Three-dimensional changes in the condylar position after intraoral vertical ramus osteotomy in patients with facial asymmetry

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The Master's Thesis
submitted to the Department of Dentistry
and the Graduate School of Yonsei University
in partial fulfillment of the requirements for the degree of
Master of Dental Science

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June 2018

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June 2018

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ABSTRACT

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The aims of the present study were to compare postoperative changes in condylar angulation and joint spaces between the deviated and non-deviated sides using CT images in patients with facial asymmetry and skeletal Class III malocclusion who underwent intraoral vertical ramus osteotomy (IVRO). The null hypotheses were that there were no differences in positional changes in the condylar segments between the deviated and non-deviated sides after asymmetric setback of the mandible and that there were no significant changes in the condylar segments between before and 12 months after surgery.

This retrospective study included 18 adult patients (8 males and 10 females; mean age, 20.67 ± 2.85 years). The inclusion criteria were facial asymmetry with menton deviation of >3 mm (mean deviation, 5.75 ± 3.42 mm) and availability of CT images taken before (T0), immediately after (T1), and 12 months after (T2) orthognathic

surgery. In order to investigate positional changes in and rotational movements of the condylar segments, four condylar segment measurements (axial condylar, coronal condylar, coronal ramus, and sagittal ramus angles) and five joint space measurements (superior, anterior, posterior, medial, and lateral joint spaces) were performed. The results are as follows:

1. At T0, the axial condylar angle and coronal ramus angle showed significant differences between the deviated and non-deviated sides ($P < 0.01$).

2. At T1, the axial condylar angle showed significant differences between the deviated and non-deviated sides ($P < 0.05$). The condyle exhibited outward, medial, and anterior–inferior rotation in the axial, coronal, and sagittal planes, respectively. This was due to overlap of the proximal segment with the distal segment after mandibular setback by IVRO.

3. At T2, the axial condylar angle was significantly different between the deviated and non-deviated sides ($P < 0.05$), while the coronal ramus angle did not show significant differences ($P > 0.05$).

4. There were no significant differences in the five joint spaces between the deviated and non-deviated sides at T0 and T2 ($P > 0.05$). There were significant differences in the superior, medial and lateral joint spaces between the deviated and non-deviated sides at T1 ($P < 0.05$).

5. At T1, most joint spaces exhibited a significant increase immediately after surgery because of condylar sag ($P < 0.05$).

6. At T2, the superior, anterior, and medial joint spaces returned to their preoperative state (T0-T2, $P > 0.05$), whereas the posterior and lateral joint spaces remained significantly increased (T0-T2, $P < 0.05$).

In conclusion, IVRO improves asymmetric structures and the facial appearance associated with the condylar segment. Physiological repositioning of the condyle gradually occurs during the postoperative follow-up period by 12 months after surgery.

Key words: Condylar segment, Joint space, IVRO, Facial asymmetry.

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I. INTRODUCTION

Facial asymmetry is one of the common craniofacial deformities accompanying skeletal Class III malocclusion, with a high prevalence rate of approximately 40% in these patients.(You et al., 2010) Recently, it was found that facial asymmetry induces joint structure asymmetry and is significantly correlated with temporomandibular disorder and condylar stress distribution.(Choi et al., 2011; Kim et al., 2016; Ueki et al., 2005)

Facial asymmetry can be corrected by complicated mandibular movement such as asymmetric mandibular setback and rotation, which can result in different position and changes in angulation of the right and left condylar segments.(Wen et al., 2015) Intraoral vertical ramus osteotomy (IVRO) and sagittal split ramus osteotomy (SSRO) are common orthognathic surgical techniques to correct skeletal discrepancy in patients with mandibular prognathism and facial asymmetry. The condyle exhibited different pattern of positional changes after SSRO between the deviated and non-deviated sides in patients with facial asymmetry, which was stable 1 year after the surgery.(Baek et al., 2006; Kim et al., 2015a; Tyan et al., 2017) On the other hand, IVRO does not require internal fixation of bone segments to each other, and this results in different amounts of condylar sag and positional changes in the right and left condylar segments. The position of the condylar (proximal) segments after IVRO may influence not only facial appearance but also postoperative stability.(Ohba et al., 2014) Therefore, it is important to investigate postoperative changes in the condylar position and joint spaces after IVRO in patients with facial asymmetry. However, there is insufficient information about the asymmetric movement of the condylar segments after IVRO.

Recent advancements in three-dimensional (3D) analysis based on computed tomography (CT) images have enabled accurate evaluation of facial asymmetry.(You et al., 2010) Previous CT study reported that immediate postoperative changes in the proximal segments after IVRO differed between the deviated and non-deviated sides.(Ohba et al., 2015; Ueki et al., 2009) However, this study selected only one two-dimensional (2D) image from multisectional CT images; therefore, the real anatomic structures may have been excluded from the image, because of which the measurements could not reflect definite changes in the condylar segments. Moreover, the previous study investigated only 3 months postoperative changes after asymmetric setback via IVRO, (Ueki et al., 2009) although postoperative follow up over a period of at least one year would be essential for proper stability assessment.

The aims of the present study were to compare positional changes in terms of the condylar angulation and joint spaces between the deviated and non-deviated sides and to investigate postoperative changes on each side using CT images in patients with facial asymmetry and skeletal Class III malocclusion who had underwent IVRO. The null hypotheses were that there were no differences in positional changes in the condylar segments between the deviated and non-deviated sides after asymmetric setback of the mandible and that there were no significant changes in the condylar segments between before and 12 months after surgery.

MATERIALS AND METHODS

1. Patients

This retrospective and patient-oriented research included consecutively selected patients diagnosed with skeletal Class III malocclusion accompanied by facial asymmetry and treated with orthodontic treatment and orthognathic surgery at NHIS Ilsan Hospital between January 2011 and September 2016.

The inclusion criteria were as follows: age >18 years; menton deviation >3 mm from the midsagittal plane; and availability of CT images obtained before (within 1 month, T0), immediately after (within 1 week, T1), and 12 months after (T2) orthognathic surgery. The exclusion criteria were as follows: systemic diseases; congenital deformities, including cleft lip and palate; osteoarthritic changes in the temporomandibular joint; a history of facial injury and fractures; and a history of orthodontic treatment or orthognathic surgery.

The study was approved by the institutional review board of NHIS Ilsan Hospital (NHIMC 2017-11-006), which waived the requirement for written informed consent because of the retrospective design of the study. The study was performed in accordance with the current Standards Recommended for the Reporting of Observational Studies in Epidemiology (STROBE).

2. Surgical and orthodontic treatments

All patients underwent pre- and postoperative orthodontic treatment and conventional bimaxillary surgery, including maxillary Le Fort I osteotomy and bilateral IVRO for mandibular setback. The orthodontic treatment and orthognathic surgery were performed by one orthodontist and one surgeon, respectively, and each doctor has over 10 years of clinical experience. Internal fixation was used to stabilize the maxilla, and intermaxillary fixation was retained to stabilize the mandible. Two weeks after intermaxillary fixation, patients were referred to undergo physiotherapy (PT) for sound postoperative rehabilitation of jaw movement. During PT, the final wafer was fixed to the maxillary dentition and used as a guide for mandibular positioning. The wafer was removed approximately 2 weeks after PT, when a maximum mouth opening of at least 30 mm was obtained and stable occlusion was confirmed.

3. Image acquisition and reorientation

CT images (SOMATOM Sensation 64-slice, Siemens, Malvern, PA, and USA) with a 1-mm slice thickness were obtained with the patients in the supine position. Three-dimensional CT data were imported as Digital Imaging and Communication in Medicine files and reconstructed into 3D models using Mimics 14.11 (Materialise Dental, Leuven, Belgium). For accurate evaluation of the condyle and joint spaces, the mandible was demarcated from the skull and saved as a separate structure in Mimics program. Thereafter, the reconstructed 3D model was imported to Simplant pro14 (Materialise Dental, Leuven, Belgium), which was used for reorientation and measurements.

The axial, sagittal, and coronal reference planes (ARP, SRP, and CRP, respectively) were registered, and the 3D model was reoriented with ARP parallel to the floor (Figure 1). ARP was defined as the plane passing through the right and left porions and left orbitale, SRP as the midsagittal plane perpendicular to ARP and passing through the nasion and basion, and CRP as the plane perpendicular to ARP and SRP and passing through the basion (Figure 1A). Three reference lines were generated by the three reference planes. The axial reference line (ARL) and coronal reference line (CRL) were defined as the intersecting line of ARP and CRP. The sagittal reference line (SRL) was defined as the intersecting line of ARP and SRP (Figure 1B).

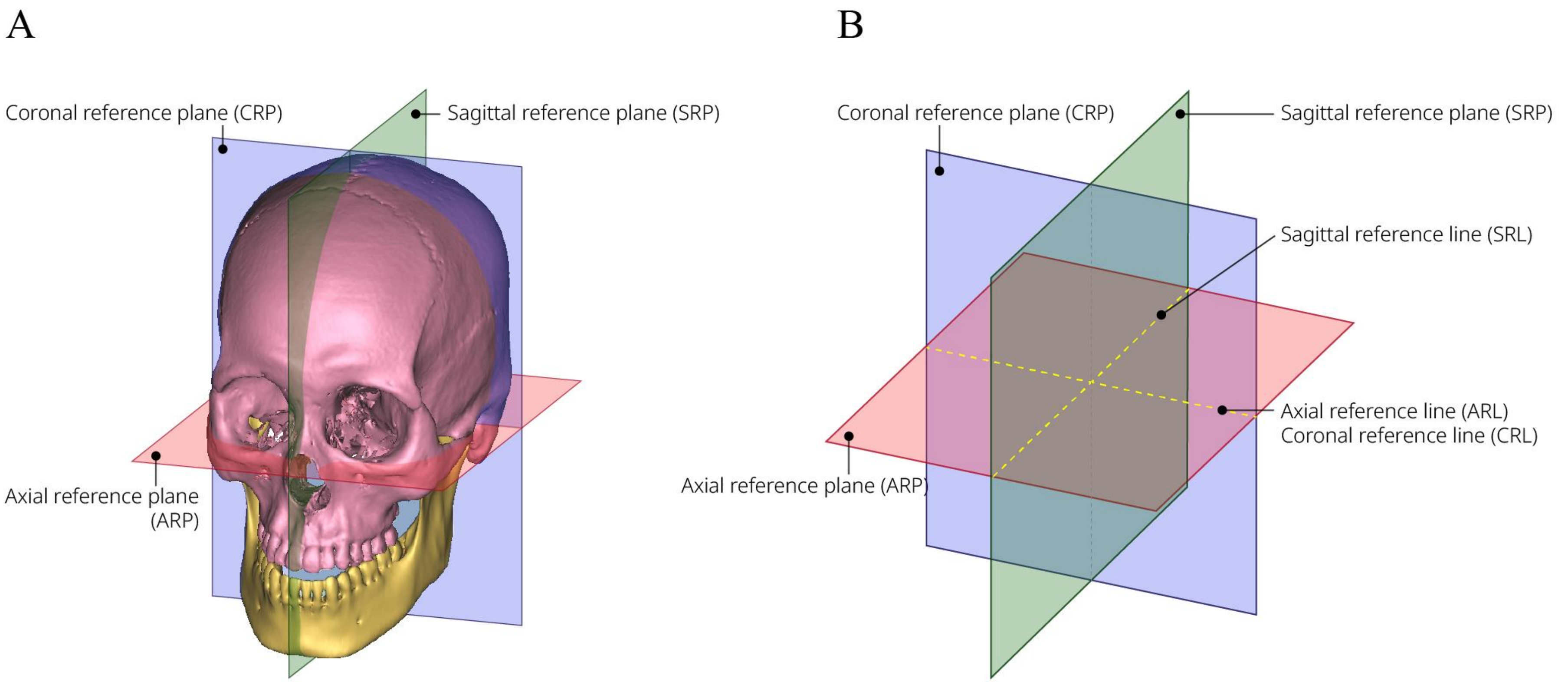

Figure 1. Craniofacial reference planes (A) and lines (B) on a reconstructed three-dimensional computed tomography image used for the assessment of changes in condylar position after orthognathic surgery

4. Measurements

The amount of menton deviation from SRP was used for evaluating asymmetry. The deviated side was defined as the side where the menton was located relative to SRP before surgery; and the non-deviated side as the contralateral side. We obtained 4 angular measurements for the condylar segments (axial condylar, coronal condylar, coronal ramus, and sagittal ramus angles) and 5 linear measurements for the joint spaces (superior, anterior, posterior, medial, and lateral joint spaces) to investigate rotational movements and positional changes in the condylar segments after surgery. For the measurements, we defined 5 landmarks for the condylar segment rotation and 6 landmarks for the condylar position in Table 1. The measurements were performed using Simplant software (Materialise Dental, Leuven, Belgium).

Table 1. Definitions of anatomical and structural landmarks used in this study

Landmarks		**Definition**
Cephalometric	Nasion (N)	The most anterior point of the frontonasal suture
	Basion (Ba)	The most anterior point of the foramen magnum
	Orbitale (Or)	The most inferior point of the bony orbit
	Menton (Me)	The most inferior point of the mandibular symphysis
	Porion (Po)	The most superior point of the external auditory meatus
Condylar segment	C_{Lat}	The most lateral point of the condylar head
	C_{Med}	The most medial point of the condylar head
	C_{Post}	The most posterior point of the condylar head
	R_{Lat}	The most lateral point of the ramus
	R_{Post}	The most posterior point of the ramus
Joint spaces	C_{Sup}	The most superior point of the condylar head
	F_{Sup}*	The most superior point of the glenoid fossa
	J_{Ant}*	The tangent point from F_{Sup} to the anterior surface of the condyle
	J_{Post}*	The tangent point from F_{Sup} to the posterior surface of the condyle
	J_{Med}†	The tangent point from F_{Sup} to the medial surface of the condyle
	J_{Lat}†	The tangent point from F_{Sup} to the lateral surface of the condyle

* The landmarks were defined on a sagittal section passing through C_{Sup} and parallel to the sagittal reference plane.
† The landmarks were defined on a coronal section passing through C_{Sup} and parallel to the coronal reference plane.
Please refer to Figures 2 and 3 for an illustration of each landmark.

1) Angular measurements for the condylar segments

Axial condylar, coronal condylar, coronal ramus, and sagittal ramus angles (ACA, CCA, CRA, and SRA, respectively) were measured to evaluate rotation of the condylar segment (Table 2). The five anatomical landmarks (C_{Lat}, C_{Med}, C_{Post}, R_{Lat}, and R_{Post}) were projected onto each reference plane (ARP, CRP, and SRP) and used to create projection lines on each plane. We calculated the angle between the created projection lines and the reference lines (Figure 2).

In the axial view, a Cd–axial line was created by connecting two points projected from C_{Lat} and C_{Med} to ARP (Figure 2A). ACA was the angle between ARL and the Cd–axial line (Figure 2B), which represented axial rotational movement (outward or inward) of the condylar segment. In the coronal view, a Cd–coronal line was created by connecting two points projected from C_{Lat} and C_{Med} to CRP, and a Ramus–coronal line was created by connecting two points projected from C_{Lat} and R_{Lat} to CRP (Figure 2C). CCA was the angle between CRL and the Cd–coronal line, and CRA was the angle between CRL and the Ramus–coronal line (Figure 2D), which represented coronal rotational movement of the condylar segment. In the sagittal view, a Ramus–sagittal line was created by connecting two points projected from C_{Post} and R_{Post} to SRP (Figure 2E). SRA was the angle between SRL and the Cd–axial line (Figure 2F), which represented sagittal rotational movement of the condylar segment.

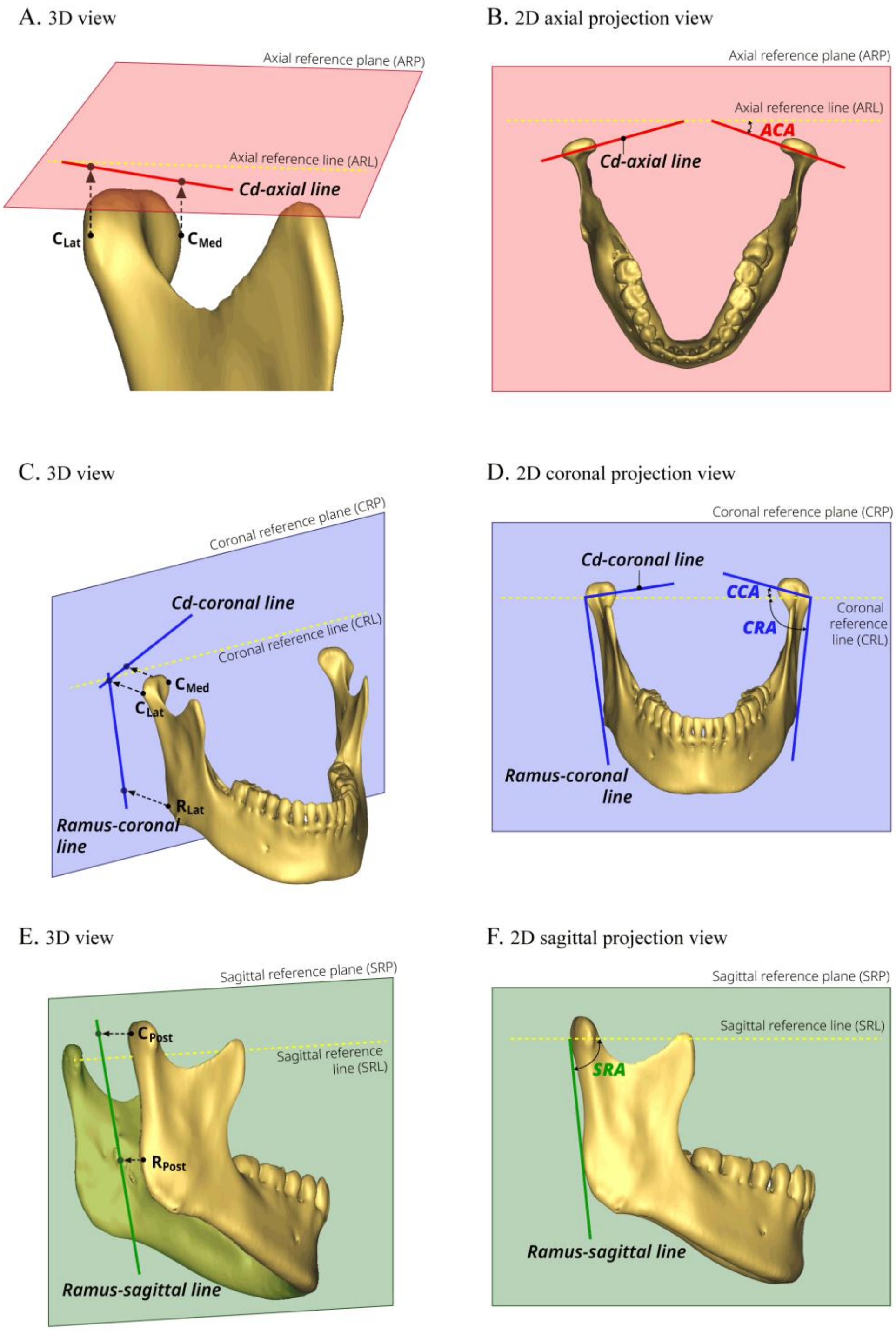

Figure 2. Angular measurements for the condylar segments

The landmarks used in this figure are defined in Tables 1 and 2.
3D, three-dimensional; 2D, two-dimensional; ACA, axial condylar angle; CCA, coronal condylar angle; CRA, coronal ramus angle; SRA, sagittal ramus angle.
A, a Cd–axial line is created by connecting two points projected from C_{Lat} and C_{Med} to ARP; B, measurement of ACA between ARL and Cd–axial line; C, a Cd–coronal line is created by connecting two points projected from C_{Lat} and C_{Med} to CRP, and a Ramus–coronal line is created by connecting two points projected from C_{Lat} and R_{Lat} to CRP; D, measurement of CCA between CRL and Cd–coronal line, and measurement of CRA between CRL and Ramus–coronal line; E, a Ramus–sagittal line is created by connecting two points projected from C_{Post} and R_{Post} to SRP;
F, measurement of SRA between SRL and Ramus–sagittal line.

2) Linear measurements for the joint spaces

The superior, anterior, posterior, medial, and lateral joint spaces (SJS, AJS, PJS, MJS, and LJS, respectively) were measured to evaluate positional changes in the condylar segment by using one sagittal and one coronal sections (Figure 3). The sagittal and coronal sections were determined as a cross section passing through C_{Sup} and parallel to SRP and CRP, respectively. Structured landmarks for each section are defined in Table 1. SJS, AJS, and PJS were measured on the sagittal section (Figure 3A). SJS was the distance between C_{Sup} and the plane passing through F_{Sup} and parallel to ARP. AJS was the shortest distance from J_{Ant} to the anterior wall of the fossa; and PJS was the shortest distance from J_{Post} to the posterior wall of the fossa. MJS and LJS were determined on the coronal section (Figure 3B). MJS was the shortest distance from J_{Med} to the medial wall of the fossa; and LJS was the shortest distance from J_{Lat} to the lateral wall of the fossa.

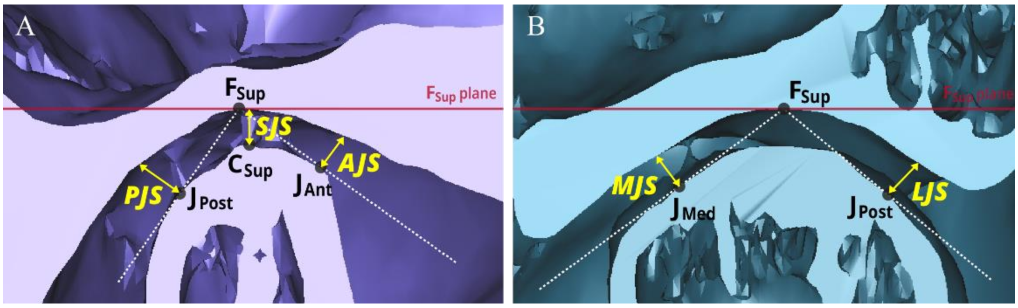

Figure 3. Linear measurements for the joint spaces
The landmarks used in this figure are defined in Tables 1 and 2.
F_{Sup} plane: The plane passing through F_{Sup} and parallel to the axial reference plane.
A, the superior, anterior, and posterior joint spaces (SJS, AJS, and PJS, respectively) are determined on the sagittal section; B, the medial and lateral joint spaces (MJS and LJS, respectively) are determined on the coronal section.

Table 2. Angular measurements to assess rotation of the condylar segment and linear measurements for the joint spaces to assess changes in the condylar position

Measurements		**Definition**
Condylar segment	Axial condylar angle (ACA)	The angle between the axial reference line and Cd–axial line
	Coronal condylar angle (CCA)	The angle between the coronal reference line and Cd–coronal line
	Coronal ramus angle (CRA)	The angle between the coronal reference line and Ramus–coronal line
	Sagittal ramus angle (SRA)	The angle between the sagittal reference line and Ramus–sagittal line
Joint spaces	Superior joint space (SJS)*	The distance between C_{Sup} and the plane passing through F_{Sup} and parallel to the axial reference plane
	Anterior joint space (AJS)*	The shortest distance from J_{Ant} to the anterior wall of the fossa
	Posterior joint space (PJS)*	The shortest distance from J_{Post} to the posterior wall of the fossa
	Medial joint space (MJS)†	The shortest distance from J_{Med} to the medial wall of the fossa
	Lateral joint space (LJS)†	The shortest distance from J_{Lat} to the lateral wall of the fossa

* Three joint spaces were measured on a sagittal section passing through C_{Sup} and parallel to the sagittal reference plane.
† Two joint spaces were measured on a coronal section passing through C_{Sup} and parallel to the coronal reference plane.
Please refer to Figures 1, 2, and 3 for illustration of the reference planes and lines and each measurement.

5. Statistical analysis

All measurements were repeated after a 4-week interval, and the intraclass correlation coefficient (ICC) was calculated to test the intraexaminer reliability and assess the reproducibility of the measurements.

Paired t-tests were used to compare the angular and linear measurements between the deviated and non-deviated sides. Repeated-measures analysis of variance with Bonferroni correction was used to evaluate the immediate and 12 months postoperative changes on each side over time (T0, T1, and T2). All statistical analyses were performed using IBM SPSS Statistics version 23 (IBM Corp., Armonk, NY, USA). A P-value <0.05 was considered statistically significant.

II. RESULTS

In total, 18 adult patients (8 males and 10 females) aged 18 to 27 years (mean age, 20.67 ± 2.85 years) at the time of surgery were evaluated. All patients had facial asymmetry with menton deviation of >3 mm (mean deviation, 5.75 ± 3.42 mm) from SRP.

1. Methodological error

The ICC value for repeated measurements ranged from 0.918 to 0.961 ($P < 0.001$), indicating high reliability.

2. Comparison of the condylar angle and joint spaces between the deviated and non-deviated sides

At T0, ACA and CRA showed significant differences between the deviated and non-deviated sides (Table 3). While ACA was significantly smaller on the deviated side than on the non-deviated side ($P < 0.01$), CRA was significantly larger on the deviated side than on the non-deviated side ($P < 0.01$). There was no significant difference in any joint space between the two sides ($P > 0.05$).

At T1, ACA was significantly smaller on the deviated side than on the non-deviated side ($P < 0.05$), while SJS, MJS, and LJS were significantly larger on the deviated side than on the non-deviated side ($P < 0.05$). The changes in the joint spaces indicated that the condylar segment had moved further down on the deviated side than on the non-deviated side.

At T2, ACA was significantly smaller on the deviated side than on the non-deviated side ($P < 0.05$). All joint spaces showed no significant differences ($P > 0.05$).

Table 3. Measurements for the deviated and non-deviated sides before, immediately after, and 12 months after orthognathic surgery

		Before			Immediately after			12 months after		
		Deviated	Non-deviated	P-value	Deviated	Non-deviated	P-value	Deviated	Non-deviated	P-value
Condylar segment	**ACA**	14.91 ± 6.38	20.28 ± 7.49	0.000†	4.73 ± 7.06	9.19 ± 8.53	0.012*	9.11 ± 6.54	12.78 ± 7.43	0.029*
	CCA	8.50 ± 8.39	10.48 ± 11.41	0.288	4.69 ± 10.55	6.62 ± 11.63	0.362	6.03 ± 9.71	8.53 ± 10.24	0.133
	CRA	78.83 ± 3.86	74.50 ± 4.43	0.001†	82.94 ± 5.54	81.10 ± 5.75	0.255	78.03 ± 5.01	77.97 ± 5.64	0.964
	SRA	81.84 ± 5.78	80.85 ± 5.16	0.124	87.38 ± 7.51	88.64 ± 7.05	0.462	77.70 ± 8.33	77.39 ± 7.31	0.832
Joint spaces	**SJS**	1.93 ± 0.61	1.93 ± 0.60	0.976	5.08 ± 1.49	4.30 ± 1.26	0.020*	2.57 ± 1.05	2.30 ± 0.97	0.080
	AJS	1.90 ± 0.71	1.62 ± 0.48	0.063	2.11 ± 0.71	1.98 ± 0.60	0.185	1.77 ± 0.50	1.56 ± 0.43	0.063
	PJS	1.79 ± 0.41	1.81 ± 0.50	0.877	5.69 ± 1.46	5.09 ± 1.52	0.184	2.60 ± 0.74	2.55 ± 0.73	0.722
	MJS	1.72 ± 0.59	1.73 ± 0.49	0.948	3.08 ± 1.89	2.02 ± 0.41	0.021*	1.63 ± 0.62	1.67 ± 0.53	0.696
	LJS	1.85 ± 0.61	1.68 ± 0.43	0.109	4.27 ± 2.13	3.08 ± 0.96	0.021*	2.63 ± 1.05	2.35 ± 0.86	0.120

Data are presented as means ± standard deviations.

Paired t-tests were used to compare the values for the deviated and non-deviated sides at each time point (*$P < 0.05$; †$P < 0.01$).
ACA, axial condylar angle; CCA, coronal condylar angle; CRA, coronal ramus angle; SRA, sagittal ramus angle; SJS, superior joint space; AJS, anterior joint space; PJS, posterior joint space; MJS, medial joint space; LJS, lateral joint space

3. Immediate and 12 months postoperative changes in the condylar segments and joint spaces

There were statistically significant changes in all the variables, which indicated postoperative movement of the condylar segments. (Table 4, Figures 4 and 5) ACA significantly decreased during T0–T1 and slightly increased during T1-T2 on both sides ($P < 0.05$). This suggested that both condylar heads rotated outward immediately after surgery and inward again during 12 months after surgery, although they did not return to the preoperative position. CCA on the non-deviated side showed a significant decrease during T0-T1 ($P < 0.05$), while the deviated side showed no significant changes at all time points ($P > 0.05$). CRA on the deviated side returned to the preoperative value during T0-T2 ($P > 0.05$), whereas that on the non-deviated side showed a significant increase during T0–T1 ($P < 0.05$), decrease thereafter during T1-T2 ($P < 0.05$), but did not return to the preoperative position during T0-T2 ($P < 0.05$). SRA showed a significant increase during T0-T1 ($P < 0.05$), followed by a decrease during T1-T2 ($P < 0.05$) on both sides, which indicated the occurrence of condylar sag after surgery (Figure 4).

SJS, PJS, and LJS showed a significant increase during T0–T1 ($P < 0.05$) because of downward movement of the condylar segments, followed by a decrease during T1-T2 ($P < 0.05$). Compared with the preoperative values, PJS and LJS showed an increase during T0–T2 ($P < 0.05$), while SJS, AJS, and MJS returned to the preoperative state during T0–T2 ($P > 0.05$, Figure 5).

Table 4. Comparison of changes between the deviated and non-deviated sides before, immediately after, and 12 months after orthognathic surgery

			Before	Immediately after	12 months after	P–value
Angle	ACA	D	14.91 ± 6.38^{A}	4.73 ± 7.06^{B}	9.11 ± 6.54^{C}	<0.001‡
		ND	20.28 ± 7.49^{A}	9.19 ± 8.53^{B}	12.78 ± 7.43^{C}	<0.001‡
	CCA	D	8.50 ± 8.39^{A}	4.69 ± 10.55^{A}	6.03 ± 9.71^{A}	<0.05*
		ND	10.48 ± 11.41^{A}	6.62 ± 11.63^{B}	8.53 ± 10.24^{AB}	<0.01†
	CRA	D	78.83 ± 3.86^{A}	82.94 ± 5.54^{B}	78.03 ± 5.01^{A}	<0.001‡
		ND	74.50 ± 4.43^{A}	81.10 ± 5.75^{B}	77.97 ± 5.64^{C}	<0.001‡
	SRA	D	81.84 ± 5.78^{A}	87.38 ± 7.51^{B}	77.70 ± 8.33^{C}	<0.001‡
		ND	80.85 ± 5.16^{A}	88.64 ± 7.05^{B}	77.39 ± 7.31^{C}	<0.001‡
Joint space	SJS	D	1.93 ± 0.61^{A}	5.08 ± 1.49^{B}	2.57 ± 1.05^{AC}	<0.001‡
		ND	1.93 ± 0.60^{A}	4.30 ± 1.26^{B}	2.30 ± 0.97^{AC}	<0.001‡
	AJS	D	1.90 ± 0.71^{A}	2.11 ± 0.71^{A}	1.77 ± 0.50^{A}	<0.05*
		ND	1.62 ± 0.48^{A}	1.98 ± 0.60^{B}	1.56 ± 0.43^{AC}	<0.01†
	PJS	D	1.79 ± 0.41^{A}	5.69 ± 1.46^{B}	2.60 ± 0.74^{C}	<0.001‡
		ND	1.81 ± 0.50^{A}	5.09 ± 1.52^{B}	2.55 ± 0.73^{C}	<0.001‡
	MJS	D	1.72 ± 0.59^{A}	3.08 ± 1.89^{B}	1.63 ± 0.62^{AC}	<0.01†
		ND	1.73 ± 0.49^{AB}	2.02 ± 0.41^{A}	1.67 ± 0.53^{B}	<0.05*
	LJS	D	1.85 ± 0.61^{A}	4.27 ± 2.13^{B}	2.63 ± 1.05^{C}	<0.001‡
		ND	1.68 ± 0.43^{A}	3.08 ± 0.96^{B}	2.35 ± 0.86^{C}	<0.001‡

Data are presented as means ± standard deviations.
*P < 0.05, †P < 0.01, ‡P < 0.001 by repeated-measures analysis of variance and multiple comparison with Bonferroni correction
The letters indicate the Bonferroni post hoc results, with different letters representing statistically significant differences (P < 0.05).

D, deviate side; ND, non-deviated side; ACA, axial condylar angle; CCA, coronal condylar angle; CRA, coronal ramus angle; SRA, sagittal ramus angle; SJS, superior joint space; AJS, anterior joint space; PJS, posterior joint space; MJS, medial joint space; LJS, lateral joint space

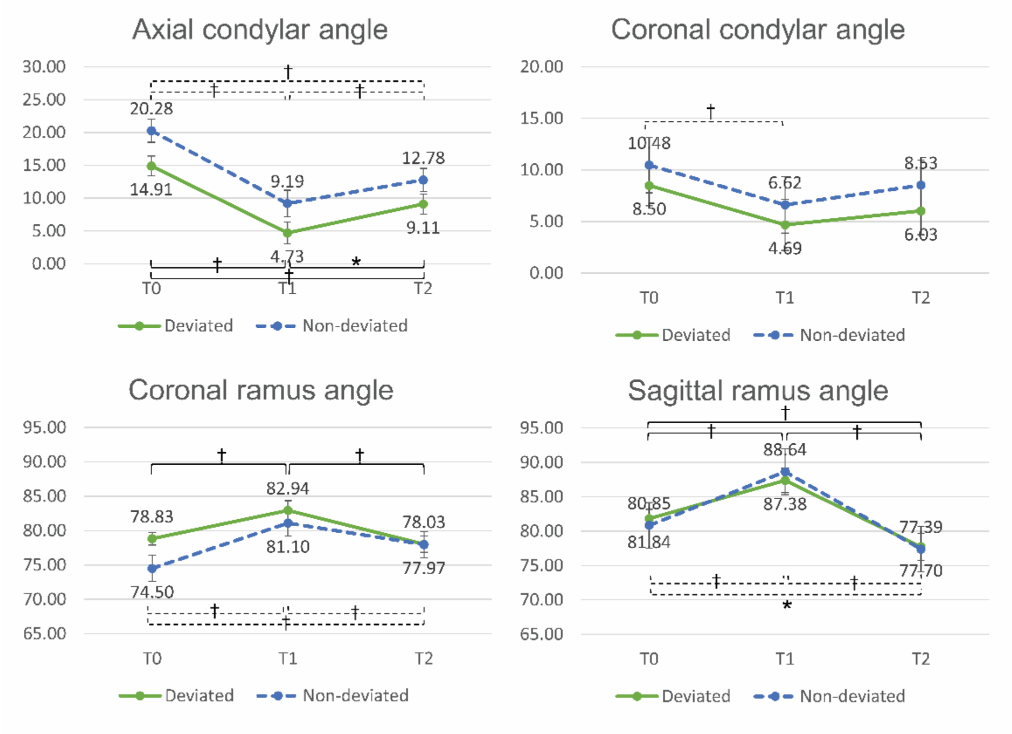

Figure 4. Angular measurements changes in condylar segments on the deviated and non-deviated sides after orthognathic surgery for skeletal Class III malocclusion and facial asymmetry

*P < 0.05, †P < 0.01.

Figure 5. Linear measurements changes in the joint spaces on the deviated and non-deviated sides after orthognathic surgery for skeletal Class III malocclusion and facial asymmetry

*P < 0.05, †P < 0.01.

IV. DISCUSSION

For the resolution of mandibular prognathism and facial asymmetry using IVRO, different amounts of mandibular yaw, roll, and pitch rotational setback are required on each side,(Kim et al., 2015b), which leads to different positional changes in the condylar segments on each side in terms of the axial, coronal, and sagittal planes.

In the present study, we compared positional changes in terms of the condylar angulation and joint spaces between the deviated and non-deviated sides and investigated the postoperative changes on each side in patients with facial asymmetry and skeletal Class III malocclusion who underwent conventional bimaxillary orthognathic surgery. The results revealed that ACA and CRA were significantly different between the deviated and non-deviated sides before surgery (T0). Immediately after surgery (T1), the values for both sides changed because of condylar sag and tended to recover by 12 months (T2). After the asymmetry was corrected by IVRO, CRA on both sides became similar; however, ACA remained different on each side. The joint spaces were also enlarged immediately after surgery and tended to recover after 12 months because of the physiological location of the condylar segments. There were no significant differences in the joint spaces between the deviated and non-deviated sides before and 12 months after surgery.

Previous studies have used 3D CT images to analyze the condylar position.(Baek et al., 2006; Ohba et al., 2014; Tyan et al., 2017; Ueki et al., 2009) However, they selected the slices that showed the greatest mediolateral dimension of the condylar head; therefore, accurate anatomical points may have been excluded, resulting in limited reproducibility at each time point. In the present study, we projected anatomical points of a 3D model onto created 2D reference planes. Our method, which was based on 3D model reconstruction, enabled us to identify accurate anatomical points and to minimize errors in slice selection.

A previous study reported that differences in the condylar morphology and muscle imbalance between the deviated and non-deviated sides persisted immediately after IVRO in patients with skeletal Class III malocclusion and facial asymmetry.(Wen et al., 2015) Over the next several months, the proximal segment would undergo remodeling to establish a stable physiological position. Therefore, it is important to study the new position and stability of the proximal segment. In the present study, we evaluated differences between pre- and postoperative values over 12 months follow-up period.

ACA represents the amount of condylar yaw rotation. In the present study, it was significantly smaller on the deviated side than on the non-deviated side before, immediately after, and 12 months after surgery. It means that the condyle on the deviated side showed a greater tendency for outward rotation in the axial view than did the condyle on the non-deviated side throughout the observation period. Based on these findings, we could conclude that facial asymmetry in the present study had been accompanied by condylar yaw rotation. However, even after asymmetry correction by orthognathic surgery, ACA was different between the deviated and non-deviated sides; this may suggest that the condyle and the glenoid fossa were morphologically and functionally adapted to each other. The axial condylar axis on both sides was significantly rotated outward immediately after surgery, followed by slight inward rotation during 12 months after surgery. This is in contrast to the inward rotation tendency of the condyle after SSRO.(Baek et al., 2006; Kim et al., 2015a; Tyan et al., 2017; Ueki et al., 2005) It seems because the pulling direction of the lateral pterygoid muscle would rotate the condylar segment to an outward position after IVRO which allows the proximal segment to move freely.

CCA and CRA indicates condylar and ramus roll rotation, respectively. CCA measurements showed no significant difference between the deviated and non-deviated sides, with wide standard deviations at T0, T1, and T2. This can be explained by the fact that the shapes of the glenoid fossa and condyle are determined in the growing stage and continuously change depending on their function.(McNamara, 1973) In particular, the medial pole of the condyle shows various vertical positions. Therefore, CCA cannot be considered a clinically significant measurement. On the other hand, CRA on the deviated side was significantly larger than that on the non-deviated side before surgery. Frontal ramus inclination, which is represented by CRA, is a major factor determining the facial appearance in the presence of asymmetry.(Yanez-Vico et al., 2011) Different amounts of setback may result in different movements of the proximal segments. If the distal segment of the mandible moves backward for the correction of scondkeletal Class III malocclusion, the inferior tip of the condylar segment on the non-deviated side tends to show more lateral widening because of a larger overlap between the proximal and distal segments. Therefore, the condylar segment angulation on both sides would become similar as the facial asymmetry decreases. In the present study, CRA did not show significant differences between deviated and non-deviated sides 12 months after surgery, indicating correction of facial asymmetry.

SRA represents pitch rotation of the condylar segment. In the present study, SRA on both sides increased immediately after surgery because of condylar sag associated with the location of the proximal segment outside the distal segment during mandibular setback. However, there were no significant differences in SRA between the deviated and non-deviated sides before, immediately after, and 12 months after surgery. These results differ from those derived by Yanez-Vico et al.(Yanez-Vico et al., 2011) In the present study, there was no anterior–posterior difference in the gonion region of patients before, immediately after, and 12 months after surgery. (data not shown) This can be attributed to gonial reduction during surgery, which suggests that CRA and SRA could be influenced by the surgical technique. First, the vertical overhang of the proximal segment after mandibular setback was resected. Therefore, the anatomical landmarks which were R_{Lat} and R_{Post} could be changed after surgery. Second, lateral and distal widening of the proximal segments differs according to the amount of overlap between proximal and distal segments. Thus, the medial surface of the proximal segments and the lateral surface of the distal segments were trimmed to obtain symmetry.,

There were no significant differences in all joint spaces between the deviated and non-deviated sides before and 12 months after surgery. Previous studies have shown that the shape of the condyle differs between the two sides in patients with asymmetry.(Akahane et al., 2001; Endo et al., 2011; Lin et al., 2013) However, the joint spaces showed no differences in our study, suggesting morphological and functional adaptation of the joint structure. After asymmetric setback of the mandible, the condyle maintained its position in the glenoid fossa, although the condyle rotated backward and inward.

Immediately after surgery, all joint spaces were increased because of condylar sag. Considering the average change (Figure 5), SJS, LJS, and PJS showed a greater increase than did AJS and MJS. By 12 months after surgery, SJS, AJS, and MJS returned to their preoperative state, whereas LJS and PJS exhibited an overall increase relative to their preoperative state. This was because the pulling direction of the muscle attached to the condylar segment can influence the postoperative position of the condyle.(Choi et al., 2002) The lateral pterygoid muscle attaches to the anterior–medial side of the condyle and pulls the condyle in the anterior–medial–inferior direction after surgery. The condyle then appears to find its physiological position in the glenoid fossa during the postoperative follow-up period.

However, the joint spaces in the present study were measured to be smaller than those in previous studies,(da Silva et al., 2018; Park et al., 2015; Zhang et al., 2016) probably because of differences between multislice CT (MSCT) and cone beam CT (CBCT).(Hofmann et al., 2013) Several studies have used CBCT to investigate joint spaces,(da Silva et al., 2018; Park et al., 2015) reporting a normal range of 2–4 mm. Joint space evaluation can be affected by various factors such as the slice thickness, window level and width, matrix size, and rendering technique.(Kawamata et al., 1998) Moreover, the image quality with respect to fine dental and bony structures is reportedly more precise with MSCT than with CBCT.(Hofmann et al., 2013) The present study used MSCT images, which appeared more efficient than CBCT images (Holberg et al., 2005) in differentiating bone with high contrast. Another possible cause of the observed joint space differences could be the use of the skeletal classification system. Compared with skeletal Class II malocclusion, skeletal Class III malocclusion is associated with a smaller joint space in the vertical direction.(Katsavrias and Halazonetis, 2005)

The findings of this study are limited by the small sample size and broad range of menton deviation (3–14 mm). Because overlap between the proximal and distal segments differs according to the amount of setback, it may affect the direction of movement of the proximal segments. However, the amount of setback is not associated with postoperative stability.(Jung et al., 2013) Moreover, soft tissue changes were also not considered in this study. The mandibular soft tissue might change because of proximal segment movement after IVRO, with normalization within 3 years.(Choi et al., 2016) Further studies using larger samples should evaluate the soft tissue changes in patients with facial asymmetry.

Identification of the structures involved in apparent facial asymmetry is important for surgical treatment planning. According to the present study, facial asymmetry affects the axial condylar axis (yaw) and frontal ramus inclination (roll). CRA, which represents frontal ramus inclination, correlates with the facial appearance in the presence of asymmetry, while ACA is less affected.

There are several factors influencing the choice of an appropriate osteotomy technique. IVRO reportedly shows good results, with an increase in the maximum mouth opening and amelioration of temporomandibular joint symptoms, the so-called "condylotomy effect".(Choi et al., 2002) Therefore, it may be superior to other surgical techniques for patients with temporomandibular disorders.

V. CONCLUSIONS

According to the present study, the null hypotheses were rejected, concluding that asymmetric mandibular setback can cause different changes in the position and angulation of the condylar segments on either side. The main findings are as follows.

1. At T0, the axial condylar angle and coronal ramus angle showed significant differences between the deviated and non-deviated sides.

2. At T1, the axial condylar angle showed significant differences between the deviated and non-deviated sides. The condyle exhibited outward, medial, and anterior–inferior rotation in the axial, coronal, and sagittal planes, respectively. This was due to overlap of the proximal segment with the distal segment after mandibular setback by IVRO.

3. At T2, the axial condylar angle was significantly different between the deviated and non-deviated sides, while the coronal ramus angle did not show significant differences.

4. There were no significant differences in the five joint spaces between the deviated and non-deviated sides at T0 and T2. There were significant differences in the superior, medial and lateral joint spaces between the deviated and non-deviated sides at T1.

5. At T1, most joint spaces exhibited a significant increase immediately after surgery because of condylar sag.

6. At T2, the superior, anterior, and medial joint spaces returned to their preoperative state, whereas the posterior and lateral joint spaces remained significantly increased.

In conclusion, IVRO can improve asymmetric structures and the facial appearance associated with the proximal segment. Physiological repositioning of the condyle gradually occurs during the postoperative follow-up period by 12 months after surgery.

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국문 요약

비대칭 환자의 구내 하악지 수직 골절단술에 의한 과두의 3차원 위치 변화

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본 연구의 목적은 안면 비대칭 및 골격성 III급 부정교합 환자의 CT 영상을 이용하여 편위측과 비편위측의 과두각도와 관절공간을 비교하고, 구내 하악지 수직 골절단술 후 각각의 수술 후 변화를 평가하는 것이다.

총 18명의 안면 비대칭을 동반한 골격성 III급 부정교합 환자 (남 : 8명, 여 : 10명)가 선정되었으며 평균 나이는 20.67 ± 2.85세 였다. 대상자는 구내 하악지 수직 골절단술을 동반하여 교정치료를 받은 환자로 이부 편위가 3mm 이상이며, 수술 전 (1달 이내, T0), 수술 직후 (1주 이내, T1), 수술 12개월 후에 CT를 촬영한 환자였다.

과두쪽 절편의 회전 변화와 위치 변화를 비교하기 위해 4개의 각도계 측치 (axial condylar, coronal condylar, coronal ramus, and sagittal ramus) 와 5개의 관절공간 (superior, anterior, posterior, medial, and lateral)이

측정되었다. 편위측과 비편위측의 대칭성을 비교하고, 시간에 따른 변화양상을 분석하여 다음과 같은 결과를 얻었다.

1. 술 전, axial condylar angle과 coronal ramus angle에서 편위측과 비편위측 사이에 유의한 차이를 보였다 ($P < 0.01$).

2. 수술 직후, axial condylar angle에서 편위측과 비편위측 사이에 유의한 차이를 보였다 ($P < 0.05$). 과두쪽 절편은 3차원적으로 회전하였다. 이는 구내 하악지 수직 골절단술에 의해 근심골편이 원심골편의 외측에 위치하게 되기 때문이다.

3. 수술 12개월 후, axial condylar angle은 편위측과 비편위측 사이에 여전히 유의한 차이를 보였다 ($P < 0.05$). 그러나 비대칭 환자에서 안모 심미와 연관이 있는 coronal ramus angle은 유의한 차이를 보이지 않았다 ($P > 0.05$).

4. 술 전과 수술 12개월 후, 모든 관절공간 계측치에서 편위측과 비편위측 사이에 유의한 차이를 보이지 않았다 ($P > 0.05$). 수술 직후 superior, medial, lateral joint space에서 편위측과 비편위측 사이에 유의한 차이를 보였다 ($P < 0.05$).

5. 수술 직후, condylar sag에 의하여 관절공간은 유의하게 증가하였다 ($P < 0.05$).

6. 수술 12개월 후, superior joint space, anterior joint space, medial joint space는 술 전과 비슷하게 되돌아 왔으나(T0-T2, $P < 0.05$) lateral joint space 와 posterior joint space는 술 전에 비해 유의하게 증가하였다 (T0-T2, $P < 0.05$).

결론적으로, 근심골편과 관련된 비대칭적인 구조와 안모 심미는 구내 하악지 수직 골절단술을 통해 개선되었다. 수술 후 12개월의 관찰 기간동안 과두쪽 절편은 점차 생리적으로 재위치되었다.

핵심 되는 말: 과두쪽 절편, 구내 하악지 수직 골절단술, 관절공간, 비대칭