Mandibular superior joint space and TMJ symptoms After intraoral vertical ramus osteotomy (IVRO)

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Mandibular superior joint space and TMJ symptoms After intraoral vertical ramus osteotomy (IVRO)

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감사의 글

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늘 딸이 잘되길 응원해 주시고 학위과정 잘 마칠 수 있게 물심양면 뒷바라지해 주신 저의 큰 버팀목인 아버님, 어머님 그리고 늘 따뜻하게 품어주신 오빠께 모두 감사의 뜻을 표하여, 무엇보다도 가장 가까이서 여자 친구의 길을 응원하고 도와준 사랑하는 나의 남친에게도 한없는 사랑과 고마움을 전합니다.

마지막으로 연세대학교 대학원에서 배움의 기회를 주신 GKS 와 이 기쁨을 나누고 싶습니다. 두서없이 적었지만, 이 모든 과정에서 힘이 되고 응원해 주신 모든 분께 다시 한번 감사를 전합니다.

2024 년 12 월
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ABSTRACT

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This study investigates the three-dimensional changes in superior joint space (SJS) and temporomandibular joint (TMJ) symptoms following intraoral vertical ramus osteotomy (IVRO), a widely used orthognathic procedure for mandibular prognathism. The research retrospectively analyzed patients who underwent IVRO with LeFort I osteotomy at Yonsei University from 2014 to 2022. Computed tomography (CT)-based 3D models were employed to evaluate changes at three time points: pre-surgery (T0), one month post-surgery (T1), and one year post-surgery (T2).

The findings revealed a significant increase in SJS immediately post-surgery, which partially reverted one year later but did not return to preoperative values. TMJ noise and pain improved markedly within a year post-surgery, highlighting the effectiveness of IVRO in alleviating TMJ disorders. However, no significant correlations were observed between SJS changes and proximal segment dimensions or the amount of mandibular setback, suggesting other factors may influence these outcomes.

These results underscore the need for further investigation into the mechanisms driving postoperative SJS alterations and their impact on TMJ function. The study provides valuable insights into the dynamics of TMJ mechanics and long-term stability following IVRO.

Keywords: Intraoral vertical ramus osteotomy (IVRO), Superior joint space (SJS), Temporomandibular joint (TMJ).

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I. INTRODUCTION

Patients with facial deformities require the ability to lead a normal life, making the restoration of both aesthetic appearance and normal masticatory function essential. The mandible plays a crucial role in facial aesthetics, particularly in orthognathic surgery, as it forms a significant part of the lower third of the face. Additionally, the mandible is fundamental to various oral functions, including mastication and speech articulation.

Intraoral vertical ramus osteotomy (IVRO) and sagittal split ramus osteotomy (SSRO) are two frequently conducted orthognathic procedures designed to address skeletal irregularities, particularly in the treatment of mandibular prognathism. [1] SSRO remains a widely employed and highly effective technique for correcting jaw deformities. However, its proximity to the inferior alveolar nerve increases the potential for nerve damage, which can result in temporary or permanent sensory deficits.[2]

IVRO is a treatment option for specific temporomandibular joint disorders (TMDs). It effectively relieves TMD symptoms and offers advantages such as being technically straightforward [3], aiding in condyle repositioning [4], and a reduced risk of damaging the inferior alveolar nerve[5]. On the other hand, IVRO has several disadvantages, including a longer recovery period due to the need for intermaxillary fixation [6], less precise control over jaw positioning, a higher risk of condylar sagging [7] and temporomandibular joint dysfunction, limited compared to (SSRO). IVRO lacks internal fixation of bony segments, resulting in variable condylar displacement, which affects both facial aesthetics and long-term surgical stability.

The most critical concern for the surgeon is the challenge of accurately predicting the extent of condylar sag that may develop after (IVRO). In fact, there have been reports of severe cases of condylar luxation occurring unexpectedly following this procedure. [7-9]

Several methods have been suggested to prevent this complication. [10] reported that modifying the shape of the oblique osteotomy line can help prevent condylar luxation. [11] described the implementation of an overcorrected occlusal splint as a method to prevent condylar displacement. However, the best approach for addressing condylar sag once it has occurred remains uncertain.

Condylar sag contributes to the improvement of temporomandibular joint (TMJ) symptoms, which are expected to diminish further over time. [12] As condylar luxation is believed to occur progressively during condylar sag, we examined the circumstances under which condylar sag is most likely to happen.

During surgery, the periosteum in specific areas of the mandibular ramus is elevated, causing the mesial bone fragment to shift anteriorly and downward after detachment from surrounding tissues. This fragment, including the mandibular condyle, gradually returns to its original position during recovery, aided by functional physical therapy. [13]

A recent study using computed tomography (CT) data showed that the position and angle of the mandibular condyle, which is displaced immediately after surgery, gradually improved over a six-month period but did not completely return to its pre-surgical condition. Condylar sagging alters the TMJ space, significantly impacting postoperative stability and contributing to TMJ disorder symptoms after IVRO. Thus, it is essential to explore the factors that affect condylar positioning and joint spaces in IVRO patients, although data on the causes of uneven condylar segment movement is limited.

This study utilized CT imaging to evaluate superior joint space during IVRO treatment for skeletal Class III deformities. It analyzed the influence of anterior-posterior length, proximal segment width, and surgical setback on variations in the superior joint space (SJS). Additionally, the research explored the relationship between SJS changes, mouth opening, and TMJ characteristics, focusing on whether TMJ symptoms improved after postoperative SJS expansion and subsequent return to the preoperative position.

Hypothesis development

Condylar sag, a potential complication following IVRO surgery, was hypothesized to be associated with bone thickness, proximal segment length, and the extent of recession. Additionally, it was hypothesized that there would be differences in the SPS and maximum mouth opening between the TMJ symptomatic and asymptomatic groups.

- The superior joint space following IVRO surgery will be greater in individuals with TMJ symptoms compared to those without.
- If the proximal segment A-P becomes longer, condylar deflection may occur more.
- Width of proximal segment -> thicker may cause condylar sagging more
- The smaller the setback, the more excessive sagging occurs [14]

II. MATERIALS AND METHODS

2.1 Patients & grouping

This retrospective, patient-centered study, patients who were diagnosed with mandibular prognathism Class III malocclusion (ANB<0) and underwent BIVRO (bilateral intraoral vertical ramus osteotomy) with a LeFort I osteotomy at Yonsei University Oral and Maxillofacial Surgery from January 2014 to December 2022 were sequentially selected and examined before (T0) and after surgery. The subjects were 1 month after (T1) surgery and 1 year after (T2) orthognathic surgery.

Exclusion criteria: The Surgery-First Approach (SFA) in orthognathic surgery, severe asymmery (Menton deviation > 4mm), irregular condylar shape &size , previous operation history (Orthognathic surgery, TMJ surgery), patients with missing patient information and treatment records, patients with too low resolution of the temporomandibular joint in 3D images at time points T0, T1 and T2. Congenital deformities, cleft lip and palate, systemic diseases. History of facial injury and fractures and orthognathic surgery. This study received approval from the institutional Research Ethics Committee of Yonsei University College of Dentistry (IRB No.2-2022-0032).

2.2 Surgical method, orthodontic treatment and postoperative management

All patients underwent pre and postoperative orthodontic treatment and with maxillary LeFort I osteotomy and bilateral IVRO for mandibular setback. Internal fixation was used to stabilize the maxilla.

The intraoral vertical ramus osteotomy (IVRO) was conducted under general anesthesia, with an incision made along the anterior border of the ramus. To enhance visualization of the ante-lingular prominence and to mitigate the risk of bleeding from the internal maxillary artery, a pair of Bauer retractors were positioned in the sigmoid and antegonial notches. A subcondylar osteotomy was executed using an oscillating saw. The distal segment was then shifted distally and repositioned medially relative to the proximal segments. In all cases, the medial pterygoid muscle was nearly detached from the proximal segment following the IVRO. The distal fragment of the mandible was placed in the intended postoperative position and stabilized with rigid maxillomandibular fixation (MMF) and a splint anchored in the maxillary dental arch. Rigid interosseous fixation was not utilized in any of the patients

Intermaxillary fixation was maintained for about 2 weeks. After this period of IMF guiding elastics were used for at least 1 months for occlusal stabilization.

2.3 Data acquisition

All patients underwent T0, T1 and T2 CT images. Three-dimensional CT data were imported as Digital Imaging and Communication in Medicine (DICOM) files and reconstructed in to 3D models using Mimics 10.01(Materialise, Leuven, Belgium).

2.4 3D model creation and Reference setting

To ensure precise evaluation of the condyle and joint spaces, the mandible was separated from the skull and saved as an individual structure using the Mimics 10.01 program. Subsequently, the reconstructed 3D model was imported into Rapidform 2006 (Inus Technology, Seoul, Korea) for reorientation and measurement purposes.

The axial, sagittal, and coronal reference planes (ARP, SRP, and CRP, respectively) were aligned, and the 3D model was reoriented with the ARP positioned parallel to the ground. The ARP was defined as the plane passing through both porions and the left orbitale, while the SRP was identified as the midsagittal plane perpendicular to the ARP, passing through the nasion and basion. The CRP was described as the plane orthogonal to both the ARP and SRP, intersecting the basion. The three-dimensional position of each landmark is defined using coordinates (x, y, z), with the horizontal plane serving as the X-axis, the coronal plane as the Y-axis, and the midsagittal plane as the Z-axis. Positive values indicate upward, backward, and leftward directions from the origin, while negative values represent forward, downward, and rightward directions. Using these coordinates, a spatial framework based on the preoperative 3D CBCT was established, and the positions of each measurement point were recorded at three time points: T0, T1 and T2 (Figure 1).

For the measurements, we identified two landmarks on the condylar segment and five landmarks on the proximal segment, as outlined in (Table 1).

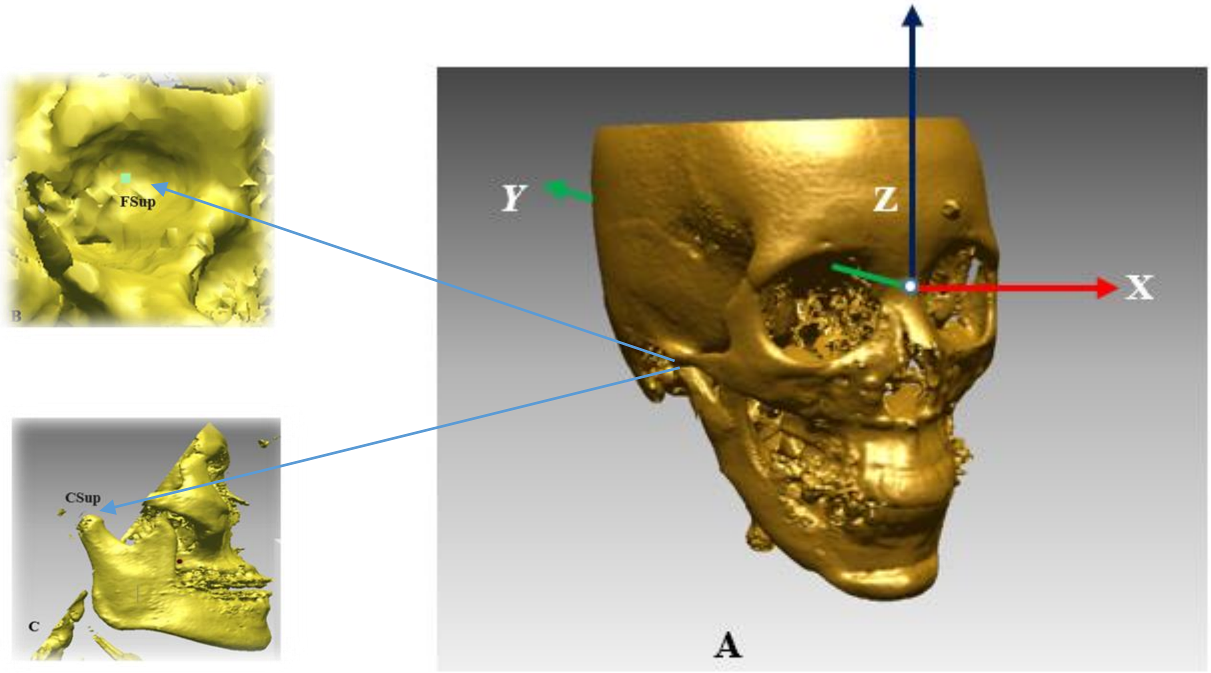


Figure 1. Anatomical reference planes of the craniofacial region

A. Anatomical reference planes (X-axis, Y-axis, Z-axis)

B. The most superior point of the glenoid fossa

C. The most superior point of the condylar head

2.5 Measurements

T0, T1 and T2 three-dimensional stereoscopic images of the skull were taken using the Rapidform program as reference points on the skull surface (Figure2). The reference points utilized in this process were chosen from the supraorbital foramen and the zygomatic-frontal suture of the skull, as well as the lambda point and the occipital protuberance posteriorly. SJS measurements were obtained at each time point (Figure 3c).

- **Superior joint space (SJS) (mm)** distance between Csup (The most superior point of the condylar head) and the plane passing through Fsup (The most superior point of the glenoid fossa) and parallel to ARP (Figure 3).

Additionally, the following surgical factors were measured, and a regression analysis was conducted. (Figure 3 a, b, c, d)

- **Proximal segment width (mm) -** Refers to the width of the superior portion of the mandibular ramus, the vertical section of the lower jaw, that remains following the osteotomy (bone incision). Reference level C1 Atlas FH parallel
- **A-P length of proximal segment (mm) -** Refers to the measurement of the proximal segment of the mandible from its anterior (front) to posterior (back) aspects, specifically after the surgical procedure. . Reference level mastoid process
- **Amount of Setback (mm)** – Describes the degree to which the distal segment of the mandible, containing the teeth, is moved backward in relation to the proximal segment, which houses the condylar portion of the jaw. Reference level mental foramen distal to distal

Table 1. Reference Landmark

Landmark	Description
CSup	The most superior point of the condylar head
FSup	The most superior point of the glenoid fossa
MF	Mental fromen
AB	Anterior border (Proximal segment)
PB	Posterior border (Proximal segment)
LB	Lateral border (Proximal segment)
MB	Mesial border (Proximal segment)

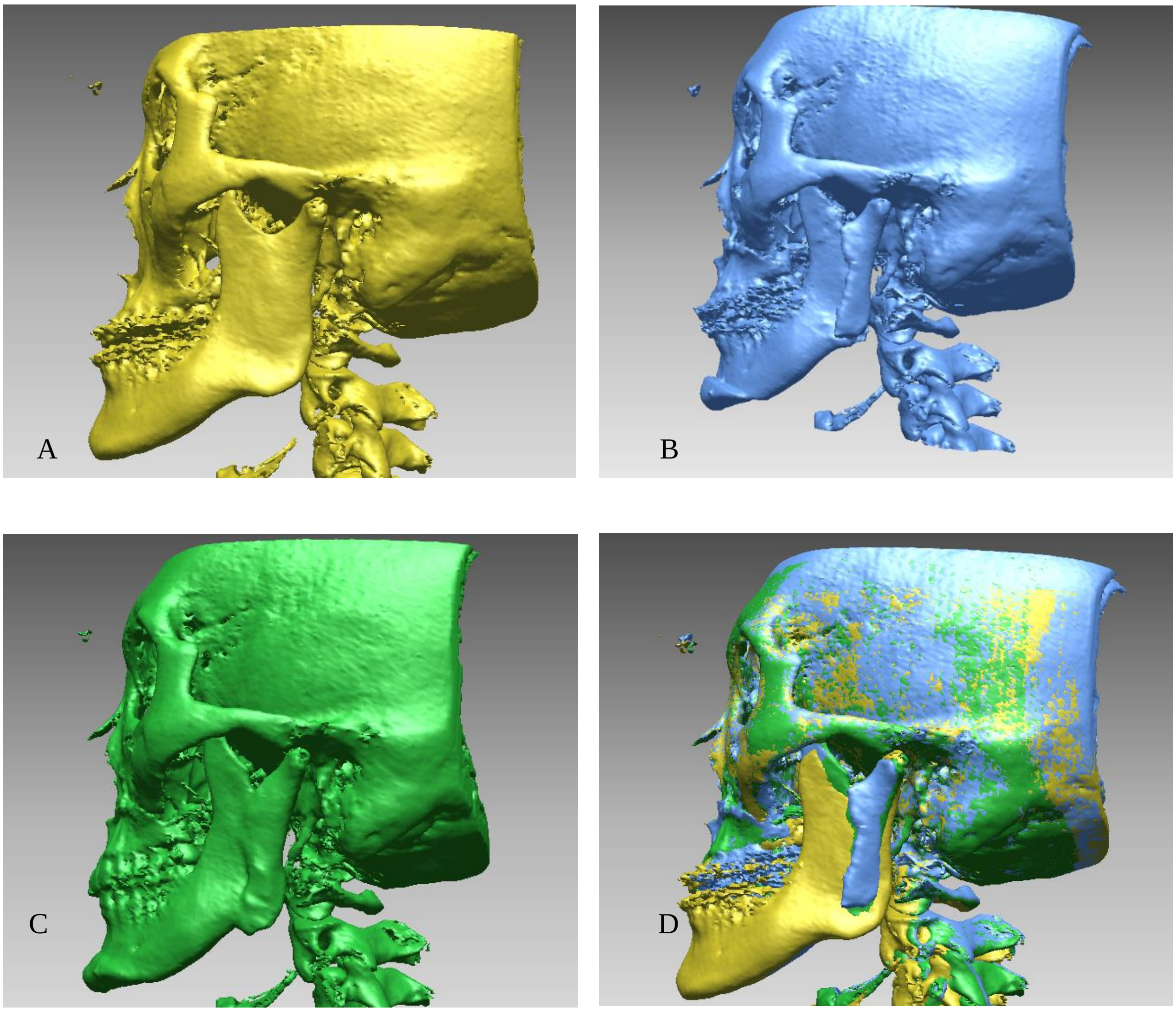


Figure 2. The comprehensive procedure of the superimposition process

A. Pre-operative 3D image

B. Post-operative image

C. Post-operative 1year image

D. Superimposition of skull images from A&B&C

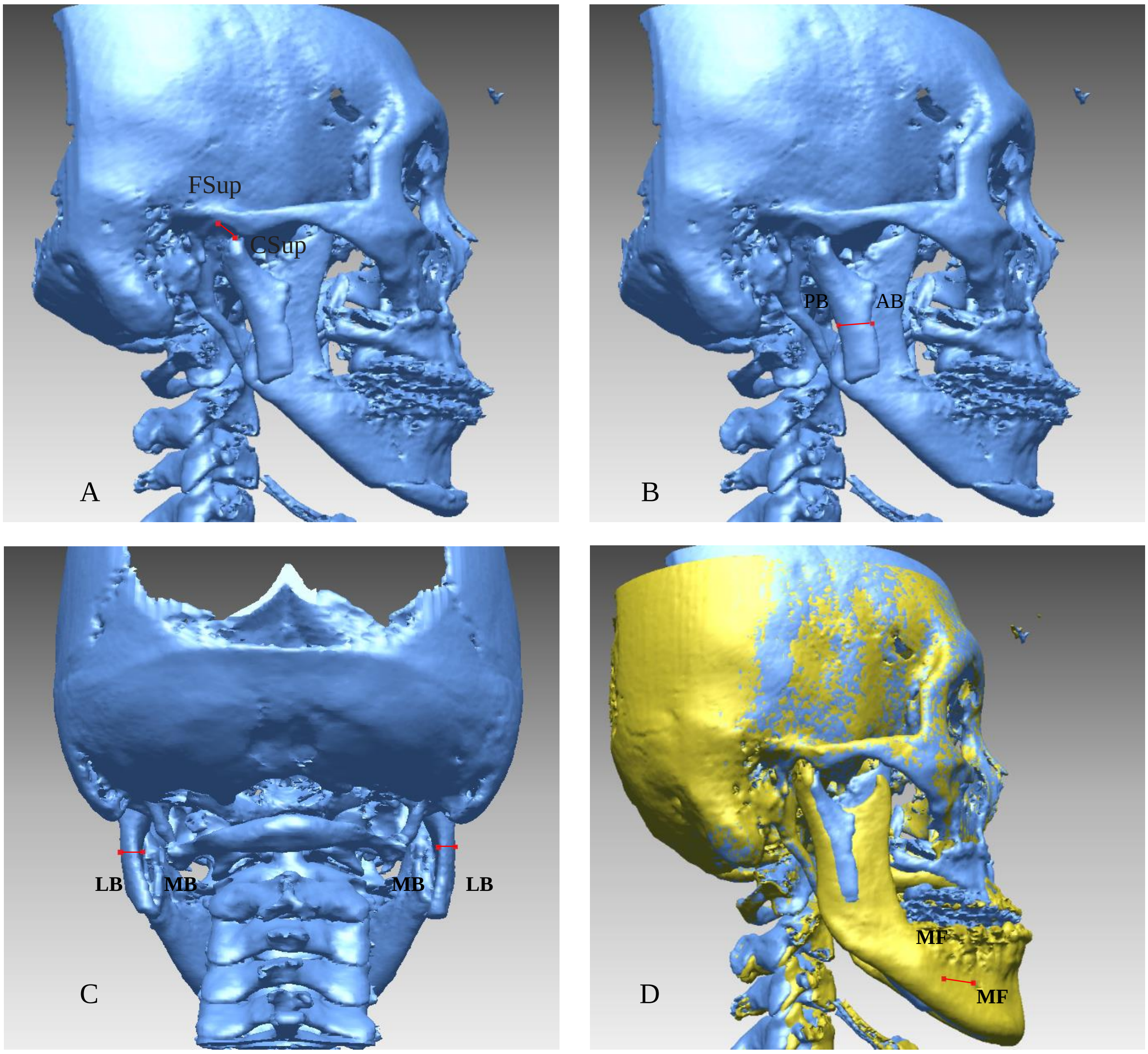


Figure 3. Measurement figure

A. Superior joint space

B. A-P length of proximal segment

C. Width of proximal segment

D. Amount of Setback

2.6 Statistical analysis

A repeated-measures analysis of variance with Bonferroni correction was employed to assess changes over time at preoperative, postoperative, and one-year follow-up stages (T0, T1, and T2) for each side. Additionally, an independent samples t-test was employed to examine whether significant differences in superior joint space and maximal mouth opening were observed between individuals with and without TMJ symptoms. All statistical analyses were performed using IBM SPSS Statistics version 29. A P-value < 0.05 was considered statistically significant.

III. RESULTS

A total of 53 patients and 106 TMJ consisting of 28 females and 25 males, aged between 18 and 41 years (mean age: 21.9 ± 4.5 years) at the time of surgery, were assessed in this study.

Table 2. Patient demographics

	Patients [a] **(n = 53), n (%)**
Sex	
Female / Male	28 (52.83%) / 25 (47.17%)
Age	
Mean ± SD	21.9±4.5 years(18-41years)
Proximal segment width	
Mean ± SD	6.0±1.2mm
Proximal segment AP length	
Mean ± SD	14.4±3.1mm
Amount of setback	
Mean ± SD	11.5±3.4 mm
TMJ pain	8 joints
TMJ noise	26 joints
Temporomandibular joint symptoms	34 of 106 temporomandibular joints (32.07 %)

3.1 Changes in the condylar segments and superior joint spaces

Changes in the condylar segments and joint spaces were evaluated at three time points: preoperatively (T0), 1 month postoperatively (T1), and 12 months post-surgery (T2). A comparison of the superior joint space (SJS) across these intervals revealed statistically significant changes, indicating movement of the condylar segments following surgery (Figures 4). The SJS exhibited a marked increase from T0 to T1, followed by a decrease from T1 to T2 ($P < 0.001$). Specifically, the SJS increased from 3.7 ± 1.5 mm preoperatively to 6.4 ± 1.9 mm postoperatively, and then gradually decreased to 4.5 ± 1.7 mm at the one-year mark, although it did not return to its preoperative value (Figure 4).

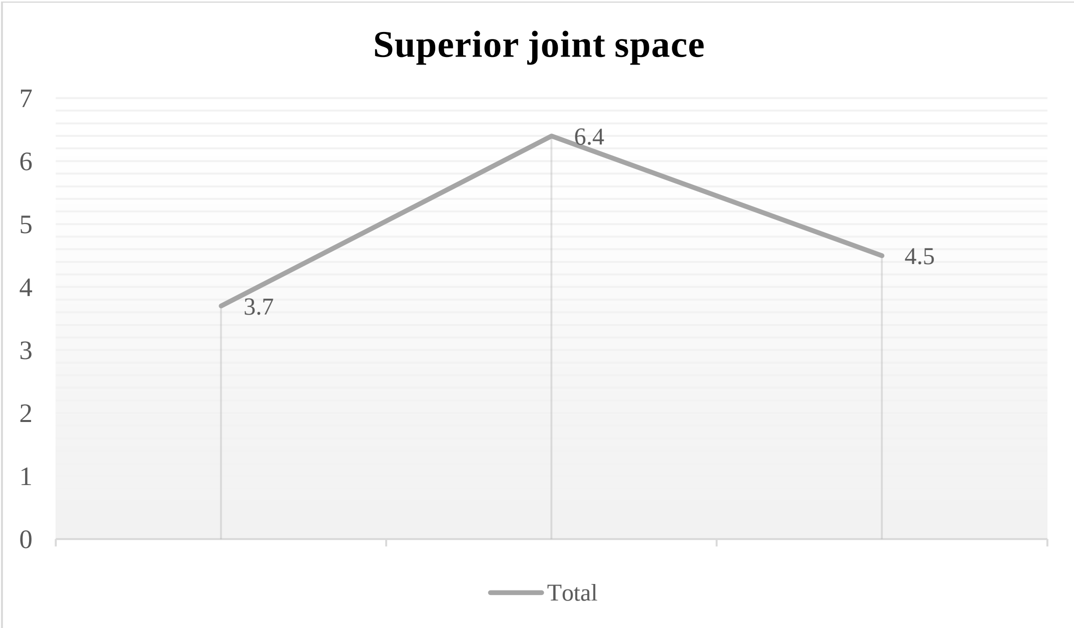
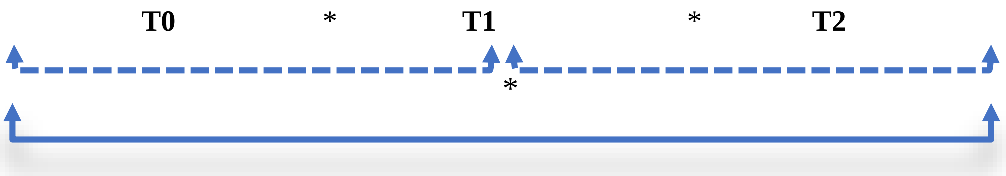


Figure 4. Superior joint space measurements



Superior joint space measurements; A repeated-measures analysis were used to compare the results at preoperative, postoperative and 1-yearfollow up time points. All observed differences are statistically significant, suggesting that the changes over time are unlikely to have occurred by chance. The results demonstrate high significance ($p < 0.001$), indicating a meaningful statistical difference between the variables.

3.2 The regression between maximum mouth opening and superior joint space

The maximum mouth opening (MMO) exhibits variation over time, characterized by a reduction immediately following surgery and a partial recovery within a year. However, MMO does not fully return to preoperative levels. These observations indicate a positive correlation between MMO measurements taken at different time intervals, with the strongest correlation found between preoperative MMO and that measured one-year post-surgery. The average MMO was 52.4 mm prior to surgery, decreasing to 40.09 mm one month after surgery, followed by an increase to 48.73 mm at 12 months postoperatively, representing a 93.9% recovery compared to the preoperative state. (Figure 5)

A simple linear regression analysis was conducted to examine the relationship between changes in superior joint space and changes in maximal mouth opening. The results are summarized in (Tables 3).The results indicated no significant correlation between the two variables ($p = 0.232$). The regression model accounted for only 1.4% of the variance in MMO_change ($R^2 = 0.014$), and the model was not statistically significant ($F(1,103) = 1.446$, $p = 0.232$).

Table 3. Simple regression analysis result of maximal mouth opening

Dependent variable	**Independent variable**	**R^2**	**F (P-value)**
Maximal mouth opening	**Supereior joint space**	0.014	1.446 (0.232)

**P < 0.01, *P < 0.05 (ANOVA)

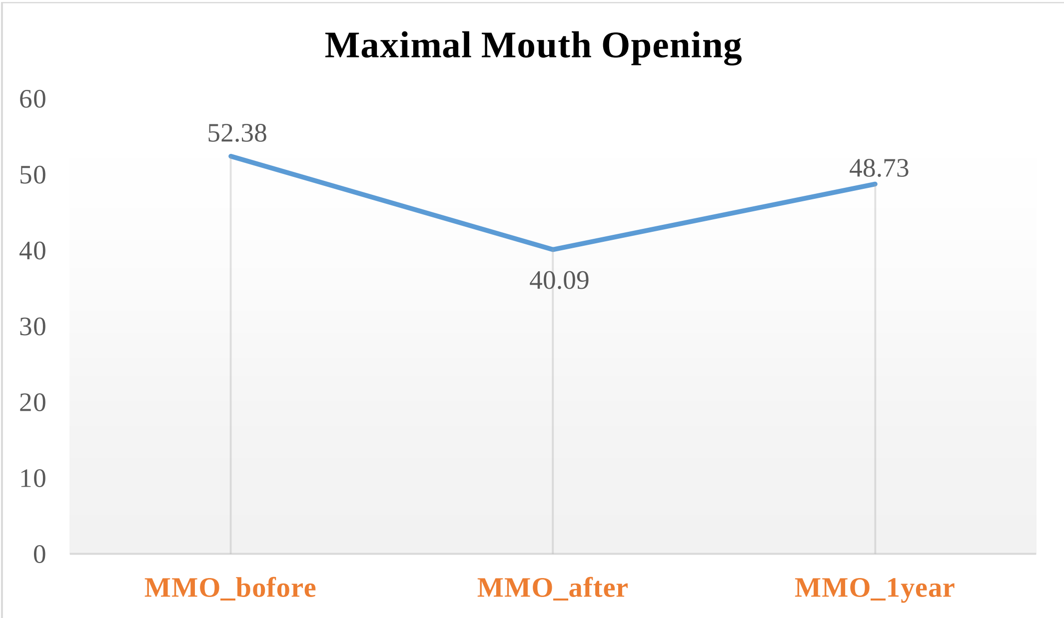
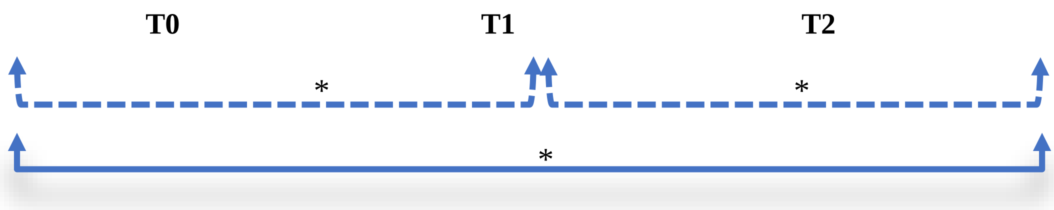


Figure 5. Maximal mouth opening



3.3 Superior joint space-Maximal mouth opening - Temporomandibular joint

The results, as shown in (Table 4) , indicated a significant reduction in TMJ symptoms over a one-year period. TMJ noise decreased from 26 joints preoperatively to 10 joints at one year postoperatively, with the number of joints without noise increasing from 80 to 96. Similarly, TMJ pain was reduced from 8 joints preoperatively to 1 joint postoperatively at one year, while the number of joints without pain increased from 98 to 106. These findings demonstrate a substantial improvement in both TMJ noise and pain symptoms following surgery.

Table 4. TMJ symptoms

	Pre-Op	1Year post-op
TMJ noise (+)	26 joints	10 joints
TMJ noise (-)	80 joints	96 joints
TMJ pain (+)	8 joints	1 joints
TMJ pain (-)	98 joints	106 joints

Table 5. Independent samples T test analysis result of TMJ symptoms

	N	SJS(T0-T1)	SJS(T1-T2)	MMO(T0)	MMO(T1)	MMO(T2)
TMJ sound before (+)	26	3.03	-2.03	52.88	39.58	48.31
TMJ sound before(-)	80	2.55	-1.84	53.25	40.26	48.85
TMJ sound 1year (+)	10	4.08	-2.75	49.60	41.00	53.50
TMJ sound 1year(-)	96	2.62	-1.85	53.30	40.06	48.52
TMJ pain before(+)	8	2.83	-1.60	51.82	39.71	45.75*p<0.026
TMJ pain before(-)	98	2.64	-1.94	53.42	40.17	49.25
TMJ pain 1year (+)	1	3.75	-1.84	47.00	40.00	48.68
TMJ pain 1year(-)	106	2.66	-1.89	53.22	40.10	52.00

**P < 0.01, *P < 0.05 (by t-test)

The association between temporomandibular joint (TMJ) sound and pain with alterations in superior joint space (SJS) and maximal mouth opening (MMO) was examined longitudinally. The results are presented in (Table 5). Patients without TMJ pain at baseline showed significantly greater maximal mouth opening 1 year later compared to those with TMJ pain, suggesting that the presence of pain may negatively affect long-term mouth opening functionality. The analysis found no significant differences in other comparisons.

3.4 Association between SJS and proximal segment measurements

In our study, the mean condylar displacement immediately post-surgery was 6.4 ± 1.9 mm (1 S.D.), with 18 out of 106 joints exhibiting condylar sag due to displacements exceeding 2 S.D. The relationship between superior joint space and potential predictors—bone width, A-P length, and setback—was assessed using simple linear regression models. As shown in Table 6, none of the predictors demonstrated a statistically significant association with changes in superior joint space. Furthermore, the low R^2 values suggest that these variables contribute minimally to explaining variations in superior joint space. These findings highlight the need for further research to identify other potential factors influencing SJS.

Table 6. Simple regression analysis result of superior joint space

Dependent variable	**Independent variable**	**R^2**	**F (P-value)**
° Supereior joint space	**° Bonewidth**	0.024	2.525 (0.115)
	° APlength	0.001	0.123 (0.727)
	° Setback	0.002	0.172 (0.679)

**P < 0.01, *P < 0.05 (by ANOVA)

IV.DISCUSSION

Immediately after IVRO, the mandibular condyle tends to sag because the proximal segment is detached from surrounding tissues, except for the lateral pterygoid muscle, joint capsule, and ligaments. The lateral pterygoid muscle causes the proximal segment to rotate, usually in an anterior-inferior direction, with the contact area between the proximal and distal bone fragments acting as the center of rotation.[15-17]

The restoration of proximal segment displacement necessitates bone healing, rehabilitation, and functional physical therapy.[18] Recent studies indicate that the downward and rotational movements of the mandibular joint, observed immediately post-surgery, partially return to preoperative levels during the rehabilitation phase but do not fully recover even after one year.[15, 19] Similarly, the results of our study demonstrated a significant increase in SJS following surgery, followed by a gradual decline; however, it was found that it had not completely reverted to its preoperative state after one year. The aim of our study was to explore the relationship between proximal segment width and anteroposterior (A-P) length and their impact on condylar sag during intraoral vertical ramus osteotomy (IVRO).

We evaluated the impact of bone thickness, proximal segment length, and the amount of setback on condylar sag, a complication associated with intraoral vertical ramus osteotomy (IVRO). Previous studies have shown that the risk of condylar sag is significantly elevated in cases with a setback of 3.25 mm or less. As the setback decreases, the force acting on the proximal segment in relation to the distal segment diminishes, thereby increasing the likelihood of condylar sag.[9] The preferred treatment for patients needing minor mandibular setbacks is bilateral sagittal split osteotomy.[8] However, in our study, participants had a minimum setback of 4.04 mm. Additionally, our sample size showed no correlation with the superior joint space (SJS) when comparing preoperative, immediate postoperative, and one-year postoperative measurements in relation to proximal segment width, amount of setback, and anteroposterior length of the proximal segment (Fig. 3). The results of this study suggest that condylar sag following IVRO is not associated with the magnitude of the setback, the anteroposterior length of the proximal segment, or the width of the proximal segment.(Table 5)

In orthognathic surgery, intraoral vertical ramus osteotomy (IVRO) has traditionally been utilized for patients with preoperative temporomandibular joint (TMJ) disorders [13] [17, 20]. Among the joints examined in our study, 26 out of 100 exhibited preoperative temporomandibular joint (TMJ) noise. Following IVRO, 16 of these 26 joints experienced resolution of the TMJ noise. Clinically, reducible anterior disc displacement is often associated with complaints of temporomandibular joint (TMJ) noise.[21] [22]

Research has demonstrated that it typically takes about 6 months to achieve 90% of the preoperative maximum mouth opening and around 12 months to fully return to preoperative levels.[23] Our findings align with these results.

Additionally, this study did not take into account changes in soft tissue. Future research with larger sample sizes should assess the soft tissue changes in patients.

V. CONCLUSIONS

In summary, our study suggests that although proximal segment width and anteroposterior (A-P) length were analyzed in relation to condylar displacement, no significant statistical associations were identified. This implies that other factors may have a more considerable influence on the development of condylar sag following intraoral vertical ramus osteotomy (IVRO). The key conclusions of our study are as follows:

1. Changes in superior joint space (SJS) were found to affect temporomandibular joint (TMJ) symptoms, with an increase in SJS postoperatively linked to improvements in TMJ pain and noise. However, as SJS gradually returned to preoperative levels, these improvements diminished. These results highlight the need for further investigation to understand the underlying mechanisms and identify other contributing factors to both condylar sag and TMJ function after IVRO.
2. Ongoing follow-up assessments revealed an initial increase in SJS immediately after surgery, with a gradual decrease over time, although it did not fully return to preoperative levels within one year.
3. Maximal mouth opening (MMO) decreased postoperatively and partially recovered within one year, reaching 93.9% of the preoperative value.
4. Of the 26 preoperative cases of TMJ injury, 10 remained after one year, while 8 preoperative cases of injury decreased to 1 after one year.
5. A simple linear regression analysis revealed no significant correlation between changes in superior joint space and changes in maximal mouth opening.

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국문 요약

하악골 상관절강과 TMD 증상: 구강 내 수직골 절골술(IVRO) 후 변화

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본 연구는 구강 내 수직지 절골술(IVRO) 후 상관절강(SJS)과 턱관절(TMJ) 증상의 3 차원적 변화를 조사한 것으로, IVRO 는 하악 전돌증 교정을 위한 널리 사용되는 악교정 수술입니다. 본 연구는 2014 년부터 2022 년까지 연세대학교에서 LeFort I 골절단술과 병행하여 IVRO 를 받은 환자들을 후향적으로 분석했습니다. 컴퓨터 단층촬영(CT) 기반 3D 모델을 활용하여 수술 전(T0), 수술 후 1 개월(T1), 그리고 수술 후 1 년(T2) 시점의 변화를 평가했습니다.

연구 결과, SJS 는 수술 직후 유의미하게 증가하였으나, 1 년 후 일부 감소하여도 수술 전 수준으로 완전히 회복되지는 않았습니다. 턱관절 소음과 통증은 수술 후 1 년 이내에 현저히 개선되어 IVRO 가 TMJ 장애를 완화하는 데 효과적임을 보여주었습니다. 그러나 SJS 변화와 근위분절의 크기 또는 하악골 이동량 간에는 유의미한 상관관계가 관찰되지 않았으며, 이는 다른 요인들이 결과에 영향을 미칠 수 있음을 시사합니다.

이 연구는 수술 후 SJS 변화의 메커니즘과 TMJ 기능에 미치는 영향을 더 깊이 이해하기 위한 추가 연구의 필요성을 강조합니다. 또한 IVRO 후 TMJ 의 역학과 장기적인 안정성에 대한 중요한 통찰을 제공합니다.

핵심되는 말: 구내 하악골 상행지 수직골 절단술(IVRO), 과두상 관절강(SJS), 측두하악(TMJ).