morphology of articular eminence in the dislocation and control groups according to gender.

	Dislocation group (N=31)			Control group (N=32)		
	Male (N=10)	Female (N=21)	p-value	Male (N=16)	Female (N=16)	p-value
EH (mm)	8.6 ± 1.5	7.3 ± 1.3	0.017*	8.3 ± 1.0	7.2 ± 1.1	0.005*
EW (mm)	10.4 ± 2.0	10.1 ± 1.8	0.651	7.9 ± 1.1	8.4 ± 1.6	0.055
TR (°)	40.5 ± 7.1	36.3 ± 6.9	0.132	46.4 ± 5.5	41.1 ± 4.9	0.007*
BF (°)	54.3 ± 12.8	50.8 ± 11.8	0.457	61.8 ± 7.5	51.9 ± 7.4	0.001*

N, number; EH, eminence height; EW, eminence width; TR, Top-roof line angle; BF, Best-fit line angle.

Values are presented as mean ± standard deviation. Values are the average of AEB, including the area where dislocation did not occur.

p-values were obtained by the independent t-test.

*$p<0.05$

Table 5. Morphology of articular eminence in the dislocation and control groups according to age.

		10-19y	20-29y	30-39y	40-49y	50-59y	60-69y	70-89y**	Pearson correlation coefficient	p-value
N (%)	E (N=31)	5(16.1)	12(38.7)	4(12.9)	1(3.2)	4(12.9)	4(12.9)	1(3.2)		
	C (N=32)	4(12.5)	8(25)	4(12.5)	4(12.5)	4(12.5)	4(12.5)	4(12.5)		
EH (mm)	AEL [E]	7.7±0.3	7.4±1.5	8.6±1.8	9.6±0	7.4±2.1	7.4±1.2	6.8±0	-0.057	0.760
	[C]	8.7±0.9	7.9±1.0	7.3±1.2	6.7±1.9	7.1±1.2	8.0±1.0	8.0±1.1	-0.121	0.511
	AER [E]	7.7±1.7	8.1±1.4	8.6±0.9	9.2±0	6.7±1.8	7.1±1.9	6.2±0	-0.269	0.144
	[C]	8.6±0.7	7.9±1.4	7.7±1.1	7.6±1.2	8.2±1.7	6.3±0.6	8.0±0.6	-0.222	0.221
	AEB [E]	7.7±0.9	7.8±1.4	8.6±1.2	9.4±0	7.1±2.0	7.3±1.6	6.5±0	-0.177	0.340
	[C]	8.6±0.8	7.9±1.1	7.5±1.0	7.2±1.3	7.7±1.3	7.2±0.6	8.0±0.9	-0.197	0.280
EW (mm)	AEL [E]	13.4±3.3	10.2±2.0	10.0±2.2	6.3±0	8.2±0.9	8.5±1.2	10.2±0	-0.461*	0.009*
	[C]	8.9±1.8	8.0±1.0	7.7±1.8	7.9±1.3	7.1±1.5	8.8±1.5	8.4±0.8	0.006	0.973
	AER [E]	11.5±1.4	9.9±1.8	10.2±1.3	11.6±0	10.3±1.5	9.5±1.3	10.3±0	-0.164	0.378
	[C]	9.7±2.4	9.0±1.1	8.8±1.6	7.6±0.8	6.6±1.1	6.5±1.2	9.0±1.6	-0.341	0.056
	AEB [E]	12.4±2.1	10.1±1.5	10.1±1.5	9.0±0	9.2±1.1	9.0±1.1	10.2±0	-0.413*	0.021*
	[C]	9.3±1.7	8.5±0.8	8.2±1.6	7.8±1.1	6.9±1.2	7.6±1.2	8.7±0.7	-0.225	0.215
TR (°)	AEL [E]	31.6±6.2	36.9±8.6	41.5±9.8	55.7±0	41.7±11.4	41.5±6.4	33.4±0	0.255	0.166
	[C]	45.2±8.9	45.4±3.6	43.9±10.0	40.6±5.8	45.4±2.8	43.1±5.2	43.8±5.6	-0.109	0.552
	AER [E]	33.5±3.4	39.2±6.1	40.3±3.4	38.3±0	33.5±9.7	36.3±7.1	31.5±0	-0.139	0.455
	[C]	42.6±8.8	40.5±7.2	41.5±7.3	44.9±4.5	50.4±3.5	44.8±5.7	42.4±4.4	0.180	0.324
	AEB [E]	32.5±3.5	38.0±6.1	40.9±5.2	47.0±0	37.6±10.5	38.9±6.4	32.5±0	0.109	0.560
	[C]	43.9±7.6	43.0±4.8	42.7±8.4	42.8±4.8	47.9±3.2	44.0±3.9	43.1±3.9	0.050	0.785
BF (°)	AEL [E]	59.0±10.1	49.6±14.8	58.1±18.1	85.1±0	54.8±18.3	59.0±14.5	44.7±0	0.054	0.774
	[C]	60.4±11.1	55.5±6.6	58.0±5.6	55.4±14.6	58.2±5.6	61.1±13.9	58.7±6.7	0.061	0.741
	AER [E]	46.9±10.6	49.5±11.7	58.1±2.9	45.1±0	42.1±18.5	47.5±9.7	46.5±0	-0.105	0.574
	[C]	60.5±14.9	48.3±9.0	55.3±12.4	65.0±4.3	60.3±5.1	54.8±10.0	54.5±3.9	0.079	0.668
	AEB [E]	52.9±9.0	49.6±10.8	58.1±8.7	65.1±0	48.5±17.6	53.3±10.8	45.6±0	-0.017	0.928
	[C]	60.4±12.6	51.9±6.0	56.6±8.7	60.2±6.9	59.2±4.3	58.0±11.7	56.6±5.1	0.082	0.654

N, number; E, experimental group; C, control group; AE, articular emience; EH, eminence height; EW, eminence width; TR, Top-roof line angle; BF, Best-fit line angle.

Values are presented as mean ± standard deviation.

p-values were obtained by the Pearson correlation analysis.

*$p<0.05$

**The 70s and 80s group were merged together as there was no subjects in 70s.

Table 6. Morphology of articular eminence at the dislocated side and the unaffected side in patients with unilateral dislocation.

	Dislocation site (n=25)	Non-dislocation site (n=25)	p-value
EH (mm)	7.7 ± 1.5	7.3 ± 1.5	0.370
EW (mm)	9.1 ± 1.9	10.9 ± 2.2	0.002*
TR (°)	40.8 ± 8.7	34.3 ± 7.4	0.006*
BF (°)	57.2 ± 15.8	45.6 ± 13.0	0.007*

N, number; EH, eminence height; EW, eminence width; TR, Top-roof line angle; BF, Best-fit line angle.

Values are presented as mean ± standard deviation.

p-values were obtained by the independent t-test.

*$p<0.05$

Table 7. Morphology of articular eminence in patients with bilateral dislocation and in the control group.

	AEL [E] (N=6)	AEL [C] (N=32)	AER [E] (N=6)	AER [C] (N=32)	AEB [E] (N=6)	AEB [C] (N=32)
EH (mm)	8.7 ± 1.8	7.7 ± 1.3	8.4 ± 2.2	7.8 ± 1.3	8.6 ± 1.7	7.7 ± 1.1
p-value	0.145		0.312		0.167	
EW (mm)	11.4 ± 2.6	8.1 ± 1.5	10.7 ± 1.9	8.3 ± 1.9	11.1 ± 1.9	8.2 ± 1.4
p-value	0.000*		0.006*		0.000*	
TR (°)	38.4 ± 8.2	44.1 ± 6.5	38.0 ± 6.9	43.5 ± 7.1	38.2 ± 6.7	43.8 ± 5.7
p-value	0.063		0.095		0.044*	
BF (°)	57.9 ± 10.8	57.9 ± 9.9	50.2 ± 13.0	55.9 ± 11.0	54.1 ± 8.5	56.9 ± 8.8
p-value	0.991		0.268		0.486	

AEL, articular eminence on the left side; AER, articular eminence on the right side; AEB, articular eminence on the both sides; E, experimental group; C, control group; N, number; EH, eminence height; EW, eminence width; TR, Top-roof line angle; BF, Best-fit line angle.

Values are presented as mean ± standard deviation.

p-values were obtained by the independent t-test.

*$p<0.05$

IV. Discussion

The highly convex anteroposterior morphology and slightly concave mediolateral morphology of the AE lead to a change in inclination [2]. The normal value of the posterior inclination of the AE in adults is 30 to 60 degrees [2]. The AE determines the path and type of the condylar disc complex movement as a part of the temporal fossa where the condyle-disc complex slides during various mandibular functional movements [2,16,24]. Changes in the slope of the AE can lead to biomechanical changes in the TMJ because the characteristics of the TMJ determine the trajectory of functional movement [24]. Naturally, the slope of the AE and the morphology of the mandibular fossa may be predisposing factors for TMD [2,12,15,22]. Therefore, the morphology of AE was analyzed in this study to broaden the understanding of the predisposing factors and treatments of TMD, including dislocation.

While only a few studies on the morphology of the AE in subjects with dislocation could be found, there were numerous studies of the AE in subjects with internal derangement, most of which suggest that the steep inclination of AE is one cause of internal derangement [1,12,13,16]. In the study of Kerstens et al. [10], most patients who underwent articular eminectomy showed significantly better symptoms of internal derangement after the surgery, which suggests that flatter AE may be more advantageous. Alternatively, Ren et al. [11] and Sümbüllü et al. [25] could not test the hypothesis that steep AE is one of the factors of internal derangement. Instead, they found that the inclination of the AE was steeper in asymptomatic volunteers with normal disc positions than in patients with disc displacement. In addition, in the study of Panmekiate et al. [14], no correlation was found between steep AE and anterior displacement of the articular disc. The posterior slope of AE of the joint with disc displacement without reduction was normal, but the slope was nevertheless significantly lower than that of disc displacement with reduction. As the ideal steepness for healthy TMJ is not yet known, conclusions about the association between steep AE and internal derangement are still uncertain [11]. In this study, the dislocation group had a wider width of AEB ($p<0.05$), and the posterior slope (TR angle) of the AER and the average of AEB were smoother ($p<0.05$) compared to the control group (Table 3). These results may mean that the greater the distance the mandibular condyle moves at the time of maximum opening, the higher the possibility of dislocation. Further research is needed to confirm whether there is any discord during the maximum opening with the masticatory muscle, its related ligaments, and neuromuscular control including nerve transmission by the mandibular branch of the trigeminal nerve.

In this study, TMJ dislocation occurred more frequently in females (21 subjects, 67.7%) than in males (10 subjects, 32.3%). However, in the study of Ugboko et al. [26], TMJ dislocation had a higher chance to occur in males than in females, although the difference was not statistically significant. In addition, Ugboko et al. [26] reported that the average age of patients with dislocation was 35.3 ± 17.4 years (ranging from 9 to 85 years old of age), which was in accordance with the result found in this study, 34.9 ± 18.5 years (ranging from 14 to 83 years old of age) (Table 2).

Some studies have reported a notable difference in the inclination or height of the AE according to gender [16,27]. Sümbüllü [25] reported that in both the TMD group and the control group, the slope and height of AE were higher in males than in females, but there was no significant difference. Maryam Paknahad et al. [16] also found that the height of the AE in males was higher than in females, which was significant in the control group but not in the TMD group. This study showed that, in the dislocation group, the males had a higher AE slope, height, and width than females, but only the height of the AE showed a statistically significant difference ($p<0.05$). In the control group, the slope and the height of the AE of males were significantly higher than those of females ($p<0.05$), and the width of the AE was wider in females but without statistically significant difference ($p>0.05$) (Table 4). In both the dislocation group and the control group, males had a significantly higher AE than females, but it is not clear whether this difference originates from the innate skeletal difference between genders or difference in the morphology of AE in males and females that affects dislocation.

Several studies [11,16,22,28] reported no statistically significant difference in the inclination of the AE with increasing age. On the other hand, Choi et al. [23] reported that the height and inclination of the AE increased with age up to adulthood. According to Sümbüllü et al. [25], the inclination of the AE would reach its highest sometime between the ages of 21 and 30 but begin to decrease after the age of 30. The results of this study show that the width of the AEL and the average of AEB decreased with age in subjects with dislocation ($p<0.05$). However, in the control group, there was no statistically significant difference in the height, the width, and the posterior slope of the AE according to age ($p>0.05$). The frequency of dislocation was also high in the 20s (38.7%), as seen in the study of Ugboko et al. [26] (Table 5). Further research is needed to elucidate precisely at what age during the 20s that the frequency of dislocation is highest and whether it is related to the period of the growth completion of the TMJ. In addition, it is necessary to study the change in the morphology of the AE with increasing age with a larger sample.

Because there is no AE at birth and the mandible moves only forward or sideways but not downward during the first few months of life, the AE is thought to develop almost exclusively after birth [2]. Several studies [2,15] have suggested that the developmental stage of the dentition may also affect the slope of the AE. The slope of AE changes rapidly until the deciduous teeth are completed, reaching 45% of the adults by 2 years of age, and reaching 71% by 10 years of age [2,15]. According to Humphreys' study [29], the mandibular fossa is shallow and lacks AE until the age of 6. However, it begins to expand slowly until the age of 10 when it receives a sudden growth stimulus and nearly completes its development by the age of 12. On the other hand, studies by Elias et al. [2] and Maryam et al. [16] find that the inclination of AE reaches 92% at the age of 20. Additionally, Robert [30] reports that the TMJ undergoes continuous morphological changes, and these changes appear to be mediated by dental occlusion. The precise time for the complete development of the AE is still controversial [15].

The results showed that, in the dislocated site, the width of the AE was narrower, and the posterior slope (TR angle and BF angle) was steeper than that of the non-dislocated site in the subjects with unilateral dislocation ($p<0.05$) (Table 6). In subjects with bilateral dislocation, AEB were wider ($p<0.05$), and the average of AEB had a smoother posterior slope (TR angle) than in the control group ($p<0.05$) (Table 7). According to the study of Elias [2], there is no statistically significant difference between the development of the AEL and the AER because the slope of the AE has a symmetrical growth pattern under normal conditions. In some studies [31,32], when measuring the slope of the AE in Asian populations, it was found that the measured values of the AEL and the AER were not significantly different. In the study of Maryam Paknahad et al. [16], there was no statistically significant difference in the slope, height, and width of the AEL and the AER in both the control group and the TMD patient group. It could not be concluded from the results of this study whether the difference in the morphology of the AE in unilateral dislocation was a cause or a result. In addition, the influence of muscles or ligaments around the TMJ may be greater than anatomical factors in inducing unilateral and bilateral dislocations. Further studies are therefore needed to elucidate how much bone remodeling from adaptation over time or from recurrent dislocation as an anatomical predisposing factor and how much the muscles or ligaments around the TMJ affect dislocation.

Several methods can be used to measure the inclination of the AE. These methods include indirect measurements using cranial impression taking, panoramic radiographs, cephalometric radiographs, arthrography, and tomography [2]. Selection of the appropriate method to measure the slope or the morphology of the AE is critical because it can affect the outcome [2,15]. Cranial impression taking involves modeling with clay and wax, which is susceptible to warping and shrinkage [2]. Inspecting the path of the anterior condyle is an indirect method to measure the inclination of the AE. However, the tracking of the condylar path compares only the inclination of AE measured on lateral cephalometric radiographs. Therefore, it is questionable whether it can accurately represent the anatomical characteristics of the posterior inclination of AE [11]. The joints are distorted in the panoramic radiographs, making their morphology difficult to interpret with good accuracy and stability [13]. There were limitations in using tomography or arthrography to diagnose the morphology of the TMJ [31]. They were later replaced by spiral CT, which evaluates skeletal components in 3D without overlap or distortion. Nowadays, CBCT is used over spiral CT because of reduced radiation dose, improved spatial resolution, shorter scan time, and better cost-effectiveness [33]. CBCT is the preferred method to evaluate the skeletal structure in the oral region, with high dimensional accuracy in measuring maxillofacial structures including the TMJ. [16,25]. In this study as well, CBCT was used to evaluate and analyze the morphology of the TMJ, especially the AE.

The slope of the AE is the angle formed by one of the lines passing through the horizontal reference plane and the AE. A horizontal reference plane is another critical factor influencing the slope of the AE, which directly determines the degree of angle. This can be the FH plane, the palatal plane, the occlusal plane, the ANS-PNS, or other defined reference planes. A study by Xiao-Chuan et al. [15] describes the FH plane, which is a line drawn from the lowest point of the inferior orbital margin (Or) to the highest point of the contour of the ear canal (Po), as an important and a commonly known reference plane. Using a stable and comparable horizontal reference plane is critical, and the FH plane seems to be a relatively ideal reference plane for evaluating the slope of the AE because the landmarks of the FH plane are independent of the TMJ structure and are not affected by changes in the mandibular fossa and the AE [15]. Therefore, with the FH plane being the horizontal reference plane, the images were rotated in this study to make sure that the reference plane and the axial plane aligned (Fig. 1).

In each of the three planes of CBCT, the most suitable image had to be selected for measuring the morphology of AE. In most studies [16,22,34], the central sagittal slice of the mandibular condyle was selected because it showed the steepest part of the AE that best represents the slice. On the other hand, the purpose of this study was to observe the morphology of the AE or mandibular fossa and not the mandibular condyle, and whether the mandibular condyle always shows the steepest part of the AE was questionable. Therefore, the parasagittal image was reconstructed using the widest part of the mandibular fossa as the center (Fig 2).

The "Top-roof line angle" method and the "Best-fit line angle" method have been used in many previous studies as the two main methods for evaluating the slope of the AE [2,15,16,22,23]. The TR angle method relates to the height of the AE, which focuses on the position of the AE to the mandibular fossa and better describes the morphology of the AE. The BF angle method directly relates to the direction of movement of the condyle-disc complex and reflects the actual condyle path [2,15,16] (fig. 3).

It is rather unreasonable to establish a causal relationship between dislocation and the morphology of AE solely from the results of this study. It was difficult to match gender and age equally between the control group and the experimental group, and additional studies with larger sample sizes are needed in the future.

In subjects with unilateral TMJ dislocation, the posterior slope of the AE is steeper, and the width is narrower at the site of dislocation compared to the site without dislocation. However, in subjects with bilateral TMJ dislocation, AEB are wider, and the mean value of the posterior slope of AEB is smoother than that of the control group. The morphological predisposing factors of TMDs including dislocation have been confirmed in this study as described, and such knowledge can be clinically applied in diagnosing and performing treatments such as manual manipulation while considering anatomical factors of AE.

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감사의 글

논문이 나오기까지 도움을 주신 많은 분들께 감사 인사를 전합니다.

항상 믿음과 지지로 묵묵히 뒤에서 지켜봐주시며 수련기간동안 부족한 저를 잘 이끌어주신 안종모 교수님께 정말 감사드립니다. 저의 부족함에도 항상 온화하게 격려해 주신 덕분에 그동안 잘 지내올 수 있었습니다. 또한 제가 어려움에 부딪힐 때마다 학문적으로든 정신적으로든 여러 면에서 도움을 주신 유지원 교수님과 박현정 교수님께도 감사드립니다. 그리고 퇴임하셨지만 마음속에 버팀목처럼 계시는 윤창륙 교수님께 감사드립니다. 바쁘신 와중에도 논문 심사를 맡아 성심성의껏 조언해주신 임영관 교수님, 서요섭 교수님, 유재식 교수님께도 진심으로 감사드립니다. 또한 어떤 순간에도 항상 마음으로 보듬어주시는 윤아향 선생님께 감사드립니다. 통계에 도움을 준 형관이와 영어번역에 많은 도움을 준 조성현 선생님께도 감사 인사를 전합니다. 교수님들과 주변 분들의 도움이 있었기에 이 논문이 완성될 수 있었습니다. 다시 한 번 진심으로 감사드립니다.

항상 믿고 응원해 주시는 부모님, 순희언니, 익섭형부, 남희언니, 원준형부, 유안이, 클로이에게 감사의 마음을 전합니다. 가족들의 사랑과 지지가 있었기에 지금까지 해올 수 있었습니다.

그동안 저의 부족한 모습을 너그러이 받아주신 구강내과 진료지원팀 선생님들, 좋을 때나 힘들 때나 늘 힘이 되어주는 준호와 친구들에게도 감사 인사를 전합니다.

그 외에도 일일이 글로 감사의 인사를 전할 수 없지만, 지금의 제가 있기까지 저를 아끼고 사랑해주신 모든 분들께 감사드립니다.

2021 년 12 월 김지후