Relationship between three-dimensional position change of mandibular proximal segment and temporomandibular disorders after intraoral vertical ramus osteotomy in skeletal Class III malocclusion with asymmetry

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Relationship between three-dimensional position change of mandibular proximal segment and temporomandibular disorders after intraoral vertical ramus osteotomy in skeletal Class III malocclusion with asymmetry

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감사의 글

박사논문 연구를 진행하고 마치며, 저 혼자만의 힘이 아닌 많은 분들의 도움으로 교정과의사로 성장할 수 있었음을 다시한번 느꼈으며, 앞으로도 계속 공부하는 교정과의사가 되기 위해 노력하고자 다짐합니다.

논문이 완성되기까지 따뜻한 배려와 함께 세심한 지도와 격려를 아끼지 않으신 유형석 지도 교수님께 진심으로 감사드립니다. 논문 심사위원을 맡아주시고 많은 관심과 조언으로 도움을 주셨던 박영철 교수님, 백형선 교수님, 이상휘 교수님, 김성택 교수님께 깊은 감사의 말씀을 올립니다. 또한 교정학을 공부할 기회를 주시고 지도해주신 황충주 교수님, 김경호 교수님, 이기준 교수님, 차정열 교수님, 정주령 교수님, 최윤정교수님께도 깊이 감사드립니다. 박사과정 동안 많은 도움을 주었던 수련동기들, 섹션 후배들, 의국원들에게도 진심을 담아 감사의 마음을 전합니다.

한결 같은 믿음과 배려로 지금의 제가 있도록 사랑으로 이끌어주신 부모님과, 딸처럼 아껴주시고 격려해주시는 시부모님, 사랑하는 동생 우정이와 진호에게 감사의 인사를 전합니다. 가까이에서 여러방면으로 멘토가 되어주시는 아주버님과 형님께도 감사의 마음을 전합니다. 무엇보다 바쁜 와중에도 부족한 아내를 위해 물심양면 애쓰고, 도와준 사랑하는 남편에게 존경과 감사의 인사를 전하며, 마지막으로 내 인생의 보물인 두 아들 은석이와 지석이에게 사랑과 감사의 마음을 전하며 이 기쁨을 함께 하고자 합니다.

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서 승 아

Table of Contents

List of figures ······ iii
List of tables ······ iv
Abstract (English) ······ v

I. Introduction ······ 1

II. Subjects and methods ······ 5
  1. Subjects ······ 5
  2. Methods ······ 7
    A. CT scanning & 3D images reconstruction ······ 7
    B. Landmarks & reference planes ······ 8
      1) Definition of landmarks ······ 8
      2) Definition of reference planes ······ 9
    C. Measurements with reconstructed 3D CT images ······ 10
      1) Measurement of horizontal & vertical asymmetry ······ 10
      2) Measurement of condylar dimension ······ 11
      3) Measurement of articular eminence, fossa depth ······ 12
      4) Measurement of mandibular proximal segments ······ 13
  3. Statistical analysis ······ 16

III. Results ······ 17
  1. Intra−examiner reliability ······ 17
  2. Comparison of horizontal & vertical asymmetry between groups according to TMD clinical sign ······ 17

3. Comparison between Group Ia (joint sound improved & maintained) and Group Ib (joint sound worsened) ······ 18
A. Comparison of condylar & articular fossa dimension ······ 18
B. Comparison of preoperative (T1) proximal segment measurements ······ 19
C. Comparison of postoperative (T2) proximal segment measurements ······ 20
D. Comparison of proximal segment measurement changes [△T(T2−T1)] ······ 21
4. Comparison between Group IIa (TMJ pain improved & maintained) and Group IIb (TMJ pain worsened) ······ 22
A. Comparison of condylar & articular fossa dimension ······ 22
B. Comparison of preoperative (T1) proximal segment measurements ······ 23
C. Comparison of postoperative (T2) proximal segment measurements ······ 24
D. Comparison of proximal segment measurement changes [△T(T2−T1)] ······ 25

IV. Discussion ······ 26

V. Conclusion ······ 35

References ······ 37

Abstract (Korean) ······ 45

List of Figures

Figure 1. Reconstruction of 3D images using OnDemand^{TM} software (CyberMed Inc., Seoul, Korea) ··· 7
Figure 2. Landmarks used in this study ··· 8
Figure 3. Reference planes used in this study ··· 9
Figure 4. Measurement of horizontal & vertical asymmetry ··· 10
Figure 5. Measurement of condylar width, height, thickness ··· 11
Figure 6. Measurement of articular eminence, sagittal & coronal fossa depth ··· 12
Figure 7. Measurement of mandibular proximal segments ··· 14
Figure 7-1. Coronal vertical axis(cva) definition ··· 15
Figure 7-2. Sagittal vertical axis(sva) definition ··· 15

List of Tables

Table 1. Description of subjects ······ 6

Table 2. Definition of landmarks used in study ······ 8

Table 3. Definition of reference planes used in study ······ 9

Table 4. Definition of horizontal & vertical asymmetry ······ 10

Table 5. Comparison of horizontal & vertical asymmetry between groups related to TMD clinical sign ······ 17

Table 6－1. Comparison of condylar & articular fossa dimension between Group Ia and Group Ib ······ 18

Table 6－2. Comparison of proximal segment measurement between Group Ia and Group Ib in Pre－ Op (T1) ······ 19

Table 6－3. Comparison of proximal segment measurement between Group Ia and Group Ib in Post－Op (T2) ······ 20

Table 6－4. Comparison of proximal segment measurement difference[△T(T2－T1)] between Group Ia and Group Ib ······ 21

Table 7－1. Comparison of condylar & articular fossa dimension between Group IIa and Group IIb ······ 22

Table 7－2. Comparison of proximal segment measurement between Group IIa and Group IIb in Pre－ Op (T1) ······ 23

Table 7－3. Comparison of proximal segment measurement between Group IIa and Group IIb in Post－Op (T2) ······ 24

Table 7－4. Comparison of proximal segment measurement difference[△T(T2－T1)] between Group IIa and Group IIb······ 25

Table 8. The rate of joint sound & TMJ pain change in Class III asymmetry in this study ······ 34

Abstract

Relationship between three-dimensional position change of mandibular proximal segment and temporomandibular disorders after intraoral vertical ramus osteotomy in skeletal Class III malocclusion with asymmetry

The purpose of the present study was to compare pre- and post-operative changes in temporomandibular joint (TMJ) sounds and pain in patients who had undergone orthognathic surgery (LeFort I osteotomy and intraoral vertical ramus osteotomy) for correction of skeletal Class III malocclusion with facial asymmetry, and to identify skeletal differences associated with these symptoms.

Preoperative (T1) and 1-year postoperative (T2) 3-dimensional CT (3D CT) imaging of 29 patients with skeletal Class III with facial asymmetry were obtained and measured. These subjects were grouped Group Ia (improved /maintained joint sound) and Group Ib (worsened joint sound), as were grouped Group IIa (improved /maintained TMJ pain) and Group IIb (worsened TMJ pain) according to changes of TMD clinical sign after surgery. Horizontal and vertical asymmetry, configuration of the condyle and fossa, preoperative (T1) mandibular proximal segment measurements, postoperative (T2) mandibular proximal segment measurements, and pre- and post-operative mandibular proximal segment changes [△T(T2-T1)] were compared and analyzed with the following results:

1. No statistically significant differences were noted in horizontal and vertical asymmetry between either group for TMJ sound and pain.

2. Preoperatively (T1), the coronal condylar long axis angle on the non-deviated side was greater in Group Ib (worsened joint sound) than Group Ia (improved/maintained joint sound) ($p<0.01$). There was also a greater difference in coronal condylar long axis angle between each side in Group Ib ($p<0.05$).

3. Postoperatively (T2), the horizontal condylar angle was noted to be smaller on the deviated side than the non-deviated side in Group Ib compared to Group Ia ($p<0.01$). Also, the coronal condylar vertical axis angle was smaller in Group Ib ($p<0.05$).

4. There was a greater increase in horizontal condylar angle on the non-deviated side than the deviated side in Group Ib compared to Group Ia when pre- and postoperative changes [$\triangle T(T2-T1)$]were compared ($p<0.01$).

5. In the postoperative period (T2), Group IIb (worsened TMJ pain) had a smaller horizontal condylar angle on the deviated side compared to the non-deviated side ($p<0.05$), and a smaller A-B distance (superior joint space) compared to Group IIa(improved/maintained TMJ pain) ($p< 0.05$).

The results of this study indicate that in skeletal Class III patients with asymmetry corrected with IVRO, a smaller postoperative horizontal condylar angle on the deviated side and less inferior movement of the deviated condyle are associated with worse TMJ sound and pain.

Key words: Temporomandibular disorders, IVRO, mandibular proximal segment, skeletal Class III, asymmetry, 3D-CT

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I. Introduction

Three-dimensional computed tomography (3D CT) has allowed more accurate diagnosis and treatment of dentofacial deformities, and many studies are vigorously investigating the postoperative stability of 3D CT-aided treatment outcomes. Maxillofacial asymmetry is a condition in which the center of the maxilla or mandible is deviated from the midline, or when there is a discrepancy in facial height or width (Peck et al., 1970). The use of 3D CT analysis in the diagnosis and treatment of patients with maxillofacial asymmetry requiring surgical correction is now widely employed, and considered indispensable. Two anatomical areas that are generally impacted after orthognathic surgery − the mandibular condyle and the temporomandibular joint (TMJ) − have been difficult to assess with traditional two−dimensional (2D) imaging due to superimposition of adjacent osseous structures and image distortion. 3D CT has allowed reproducible and more accurate assessment of morphology, position, and measurements along with MRI (Kawamata et al., 2000; Katsumata et al., 2005).

Temporomandibularjoint disorder (TMD) is a collective term used to describe various clinical problems that can arise from dysfunction associated with the bilateral TMJ, muscles of mastication, and neurovascular structures in the region (Dworkin & Lereche, 1992). Major symptoms include pain, joint sounds, and limitation of mandibular range of motion.

The incidence of TMD is reported to be higher in the facial asymmetry population, with some attributing this to alterations of the musculoskeletal system secondary to the asymmetry. Inui et al. reported that internal derangement of the TMJ is relatively common in facial asymmetry due to mandibular asymmetry (Inui et al., 1999), and Goto et al. found that the condyles of the deviated side tended to be smaller compared to the non−deviated side, with a higher frequency of disc displacement (Goto et al., 2005). Ueki et al. observed a remarkably high incidence (56.8%) of disc displacement in patients with skeletal Class III facial asymmetry (Ueki et al., 2000).

Sagittal split ramus osteotomy (SSRO) and intraoral vertical ramus osteotomy (IVRO) are the typically used techniques for mandibular setback, and are both very useful in treating facial asymmetry. The condyle to articular fossa relationship invariably changes after mandibular setback, and is affected by factors such as the surgeon's experience, the amount and direction of movement of the distal segment, the tensional balance of the surrounding musculature, the morphology and orientation of the proximal segment, and the method of mandibular fixation (Hackney et al., 1989; Magalhaes et al., 1995; Lee et al., 2002). Changes in the condyle to articular fossa relationship can also affect signs and symptoms of TMD.

Because there is a rather high incidence of TMD in patients with facial asymmetry, symptomatic relief is usually anticipated after surgery, and several studies report decrease in TMD signs and symptoms, supporting this belief (Kerstens et al., 1989; White et al., 1992; Hu et al, 2000; Ueki et al., 2002, 2012). Buckley et al. hypothesized that greater changes occur in condylar position when rigid fixation is used in SSRO, and reported a higher incidence of TMD (Buckley et al., 1989). Several reports advocate the use of a condylar positioning device to minimize condylar changes after rigid fixation (Helm et al., 1997; Renzi et al., 2003).

IVRO is a widely accepted and used technique for patients with TMD requiring mandibular setback. Bell et al. reported a very low incidence of TMJ internal derangement after IVRO (Bell et al., 1992), while Ueki et al. reported improvement of the disc to condylar relationship in patients with mandibular deformities. The latter study saw improvements of TMD symptoms in 88% of the IVRO group and 66.7% in the SSRO group 6 months after surgery (Ueki et al., 2002). Another study evaluating TMJ morphology and clinical symptoms of 50 patients who had undergone IVRO with or without LeFort I osteotomy reported absence of symptoms in 97% of patients who had undergone IVRO only, and 90% of patients who had undergone concomitant LeFort I osteotomy (Ueki et al., 2007).

Although identifying the cause of a disease is crucial to its treatment, the etiology of TMD is complex. In the case of postoperative TMD, preoperative characteristics, postoperative skeletal changes (especially changes in the condyle-fossa relationship), and the correlation between anatomical changes and TMD signs and symptoms are perhaps of greatest interest to the clinician.

Despite a wealth of literature on postoperative changes of the mandibular proximal segment and condyle-fossa relationship (Baek et al., 2006; Katsumata et al., 2006; Ueki et al., 2007, 2009; Fang et al., 2009; Kawakami et al., 2009), and despite the advantages of IVRO for patients with TMD symptoms compared to SSRO, most studies have been based on SSRO. Although some of these studies have shown decrease in TMD symptoms after asymmetry correction, the outcome measures, which included subjective changes in patient symptoms, were grossly simplified to percentages (Kerstens et al., 1989; White et al., 1992; Ueki et al., 2012). Overall, detailed investigation into which pre- and post-operative anatomical characteristics of the mandible correlate to changes in TMD signs and symptoms are largely lacking. Also, although less changed after orthognathic surgery, three-dimensional measurements of temporomandibular joint apparatus (articular eminence, glenoid fossa, and the condyle), because of their anatomical proximity to the TMJ and thus affecting TMD, can be helpful elements in understanding postoperative TMD symptom changes that are frequently ignored in the literature.

As such, the purpose of the present study was to compare pre- and post-operative changes in temporomandibular joint (TMJ) sounds and pain in patients who had undergone orthognathic surgery (LeFort I osteotomy and intraoral vertical ramus osteotomy) for correction of skeletal Class III malocclusion with facial asymmetry, and to identify skeletal differences associated with joint sound and pain in different TMD prognosis groups (improved/maintained group vs worsened group) after IVRO.

II. Subjects and Methods

1. Subjects

Patients undergoing combined surgical and orthodontic treatment for skeletal Class III malocclusion with asymmetry at the Orthodontics Department at Yonsei University Dental Hospital from 2004 to 2011 were included in this study. Preliminary inclusion criteria, which were based on clinical examination and lateral & postero-anterior cephalometric analysis, were: 1) unilateral or bilateral Angle Class III molar key, 2) overjet of 0mm or less, 3) ANB difference of 0 or less (average −2.64°), 4) menton deviation of more than 2.5mm from the facial midline (average 5.30mm).

Of these patients, 56 patients who were clinically examined at the Department of Oral Medicine one month before and one year after the operation were selected (Dworkin & Lereche, 1992). Twenty-nine of these patients with joint sound and/or TMJ pain (tenderness to palpation on the TMJ) before and/or after surgery and 3D CT taking before and one year after surgery were included. Patients with progressive TMJ arthritis or systemic disease, and patients with syndromic jaw deformities were excluded. The subjects were regrouped as follows (Table 1):

1. ***Groups according to joint sound change*** : Patients whose joint sound decreased or were unchanged after surgery were grouped as Group Ia(improved/maintained group), and those with new-onset joint sound or worsened joint sound (louder, more frequent sound) were grouped as Group Ib(worsened group). Patients without any joint noises before and after surgery were excluded.

2. ***Groups according to TMJ pain change*** : Patients whose TMJ pain improved or remained stable at a mild level were grouped as Group IIa (improved/maintained group), and those who have developed moderate to severe TMJ pain, or worsened pain after surgery were grouped as Group IIb(worsened group). Patients without any TMJ pain before and after surgery were excluded.

Table 1. Description of subjects

	N	Gender		Age(yr)
		Male	Female	
Group Ia (Joint sound improved/maintained)	13	7	6	24.4
Group Ib (Joint sound worsened)	7	3	4	26
Group IIa (TMJ pain improved/maintained)	11	3	8	26.1
Group IIb (TMJ pain worsened)	10	5	5	23.6

N : Number of subjects ; Age : Average value is used.

2. Methods

A. CT Scanning and 3D Images Reconstruction

A spiral CT scanner (GE Medical System, Milwaukee, Wis, USA) was used for CT scanning at 12 Kv and 200mA. CT scans were obtained for all patients one month before surgery (T1) and one year after surgery (T2). The Frankfort Horizontal plane of the patient was adjusted perpendicular to the ground, and the midline and major axis were placed in the same position. The axial images were 1mm thickness and were obtained at a table speed of 6mm per second. The axial images were saved as digital imaging and communication in medicine (DICOM) files and were reconstructed into 3D images using OnDemand^{TM} software (CyberMed Inc., Seoul, Korea) (Figure 1)

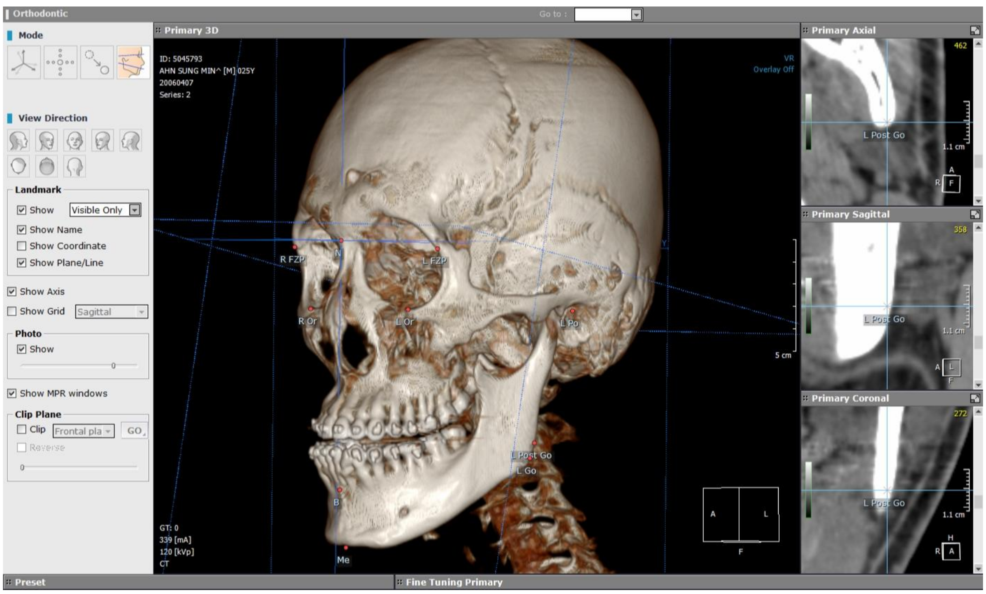

Figure 1. Reconstruction of 3D images using OnDemand^{TM} software (CyberMed Inc., Seoul, Korea).

B. Landmarks & Reference planes

Methods suggested by Cho were used in this study (Cho HJ, 2009).

1) Definition of landmarks (Table 2, Figure 2)

Table 2. Definition of landmarks used in study

Landmark	Definition
N (nasion)	the middle point of the frontonasal suture in the frontal plane
R/L FZP (frontozygomatic point)	the intersection of the frontozygomatic suture and the inner rim of the orbit in the frontal plane
R/L Or (orbitale)	the most inferior point of the orbital rim in the frontal plane
R/L Po (porion)	the most superior point of the external auditory meatus
R/L TFP (temporal-fossa point):	the most superior point of the inferior zygomatic arch border, above the condylar head as seen from the sagittal perspective
Me (menton)	the most inferior point in the middle of the mandibular chin in the frontal plane
R/L Go (gonion)	Midpoint of inferior and posterior border of mandibular angle
R/L Post Go (posterior gonion)	Most posterior point of posterior border of ramus
R/L Post Condylar Point	Most upper and posterior aspect of condyle

* R/L = right and left

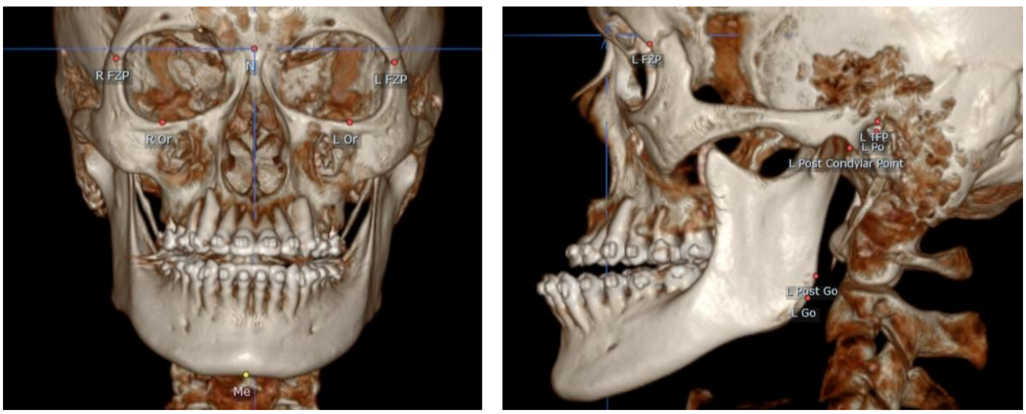

Figure 2. Landmarks used in this study.

2) Definition of reference planes (Table 3, Figure 3)

The shifted side of menton for the midsagittal plane was defined as deviated side and the opposite side was defined as non−deviated side.

Table 3. Definition of reference planes used in study

Plane	Definition
NFZ plane	anterior cranial base, established by three skeletal landmarks, RL FZP and N (NFZ plane is used to reorient axial and coronal axes of images)
Frontal plane	perpendicular to the NFZ plane passing through RL FZP
Horizontal reference plane	parallel to the FH plane, which was constructed on RL Po(or RL TFP) and R Or, passing through N
Sagittal reference plane (Midsagittal plane)	perpendicular to both the NFZ plane and the frontal plane passing through N
Coronal reference plane	perpendicular to the horizontal reference plane and midsagittal plane passing through N

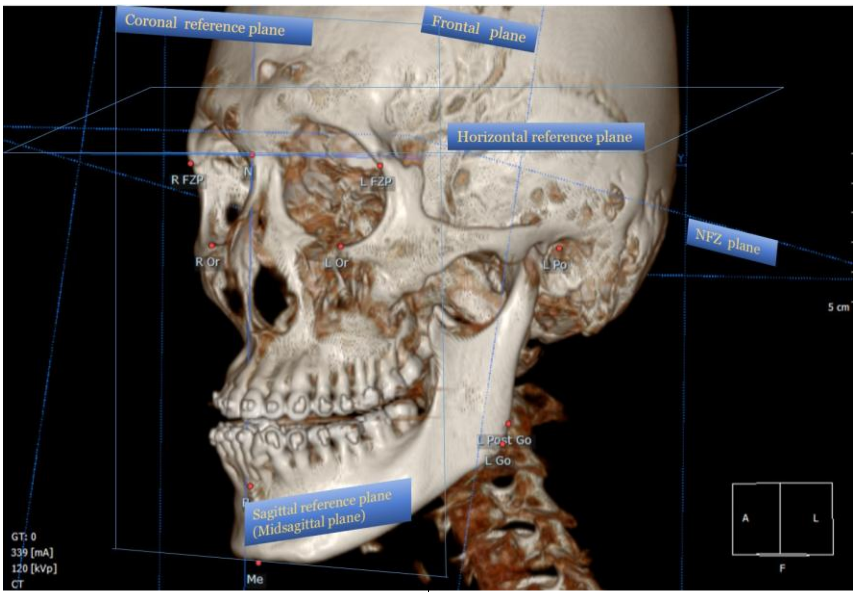

Figure 3. Reference planes used in this study.

C. Measurements with reconstructed 3D CT images

OnDemand™ software was used to make measurements on the 3-dimensionally reconstructed mandible and articular fossa. In the 3D ceph mode, measurements included horizontal and vertical mandibular asymmetry, ramus height, and intergonial distance. Using the multiplanar reconstruction (MPR) mode, the dimensions of the condyle and the articular eminence, as well the depth of the coronal and sagittal fossa were measured on axial, coronal and sagittal slices. Also, pre- and postoperative changes to the mandibular proximal segment were measured.

1) Measurement of horizontal & vertical asymmetry

Measurement points and reference planes were formed in the 3D-rendered mandible, and horizontal and vertical asymmetry were measured. (Table 4, Figure 4).

Table 4. Definition of horizontal & vertical asymmetry

	Definition
Horizontal asymmetry (Menton deviation)	Distance from [Me] to Midsagittal plane
Vertical asymmetry (Mandibular canting)	90^o - [Angle between Midsagittal plane and intergonial line] * Intergonial line = distance from [R Go] to [L Go]

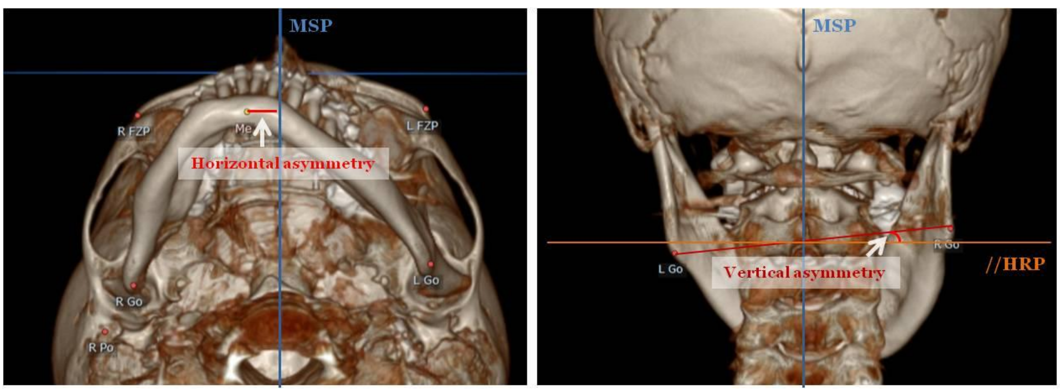

Figure 4. Measurement of horizontal & vertical asymmetry.

2) **Measurement of condylar dimension** (Figure 5)

In the coronal slice images parallel to the coronal reference plane, condylar width and height were measured. In the axial slice images parallel to the horizontal reference plane, condylar thickness was measured.

a. **Condylar Width** (Con Width): the distance between the lateral (L) and medial (M) pole of the condyle on the coronal slice.
b. **Condylar Height** (Con Height): the distance between a line drawn across the lateral pole parallel to the horizontal reference plane and the superior point of the condyle (S).
c. **Condylar Thickness** (Con Thickness): the axial slice at the approximate level of the vertical midpoint between the lateral (L) and medial (M) poles was used to measure the condylar thickness, which was defined as the longest distance between the tangent of the condylar posterior border and the anterior contour of the condyle.

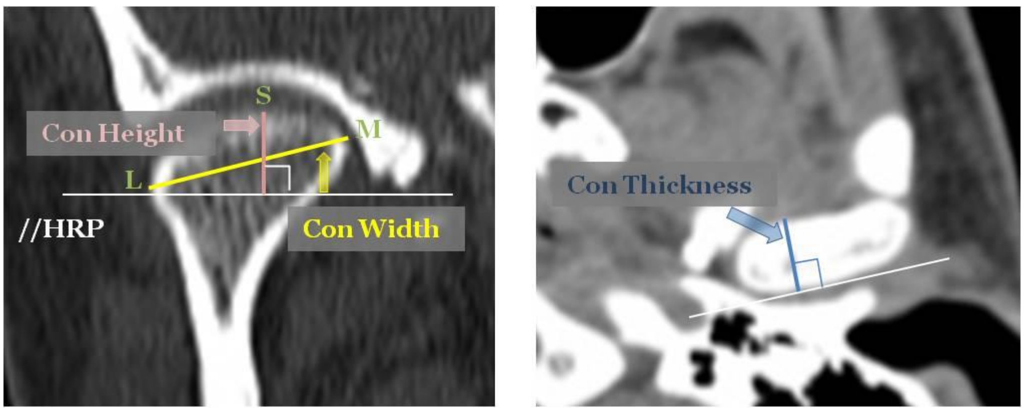

Figure 5. Measurement of condylar width, height, thickness.

Con Width : Condylar Width   Con Height : Condylar Height

Con Thickness : Condylar Thickness

3) **Measurement of articular eminence, fossa depth** (Figure 6)

The sagittal slice images parallel to the midsagittal plane and coronal slice images parallel to the coronal reference plane including the condylar head were selected for measurement.

a. **Articular eminence**(AE): the angle between horizontal reference plane and a line connecting the highest point of fossa (A) and the most inferior point of tuberculum (T) on the central slice of the sagittal sections of condyle.
b. **Sagittal fossa depth** (SFD): the distance from the most inferior point of tuberculum (T) to the intersection point between the posterior border on glenoid fossa and parallel line of horizontal reference plane (D) on the sagittal slice (line tangent to the most superior point of the fossa on the coronal slice).
c. **Coronal fossa depth** (CFD): the distance from the most inferior & outer point of temporal bone (OT) to the intersection point between the mesial border on glenoid fossa and parallel line of horizontal reference plane(E) on the coronal slice (line tangent to the most superior point of the fossa on the sagittal slice).

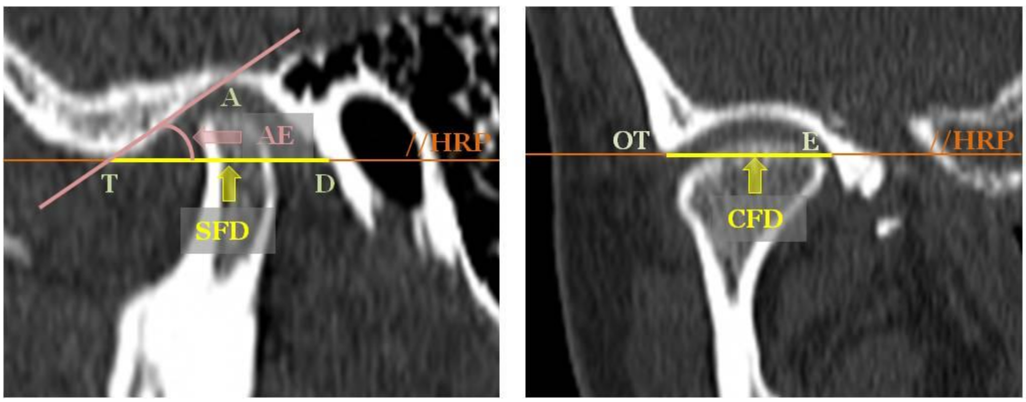

Figure 6. Measurement of articular eminence, sagittal & coronal fossa depth.

4) Measurement of mandibular proximal segments (Figure 7, 7−1, 7−2)

− Methods proposed by Han et al. (Han et al., 2012) were used.

Each measurement were measured preoperatively (T1) and one year postoperatively (T2), on both the deviated and non−deviated side.

a. **Intergonial distance** (IGD): distance between [R Go] and [L Go]
b. **Ramus height** (RH): distance between [Post Condylar Point] and [Post Go] + distance between [Post Go] and [Go]
c. **Horizontal condylar angle** (HCA): angle between condylar long axis − horizontal(cla−H) and midsagittal plane(MSP); Condylar long axis−horizontal(cla−H) is a line passed medial pole and lateral pole of condyle on the axial slice image.
d. **Coronal condylar long axis angle** (CCLA): angle between condylar long axis−vertical (cla−V), a line passed lateral pole and medial pole of condyle and horizontal reference plane on the coronal slice image.
e. **Coronal condylar vertical axis angle** (CCVA): angle between condylar vertical axis (cva), a line bisecting the medial and lateral border of the proximal segment and horizontal reference plane on the coronal slice image.
f. **Coronal ramus angle** (CRA): angle between condylar ramus axis (cra), a tangent line of lateral ramus directly under condyle curvature and horizontal reference plane on the coronal slice image.
g. **Sagittal condylar angle** (SCA): angle between sagittal vertical axis (sva), a line bisecting the anterior and posterior border of the proximal segment and coronal reference plane on the sagittal slice image.
h. **Temporomandibular joint space distance** (A−B, C−D): measured on the central slice of the sagittal sections of condyle.
    - **A−B distance** (superior joint space): distance from the most superior point on the curvature of the glenoid fossa(A) to the intersection point between the superior curvature of the condyle and a line parallel to the coronal reference plane(B).
    - **C−D distance** (posterior joint space): distance from the most posterior curvature of the condyle (C) to the intersection point between the posterior border on glenoid fossa and parallel line of horizontal reference plane (D).

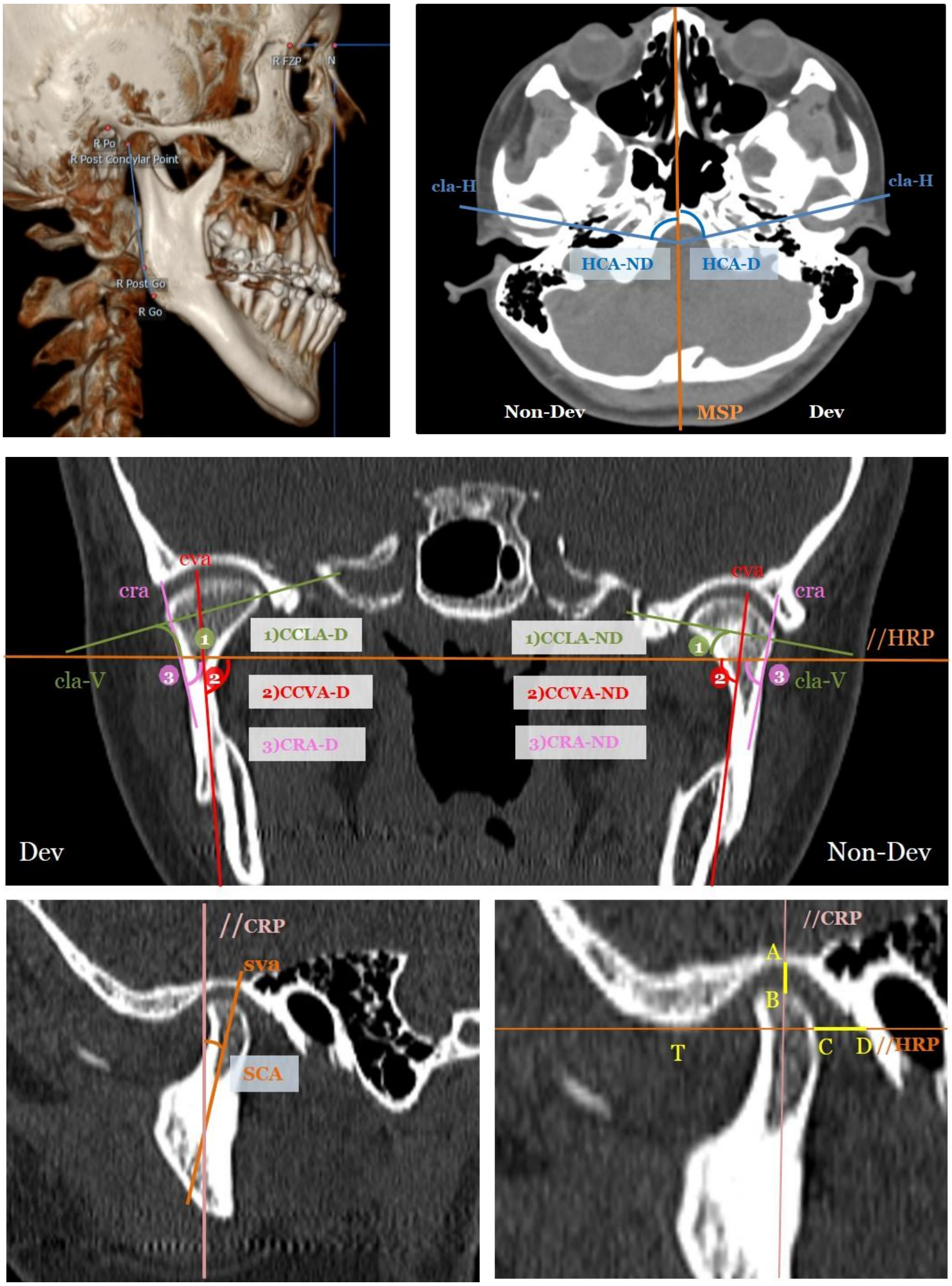

Figure 7. Measurement of mandibular proximal segments.

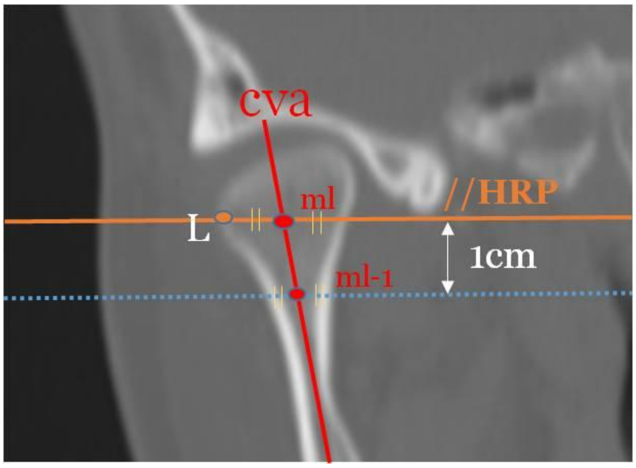

Figure 7-1. Coronal vertical axis (cva) definition.

* //HRP indicates parallel plane to the horizontal reference plane; L, lateral pole of condyle; ml, midpoint between lateral and medial border of the proximal segment at the level of the lateral pole on the //HRP; ml-1, midpoint between lateral and medial border of the proximal segment at the 1cm lower level from the lateral pole parallel to HRP; cva (coronal vertical axis), the line passed ml and ml-1.

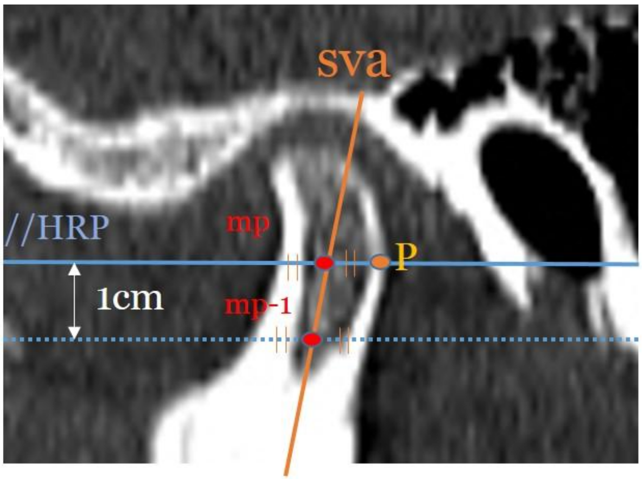

Figure 7-2. Sagittal vertical axis (sva) definition.

* //HRP indicates parallel plane to the horizontal reference plane; P, posterior pole of condyle; mp, midpoint between anterior and posterior border of the proximal segment at the level of the posterior pole on the //HRP; mp-1, midpoint between anterior and posterior border of the proximal segment at the 1cm lower level from the posterior pole parallel to HRP; sva(sagittal vertical axis), the line passed mp and mp-1.

3. Statistical Analysis

All variables were measured by one author and repeated after 1 week by the same author. For determining errors associated with CT measurements, 10 subjects were selected randomly. The first measurements were selected for the statistical analysis. All measurements were calculated to the nearest 0.01 degree and 0.01 mm.

All statistical evaluations were performed with SPSS version 21.0(Statistical Package for the Social Science Inc., Chicago, IL, U.S.A.).

A. A paired t−test was used to examine intra−examiner error.

B. Statistical analysis was performed using the Mann−Whitney U Test for the following measurements from Group Ia and Ib, and Group IIa and IIb.

1) Degree of horizontal and vertical asymmetry.
2) Condylar & articular fossa dimensions.
3) Preoperative (T1) measurements of the mandibular proximal segment.
4) Postoperative (T2) measurements of the mandibular proximal segment.
5) Changes in the mandibular proximal segments [△T(T2−T1)].

III. Results

1. The intra-examiner reliability

All CT images were measured by the same examiner. For determining the errors associated with CT measurements, 10 subjects were selected randomly, and their measurements were repeated a minimum of 1 week after the first. The intra-examiner reliability test showed no significant differences ($p<0.05$). The intra-class correlation coefficients were within acceptable value (mean of 0.92, with range of 0.90-0.95).

2. Comparison of horizontal & vertical asymmetry between groups according to TMD clinical sign.

There was no statistically significant difference in horizontal and vertical asymmetry between Group Ia & Ib and Group IIa and IIb. (Table 5)

Table 5. Comparison of horizontal & vertical asymmetry between groups related to TMD clinical sign

	Group Ia			**Group Ib**			
	Median	**Min.**	**Max.**	**Median**	**Min.**	**Max.**	**Sig.**
Horizontal asymmetry	4.82	2.50	9.57	5.91	3.00	14.23	NS
Vertical asymmetry	2.28	0.94	6.51	3.21	0.97	4.20	NS

	Group IIa			**Group IIb**			
	Median	**Min.**	**Max.**	**Median**	**Min.**	**Max.**	**Sig.**
Horizontal asymmetry	3.76	2.50	9.35	3.58	3.00	8.78	NS
Vertical asymmetry	1.89	0.94	3.19	2.74	0.97	6.51	NS

Min.: Minimum **Max.**: Maximum NS : not significant

♠ Key to abbreviations in Table 5
Horizontal asymmetry (mm) : menton deviation
Vertical asymmetry (°) : mandibular canting

3. Comparison between Group Ia (joint sound improved and maintained group) and Group Ib (joint sound worsened group).

A. Comparison of condylar and articular fossa dimensions.

Condylar height on the deviated side was greater in Group Ib than Group Ia. (Table 6−1)

Table 6-1. Comparison of condylar & articular fossa dimensions between Group Ia and Group Ib

Variables	Group Ia			Group Ib			
	Median	**Min.**	**Max.**	**Median**	**Min.**	**Max.**	**Sig.**
AE_dev	26.3	22.70	37.60	28.9	17.50	34.00	NS
AE_nondev	27.6	17.50	36.30	24.4	14.40	33.10	NS
AE_diff	2.7	-5.30	9.00	3.1	-3.00	10.00	NS
SFD_dev	17.6	14.50	23.40	18.5	16.30	21.30	NS
SFD_nondev	17.6	14.60	22.50	19.5	16.00	22.00	NS
SFD_diff	0.6	-3.30	3.00	-1	-1.70	1.60	NS
CFD_dev	18.8	17.90	24.20	18.4	15.80	22.40	NS
CFD_nondev	19.5	17.60	23.90	19.7	18.20	24.30	NS
CFD_diff	0	-3.10	1.80	-0.7	-5.90	2.20	NS
Con_W_dev	20.4	11.60	23.70	19	15.40	21.00	NS
Con_W_nondev	20.7	16.40	23.60	21.6	18.60	26.20	NS
Con_W_diff	-1.3	-6.60	1.80	-2.2	-10.80	-0.60	NS
Con_T_dev	8.9	7.80	10.20	9.7	8.40	10.70	NS
Con_T_nondev	9.1	7.80	10.50	9.7	7.80	10.80	NS
Con_T_diff	-0.4	-1.20	0.70	-0.1	-0.90	1.30	NS
Con_H_dev	10.2	6.80	10.90	10.8	9.20	12.40	*
Con_H_nondev	10.5	7.60	12.10	11.4	9.50	18.00	NS
Con_H_diff	-0.8	-1.40	0.90	0.5	-8.70	1.60	NS

* : $p < 0.05$

Min.: Minimum **Max.**: Maximum NS : not significant

♠ Key to abbreviations in Table 6-1

AE (º) : articular eminence **SFD** (mm) : sagittal fossa depth
CFD (mm) : coronal fossa depth **Con_W** (mm) : condylar width
Con_T (mm) : condylar thickness **Con_H** (mm) : condylar height
_dev : measurement in deviated side
_nondev : measurement in non-deviated side
_diff : difference between deviated and non-deviated side [dev – nondev]

B. Comparison of preoperative (T1) proximal segment measurements.

In the preoperative period, the coronal condylar long axis angle on the non-deviated side was greater in Group Ib than Group Ia ($p<0.01$), as was the coronal condylar long axis difference between the deviated and non-deviated side ($p<0.05$). (Table 6-2)

Table 6-2. Comparison of proximal segment measurements between Group Ia and Group Ib in Pre- Op (T1)

	Pre – Op						
Variables	**Group Ia**			**Group Ib**			
	Median	**Min.**	**Max.**	**Median**	**Min.**	**Max.**	**Sig.**
IGD	96.51	86.20	107.46	100.76	90.69	103.40	NS
RH_dev	55.75	40.91	64.72	54.75	51.26	60.66	NS
RH_nondev	55.41	50.22	67.22	59.88	55.14	61.14	NS
RH_diff	-2.21	-9.41	1.10	-4.98	-9.54	0.78	NS
HCA_dev	71.5	66.10	83.20	74	63.50	82.60	NS
HCA_nondev	78.1	63.10	86.00	76.8	69.30	87.40	NS
HCA_diff	-2.8	-14.50	11.40	-4.8	-9.70	5.70	NS
CCLA_dev	11.1	2.40	22.70	13.3	5.60	23.50	NS
CCLA_nondev	12	3.20	26.00	20.3	15.20	31.60	**
CCLA_diff	-2.8	-6.20	5.10	-8.1	-16.70	2.80	*
CCVA_dev	85.4	76.00	89.00	80.7	72.40	90.00	NS
CCVA_nondev	79.2	73.10	87.50	78	63.40	83.70	NS
CCVA_diff	2.6	-7.00	14.60	8.5	-5.00	11.80	NS
CRA_dev	72.8	52.00	82.40	73.1	62.80	78.60	NS
CRA_nondev	67.9	55.70	78.00	63.4	56.50	74.10	NS
CRA_diff	5.2	-5.20	12.00	9.9	-1.20	16.10	NS
SCA_dev	15	7.50	22.90	14.9	10.70	26.30	NS
SCA_nondev	14.6	3.10	23.80	13.9	8.50	19.00	NS
SCA_diff	-0.3	-5.50	8.60	2.2	-2.10	8.80	NS
A_B_dev	0.4	0.00	3.70	1.4	0.50	3.10	NS
A_B_nondev	1.00	0.00	2.60	1.00	0.30	2.20	NS
A_B_diff	0.00	-0.90	1.90	0.30	-1.70	2.50	NS
C_D_dev	2.00	0.00	5.00	2.20	0.00	4.00	NS
C_D_nondev	2.20	1.00	5.10	2.30	0.00	4.40	NS
C_D_diff	-0.20	-2.20	0.80	-0.20	-0.70	0.70	NS

**: $p<0.01$ * : $p < 0.05$

Min.: Minimum **Max.**: Maximum NS : not significant

♠ **Key to abbreviations in Table 6-2**

IGD(mm) : intergonial distance **RH**(mm) : ramus height **HCA** (°) : horizontal condylar angle **CCLA** (°) : coronal condylar long axis angle **CCVA** (°) : coronal condylar vertical axis angle **CRA** (°) : coronal ramus angle **SCA** (°) : sagittal condylar angle **A_B** (mm) : A-B distance(superior joint space) **C_D** (mm) : C-D distance(posterior joint space)

C. Comparison of postoperative (T2) proximal segment measurements.

In the postoperative period, the horizontal condylar angle on the deviated side was smaller than the non- deviated side ($p<0.01$), coronal condylar vertical axis angle on the deviated side was smaller in Group Ib compared to Group Ia ($p<0.05$). (Table 6-3)

Table 6-3. Comparison of proximal segment measurements between Group Ia and Group Ib in Post- Op (T2)

Variables	*Post – Op*						
	Group Ia			**Group Ib**			
	Median	**Min.**	**Max.**	**Median**	**Min.**	**Max.**	**Sig.**
IGD	94.43	84.10	106.75	97.96	90.15	101.49	NS
RH_dev	46.43	41.48	54.62	51.84	44.64	52.41	NS
RH_nondev	45.99	41.36	59.65	50.16	46.23	54.24	NS
RH_diff	-0.68	-5.03	3.73	-0.79	-2.40	3.34	NS
HCA_dev	79.9	72.40	89.70	72.5	60.50	86.80	NS
HCA_nondev	80.5	65.10	93.10	85.1	73.90	94.10	NS
HCA_diff	-0.7	-8.30	11.40	-5.8	-14.90	0.00	**
CCLA_dev	12	1.00	22.80	15.2	7.70	31.90	NS
CCLA_nondev	11.6	2.70	18.20	16.9	4.10	38.50	NS
CCLA_diff	0.7	-5.20	10.30	-3	-6.60	4.90	NS
CCVA_dev	84.5	76.40	92.50	80	67.00	94.50	*
CCVA_nondev	85.3	74.80	90.00	81.2	68.10	88.40	NS
CCVA_diff	2	-6.60	12.10	-1.7	-4.30	6.10	NS
CRA_dev	77.3	60.10	87.00	76.5	63.10	83.50	NS
CRA_nondev	74.1	61.00	85.30	73.51	61.60	81.50	NS
CRA_diff	-0.5	-9.20	13.30	1.5	-3.80	8.00	NS
SCA_dev	8.7	3.30	19.00	13.6	8.50	14.30	NS
SCA_nondev	10.6	3.00	17.80	9.4	5.10	14.00	NS
SCA_diff	-0.2	-7.30	13.80	2.4	-3.70	5.00	NS
A_B_dev	2	0.00	4.30	2.3	0.50	7.60	NS
A_B_nondev	1.50	0.00	4.20	2.40	0.50	3.50	NS
A_B_diff	0.30	-2.30	4.30	0.00	-0.50	5.10	NS
C_D_dev	3.50	1.30	5.60	3.80	0.00	7.20	NS
C_D_nondev	3.20	0.50	5.90	3.80	0.70	6.10	NS
C_D_diff	-0.20	-3.30	4.30	0.00	-0.70	2.80	NS

** : $p < 0.01$ * : $p < 0.05$

Min.: Minimum **Max.**: Maximum NS : not significant

D. Comparison of proximal segment measurement changes [△T (T2−T1)].

The horizontal condylar angle had a greater postoperative increase on the non−deviated side than on the deviated side in Group Ib compared to Group Ia ($p<0.01$). There was a tendency toward greater changes in the coronal condylar vertical axis angle on the deviated side in Group Ib, but there was no statistical significance. (Table 6−4)

Table 6-4. Comparison of proximal segment measurement changes [ΔT(T2-T1)] between Group Ia and Group Ib

Variables	Group Ia			Group Ib			
	Median	Min.	Max.	Median	Min.	Max.	Sig.
DIGD	-1.26	-6.90	5.61	-2.8	-3.87	2.19	NS
DRH_dev	-5.75	-14.77	1.93	-3.09	-8.25	-0.26	NS
DRH_nondev	-7.57	-18.01	-0.79	-9.72	-13.08	-3.64	NS
DRH_diff	1.89	-2.53	7.75	4.19	0.55	9.73	NS
DHCA_dev	6.3	0.20	18.20	2.2	-3.00	11.80	NS
DHCA_nondev	2	-1.70	10.70	6.5	1.20	17.50	NS
DHCA_diff	3.8	-4.50	17.80	-4.4	-7.80	1.50	**
DCCLA_dev	0.1	-5.20	3.90	3.1	-4.80	8.40	NS
DCCLA_nondev	-2.8	-9.80	1.20	-2.5	-11.10	6.90	NS
DCCLA_diff	3	-1.80	5.30	8.1	-3.40	13.70	NS
DCCVA_dev	0.8	-4.10	6.40	-5.4	-9.00	15.80	NS
DCCVA_nondev	3.1	-3.20	9.60	4.7	-0.90	6.80	NS
DCCVA_diff	-2.5	-9.00	3.60	-10.1	-14.30	11.10	NS
DCRA_dev	4.2	-5.30	17.10	0.2	-9.50	20.70	NS
DCRA_nondev	6.4	-4.70	15.20	5.1	0.60	19.20	NS
DCRA_diff	-2.7	-12.00	9.50	-4.8	-19.10	6.90	NS
DSCA_dev	-4.8	-14.10	0.50	-3.6	-12.70	3.60	NS
DSCA_nondev	-3.7	-12.90	1.60	-2.3	-10.40	3.40	NS
DSCA_diff	-1.2	-10.50	6.10	-1.2	-4.20	5.50	NS
DA_B_dev	0.7	-1.80	3.40	0.2	-0.90	4.80	NS
DA_B_nondev	0.30	-0.40	3.50	0.20	-0.70	2.90	NS
DA_B_diff	0.00	-3.40	3.40	-0.20	-3.00	3.00	NS
DC_D_dev	1.50	-2.70	4.50	1.20	-0.20	4.20	NS
DC_D_nondev	0.50	-1.10	4.40	0.90	-0.30	2.90	NS
DC_D_diff	0.80	-3.20	3.50	0.30	-0.70	2.20	NS

D-: ΔT(T2-T1)

** : $p < 0.01$

Min.: Minimum **Max.**: Maximum NS : not significant

4. Comparison between Group IIa (TMJ pain improved and maintained group) and Group IIb (TMJ pain worsened group).

A. Comparison of condylar & articular fossa dimensions.

Condylar thickness was greater on the non−deviated side compared to the deviated side in Group IIb. And then condylar thickness difference variable was statistically significant ($p<0.05$). (Table 7−1)

Table 7-1. Comparison of condylar & articular fossa dimensions between Group IIa and Group IIb

Variables	Group IIa			Group IIb			
	Median	Min.	Max.	Median	Min.	Max.	Sig.
AE_dev	25.5	17.00	34.90	25.6	18.20	35.90	NS
AE_nondev	25.7	14.40	36.30	25.05	17.50	31.20	NS
AE_diff	0.4	-5.30	4.40	0.25	-3.00	9.00	NS
SFD_dev	17.6	14.50	22.20	18.2	14.80	21.60	NS
SFD_nondev	17	14.60	22.20	18.1	15.10	20.50	NS
SFD_diff	0	-1.80	3.00	-0.15	-3.30	6.50	NS
CFD_dev	19.9	16.80	24.20	19.3	14.70	22.50	NS
CFD_nondev	19.5	17.30	23.90	18.6	17.40	22.90	NS
CFD_diff	0.3	-2.50	1.80	0.15	-3.10	1.70	NS
Con_W_dev	20.2	17.20	22.40	19.05	11.60	22.30	NS
Con_W_nondev	20.8	17.20	22.90	20.15	16.40	23.60	NS
Con_W_diff	-0.6	-3.60	1.80	-1.2	-6.60	0.40	NS
Con_T_dev	9.6	6.80	11.20	9.1	7.80	10.20	NS
Con_T_nondev	9	6.70	11.60	9.4	7.80	11.00	NS
Con_T_diff	0.3	-0.70	1.30	-0.25	-1.20	0.60	*
Con_H_dev	10.2	7.20	12.40	10.5	6.80	12.50	NS
Con_H_nondev	10.5	6.80	11.60	10.6	7.70	12.50	NS
Con_H_diff	-0.3	-1.40	1.40	-0.4	-1.80	2.80	NS

* : $p < 0.05$

Min.: Minimum **Max.**: Maximum NS : not significant

B. Comparison of preoperative (T1) proximal segment measurements.

There were no statistically significant differences in measurements between Group IIa and IIb in any of the preoperative measurements. (Table 7−2)

Table 7-2. Comparison of proximal segment measurements between Group IIa and Group IIb in Pre- Op (T1)

	Pre – Op						
Variables	**Group IIa**			**Group IIb**			
	Median	**Min.**	**Max.**	**Median**	**Min.**	**Max.**	**Sig.**
IGD	96.51	92.98	103.40	94.47	89.87	105.47	NS
RH_dev	53.32	49.00	57.91	57.27	40.91	61.73	NS
RH_nondev	55.2	47.79	57.89	55.79	49.34	62.10	NS
RH_diff	-0.04	-3.85	4.97	-1.63	-9.41	4.40	NS
HCA_dev	77	67.00	87.00	73.5	66.10	84.70	NS
HCA_nondev	80.1	63.10	86.00	77.25	70.60	86.00	NS
HCA_diff	-0.8	-14.50	11.40	-2.8	-12.60	2.60	NS
CCLA_dev	16	5.80	20.00	16.35	2.40	22.10	NS
CCLA_nondev	15.2	8.70	26.00	16.5	3.20	24.30	NS
CCLA_diff	-1.6	-6.20	3.80	-1.45	-9.60	6.30	NS
CCVA_dev	83.3	76.00	86.50	84.25	76.90	90.00	NS
CCVA_nondev	81.1	73.70	89.60	79	73.60	86.40	NS
CCVA_diff	2.1	-7.00	9.80	3.7	-1.70	14.60	NS
CRA_dev	71.7	52.00	84.10	70.85	66.20	76.90	NS
CRA_nondev	67.4	55.70	77.10	66.1	57.70	77.70	NS
CRA_diff	3.9	-3.70	14.00	4.9	-4.90	11.70	NS
SCA_dev	17.1	10.80	26.30	15.9	7.50	21.10	NS
SCA_nondev	17.2	8.90	22.00	16.85	7.50	22.20	NS
SCA_diff	-0.3	-2.00	8.60	0.2	-6.60	5.00	NS
A_B_dev	0.5	0.30	2.90	0.65	0.00	3.70	NS
A_B_nondev	0.90	0.30	1.90	0.85	0.00	2.60	NS
A_B_diff	-0.10	-1.10	1.90	0.00	-1.70	1.10	NS
C_D_dev	2.00	0.00	4.00	1.70	0.00	5.00	NS
C_D_nondev	2.10	0.00	4.20	1.60	0.20	5.10	NS
C_D_diff	-0.30	-1.60	0.50	-0.20	-0.70	1.10	NS

* : $p < 0.05$

Min.: Minimum **Max.**: Maximum NS : not significant

C. Comparison of postoperative (T2) proximal segment measurements.

Postoperatively, the horizontal condylar angle was smaller on the deviated side than the non−deviated side in Group IIb compared to Group IIa and then horizontal condylar angle difference variable was statistically significant ($p<0.05$). the A−B distance (superior joint space) on the deviated side was smaller in Group IIb compared to Group IIa ($p<0.05$). (Table 7−3)

Table 7-3. Comparison of proximal segment measurements between Group IIa and Group IIb in Post- Op (T2)

	Post - Op						
Variables	**Group IIa**			**Group IIb**			
	Median	**Min.**	**Max.**	**Median**	**Min.**	**Max.**	**Sig.**
IGD	94.43	88.61	99.60	91.875	88.13	110.27	NS
RH_dev	46.43	38.56	53.88	48.045	42.09	52.85	NS
RH_nondev	45.95	38.25	54.60	47.695	41.36	54.37	NS
RH_diff	-0.11	-2.40	3.73	0.075	-2.04	2.25	NS
HCA_dev	84.1	76.50	91.00	80.6	72.40	87.50	NS
HCA_nondev	85.6	65.10	90.00	83.4	73.10	93.10	NS
HCA_diff	0	-11.20	11.40	-3.8	-8.30	1.00	*
CCLA_dev	12	1.00	20.80	10.4	1.50	29.80	NS
CCLA_nondev	16.2	5.70	17.80	11.4	2.70	18.70	NS
CCLA_diff	-2.8	-11.50	9.10	0.5	-5.00	11.10	NS
CCVA_dev	87.45	76.40	94.50	83.45	69.20	91.50	NS
CCVA_nondev	86.5	74.80	90.00	85.7	70.30	89.00	NS
CCVA_diff	1.6	-6.60	9.40	1.05	-13.90	12.10	NS
CRA_dev	76	66.80	83.50	78	63.30	87.00	NS
CRA_nondev	78.5	61.00	83.50	74.2	56.30	85.30	NS
CRA_diff	-0.5	-8.60	8.00	1.4	-3.00	14.80	NS
SCA_dev	11.3	3.30	19.00	7.4	1.00	15.70	NS
SCA_nondev	10.5	5.20	14.80	11.4	2.00	17.70	NS
SCA_diff	0	-7.20	13.80	-2.9	-6.80	3.10	NS
A_B_dev	2.2	0.50	3.10	1.3	0.00	2.30	*
A_B_nondev	1.50	0.50	4.00	1.00	0.00	4.20	NS
A_B_diff	0.20	-1.00	1.50	0.00	-2.30	0.90	NS
C_D_dev	3.80	0.00	5.00	2.65	0.60	5.30	NS
C_D_nondev	3.70	0.50	5.80	3.40	1.00	5.60	NS
C_D_diff	-0.20	-2.00	2.50	-0.30	-3.30	2.00	NS

* : $p < 0.05$

Min.: Minimum **Max.**: Maximum NS : not significant

D. Comparison of proximal segment measurement changes [△T(T2−T1)] .

There was a tendency toward less changes in A−B distance (superior joint space) on the deviated side in Group IIb compared to Group IIa, however, there was no statistical significance. (Table 7−4)

Table 7-4. Comparison of proximal segment measurement changes [∆T (T2-T1)] between Group IIa and Group IIb

Variables	Group IIa			Group IIb			
	Median	Min.	Max.	Median	Min.	Max.	Sig.
DIGD	-3.8	-6.90	1.99	0.05	-5.52	5.61	NS
DRH_dev	-5.75	-14.27	-2.16	-8.34	-14.77	1.93	NS
DRH_nondev	-6.95	-16.16	-0.79	-8.22	-18.01	-3.33	NS
DRH_diff	0.55	-4.91	4.49	1.4	-6.44	7.75	NS
DHCA_dev	6.6	0.20	18.20	4.95	-1.50	14.70	NS
DHCA_nondev	3.3	-1.10	17.50	5.8	-1.00	10.80	NS
DHCA_diff	-0.5	-5.70	14.90	-2.4	-4.00	4.30	NS
DCCLA_dev	-1.3	-11.10	3.90	-0.85	-12.30	7.70	NS
DCCLA_nondev	-1.2	-9.80	4.80	-4.3	-11.10	-0.50	NS
DCCLA_diff	1.2	-9.90	6.50	4.15	-11.30	13.20	NS
DCCVA_dev	2.5	-2.70	15.80	0.65	-12.00	9.00	NS
DCCVA_nondev	3.1	-3.20	11.60	4.45	-4.90	8.80	NS
DCCVA_diff	0.4	-7.80	11.10	-3.15	-16.80	5.40	NS
DCRA_dev	4.2	-7.60	20.70	6.25	-4.20	17.10	NS
DCRA_nondev	9.2	1.20	21.40	8.8	-5.40	15.20	NS
DCRA_diff	-6.9	-14.50	9.50	-0.65	-7.50	9.70	NS
DSCA_dev	-4.1	-14.10	0.50	-6.5	-14.60	3.60	NS
DSCA_nondev	-5.6	-12.90	1.60	-4.8	-14.50	3.40	NS
DSCA_diff	0.3	-10.50	6.10	0.05	-7.10	0.90	NS
DA_B_dev	1	-0.30	2.70	0.3	-1.80	2.20	NS
DA_B_nondev	0.60	-0.40	3.50	0.10	-0.80	1.60	NS
DA_B_diff	0.00	-0.80	1.40	0.20	-3.40	2.40	NS
DC_D_dev	1.90	-0.20	3.00	1.05	-2.70	3.10	NS
DC_D_nondev	1.20	-0.60	4.40	1.15	-0.70	2.50	NS
DC_D_diff	0.70	-1.80	2.80	-0.55	-3.20	1.40	NS

D-: ∆T(T2-T1)

Min.: Minimum **Max.**: Maximum NS : not significant

IV. Discussion

The use of CT in orthodontics and oral and maxillofacial surgery has allowed improved diagnostic accuracy as well as assessment of treatment outcome, thus improving the quality of care. The goals of orthognathic surgery in facial asymmetry patients are to restore structure, esthetics, and function. In addition to occlusion and facial esthetics, restoring normal TMJ function is an important factor in achieving good treatment outcome and stability.

Three-dimensional computed tomography (3D CT) allows examination of complex skeletal structures in serial cuts, allowing accurate and reproducible measurements and evaluation without superimposition (Bontrager, 2005), and is proper tool for evaluating small and complex structures such as the TMJ. The present study used 3D CT to compare pre- and post-operative changes in mandibular asymmetry, condylar and articular fossa dimensions, and mandibular proximal segment position in two groups of patients who had undergone IVRO with LeFort I osteotomy for Class III skeletal malocclusion with asymmetry, who had preoperative TMJ sound and/or pain. The groups included patients whose symptoms improved or were unchanged, and those whose symptoms worsened. The purpose of this investigation is to identify skeletal differences in different TMD prognosis group after IVRO.

Although studies investigating the relationship between TMD signs and symptoms and condyle-articular fossa relationship generally report improvement (Ueki et al., 2002, 2012), not all subjects had improvement, and some studies even report aggravation in a significant portion of the study sample (Kerstens et al., 1989; White et al., 1992). These studies lack detailed analysis of specific skeletal differences associated with TMD signs, and therefore do not adequately correlate the various pre- and postoperative structural changes to changes in TMD signs. Magnetic resonance imaging (MRI) is usually used to evaluate changes in disc position in studies investigating objective changes in the TMJ (Ueki et al., 2000, 2002, 2012; Kim et al., 2009). However, despite some association between disc position and TMD signs and symptoms, no definite correlation between the two exists. Several studies found no TMD symptoms even with the presence of anterior disc displacement on MRI (Kirkos et al., 1987; Takaku et al., 1995; Katzberg et al., 1996), and Boering attributed this to accuracy of physical examination, patient cooperation, posterior ligament functioning as a pseudodisc, and remission phase during progression to osteoarthritis (Boering G., 1996).

This study aimed to identify the relationship between TMD signs and several variables such as structures less changed by surgery including the condyle and articular fossa, as well as changes in the mandibular proximal segment.

Although mandibular dysfunction (open or closed lock) is another major symptom of TMD, when unresolved, it is generally regarded as a contraindication to combined surgical and orthodontic treatment. This, in addition to the lack of available cases, led the authors to exclude mandibular dysfunction as a group distinguishing factor. Another distinguishing factor – muscle tenderness to palpation – was evaluated but excluded, because there were no subjects with mild or greater pain after surgery.

Because skeletal asymmetry is believed to be a cause of TMD, the degree of horizontal and vertical asymmetry was compared. Buranastidporn et al. reported that mandibular canting is more closely associated with TMD symptoms than menton deviation (Buranastidporn et al., 2006), and given that facial asymmetry is a complex combination of horizontal and vertical dimensions and angles, it is deemed critical to evaluate both horizontal and vertical asymmetry in the TMD patient. Antegonial notching, a structure commonly used in frontal two-dimensional imaging to evaluate mandibular canting, generally does not reflect the location of the actual gonion. Because of this inaccuracy, the present study used software to 3-dimensionally reconstruct the mandible and designated the gonion as the intersection between the inferior and posterior borders, and measured the angle between a line connecting the bilateral gonion and the midsagittal plane to measure mandibular canting. To evaluate the effect of preoperative degree of asymmetry on TMD symptoms, the horizontal and vertical asymmetry of each group was compared and analyzed, and no statistically significant differences were found, suggesting that the degree of preoperative asymmetry was not associated with postoperative TMJ sound and pain. This indicates that the amount of IVRO setback on the non-deviated side, which is proportial to the degree of asymmetry, does not affect TMJ sound and pain.

The present study measured structures that are less changed by surgery yet can influence TMD signs, namely the condyle and articular fossa. These were analyzed because if objective measures of improvement of asymmetry after IVRO were within a certain range, the changes in the original dimensions of the fossa and condyle could be attributed to postoperative TMD sign changes.

The articular eminence is defined as the angle between a horizontal reference plane (FH plane, occlusal plane, palatal plane) and the posterior wall of the articular eminence (Katsavrias et al., 2002), and the FH plane was used in this study as the horizontal reference plane. Articular eminence is known as a contributing factor to TMJ internal derangement (Ozkan et al., 2012), and large angles of greater than 60° (normal range 30-60°) have been associated with a higher incidence of TMD (Isberg et al., 1998; SHahidi et al., 2013). In this study, the articular eminence angle varied from 15.1° to 34.9°, generally in the 25-30° range.

Coronal fossa dimensions were measured from the sagittal slice corresponding to superiormost point of the fossa on the coronal view. Sagittal fossa dimensions were measured from the coronal slice corresponding to superiormost point of the fossa on the sagittal view. Rodrigues et al. argued that simple anteroposterior sagittal measurements of the articular fossa space is inadequate for evaluating condylar position, and that three-dimensional measurements in all planes of space is crucial in accurately assessing asymmetry (Rodrigues et al., 2009).

In addition, condyle width and height, as well as condyle thickness were measured in the coronal and axial views, respectively. Yáñez-Vico et al. reported asymmetries in the condylar height, width, and thickness in TMD patients compared to asymptomatic controls, and that condyle height tended to be shorter in the TMD group (Yáñez-Vico et al., 2011). Based on this data, the authors viewed that different outcomes in TMD symptoms in patients who had undergone the same IVRO procedure could be attributed to asymmetry of the condyles, hence the addition of these variables.

In a study investigating changes of the mandibular proximal segment 1 and 4 years after IVRO in skeletal Class III patients with asymmetry, Han et al. reported outward rotation of the condyles, medial displacement and setback of the proximal segment tip on the deviated side, and anterior-inferior movement of the condyles seen in the one year postoperative period (Han et al., 2012). In this study, mandibular proximal segment measurements of each group were compared and analyzed at the preoperative (T1) and one year postoperative (T2) periods, and the pre- and post-operative changes [△T(T2-T1)]were analyzed as well. Each variable from the deviated side was subtracted by that from the non-deviated side (_diff variable), and this was regarded as an important factor as it could affect the degree of asymmetry and TMD symptoms.

Groups according to joint sound change. Anterior disc displacement is thought to be the cause of TMJ clicking (Liu et al., 2013), and all subjects in this study exhibited TMJ clicking, but none had crepitus with concomitant arthritis. Condylar height was greater in Group Ib (worsened group) than Group Ia (improved/maintained group). In comparing preoperative measurements, Group Ib (worsened group) had a greater coronal condylar long axis angle on the non−deviated side ($p<0.01$), as well as a greater discrepancy in this angle between each the deviated and non−deviated side ($p<0.05$) than Group Ia (improved/maintained group). This indicates that in the group which had worsened TMJ sound, preoperatively the non−deviated condyle was more laterally rotated from a frontal view. A comparison of postoperative measurements showed a smaller horizontal condylar angle on the deviated side, with a large resultant discrepancy between each side ($p<0.01$) in Group Ib (worsened group) than Group Ia (improved/maintained group), as well as a smaller coronal condylar vertical axis angle ($p<0.05$). Postoperative changes of the horizontal condylar angle were greater in the non−deviated side than the deviated side in Group Ib (worsened group) compared to Group Ia (improved/maintained group), reaching statistical significance ($p<0.01$). Although changes in the coronal condylar vertical axis angle tended to be greater on the deviated side, there was no statistically significant difference.

The coronal condylar vertical axis angle was larger postoperatively on the deviated side with a small postoperative change in the TMJ sound improved/maintained group, whereas in the TMJ sound worsened group, this angle was small postoperatively with a large postoperative change. The condyle was more upright within the articular fossa with little movement in the improved/maintained group, and in the worsened group, changes in the vertical axis angle would have likely allowed greater lateral movement.

However, further research involving measuring the lateral joint space from a coronal view with statistically significant changes, will be necessary to support this.

The significantly larger postoperative horizontal condylar angle difference between each sides in the TMJ sound worsened group, suggested that even with improved symmetry of the mandible after surgery, there may be significant residual asymmetry from horizontal rotation of the condyles. In a study utilizing MRI to assess the horizontal axis angle of the condyle, Westesson et al. reported that greater inward rotation was associated with disc displacement and degenerative joint disease. They attributed this to either the inward rotation itself or due to bone remodeling process. They hypothesized that inward rotation of the condyle stretches the lateral attachment of the disc, and that further stretching with mouth opening and lateral excursion causes alteration of the joint apparatus (Westesson et al., 1991). Sanroman et al. also found that a larger condylar angle, namely more inward horizontal rotation of condyle, can be an etiologic factor in disc displacement and degenerative joint disease (Sanroman et al., 1997). In the present study, the condyle on the deviated side showed more inward rotation preoperatively, and the limited outward rotation of the deviated condyle in the worsened group may explain the worsening of TMJ sound. Choi et al. studied the remodeling pattern of the mandible after IVRO, and found that the horizontal condylar angle immediately increased 15.05° laterally after surgery, and on average 4.46° one year after surgery, demonstrating lateral rotation with a tendency to decrease with time (Choi et al., 2013). Changes in the horizontal condylar angle have been reported in other studies, up to 4 years postoperatively by Han, et al (Han et al., 2012). In this study, the horizontal condylar angle difference between the deviated and non-deviated side one year after IVRO was 0.7° in the improved/maintained group, whereas it was -

5.8 ° in the worsened group. This shows a postoperative decrease in the improved/maintained group and an increase in the worsened group, suggesting that discrepancies in the degree of horizontal condylar rotation after correction of mandibular asymmetry may have directly or indirectly impacted TMJ sound change. However, because the position of the proximal segment and the condyle change for longer than one year, long-term studies will be needed for a clearer understanding.

Groups according to TMJ pain change. Condylar thickness was greater on the non-deviated side compared to the deviated side in Group IIb (worsened group). And then condylar thickness difference variable was statistically significant ($p<0.05$). Because TMJ pain is anatomically caused by stress and compression of the ligament, muscles, and the neurovascular system from rotation and nonconcentric position of the condyle along with progressive anterior displacement of the articular disc (Katzberg et al., 1983; Sanroman et al., 1997; Liu et al., 2013), a thicker condyle on the non-deviated side – which typically undergoes greater setback in asymmetry patients – can lead to greater compression & distortion of the joint tissues. However, because the difference in condylar thickness was within 1-2 mm in the raw data, and because the average sagittal fossa depth was 18-20 mm, the effect of condylar thickness on TMJ pain is likely minimal.

There were no statistically significant differences in any of the preoperative measurements between Group IIa (improved/maintained group) and Group IIb (worsened group). Postoperatively, the horizontal condylar angle was smaller on the deviated side than the non-deviated side ($p<0.05$), the A-B distance (superior joint space) on the deviated side was smaller in Group IIb (worsened group) compared to Group IIa (improved/maintained group). The A-B distance (superior joint space) had a smaller postoperative increase in Group IIb (worsened group) compared to Group IIa (improved/maintained group), although the difference was not statistically significant. As in joint sound, the worsening TMJ pain may be attributed to insufficient condylar outward rotation on the deviated side, resulting in a large discrepancy in horizontal condylar angle between the deviated and non-deviated side.

Many studies have shown that unlike SSRO, IVRO causes an anterior-inferior movement of the condyle, and is therefore more effective for decreasing TMD symptoms (Egyedi et al., 1981; Bell et al., 1990, 1991; Boyd et al., 1991; Ueki et al., 2007). The smaller increase in superior joint space observed in the worsened group can be attributed to worsened TMD symptoms. In a study investigating TMD symptoms after IVRO, Jung et al. noted TMJ sound and pain in 3.23% and 1.15% of subjects, respectively, one month post operation. They observed minimal recurrence for two years after surgery, and attributed the superior effects to unloading of the TMJ during intermaxillary fixation as well as the condylotomy effect from anteroinferior movement of the condyle after surgery (Jung et al., 2009). Although differences in the increase in superior joint space did not reach statistical significance in this study, there tended to be a greater increase in the improved/maintained group for TMJ pain. Sufficient inferior movement of the condyle after IVRO appears to be a factor affecting TMJ pain alleviation.

There were no statistically significant differences in coronal and sagittal fossa dimensions as well as articular eminence in all subjects. Also, the amount of condylar asymmetry was less than expected. This is likely because this study was limited to skeletal Class III patients without progressive TMD. The authors believe that different outcomes may be seen in patients with severe signs and symptoms of TMD such as limited mandibular function, or pr ogressive arthritis.

Table 8. The rate of joint sound & TMJ pain change in Class III asymmetry in this study.

	Number of patients		Rate of improvement& maintenance(%)	Rate of worsening(%)
Pre & Post-op TMD examination	**56**	**Joint sound**	87.5 (49 / 56)	12.5 (7 / 56)
		TMJ pain	78.6 (44/ 56)	21.4 (12 / 56)
Subjects used in this study	**29**	**Joint sound**	75.9 (22 / 29)	24.1 (7 / 29)
		TMJ pain	65.5 (19 / 29)	34.5 (10 / 29)

There are several limitations in this study. First, although there was a remarkably high number of patients with improved TMD symptoms after IVRO, many patients with alleviated TMD symptoms failed to follow up with TMJ clinical examinations. Among 56 patients who had pre- and post-operative TMJ clinical examinations, improved/maintained subjects noticeably had lacking postoperative CT compared to worsened subjects. The lower rate of improvement of TMD in this study compared to others can be attributed to insufficient follow-up data in the improved/maintained group. However, the improvement rate of this study in 56 Class III asymmetry subjects without post-operative 3D CT were similar to previous studies on the relationship between mandibular proximal segment change and TMD signs & symptoms (Kerstens et al., 1989; White et al., 1992; Hu et al, 2000; Ueki et al., 2002, 2012) (Table 8). Also, TMJ clinical examinations were not performed by a single examiner, and the laterality of symptoms was not specified. Additionally, because the condyle-articular fossa relationship undergoes constant change past the one year postoperative period (Han et al., 2012; Choi et al., 2013), a larger, longer-term prospective study will give a clearer understanding of postoperative TMD sign and symptom changes after IVRO.

V. Conclusion

The purpose of the present study was to compare pre- and post-operative changes in TMJ sounds and pain using 3D CT in patients who had undergone orthognathic surgery (LeFort I osteotomy and IVRO) for correction of skeletal Class III malocclusion with facial asymmetry, and to identify skeletal differences (specifically those related to the mandibular proximal segment), associated with these symptoms. The following results were observed:

1. No statistically significant differences were noted in horizontal and vertical asymmetry between either group for TMJ sound and pain.

2. Preoperatively (T1), the coronal condylar long axis angle on the non-deviated side was greater in Group Ib (joint sound worsened group) than Group Ia (joint sound improved/maintained group) ($p<0.01$). There was also a greater difference in coronal condylar long axis angle between each side in Group Ib ($p<0.05$).

3. Postoperatively (T2), the horizontal condylar angle was noted to be smaller on the deviated side than the non-deviated side in Group Ib compared to Group Ia ($p<0.01$). Also, the coronal condylar vertical axis angle was smaller in Group Ib ($p<0.05$).

4. There was a greater increase in horizontal condylar angle on the non-deviated side than the deviated side in Group Ib compared to Group Ia when pre- and postoperative changes [$\triangle T(T2-T1)$]were compared ($p<0.01$).

5. In the postoperative period (T2), Group IIb (TMJ pain worsened group) had a smaller horizontal condylar angle on the deviated side compared to the non-deviated side ($p<0.05$), and a smaller A-B distance (superior joint space) compared to Group IIa (TMJ pain improved/maintained group) ($p< 0.05$).

The results of this study indicate that in skeletal Class III patients with asymmetry corrected with IVRO, a smaller postoperative horizontal condylar angle on the deviated side and less inferior movement of the deviated condyle are associated with worse TMJ sound and pain.

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국문요약

비대칭을 동반한 골격성 제III급 악교정 수술전후의 하악 근심 골편의 삼차원적 위치 변화와 측두하악장애의 관계

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서 승 아

이번 연구의 목적은 안면 비대칭을 동반한 골격성 III급 환자에서 악교정 수술(LeFort I + IVRO) 전후에 측두하악장애의 주 증상인 관절음(joint sound)과 통증(TMJ pain)이 완화, 유지된 군과 악화된 군의 비교를 통해 두군간의 골격적 차이점을 알아보는 것이었다.

29명의 안면 비대칭을 동반한 골격성 III급 환자를 술전(T1), 술후 1년(T2)에 각각 3차원 CT를 촬영하여 3차원 입체영상을 획득하고 계측하였으며, 수술후 악관절음이 완화, 유지된 군을 Group Ia, 악관절음이 악화된 군을 Group Ib로, 악관절 통증이 완화, 유지된 군을 Group IIa, 악관절 통증이 악화된 군을 Group IIb로 재분류하고 1) 수평적, 수직적 비대칭 정도 2)과두, 측두와 형태 3) 술전(T1) 하악근심골편 계측치 4)술후(T2) 하악근심골편 계측치 5) 수술전후 하악근심골편 변화량[△T(T2−T1)]을 비교, 분석한 결과 다음과 같은 결과를 얻었다.

1. Group Ia (악관절음 완화, 유지군)과 Group Ib(악관절음 악화군), Group IIa (악관절통증 완화, 유지군)과 Group IIb(악관절통증 악화군)간에 통계적으로 유의한 수평적, 수직적 비대칭의 차이는 없었다.

2. 술전(T1)에 Group Ib에서 Group Ia에 비하여 비편위측 coronal condylar long axis angle이 크고($p<0.01$), 편위-비편위측 coronal condylar long axis angle 차이값이 더 컸다 ($p<0.05$).

3. 술후(T2)에 Group Ib에서 Group Ia에 비해 편위측 horizontal condylar angle이 비편위측 보다 작고 ($p<0.01$), 편위측 coronal condylar vertical axis angle이 더 작았다 ($p<0.05$).

4. 술전, 술후 변화량[ΔT(T2-T1)] 비교에서 Group Ib에서 Group Ia에 비해 편위측 보다 비편위측 horizontal condylar angle이 더 증가하였다 ($p<0.01$).

5. 술후(T2)에 Group IIb에서 Group IIa에 비해 편위측 horizontal condylar angle이 비편위측 보다 작고($p<0.05$), 편위측 A-B distance(superior joint space)가 더 작았다 ($p<0.05$).

이상의 연구 결과, IVRO 수술 이후 비대칭이 개선된 골격성 III급 환자에서, 수술 후에 비편위측에 비해 편위측의 horizontal condylar angle이 더 작고, 편위측 과두의 하방이동이 적은 환자군이 그렇지 않은 환자군에서 보다 악관절음과 악관절 통증이 악화됨을 관찰 할 수 있었다.

핵심이 되는 말: 측두하악장애, IVRO, 근심 골편, 골격성 III급, 비대칭, 3D CT