Factors related to postoperative downward displacement of anterior mandible after surgery-first approach with intraoral vertical ramus osteotomy

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감사의 글

저에게 치과교정의 길을 열어주시고 치과의사로서 나아갈 길을 가르쳐주신 유형석 교수님께 진심으로 감사드립니다. 논문 작성 및 투고와 더불어 일상에서도 가까이서 많은 격려와 도움을 주신 최성환 교수님께도 진심으로 감사드립니다. 항상 진료와 교육으로 바쁘신 와중에도 소중한 시간을 내어 훌륭한 논문이 완성될 수 있도록 조언해주신 이기준, 차정열 교수님께 깊이 감사드립니다. 수련의 시절부터 악교정수술에 대하여 많이 가르쳐주시고 아낌없는 조언을 해주신 이상휘 교수님께 또한 감사드립니다.

연세대학교 치과교정학교실의 일원이 되어 공부할 수 있도록 기회를 주시고 올바른 의술을 펼칠 수 있도록 이끌어 주신 김경호 교수님, 정주령 교수님, 박선형 교수님, 이지현 교수님, 최재훈 교수님, 김하림 교수님께도 깊이 감사드립니다. 펠로우 기간동안 많은 의지가 되어준 최은학 선생님께도 진심으로 감사드립니다.

3년의 수련기간 동안 많은 시간을 같이 보내며 동고동락한 교정과 의국 동기들과 더불어 진료 및 의국 생활에 잘 적응할 수 있도록 도와준 의국 선배님들 그리고 든든한 의국 후배님들께도 감사의 마음을 전합니다.

마지막으로 무슨 일을 하든 항상 믿어주시고 제 편이 되어주시고 멀리서도 응원해주시는 사랑하는 어머니, 아버지께 감사의 마음을 전합니다. 따뜻한 마음으로 동생을 잘 챙겨주어 인생의 큰 의지가 되는 사랑하는 언니에게도 고마움을 전합니다. 지면에 미처 언급하지 못했지만 저에게 많은 격려와 응원을 해주신 분들에게도 감사하다는 말씀을 전합니다.

2024년 11월 저자 씀

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ABSTRACT

Factors related to postoperative downward displacement of anterior mandible after surgery-first approach with intraoral vertical ramus osteotomy

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(Directed by Professor Hyung-Seog Yu, D.D.S., M.S., Ph.D.)

Some patients who have undergone surgery-first approach with intraoral vertical ramus osteotomy (IVRO) exhibit downward displacement of anterior mandible even up to 1-year post surgery, which makes it difficult for orthodontists to stabilize the occlusion during the postoperative orthodontic period. The aim of this study was to identify factors related to downward displacement of the anterior mandible 1-year after surgery-first approach using IVRO, while focusing on cephalometric values.

This retrospective cohort study sample was divided into two groups based on the amount of vertical displacement of the B-point 1-year post surgery (Group U, upward displacement; Group D, downward displacement greater than 2 mm). To evaluate cephalometric changes between the two groups, cephalograms were obtained before surgery, 1 day after surgery, 1 month after surgery, and 1 year after surgery. The data were analyzed using the independent *t*-test, Mann-Whitney *U* test with Bonferroni correction, Pearson correlation analysis, and multiple regression analysis.

At the initial examination, Group D showed a shallower anterior overbite. The vertical surgical change in the B-point was statistically different between the two groups ($p < 0.001$), indicating that Group D exhibited more upward movement of the anterior mandible during surgery. Group D showed significant downward displacement of the anterior mandible 1 month after surgery, and this finding persisted until 1 year postoperatively. Clockwise rotation of the mandible was also observed. Surgical vertical movement of the B-point showed a strong correlation with postoperative vertical displacement of anterior mandible ($r = -0.674$; $p < 0.001$) along a linear relationship, indicating that the amount of postoperative vertical downward displacement of the anterior mandible increased as the amount of surgical upward movement of the B-point increased ($R^2 = 0.449$; $p < 0.001$).

This study revealed that downward displacement of the anterior mandible after a surgery-first approach using IVRO is correlated with the amount of upward movement during the surgery. When planning surgery, in cases in which a significant upward movement of the anterior mandible is anticipated, orthodontists should prepare for the possibility of subsequent atypical downward displacement of the anterior mandible during the postoperative orthodontic period.

Key words: Surgery-first, POGS, IVRO, Stability, Mandibular downward displacement

I. Introduction

Skeletal Class III malocclusion has a prevalence of 4 to 14% among Asian people, which is higher when compared to the corresponding prevalence among other races, and the majority of these cases show an overdeveloped mandible (Abdolreza et al., 2016; Hardy et al., 2012; Ngan and He, 2010). To treat patients with severe skeletal Class III, for which orthodontic treatment alone cannot achieve normal occlusion, bimaxillary surgery, including maxillary Le-fort I osteotomy and mandibular set-back, is often performed (Kor et al., 2014; Kwon et al., 2014). Recently, the development of TADs (temporary anchorage devices) has expanded the scope of orthodontic treatment (Choi et al., 2021) and led to an increase in the surgery-first approach that bypasses the preoperative orthodontic treatment. The surgery-first approach is increasingly being performed because it provides immediate aesthetic improvements to patients, high patient satisfaction, and more efficient tooth movement postoperatively, particularly in asymmetric cases, which shortens the total treatment duration (Huang et al., 2014; Liao et al., 2010; Nagasaka et al., 2009; Tsuruda and Miyamoto, 2003).

Numerous studies have examined stability after a surgery-first approach. In their systematic review, Soverina et al. (Soverina et al., 2019) reported that the surgery-first approach shows stability and predictability comparable to conventional surgery. From the perspective of vertical stability, Choi et al. (Choi et al., 2016b; Choi et al., 2016c), Ann et al. (Ann et al., 2016), Kim et al. (Kim et al., 2014), and Jeong et al. (Jeong et al., 2018) reported that, in a surgery-first approach using IVRO (Intraoral Vertical Ramus Osteotomy), the mandible primarily moves upward 1-year post surgery. In other studies, Yoshioka et al. (Yoshioka et al., 2008) and Nihara et al. (Nihara et al., 2013) reported that clockwise rotation of the mandible occurred within 3 months of IVRO, and that such rotation is likely attributable to condylar sag and muscular pull occurring immediately after surgery. However, after a surgery-first approach, premature occlusal contacts disappear during postoperative orthodontic treatment, and the masticatory muscles are rehabilitated, and these outcomes contribute to upward movement of the mandible 1-year post surgery (Choi et al., 2016b).

As was expected, almost all patients who have undergone a surgery-first approach using IVRO exhibited upward displacement of the mandible 1-year post surgery. However, in some cases, patients exhibited downward displacement of the anterior mandible even up to 1-year post surgery, and these displacements make it difficult for orthodontists to stabilize occlusion during postoperative orthodontic treatment. To our knowledge, there have been few studies investigating the factors that affect the clinically challenging downward displacement occurring in the anterior mandible after a surgery-first approach using IVRO.

Conventionally, when surgical healing is complete, jaw movements exceeding a distance of 2 mm from the position of the time of surgery are considered clinically significant (Proffit et al., 2007). Therefore, the aim of this study was to identify factors related to downward displacement of the anterior mandible exceeding 2 mm 1-year after the surgery-first approach using IVRO, while focusing specifically on cephalometric values. This study also investigated the correlation between the considered factors and postoperative downward displacement of the anterior mandible post-surgery.

II. Subjects and methods

1. Study design and patients

This retrospective cohort study included adult patients who were diagnosed with skeletal Class III malocclusion and who were treated with bimaxillary surgery using IVRO in a surgery-first approach by the same surgeon between 2010 and 2020 at the Department of Oral and Maxillofacial Surgery, Yonsei Dental Hospital, Seoul, Republic of Korea.

The inclusion criteria for this study were as follows: 1) Age 18 years or older; 2) Skeletal Class III malocclusion with an ANB angle (the angle formed by point A, the nasion, and point B) < 0°; 3) Requirement of bimaxillary surgery (one-piece Le Fort I osteotomy and bilateral IVRO with or without genioplasty); 4) Surgery-first approach without preoperative orthodontic treatment; 5) Abscence of maxillomandibular transverse discrepancy; 6) Complete series of lateral and posterior-anterior cephalogram.

The exclusion criteria were as follows: 1) History of previous orthognathic surgery; 2) Requirement of single-jaw surgery; 3) Requirement of conventional surgery with preoperative orthodontic treatment; 4) Congenital craniofacial anomalies; 5) Temporomandibular joint or muscle disorder.

Patients who showed an upward displacement of the anterior mandible 1-year post surgery were assigned to Group U (Figure 1, A). As previously mentioned, a jaw movement greater than 2 mm, when compared from the position at the time of surgery, is considered clinically significant once surgical healing is complete (Proffit et al., 2007).; accordingly, this study included patients whose B-point shifted downward more than 2mm 1-year after surgery as Group D (Figure 1, B). Hereafter, this study defines 'vertical instability' or being 'vertically unstable' as instances in which the B-point of the mandible shifted downward more than 2mm 1-year post surgery. This study was conducted in full compliance with the Declaration of Helsinki (2013). The Institutional Review Board of Yonsei Dental Hospital (IRB No. 2–2024-0020) waived the need for ethics approval and informed consent to use anonymized and retrospectively analyzed data.

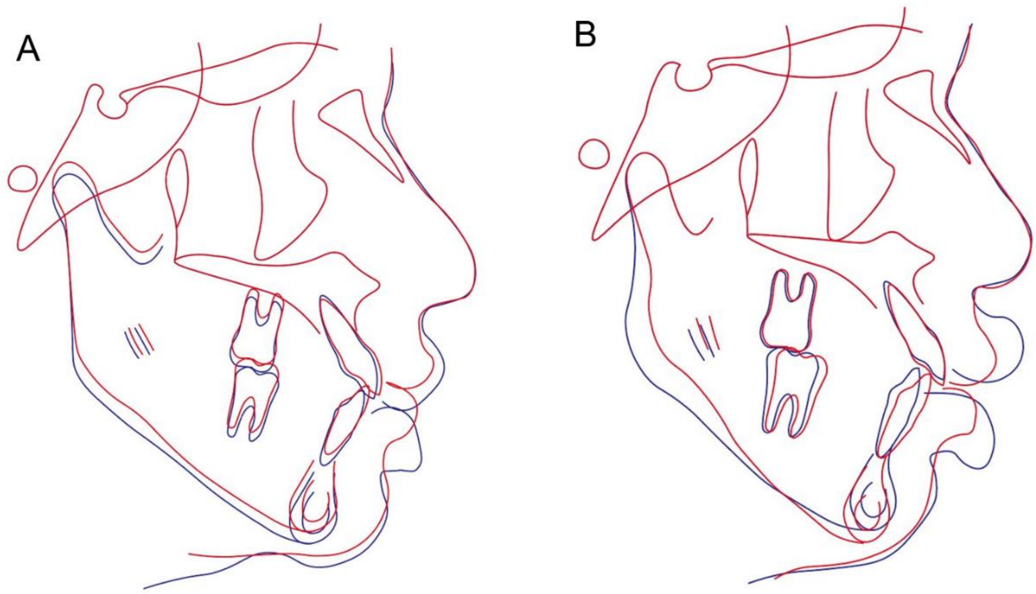

Figure 1. Displacement of the mandible 1-year post surgery. A, demonstrates upward displacement of the anterior mandible; B, shows downward displacement of the anterior mandible; Blue line: 1 day after surgery; Red line: 1 year after surgery.

2. Surgical and orthognathic treatment

Five weeks before surgery, surgical archwires made of 0.017 x 0.025-inch stainless steel were directly bonded to the teeth for intermaxillary fixation (IMF) after surgery. No orthodontic forces were applied before surgery. All orthodontic treatments were done by the same orthodontist at the Department of Orthodontics, Yonsei Dental Hospital.

All surgeries were performed by the same surgeon, and all patients were treated according to the same surgical and postoperative protocol. After the maxillary Le Fort I osteotomy, four prefabricated rigid L-shaped titanium plates were fixed with screws in both the canine fossa and the zygomatic buttress. The mandible was setback bilaterally using IVRO, and no fixation was performed between the proximal and distal segments. The osteotomy line of the mandible extended from the mandibular angle to the sigmoid notch. Post-surgery, IMF was implemented for one week, followed by active physiotherapy (PT) three times a day, comprising of 30-40 repetitions of mouth opening to guide the mandible into the planned position. For eight weeks post-surgery, patients were instructed to wear bilateral intermaxillary elastics throughout the day while changing them once daily. Postoperative PT was conducted with the goal of achieving a maximum mouth opening of over 40 mm, and it included a cooperation assessment that was administered during outpatient visits occurring every week for about eight weeks. The final wafer was removed from the patient at three weeks post-surgery, but they were instructed to wear it with elastics at night. Eight weeks after the surgery, the patients were referred to the orthodontic department to begin postoperative orthodontic treatment.

3. Data collection methods

Skeletal and dental changes were evaluated and compared before and after the surgery using lateral cephalograms and posterior-anterior cephalograms. Cephalograms were taken before surgery (T1), 1 day after surgery (T2), 1 month after surgery (T3), and 1 year after surgery (T4). Surgical changes were assessed from T2-T1, immediate postoperative changes were assessed from T3-T2, and final postoperative changes were assessed from T4-T2. The lateral cephalogram and posterior-anterior cephalogram measurements were performed using V-ceph 5.5 (Osstem, Seoul, Korea), and changes were assessed by superimposing these measurements on the sella-nasion (SN) plane in the lateral cephalogram.

Measurements in the lateral cephalogram were made according to an x-y coordinate system where the x-axis was defined as a line passing through N and forming 7° upwards from the SN plane, while the y-axis was defined as a line passing through S and perpendicular to the x-axis. The locations of the measurement points were determined by their distances from the x- and y-axes. In the posterior-anterior cephalogram, the amount of mandibular menton deviation was evaluated based on a horizontal reference line passing through bilateral Z-points and a vertical reference line perpendicular to the horizontal reference line passing through the crista galli. The distance of the menton from the vertical reference line was measured.

This study identified nine linear measurements and seven angular cephalometric measurements. The nine linear measurements included the horizontal distance from point A and point B to y-axis; the vertical distances from each of point A, point B, the tip of the upper central incisor (U1), and the tip of the distal cusp of the upper first molar (U6) to the x-axis; anterior overjet (OJ) and overbite (OB, Figure 2, A); and amount of menton deviation.

The seven angular measurements included the angle of the lines formed by S, N, and point A (SNA); the angle of the lines formed by S, N, and point B (SNB); the angle of the lines formed by point A, N, and point B (ANB); the angle between the SN plane and the palatal plane (SN-PP); the angle between the SN plane and the mandibular plane (SN-MP); the angle of the SN plane to the upper incisor (U1-SN); and the angle of the mandibular plane to the lower incisor (IMPA, Figure 2, B).

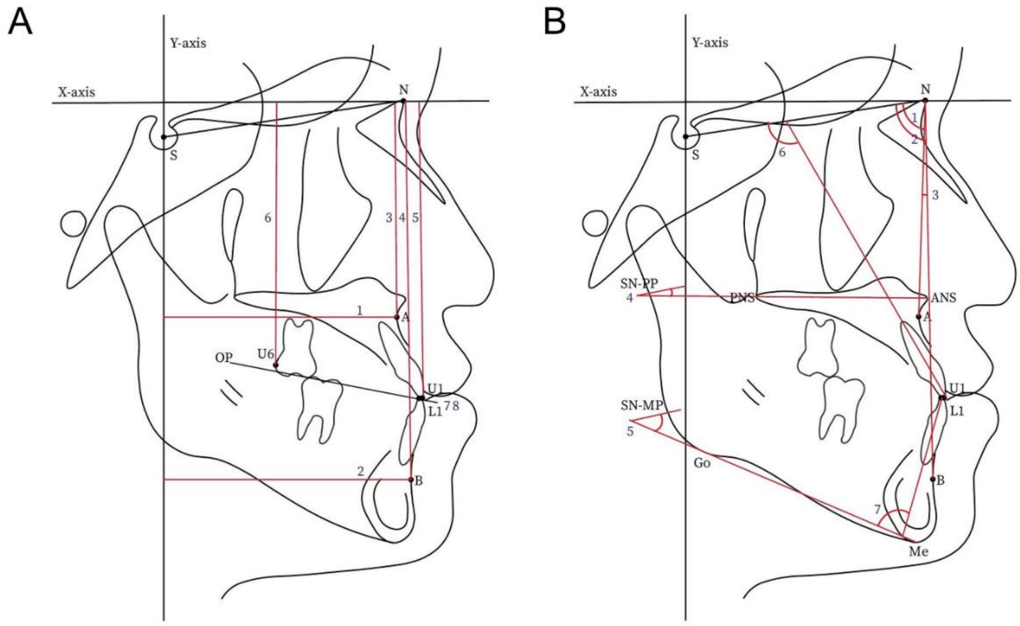

Figure 2. A, Cephalometric linear measurements. 1, A[X], horizontal position of point A; 2, B[X], horizontal position of point B; 3, A[Y], vertical position of point A; 4, B[Y], vertical position of point B; 5, U1[Y], vertical position of upper central incisor; 6, U6[Y], vertical position of upper first molar; 7, OJ, Subtract distance of L1 from U1 parallel to OP; 8, OB, Subtract distance of L1 from U1 perpendicular to OP; A, point A; B, point B; S, sella; N, nasion; U1, tip of upper central incisor; U6, tip of distal cusp of upper first molar; OP, occlusal plane; X-axis, defined by origin of nasion and forming 7º angle upward from SN plane; Y-axis, defined as a line perpendicular to X-axis and passing through sella.

B, Cephalometric angular measurements. 1, SNA, angle of lines formed by S, N, and point A; 2, SNB, angle of lines formed by S, N, and point B; 3, ANB, angle of lines formed by point A, N, and point B; 4, SN-PP, angle between the SN plane and the palatal plane; 5, SN-MP, angle between the SN plane and the mandibular plane; 6, U1-SN, angle of the SN plane to the upper incisor; 7, IMPA, angle of the mandibular plane to the lower incisor; A, point A; B, point B; S, sella; N, nasion; U1, tip of upper central incisor; L1, tip of lower central incisor; ANS, anterior nasal spine; PNS, posterior nasal spine; Go, gonion; Me, menton.

4. Reliability

Reproducibility was evaluated by comparing the measurements obtained from initial examinations with those obtained from repeated examinations. All measurements were repeated by the same examiner at 1-week intervals. The method error was calculated using the intraclass correlation coefficient, which was between 0.85-0.90 for all linear and angular measurements in this study.

5. Statistical analysis

All statistical analyses were performed using IBM SPSS 26.0 for Windows (IBM Korea Inc., Seoul, Korea). The minimum sample size for detecting differences in cephalometric changes at each time point between groups using the independent *t*-test was calculated based on the previous study by Kwon et al. (Kwon et al., 2019): Using G*Power 3 (Düsseldorf, Germany) with targets of a significance level of a *p* value less than 0.05, a power of 80%, and an effect size of 1.26, the minimum sample size was confirmed as 8. The Shapiro-Wilk test was used to verify the normality of the data distribution. The values included in the sample characteristics were presented in the forms of means and standard deviations (SD). The Fisher's exact test and independent *t*-test were used for comparisons of the sample characteristics between groups. The independent *t*-test or Mann-Whitney *U* test with Bonferroni correction was used to compare the initial condition (T1) between the two groups, as well as the surgical change (T2-T1), immediate postoperative change (T3-T2), and final postoperative change (T4-T2). Changes over time within each group were analyzed using either the paired *t*-test or the Wilcoxon signed rank test with Bonferroni correction. A *p* value less than 0.008 (=0.05/6) was considered to represent a statistically significant difference.

Factors influencing the vertical downward displacement of the anterior mandible 1 month and 1 year after surgery were analyzed separately. To explore factors that might affect downward displacement of the anterior mandible post-surgery, Pearson correlation analysis was conducted. In assessing the degree of correlation, an *r* value greater than 0.40 was considered to indicate a moderate-to-strong correlation, while an *r* value less than 0.40 indicated a weak correlation (Hinkle et al., 1988). Multiple regression analysis was performed along with the stepwise method to determine the association between factors, with the results showing a strong association and downward displacement of the anterior mandible post-surgery. A *p* value less than 0.05 was interpreted as being statistically significant.

III. Results

1. Sample characteristics

There were total of 91 patients who underwent surgery-first approach. Among these, twenty-four patients (Group U, 11 men and 13 women; mean age, 20.9 ± 2.9 y, Table 1) showed a vertical upward displacement of the anterior mandible 1-year post surgery. Ten patients (Group D, 7 men and 3 women; mean age, 20.5 ± 1.8 y, Table 1) exhibited a vertical downward displacement of the anterior mandible exceeding 2mm 1-year post surgery (Figure 1, B). Twenty-four patients in Group U were selected based on the absence of significant differences in preoperative ANB and SN-MP values compared to the ten patients in Group D, ensuring no horizontal or vertical skeletal discrepancies between the two groups prior to surgery.

There were no significant between-group differences in the sample characteristics in terms of sex, age, or postoperative treatment period. The mean vertical displacement of the B-point 1-year post surgery was 1.5 mm (SD, 1.2 mm) upward in Group U and 4.7 mm (SD, 1.9 mm) downward in Group D. There was a significant difference in the vertical displacement of B-point 1-year post surgery between the two groups ($p < 0.001$).

Table 1. Sample Characteristics

Variable	Group U (*n* = 24)	Group D (*n* = 10)	*p* value
Sex, *n* (%)			0.270 [a]
Men	11 (45.8)	7 (70.0)	
Women	13 (54.2)	3 (30.0)	
Age (y)			
Mean ± SD	20.9 ± 2.9	20.5 ± 1.8	0.926 [b]
Postoperative treatment period (m)			
Mean ± SD	12.8 ± 7.9	13.1 ± 4.5	0.322 [b]

Abbreviations: Group U, upward displacement group; Group D, downward displacement group.
[a] The *p* value was calculated using the Fisher exact *t*-test.
[b] The *p* value was calculated using the independent *t*-test.

2. Observation at the initial examination

Meaningful between-group cephalometric differences (defined as $p < 0.05/6$) were observed in OB at the initial examination (Table 2). The mean OBs were 1.3 mm (SD, 2.8 mm) in Group U and -1.6 mm (SD, 2.5 mm) in Group D ($p = 0.007$), indicating that Group D had a shallower anterior overbite.

Table 2. Comparison of cephalometric measurements at initial examination between groups

T1	Group U	Group D	*p* value
Linear measurements (mm)			
A[X]	67.9 ± 5.6	70.6 ± 4.0	0.169
B[X]	71.4 ± 8.0	73.9 ± 9.4	0.427
A[Y]	67.5 ± 4.0	66.8 ± 3.4	0.642
B[Y]	115.1 ± 7.7	122.5 ±7.2	0.014
U1[Y]	92.4 ± 5.5	93.4 ± 5.0	0.614
U6[Y]	81.5 ± 2.2	84.0 ± 5.8	0.219
OJ	-2.0 ± 3.3	-2.3 ± 4.0	0.826
OB	1.3 ± 2.8	-1.6 ± 2.5	0.007†
Menton deviation	5.1 ± 3.9	4.9 ± 3.9	0.904
Angular measurements (º)			
SNA	79.8 ± 4.5	81.7 ± 4.3	0.267
SNB	82.8 ± 3.3	83.8 ± 5.0	0.521
ANB	-3.0 ± 3.5	-2.1 ± 2.3	0.441
SN-PP	10.4 ± 3.3	8.2 ± 2.7	0.068
SN-MP	34.4 ± 6.2	37.5 ± 3.5	0.137
U1-SN	108.6 ± 6.8	113.6 ± 7.2	0.062
IMPA	80.8 ± 8.6	83.7 ± 6.4	0.347

Note: Data are presented as mean ± deviation. Group comparisons were tested using the independent *t*-test or Mann–Whitney *U* test with Bonferroni correction.

Abbreviations: Group U, upward displacement group; Group D, downward displacement group. A[X], horizontal position of point A; B[X], horizontal position of point B; A[Y], vertical position of point A; B[Y], vertical position of point B; U1[Y], vertical position of upper central incisor; U6[Y], vertical position of upper first molar; OJ, Subtract distance of L1 from U1 parallel to OP; OB, Subtract distance of L1 from U1 perpendicular to OP; Asymmetry, amount of menton deviation; SNA, angle of lines formed by the S,N, and point A; SNB, angle of lines formed by the S.N, and point B; ANB, angle of lines formed by point A, the N, and point B; SN-PP, angle between the SN plane and the palatal plane; SN-MP, angle between the SN plane and the mandibular plane; U1-SN, angle of the SN plane to the upper incisor; IMPA, angle of the mandibular plane to the lower incisor; T1. 1 month before surgery.

† $p < 0.05/6$, significant difference between groups by independent *t*-test or Mann-Whiteny *U* test.

‡ $p < 0.001$, significant difference between groups by independent *t*-test or Mann-Whiteny *U* test.

3. Observation 1 day after surgery

The mean surgical movements at point A were 0.1 mm (SD, 3.1 mm) posteriorly and 0.8 mm (SD, 2.6 mm) superiorly in Group U, while the corresponding values were 2.3 mm (SD, 3.1 mm) posteriorly and 1.7 mm superiorly (SD, 2.4 mm) in Group D (Table 3). The differences in the horizontal and vertical surgical change of point A between the two groups were not statistically significant ($p > 0.05/6$).

The mean surgical movement at point B was 9.3 mm (SD, 4.9 mm) posteriorly ($p < 0.001$) and 0.9 mm (SD, 3.8 mm) inferiorly in Group U, while the corresponding values were 10.6 mm (SD, 6.5 mm) posteriorly ($p < 0.05/6$) and 4.6 mm (SD, 3.3 mm) superiorly ($p < 0.05/6$) in Group D (Table 3). There was a statistically significant difference in the vertical surgical change of point B between the two groups ($p < 0.001$), indicating that Group D had more upward movement of the anterior mandible compared to Group U during surgery.

Table 3. Comparison of surgical changes in cephalometric measurements between groups

T2-T1	Group U	Group D	*p* value
Linear measurements (mm)			
A[X]	-0.1 ± 3.1	-2.3 ± 3.1	0.066
B[X]	-9.3 ± 4.9**	-10.6 ± 6.5*	0.525
A[Y]	-0.8 ± 2.6	-1.7 ± 2.4	0.353
B[Y]	0.9 ± 3.8	-4.6 ± 3.3*	0.000‡
U1[Y]	0.5 ± 2.2	-1.0 ± 2.0	0.071
U6[Y]	-3.1 ± 2.2**	-3.8 ± 3.2*	0.461
OJ	6.2 ± 3.9**	7.0 ± 3.9**	0.583
OB	-0.5 ± 2.4	1.7 ± 2.5	0.025
Menton deviation	4.8 ± 3.9**	5.1 ± 3.6*	0.865
Angular measurements (º)			
SNA	-0.1 ± 3.0	-2.2 ± 3.1	0.083
SNB	-4.5 ± 2.6**	-5.1 ± 3.0*	0.623
ANB	4.4 ± 3.5**	2.9 ± 3.2*	0.244
SN-PP	4.4 ± 3.4**	3.7 ± 2.9*	0.601
SN-MP	4.0 ± 3.8**	0.7 ± 4.0	0.031
U1-SN	-3.6 ± 5.3*	-2.7 ± 6.7	0.678
IMPA	1.7 ± 3.0*	0.5 ± 2.4	0.264

Note: Data are presented as mean ± deviation. Positive and negative values indicate anterior and posterior horizontal changes, respectively; inferior and superior vertical changes, respectively; or increased or decreased dimensional changes, respectively. Group comparisons were tested with independent *t*-test or Mann–Whitney *U* test with Bonferroni correction.

Abbreviations: Group U, upward displacement group; Group D, downward displacement group. A[X], horizontal position of point A; B[X], horizontal position of point B; A[Y], vertical position of point A; B[Y], vertical position of point B; U1[Y], vertical position of upper central incisor; U6[Y], vertical position of upper first molar; OJ, Subtract distance of L1 from U1 parallel to OP; OB, Subtract distance of L1 from U1 perpendicular to OP; Asymmetry, amount of menton deviation; SNA, angle of lines formed by the S,N, and point A; SNB, angle of lines formed by the S.N, and point B; ANB, angle of lines formed by point A, the N, and point B; SN-PP, angle between the SN plane and the palatal plane; SN-MP, angle between the SN plane and the mandibular plane; U1-SN, angle of the SN plane to the upper incisor; IMPA, angle of the mandibular plane to the lower incisor; T1, 1 month before surgery; T2, 1 day after surgery.

* $p < 0.05/6$, significant difference between T1 and T2 by paired *t*-test or Wilcoxon signed rank test.
** $p < 0.001$, significant difference between T1 and T2 by paired *t*-test or Wilcoxon signed rank test.
† $p < 0.05/6$, significant difference between groups by independent *t*-test or Mann-Whiteny *U* test.
‡ $p < 0.001$, significant difference between groups by independent *t*-test or Mann-Whiteny *U* test.

4. Observation 1 month after surgery

At 1 month after surgery, point A was found to shift 0.3 mm (SD, 1.2 mm) anteriorly and 0.1mm (SD, 2.3 mm) superiorly in Group U, while it was found to shift 0.3 mm (SD, 1.3 mm) anteriorly and 0.1 mm (SD, 1.7 mm) superiorly in Group D (Table 4). These changes did not differ significantly between the two groups. However, point B shifted 1.8 mm (SD, 2.5mm) posteriorly ($p < 0.05/6$) and 0.3mm (SD, 2.0 mm) inferiorly in Group U, while it shifted 1.8 mm (SD, 2.1 mm) posteriorly and 2.8 mm (SD, 0.9 mm) inferiorly ($p < 0.001$) in Group D (Table 4). The vertical change of the B-point 1-month post-surgery differed significantly between the groups ($p < 0.001$), indicating that immediate downward displacement of the anterior mandible occurred after surgery in Group D. No meaningful between-group differences were observed for the angular measurements.

Table 4. Comparison of immediate postoperative changes in cephalometric measurements between groups

T3-T2	Group U	Group D	*p* value
Linear measurements (mm)			
A[X]	0.3 ± 1.2	0.3 ± 1.3	0.929
B[X]	-1.8 ± 2.5*	-1.8 ± 2.1	0.940
A[Y]	-0.1 ± 2.3	-0.1 ± 1.7	0.944
B[Y]	0.3 ± 2.0	2.8 ± 0.9**	0.000‡
U1[Y]	0.2 ± 1.2	0.6 ± 0.7	0.287
U6[Y]	-0.6 ± 1.1	-0.9 ± 1.7	0.616
OJ	0.2 ± 1.0	-0.7 ± 1.4	0.046
OB	-0.3 ± 1.3	-0.6 ± 1.3	0.556
Menton deviation	0.5 ± 0.5	0.4 ± 0.2	0.363
Angular measurements (º)			
SNA	0.5 ± 1.4	0.6 ± 1.4	0.912
SNB	-0.7 ± 1.4	-0.7 ± 1.1	0.931
ANB	1.2 ± 1.2**	1.3 ± 1.7	0.845
SN-PP	-0.2 ± 3.0	0.6 ± 2.1	0.454
SN-MP	2.6 ± 1.6**	4.1 ± 1.8**	0.026
U1-SN	-1.1 ± 3.2	-2.4 ± 3.9	0.327
IMPA	-1.0 ± 3.6	-2.1 ± 2.7	0.413

Note: Data are presented as mean ± deviation. Positive and negative values indicate anterior and posterior horizontal changes, respectively; inferior and superior vertical changes, respectively; or increased or decreased dimensional changes, respectively. Group comparisons were tested with independent *t*-test or Mann–Whitney *U* test with Bonferroni correction.

Abbreviations: Group U, upward displacement group; Group D, downward displacement group. A[X], horizontal position of point A; B[X], horizontal position of point B; A[Y], vertical position of point A; B[Y], vertical position of point B; U1[Y], vertical position of upper central incisor; U6[Y], vertical position of upper first molar; OJ, Subtract distance of L1 from U1 parallel to OP; OB, Subtract distance of L1 from U1 perpendicular to OP; Asymmetry, amount of menton deviation; SNA, angle of lines formed by the S,N, and point A; SNB, angle of lines formed by the S.N, and point B; ANB, angle of lines formed by point A, the N, and point B; SN-PP, angle between the SN plane and the palatal plane; SN-MP, angle between the SN plane and the mandibular plane; U1-SN, angle of the SN plane to the upper incisor; IMPA, angle of the mandibular plane to the lower incisor; T2, 1 day after surgery; T3, 1 month after surgery.

* $p < 0.05/6$, significant difference between T2 and T3 by paired *t*-test or Wilcoxon signed rank test.
** $p < 0.001$, significant difference between T2 and T3 by paired *t*-test or Wilcoxon signed rank test.
† $p < 0.05/6$, significant difference between groups by independent *t*-test or Mann-Whiteny *U* test.
‡ $p < 0.001$, significant difference between groups by independent *t*-test or Mann-Whiteny *U* test.

5. Observation 1 year after surgery

Lastly, at 1 year after surgery, point A shifted 0.8 mm (SD, 1.1 mm) posteriorly ($p < 0.05/6$) and 0.5 mm (SD, 1.9 mm) superiorly in Group U, while it shifted 0.4 mm (SD, 1.4 mm) posteriorly and 0.2 mm (SD, 1.3 mm) inferiorly in Group D (Table 5). There were no significant differences in the horizontal and vertical displacement of point A 1-year post surgery between the groups. However, point B shifted 1.3 mm (SD, 2.5 mm) posteriorly and 1.5mm (SD, 1.2 mm) superiorly ($p < 0.001$) in Group U, while it shifted 1.2 mm (SD, 2.7 mm) posteriorly and 4.7 mm (SD, 1.9 mm) inferiorly ($p < 0.001$) in Group D (Table 5). The vertical change in point B 1-year post surgery showed statistically significant differences between the two groups ($p < 0.001$), indicating that Group D had downward displacement of the anterior mandible, compared to the upward displacement of the anterior mandible in Group U (Figure 3).

In both groups, the SN-MP angle increased significantly ($p < 0.001$), and there was a significant difference between the two groups ($p < 0.001$), indicating more clockwise rotation of the mandible in Group D.

Table 5. Comparison of final postoperative changes in cephalometric measurements between groups

T4-T2	Group U	Group D	*p* value
Linear measurements (mm)			
A[X]	-0.8 ± 1.1*	-0.4 ± 1.4	0.471
B[X]	-1.3 ± 2.5	-1.2 ± 2.7	0.879
A[Y]	-0.5 ± 1.9	0.2 ± 1.3	0.284
B[Y]	-1.5 ± 1.2**	4.7 ± 1.9**	0.000‡
U1[Y]	0.3 ± 1.6	1.6 ± 1.8	0.050
U6[Y]	-0.8 ± 1.2*	-0.4 ± 1.7	0.422
OJ	-0.1 ± 1.5	-1.5 ± 2.2	0.049
OB	1.2 ± 1.6*	0.6 ± 1.6	0.385
Menton deviation	0.7 ± 0.5	0.5 ± 0.3	0.227
Angular measurements (º)			
SNA	-0.7 ± 1.2*	-0.8 ± 1.8	0.913
SNB	-0.7 ± 1.3	-0.8 ± 1.6	0.901
ANB	0.0 ± 1.2	0.0 ± 1.2	0.986
SN-PP	0.3 ± 2.1	0.1 ± 1.8	0.771
SN-MP	2.1 ± 2.0**	6.1 ± 3.0**	0.000‡
U1-SN	1.1 ± 5.2	-1.5 ± 5.1	0.193
IMPA	0.6 ± 5.5	-2.1 ± 3.8	0.179

Note: Data are presented as mean ± deviation. Positive and negative values indicate anterior and posterior horizontal changes, respectively; inferior and superior vertical changes, respectively; or increased or decreased dimensional changes, respectively. Group comparisons were tested with independent *t*-test or Mann–Whitney *U* test with Bonferroni correction.

Abbreviations: Group U, upward displacement group; Group D, downward displacement group. A[X], horizontal position of point A; B[X], horizontal position of point B; A[Y], vertical position of point A; B[Y], vertical position of point B; U1[Y], vertical position of upper central incisor; U6[Y], vertical position of upper first molar; OJ, Subtract distance of L1 from U1 parallel to OP; OB, Subtract distance of L1 from U1 perpendicular to OP; Asymmetry, amount of menton deviation; SNA, angle of lines formed by the S,N, and point A; SNB, angle of lines formed by the S.N, and point B; ANB, angle of lines formed by point A, the N, and point B; SN-PP, angle between the SN plane and the palatal plane; SN-MP, angle between the SN plane and the mandibular plane; U1-SN, angle of the SN plane to the upper incisor; IMPA, angle of the mandibular plane to the lower incisor; T2, 1 day after surgery; T4, 1 year after surgery.

* $p < 0.05/6$, significant difference between T2 and T4 by paired *t*-test or Wilcoxon signed rank test.
** $p < 0.001$, significant difference between T2 and T4 by paired *t*-test or Wilcoxon signed rank test.
† $p < 0.05/6$, significant difference between groups by independent *t*-test or Mann-Whiteny *U* test.
‡ $p < 0.001$, significant difference between groups by independent *t*-test or Mann-Whiteny *U* test.

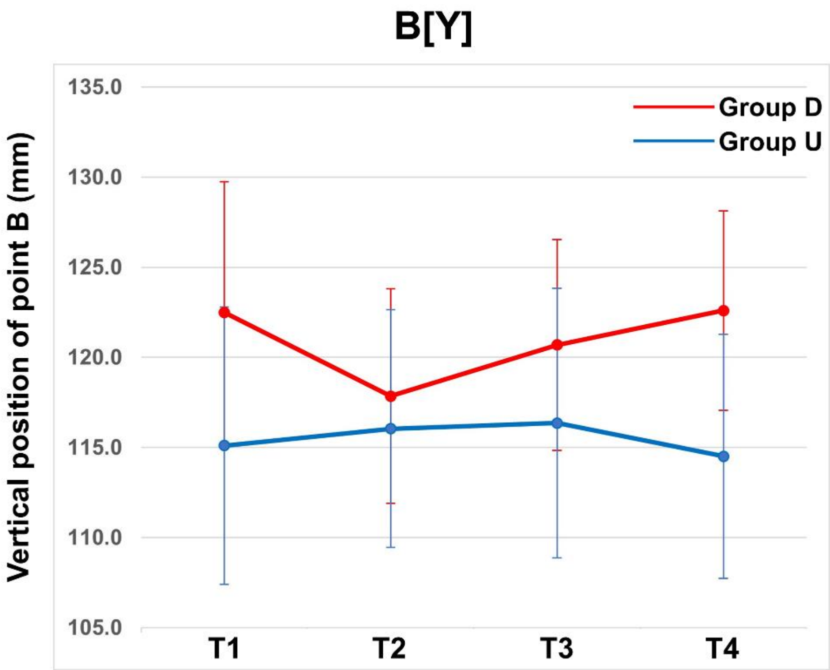

Figure 3. Vertical position of point B in the 2 groups at different time points. B[Y], vertical position of point B; T1, 1 month before surgery; T2, 1 day after surgery; T3, 1 month after surgery; T4, 1 year after surgery.

6. Correlation between postoperative vertical displacement of mandible and variables

At both 1-month and 1-year post surgery, the results of the analysis showed a moderate-to-strong correlation ($r > 0.40$) between postoperative vertical displacement of the anterior mandible and B[Y] and OB at initial examination, surgical vertical movement of the B-point, and surgical change of OB and SN-MP angle (Table 6). In terms of Pearson correlation coefficient, the highest correlation was seen between both 1-month ($r = -0.604$, $p < 0.001$) and 1-year ($r = -0.674$, $p < 0.001$) postoperative vertical displacement of the anterior mandible and surgical vertical movement of the B-point.

Five significant variables (B[Y] and OB at initial examination, surgical vertical movement of B-point, and surgical change of OB and SN-MP angle) that showed moderate-to-strong correlation were included in the multiple regression analysis. In the final model, only surgical vertical movement of the B-point was included at both 1-month ($R^2 = 0.364$; $p < 0.001$) and 1-year post surgery ($R^2 = 0.449$; $p < 0.001$), and showed a linear relationship (Figure 4).

Table 6. Correlation between postoperative vertical relapse and variables

	B[Y](T3-T2) (mm)		B[Y](T4-T2) (mm)	
	r	*p* value	*r*	*p* value
B[Y] (T1) (mm)	0.544	0.001	0.424	0.013
OB (T1) (mm)	-0.538	0.001	-0.487	0.004
B[Y] (T2 – T1) (mm)	-0.604	< 0.001	-0.674	< 0.001
OB (T2 – T1) (mm)	0.558	0.001	0.440	0.009
SN-MP (T2 - T1) (º)	-0.556	0.001	-0.415	0.015

Abbreviations: B[Y], vertical position of point B; OB, Subtract distance of L1 from U1 perpendicular to OP; A[X], horizontal position of point A; SN-MP, angle between the SN plane and the mandibular plane; *r*, Pearson correlation coefficient; T1, 1 month before surgery; T2, 1 day after surgery; T3, 1 month after surgery; T4, 1 year after surgery.

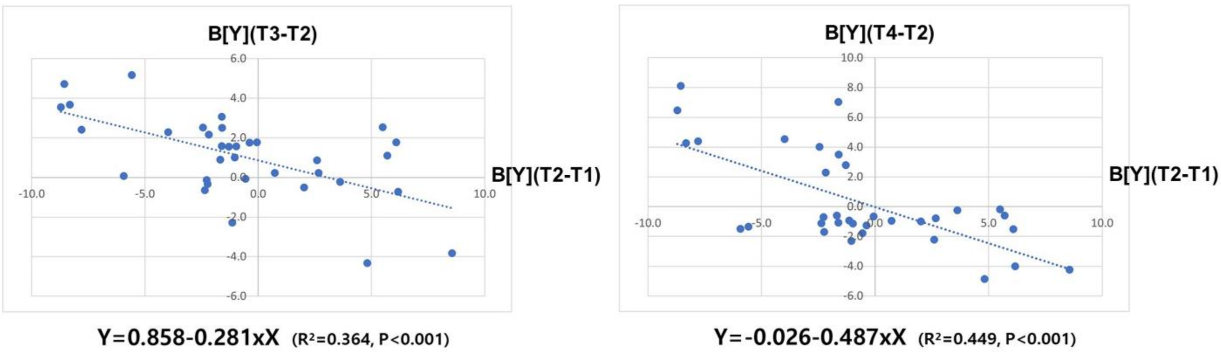

Figure 4. Associations between the amount of vertical change of point B during surgery and the amount of immediate, final postoperative vertical change of point B, respectively. Best-fit lines with determinant coefficient; R^2 from multiple linear regression analysis. B[Y], vertical position of point B; T1, 1 month before surgery; T2, 1 day after surgery; T3, 1 month after surgery; T4, 1 year after surgery.

IV. Discussion

The aim of this study was to identify factors related to downward displacement of the anterior mandible exceeding 2 mm 1-year after the surgery-first approach using IVRO, focusing on cephalometric values. Additionally, we determined that a negative correlation exists between the amount of surgical vertical movement of anterior mandible and postoperative vertical displacement of anterior mandible. Although the downward displacement of the anterior mandible after surgery-first approach with IVRO is uncommon, when it does occur, it can present challenges for orthodontists during the postoperative orthodontic period. Therefore, investigating the factors related to this atypical downward displacement of the anterior mandible after surgery could enhance the predictability of postoperative mandibular changes, providing clinicians with an advantage when planning surgery and postoperative orthodontic treatment.

Previous studies have evaluated the changes occurring after the surgery-first approach using IVRO, with their results confirming its stability even in cases with asymmetry (Guo et al., 2018; Hwang et al., 2020) or according to the facial vertical pattern (Choi et al., 2016a). Choi et al. (Choi et al., 2016b; Choi et al., 2016c) reported that 1 year after surgery, the vertical displacement of the B-point was -1.9 ± 2.0 mm; Kim et al. (Kim et al., 2014) reported a corresponding value of -2.86 ± 1.39 mm, while Jeong et al. (Jeong et al., 2018) reported a corresponding value of -0.6 ± 1.0 mm. Immediately after the surgery-first approach with IVRO, which does not implement rigid fixation between the proximal and distal segments, the distal segment may rotate clockwise and the anterior mandible may shift downward. However, once the mandible achieves union between segments and premature occlusal contacts are eliminated during postoperative orthodontic treatment, along with rehabilitation of the pterygomasseteric sling, an upward displacement of the anterior mandible of approximately 0-2 mm is observed, which leads to a stable outcome (Choi et al., 2016b; Choi et al., 2016c). While almost all patients followed this typical movement pattern, there were some cases in which patients exhibited an atypical downward displacement of anterior mandible from immediately after the surgery up to 1 year post-operatively, thus resulting in a clinical presentation of overbite relapse. These instances required additional efforts from the orthodontist to stabilize the post-surgical occlusion. Despite representing a small minority of cases, these atypical movements posed significant stressors for the orthodontist. Identifying the characteristics of these patients and defining at-risk groups could allow for more predictable outcomes of the surgery-first approach with IVRO. Therefore, the present study intended to identify factors related to downward displacement of the anterior mandible 1 year after the surgery-first approach with IVRO, with the ultimate aim of enhancing the predictability. Traditionally, any movement exceeding 2 mm post-surgical healing is considered to be significant (Proffit et al., 2007); therefore, this study labeled patients who showed more than 2 mm of anterior mandibular downward displacement 1-year post-surgery as vertically unstable and evaluated the factors related to this group. We found that the surgical vertical movement of the B-point is the most statistically important factor affecting the 1-year postoperative downward displacement of the B-point after the surgery-first approach with IVRO.

At the initial examination, Group D showed a shallower anterior overbite with openbite of 1.6 mm. An anterior openbite can occur as a result of vertical skeletal patterns of either posterior downward rotation of the maxilla or clockwise rotation of the mandible (Proffit et al., 2000). However, there were no significant differences in the SN-PP and SN-MP angles between the groups at the initial examination, confirming that there were no differences in vertical facial patterns such as dolichofacial or brachyfacial between the groups. Further, although not statistically significant, it was observed that the vertical value of the mandibular B-point was greater by 7.4 mm in Group D, indicating a longer anterior facial height pre-surgery.

1 day after the surgery, the amount of posterior superior movement of the maxilla was approximately the same for both groups; however, in Group D, the vertical movement of the anterior mandible was significantly greater by 5.5 mm upward. Although not statistically significant, the anterior overbite in Group D was increased 2.2 mm greater than that in Group U. The greater surgical changes in the vertical position of the B-point and anterior overbite in Group D can be attributed to the fact that Group D had greater B[Y] values and smaller OB values at the initial examination, requiring greater surgical correction. Further, while not statistically significant, the mandible in Group U rotated more clockwise compared to Group D, ultimately resulting in a larger increase in the SN-MP value.

1 month after surgery, the mandible's B-point in Group U showed a significant downward displacement of 2.8 mm compared to immediately post-surgery. Although not statistically significant, Group D exhibited more clockwise rotation of the mandible, while the anterior overjet decreased in a manner that was different than that shown in Group U. This pattern persisted until 1 year after the surgery, at which point it was confirmed that the B-point of the mandible in Group D had shifted downward by 4.7 mm, the mandible had rotated clockwise by 6.1° and the anterior overjet had decreased by 1.5 mm compared to 1-day post-surgery. Choi et al. (Choi et al., 2016b; Choi et al., 2016c), Ahn et al. (Ann et al., 2016), and Jeong et al. (Jeong et al., 2018) reported that after IVRO, mandibular clockwise rotation occurs; however, in the case of a surgery-first approach, compensatory counter-clockwise rotation of the mandible, particularly the distal segment, occurs as premature occlusal contact disappears, and the masticatory muscles recover during the postoperative orthodontic period (Choi et al., 2016b; Choi et al., 2016c). As a result, primarily upward displacement of the mandible is observed compared to the immediate postoperative state. In the case of Group D in this study, significant clockwise rotation of the mandible occurred along with a downward displacement of

more than 2 mm 1 year after surgery, despite the surgery-first approach. Additionally, the anterior overjet showed a decreasing trend in Group D during the postoperative period, suggesting that the center of rotation of the mandible is located between the central and anterior parts of the mandible body. Nihara et al. (Nihara et al., 2013) discussed the adaptive rotation of the mandible following IVRO due to the pulling force of the masticatory muscles but found it difficult to define a specific point for the center of adaptive rotation, as it is broadly located between the coronoid process and the menton. In the current study, the patients in Group D showed significant upward movement of the anterior mandible during surgery, and the subsequent considerable downward displacement during the postoperative period affected the shifting of the center of rotation forward, which likely contributed to the reduction in anterior overjet during clockwise rotation. Efforts to resolve this decreased anterior overjet during the postoperative orthodontic treatment were evident from the decrease in IMPA in Group D 1-year post-surgery, although this was not statistically significant.

1 month and 1 year postoperatively, five variables (B[Y] and OB at initial examination, surgical vertical movement of B-point, and surgical change of OB and SN-MP angle) demonstrated a moderate-to-strong correlation with the downward displacement of the mandible's B-point, but the results of multiple regression analysis revealed that only the surgical vertical movement of B-point exhibited a significant association and a linear relationship. Similarly, Choi et al. (Choi et al., 2016b) confirmed that an extensive upward movement of B-point during surgery is associated with a considerable postoperative downward displacement of B-point 1 year later. Clinically, a vertical downward movement exceeding 2 mm is considered significant. Based on the regression equations derived from the multiple regression analysis (Figure 4. 1-month post surgery: Y=0.858-0.281xX, 1-year post surgery: Y=-0.026-0.487xX), this study suggests that, when the surgical upward movement of B-point exceeds 4 mm, vertical downward displacement of anterior mandible should be antici-

pated and monitored carefully. In practice, while the orthodontist faced challenges during postoperative orthodontic treatment in Group D, the use of TADs expanded the scope of orthodontic treatment, and the final treatment outcomes of Group D were comparable to those of patients in Group U. However, if a surgery-first approach using IVRO anticipates an upward movement of the anterior mandible exceeding 4 mm for correction of a longer anterior facial height or shallow anterior overbite at initial examination, it is prudent to prepare for an atypical downward displacement of anterior mandible. Orthodontists should be prepared for this possibility, and it may be advisable to inform patients about the potential for a prolonged postoperative orthodontic period and the possibility of additional surgery.

This study is the first to identify the factors related to downward displacement of the anterior mandible 1-year after the surgery-first approach using IVRO, and it has a specific focus on cephalometric values. The limitations of this study include its retrospective nature and the short duration of the postoperative observation period. Additionally, although there are studies reporting stable outcomes when the surgery-first approach is performed on patients with facial asymmetry (Guo et al., 2018; Hwang et al., 2020), these studies involved SSRO. In contrast, this study utilized IVRO, and therefore, the potential impact of facial asymmetry on postoperative stability was not considered, which is a limitation of this study. Moreover, despite calculating the sample size, the number of samples remains small. In future research, it would be beneficial to increase the number of samples if similar results are observed in other patients, and it would also be useful to conduct studies that include longer-term follow-up periods.

V. Conclusion

Most patients who underwent the surgery-first approach using IVRO exhibited the upward displacement of the anterior mandible 1 year postoperatively, resulting in a stable outcome. However, some patients showed downward displacement of the anterior mandible up to 1-year post-surgery, which posed challenges for orthodontists in stabilizing the occlusion during the postoperative orthodontic period. The findings in this study revealed that such downward displacement of the anterior mandible occurred with mandibular clockwise rotation after a surgery-first approach using IVRO and is correlated with the amount of upward movement of anterior mandible during the surgery. If a significant upward movement of the anterior mandible is anticipated while planning surgery, orthodontists should prepare for the possibility of subsequent atypical anterior openbite tendency during the postoperative orthodontic period. Also, it may be advisable to inform patients about the potential for a prolonged postoperative orthodontic period and the possibility of additional surgery.

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국문 요약

구내 수직 하악지 골절단술을 동반한 선수술에서 수술 후 하악골 전방부의 하방 이동에 연관된 요인

(지도교수: 유 형 석)

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남 수 현

구내 수직 하악지 골절단술을 동반한 선수술을 시행한 일부 환자에서 수술 후 1년까지 하악골 전방부의 하방 이동이 나타나며, 이는 수술 후 교정 치료 기간 동안 교정의사가 교합을 안정시키는 데 어려움을 초래할 수 있다. 본 연구의 목적은 구내 수직 하악지 골절단술을 이용한 선수술 후 1년째 나타나는 하악골 전방부의 하방 이동

에 연관된 요인을 두개계측치에 중점을 두고 규명하는 것이다.

이 후향적 코호트 연구에서는 수술 후 1년째 B점의 수직 이동량을 기준으로 두 그룹으로 나누었다 (그룹 U: 상방 이동, 그룹 D: 2 mm 이상의 하방 이동). 두 그룹 간의 두개계측 변화를 평가하기 위해 수술 전, 수술 후 1일, 수술 후 1개월, 수술 후 1년의 두부방사선사진을 획득하였다. 데이터는 독립 *t*-검정, Mann-Whitney *U* 검정 (Bonferroni 보정 포함), Pearson 상관 분석, 다중 회귀 분석을 사용하여 분석하였다.

초기 검사에서 그룹 D는 얕은 전치부 수직피개를 보였다. B점의 수직적 수술 변화는 두 그룹 간에 통계적으로 유의미한 차이를 보였으며 (p < 0.001), 그룹 D는 수술 중 하악골 전방부가 더 상방 이동하는 경향을 보였다. 그룹 D는 수술 후 1개월째 하악골 전방부의 유의미한 하방 이동을 보였으며, 이 소견은 수술 후 1년까지 지속되었다. 또한, 하악골의 시계방향 회전이 관찰되었다. B점의 수직적 수술 변화는 수술 후 하악골 전방부의 수직적 이동과 강한 상관관계를 나타냈으며 ($r = -0.674$; $p <$ 0.001), 선형 관계를 통해 B점의 상방 수술 이동량이 증가할수록 하악골 전방부의 수술 후 수직적 하방 이동량이 증가함을 알 수 있었다 ($R^2 = 0.449$; $p < 0.001$).

본 연구는 구내 수직 하악지 골절단술을 이용한 선수술 후 하악골 전방부의 하방

이동이 수술 중 상방 이동량과 상관관계가 있음을 밝혀냈다. 수술 계획 시, 하악골 전방부의 상당한 상방 이동이 예상되는 경우 교정의사는 수술 후 하악골 전방부의 하방 이동 가능성에 대비해야 한다.

핵심이 되는 말: 선수술, 구내 수직 하악지 골절단술, 안정성, 하악골 하방 이동