2022년 2월
석사학위 논문

Vertical bony step between proximal and distal segments after mandibular setback affects relapse: A cone-beam computed tomographic study

조선대학교 대학원

치의학과

Myagmarsuren Batbold

Vertical bony step between proximal and distal segments after mandibular setback affects relapse: A cone-beam computed tomographic study

하악 후퇴술 시 근·원심 골편 하연의 높이 차이가 재발에 미치는 영향

2022년 2월 25일

조선대학교 대학원

치 의 학 과

Myagmarsuren Batbold

Vertical bony step between proximal and distal segments after mandibular setback affects relapse: A cone-beam computed tomographic study

지도교수 임 성 훈

이 논문을 치의학 석사학위 신청 논문으로 제출함

2021년 10월

조선대학교 대학원

치 의 학 과

Myagmarsuren Batbold

Myagmarsuren Batbold의
석사학위 논문을 인준함

위원장 조선대학교 교 수 오 지 수 (인)

위 원 조선대학교 교 수 정 서 린 (인)

위 원 조선대학교 교 수 임 성 훈 (인)

2021년 12월

조선대학교 대학원

Contents

List of Tables

List of Figures

초록

하악 후퇴술 시 근·원심 골편 하연의 높이 차이가 재발에 미치는 영향

막머르수렝 바트벌드
지도교수: 임성훈, 치의학박사
조선대학교 대학원 치의학과

연구목적: 양측 하악 상행지 시상분할 골절단술을 이용한 하악 후퇴 수술 시 근·원심 골편 하연의 높이 차이(vertical bony step, VBS)가 발생한다. 이 연구의 목적은 3차원 콘빔 컴퓨터 토모그래프(cone-beam computed tomography, CBCT)를 이용하여 VBS가 하악 후퇴의 재발과 관련이 있는지 알아보는 것이었다.
재료 및 방법: 피험자는 양측 시상분할 골절단술을 이용한 하악 후퇴 수술을 받은 30명의 환자로 구성되었다. 18명의 환자가 양악 수술을 받았고 12명의 환자는 하악 편악 수술을 받았다. 치료 전(T0), 수술 직후(T1), 치료 종료 후(T2)에 촬영한 CBCT에서 치료 변화를 계측하였으며, 계측치들 간의 상관관계를 평가했다.
결과: 하악 후퇴량은 평균 -11.9mm였으며, VBS 발생량은 평균 -5.6mm였다. 하악 후퇴의 재발은 수술 시(T1-T0)의 계측치 중에서는 하악 후퇴량, VBS의 발생량, 근심 골편의 후방 이동량과 상관관계가 있었으며, 수술 후 교정치료 동안(T2-T1)의 계측치 중에서는 하악결합의 반시계 방향 회전량 및 VBS의 해소량과 상관관계가 있었다.
결론: VBS의 발생량 및 해소량이 하악 후퇴의 재발과 상관관계를 보였다. 하악 후퇴의 재발을 줄이기 위해 VBS를 최소화하는 것이 바람직하다.

I. INTRODUCTION

Mandibular setback is usually performed along the occlusal plane unless the maxillary occlusal plane is changed. The normal occlusomandibular plane angle has been reported to be 17° ± 6.2°.[1] The angular difference between the mandibular setback plane and mandibular plane naturally causes the a vertical bony step (VBS) between the proximal segment (PS) and distal segment (DS) of the mandible during mandibular setback using a bilateral sagittal split ramus osteotomy (BSSRO) (Fig 1 A and B). The VBS might not occur if the occlusomandibular plane angle is zero and the mandible is setback along the mandibular plane. VBS increases as the occlusomandibular plane angle increases.

An anteroposterior relapse of 20 - 55% was reported with mandibular setback.[2–10] A positive correlation between the clockwise (CW) rotation of the PS and the mandibular setback has been reported.[8] The PS can be intentionally rotated CW to level the lower borders or the PS and DS of the mandible[10] (Fig 1C). It has been suggested that surgically induced CW rotation of the PS may be caused by the increased backward force of soft tissue related to the mandibular setback movement.[5,11–13] This means there might be an unintentional CW rotation of the PS during surgery. The lengthening of the pterygomasseteric sling that results from the CW rotation of the PS during mandibular setback tends to return the PS to its original position, leading to a relapse[5,8,9,11,14–16] (Fig 1 C and D). The relationship between the VBS and CW rotation of the PS, and the contribution of this CW rotation of the PS to an anteroposterior relapse of the mandibular setback has already been reported;[10] however, the focus of the previous study[10] was on the CW rotation of PS during surgery, so the direct relationship between the VBS and relapse was not elucidated. Also, the previous study[10] was done using 2-dimensional lateral cephalometric radiographs, making an exact determination of the VBS difficult.

The purpose of this study was to investigate whether VBS is correlated with the relapse of mandibular setback using 3-dimensional models constructed from cone-beam computed tomography (CBCT). The null hypothesis was that there is no correlation between VBS and the relapse of mandibular setback.

II. MATERIALS AND METHODS

Data collection

Thirty sets of CBCT data were collected retrospectively from a large artificial intelligence study data. The data came from 18 patients at Kyung Hee University, 6 patients at Chosun University, 2 patients at Ewha Woman’s University, 3 patients at Chonnam National University, 1 patient at Korea University. Patients ranged in age from 16 to 39 years, with a mean age of 22.3 ± 5.0 years. The presurgical and postsurgical orthodontic treatment duration was 11.9 ± 7.4 and 14.8 ± 8.7 months, respectively. The average overall treatment duration (T2-T0) was 26.6 ± 9.1 months. The study protocol was reviewed and approved by the institutional review boards of KHUDH (D19-007-003), CSUDH (CUDHIRB 1901 005), EUMC (EUMC 2019-04-017-003), CNUDH (CNUDH-2019-004), KUAH (2019AN0166).

Inclusion criteria were as follows: 1) Presence of pretreatment (T0), postsurgery (T1), and posttreatment (T2) CBCTs. Postsurgery CBCTs were taken within one month after surgery. 2) No other surgeries such as genioplasty or bone contouring except for BSSRO and Le Fort I osteotomy. 3) Mandibular setback greater than 5 mm.

Exclusion criteria were as follows: 1) Presence of congenital abnormalities including cleft lip and palate. 2) Asymmetry of the pogonion greater than 5 mm. 3) More than 1.2 mm of anterior open bite or open bite of second molar at postsurgery CBCT. 4) Superior movement of the mandibular border of the distal segment during surgery resulting in reverse VBS. 5) Surgery-first approach cases.

Bite opening during surgery to ensure sufficient thickness of the surgical splint can cause postsurgical autorotation of the mandible at the time of removal of the surgical splint. Because this mandibular autorotation should be separated from the postsurgical forward rotation of mandible related to the true relapse of mandibular setback accompanied by tooth movements, cases with an anterior or posterior open bite of more than 1.2 mm at T1 were excluded. In the present sample, the anterior overbite was 1.2 ± 1.1 mm, and the bite opening of the second molar was 0.4 ± 0.4 mm at T1.

Double jaw surgery was performed on 18 patients while isolated single mandibular setback surgery was done on the other 12 patients. Only BSSRO was used for the mandibular setback, and intraoral vertical ramus osteotomy was excluded because VBS cannot be measured accurately in IVRO cases.

Surgical phase

All patients underwent BSSRO for mandibular setback. The distal segment protruding posteriorly from the proximal segment was removed after the split had been completed. The medial pterygoid muscle and stylomandibular ligament were detached from the medial side of the distal segment. Also, the pterygomasseteric sling of the inferior border of the distal segment was stripped. Two straight titanium miniplate were used for the fixation of bone segments on each side. During fixation of bone segments, CW rotation of the PS was avoided to reduce relapse.[5,8–11,14–16] Intermaxillary fixation was maintained for two weeks.

Measurements of 3D models fabricated from CBCT

Mesh files (STL format) of jaws were created using InVivoDental 5.3.5 (Anatomage, San Jose, CA), and were imported and measured with scan-based design software (Geomagic Design X 2014, 3D Systems, Rock Hill, SC). For the measurements, a right-handed X, Y, Z coordinate system was used after aligning the FH plane of the T0 3D models parallel to the top (axial) plane of the software. The origin of this coordinate system was set at the nasion. 3D models of T1 and T2 were superimposed on the T0 3D models, aligned by registration to areas that did not change due to surgery or orthodontic treatment such as the cranial base and orbit, using the software's mesh registration tool that has an iterative closest point algorithm. Measurements of changes between time points were made after the superimposition of CBCT 3D models. For bilateral landmarks, only those on the right side were used. All landmarks were projected on the midsagittal plane, and then measurements were made on this plane. Transverse measurements were made only to exclude cases with pogonion deviation from the midsagittal reference plane exceeding 5 mm.

Variables were classified into PS measurements and DS measurements. PS landmarks were condylion (Cd),17 coronion (Cor),17 corpus left (CL), and ramus down (RD), while DS landmarks were Vertical bony step (VBS), pogonion (Pog),17,18 and menton (Me),17,18 (Table I, Fig 2). Measurements were made along the vertical axis (Y-axis) and anteroposterior axis (Z-axis), to interpret the movements of landmarks as vertical and anteroposterior movements, and also to increase the reliability of the measurements. Sign convention followed the right-handed coordinate system, assigning positive values to superior or anterior movements and CW rotations, and negative values to inferior or posterior movements and counter-clockwise (CCW) rotations. For many landmarks, the most anterior, superior, or inferior points were determined by the tangential contacts to the bony surfaces. When bony segments are rotated, the positions of tangential contacts are changed. Therefore, only the Y-axis and Z-axis measurements of landmarks were used (Table I). For PS movements, Cd-Y, Cor-Y, CL-Y, RD-Z, and PS rotation were measured. For DS movements, Pog-Z, Me-Y, symphysis rotation, and DS rotation were measured for the evaluation of DS movements. Pog-Y and Me-Z were not measured because they cannot be measured consistently when DS rotates.

The PS rotation angle was measured as the angular change of the posterior ramal plane that was determined by a tangent to the posterior border of the condyle and the RD. Symphysis rotation was measured by finding the amount of X-axis rotation required for the best fit registration of two symphyses at different time points. DS rotation was calculated by subtracting the PS rotation from the symphysis rotation. DS rotation was measured only from T2-T1 because the rotation of the completely separated PS at the time of surgery cannot affect the symphysis rotation.

Measurement errors were calculated using the Dahlberg formula19 and intraclass correlation coefficient (ICC) by remeasuring 10 sets of randomly selected 3D models from CBCTs twice over a two-month interval. Changes between T1-T0, and between T2-T1 were measured on each set (Table II). All measurement errors were within an acceptable range.

Dahlberg formula: $S = \sqrt{\Sigma d^2/2n}$ (d, the difference between remeasured values; n, the number of double measurements).19

Statistical analysis

Statistical analyses were performed using R 3.5.3 (R Foundation for Statistical Computing, Vienna, Austria). The Shapiro-Wilk test was first performed to determine whether the data had normality. The changes between different time points were tested using a one-sample *t*-test or Wilcoxon signed-rank test depending on the normality of the data. Also, Pearson's or Spearman's correlation was used to find the correlations between measurements depending on the normality of data.

III. RESULTS

Results of surgical changes, relapse during postsurgical orthodontic treatment, relapse ratio, and overall treatment changes are shown in Table III.

Surgical changes (T1-T0)

During T1-T0, the Cd-Y moved -0.7 mm. Cor-Y, CL-Y, and RD-Z moved -1.8 mm, -1.7 mm, and -2.0 mm, respectively, indicating CW rotation of the PS. This minimal movement of Cd-Y and larger movement of Cor-Y, CL-Y, and RD-Z indicate that the center of PS rotation during surgery was closer to the Cd. Pog-Z (T1-T0) was -11.9 mm. VBS developed by -5.6 mm. The Me-Y did not change significantly. PS rotated 2.2° CW, although the surgeons reported that they tried to avoid PS rotation. Symphysis rotated 4.2° CW.

Postsurgical changes (T2-T1)

The Cd-Y did not change significantly. Cor-Y and CL-Y also moved superiorly by 1.9 mm and 2.5 mm, respectively. These are more than 100% recovery to the pretreatment position. RD-Z moved anteriorly by 2.2 mm, 110% opposite of the posterior movement during surgery. With these movements, the PS rotated -2.8°. This CCW rotation of the PS was 129% opposite of the CW rotation of the PS during surgery. Along with this rotation, Pog-Z moved anteriorly by 3.4 mm, indicating a 29% relapse of the mandibular setback. The VBS decreased by 3.9 mm during postsurgical orthodontic treatment. This is a 70% resolution of the VBS that developed during surgery. Me-Y moved superiorly by 2.0 mm, despite there was no significant inferior movement during surgery. The symphysis rotated by -1.7°, less than the CCW rotation of the PS. This indicates that the CCW rotation of the PS was partly compensated for by the 1.2° CW rotation of the DS.

Overall treatment changes (T2-T0)

Cd-Y moved -0.5 mm. Cor-Y, CL-Y, RD-Z, and PS rotation did not change significantly. 1.6 mm of VBS remained after 70% resolution of the VBS during postsurgical orthodontic treatment. Pog-Z was setback by 8.5 mm after a 29% relapse during postsurgical orthodontic treatment. Me-Y moved superiorly by 1.7 mm. The symphysis rotated CW by 2.5°.

Comparison between double jaw and single jaw surgeries

In the present study, Pog-Z (T1-T0) was -11.8 ± 4.7 mm in the double jaw surgery patients, and -12.0 ± 4.9 mm in the single jaw surgery patients. VBS (T1-T0) was -5.2 ± 3.1 mm in the double jaw surgery patients, and -6.1 ± 1.7 mm in the single jaw surgery patients. Pog-Z (T2-T1) was 2.9 ± 2.0 mm in the double jaw surgery patients, and 4.1 ± 1.4 mm in the single jaw surgery patients. These group measurements satisfied normality, and independent *t*-tests showed that there were no significant differences in Pog-Z (T1-T0) (P = 0.92), VBS (T1-T0) (P = 0.39), and Pog-Z (T2-T1) (P = 0.11). This indicates that if there are no differences in the amount of setback or the development of VBS, double jaw surgery may not reduce the relapse.

Correlation between VBS and other surgical changes (T1-T0)

In the PS, inferior movement of Cor-Y and posterior movement of RD-Z were correlated positively with the development of VBS, but Cd-Y and CL-Y were not correlated with the VBS (Table IV). PS rotation showed a correlation with VBS (r = -0.42, P = 0.022).

In the DS, Pog-Z was correlated positively with the VBS, indicating that the amount of setback was a factor in the increase of VBS.

Correlation between VBS and postsurgical changes (T2-T1)

In the PS, postsurgical superior movement of Cor-Y and anterior movement of RD-Z were correlated positively with the resolution of VBS (T2-T1) (Table IV). And in the DS, Pog-Z, and Me-Y were correlated positively with the resolution of VBS (T2-T1), indicating postsurgical CCW rotation of mandible was related with the resolution of VBS. The symphysis rotation had a negative correlation with the resolution of VBS (T2-T1), indicating CCW rotation of symphysis is related to the resolution of VBS (T2-T1). Also, the correlation between the resolution of VBS (T2-T1) and the development of VBS (T1-T0) was $r = -0.57$, $P = 0.001$ (not shown in the Table). This indicates that as the development of the VBS during surgery increases, the postsurgical resolution of the VBS also increases (Fig 4).

Correlation between PS rotation and other variables

During T1-T0, the inferior movement of Cor-Y and the posterior movement of RD-Z were highly correlated with the CW rotation of PS, because these landmarks move greatly along with PS rotation (Table V). The VBS was correlated with the CW rotation of PS during T1-T0. During T2-T1, RD-Z and DS rotation showed a negative correlation with PS rotation. The latter indicates that DS rotation occurs in the opposite direction to the PS rotation during T2-T1. The VBS was not correlated with PS rotation during T2-T1. Cd-Y, CL-Y, Pog-Z, and symphysis rotation were not correlated with the PS rotation during both T1-T0 and T2-T1.

Correlation between relapse of a mandibular setback with other variables

Among T1-T0 measurements, Pog-Z (T1-T0) showed the strongest negative correlation with Pog-Z (T2-T1), indicating that the amount of setback affects the relapse (Table VI). The development of VBS (T1-T0) showed the second strongest negative correlation with the Pog-Z (T2-T1) indicating that the VBS affects the relapse (Fig 4). Therefore, the null hypothesis was rejected. The posterior movement of RD-Z (T1-T0) showed the third negative correlation with Pog-Z (T2-T1). Also, the inferior movement of Cor-Y, CW rotation of PS, and CW rotation of symphysis were correlated with Pog-Z (T2-T1).

Among T2-T1 measurements, CCW rotation of symphysis showed the strongest correlation with the Pog-Z (T2-T1). The second strongest correlation was found in the resolution of VBS (T2-T1). Also, the anterior movement of RD-Z (T2-T1) and DS rotation (T2-T1) were correlated with Pog-Z (T2-T1).

IV. DISCUSSION

In this study, the amount of mandibular setback showed the strongest correlation with the relapse of mandibular setback. This result was contrary to a previous study,20 but consistent with other earlier studies.8,21–24 In the previous studies,14,24 the posterior movement of RD-Z14 or CW rotation of PS24 was related to the relapse of mandibular setback. In the study of Yang et al,10 the CW rotation of PS was considered to be the main causative factor for the relapse of mandibular setback rather than the VBS itself, while VBS was considered to be a contributing factor for the development of CW rotation of PS. In the present study, the development of VBS showed a stronger correlation with the relapse of the mandibular setback than did the PS rotation during surgery. Creating a large VBS itself can cause elongation of the pterygomasseteric sling by moving the antegonial notch inferiorly, resulting in an increased relapse of mandibular setback. If PS rotation was the major cause of the relapse of the mandibular setback, then just preventing PS rotation would reduce the relapse of mandibular setback, regardless of the VBS. Also, mandibular angle shaving including the RD area would reduce the relapse. However, minimal PS rotation or angle shaving does not seem to reduce relapse in cases with large VBS, especially considering the 129% relapse of the PS rotation during postsurgical orthodontic treatment. This 129% relapse indicates that PS rotates more than the pretreatment position and this CCW rotation of PS is caused by something other than just the CW rotation of PS during surgery. This needs to be studied more sometime in the future.

Of all the T2-T1 measurements, symphysis rotation and the resolution of VBS showed the strongest correlation with the relapse of mandibular setback. This indicates that the postsurgical resolution of the VBS accompanied by the CCW rotation of the symphysis contributed to the relapse of the mandibular setback. This implies that the elongation of the pterygomasseteric sling by the development of VBS could be resolved partly by the CCW rotational relapse of the mandibular setback. An equation was developed to predict the development of VBS during mandibular setback based on trigonometric functions (Fig 5). Fig 1 shows an application of this equation. As shown in Fig 5, the amount of mandibular setback and the occlusomandibular plane angle affects the VBS. Therefore, a greater relapse can be expected in patients who require more mandibular setback and have a larger occlusomandibular plane angle.

During surgery, posterior movement of RD-Z showed the strongest correlation with the CW rotation of the PS, because the PS rotation was measured by a tangent contacting the RD and posterior border of the condyle. The inferior movement of Cor-Y had the second-strongest correlation with the PS rotation. RD-Z and Cor-Y measurements show PS rotation and they were positively correlated with the development of VBS during T1-T0. In a study by Yang et al,10 VBS had the greatest correlation with the PS rotation. However, in the present study, the development of VBS had the greatest correlation with the amount of Pog-Z (T1-T0) and this correlation was much stronger than the correlation between the VBS and PS rotation. This indicates that the development of VBS is directly affected by the amount of mandibular setback rather than the amount of PS rotation. The PS rotation can be a result of the development of the VBS rather than the cause of the VBS because VBS can elongate the pterygomasseteric sling, which might cause CW rotation of the PS.

It was reported that the relapse of mandibular setback occurs more by the CCW rotation of the mandible rather than the anterior movement of the mandible.7,25 In the present study, PS and DS rotations were evaluated separately during T2-T1 because they rotated differently. The separate rotations of PS and DS have not ever been evaluated before to the authors' knowledge. During T2-T1, PS rotated CCW, but DS rotated CW. By these two opposite rotations during T2-T1, the mandible relapsed rather linearly antero-superiorly rather than rotating with the center rotation near Cd. The rotations of PS and DS had a strong negative correlation. DS rotation also had a negative correlation with the Pog-Z (T2-T1), indicating that the CW rotation of DS during T2-T1 decreased the amount of relapse. Symphysis rotated CW during T1-T0 but rotated CCW during T2-T1, partly recovering to the pretreatment inclination.

Considering that the VBS and RD-Z contributed to the relapse, invading the soft tissue envelope of the mandible by either PS or DS should be minimized during surgery. This means setback should be done along the mandibular plane rather than along the occlusal plane. To achieve this, maxillary posterior impaction using Le Fort I osteotomy can be combined with a mandibular setback. Yang et al10 suggested maxillary posterior impaction or intentional guidance of the PS to maintain the original position of the PS. This maxillary posterior impaction can be replaced by the orthodontic intrusion of maxillary posterior teeth,26,27 although the amount of orthodontic intrusion is likely to be less than the maxillary posterior impaction. When performing Le Fort I osteotomy, advancement of the maxilla along the Frankfort horizontal plane or palatal plane also can make more room for the mandible to go upward during setback because there are angular differences between these planes and the occlusal plane.

When comparing the BSSRO and intraoral vertical ramus osteotomy (IVRO), no significant differences were reported.2,28,29 However, the reported relapse rates of IVRO setback surgeries were 0.7% to 15.3%,30–33 that is much lower than the reported 20 - 55% relapse rates of BSSRO setback surgeries with rigid fixation.2–10 In the present study, the relapse rate was 29%. Posterior movement of the mandible after setback surgery is frequently seen in IVRO surgeries.30,34 Choi et al34 reported that more than 2 mm of mandibular posterior movement occurred in 48.9% of IVRO setback surgeries. Jung et al30 reported that 0.8 mm of posterior movement of mandible occurred after IVRO setback of 10.5 mm in a sample of 94 patients. This kind of general posterior movement after setback surgery was not reported in BSSRO setback surgeries to the authors' knowledge. In IVRO setback, VBS does not occur and the proximal segment may not be rotated CW. However, the pterygomasseteric sling still can be stretched even in IVRO when the setback is made along the occlusal plane. Maxillary posterior impaction can be helpful also in the IVRO setback surgeries to make the mandible setback along the mandibular plane. Mandibular angle ostectomy also can help reduce the stretching of pterygomasseteric sling in both IVRO and BSSRO setback surgeries.16 The possible superiority of IVRO to BSSRO in the stability of mandibular setback surgeries needs to be investigated in the future.

Concerning manipulating the PS during surgery, intentional CW rotation of the PS to level the lower border of the PS to the lower border of DS should be avoided because CW rotation of PS and accompanying posterior movement of RD-Z are correlated with the relapse of mandibular setback. When VBS develops, an ostectomy or trimming of the lower border of the DS at the location of the VBS to level the lower borders of the PS and DS is recommended rather than the intentional CW rotation of the PS.

A surgical guide for border trimming can be used to mark the trimming line of the DS before splitting using a piezoelectric cutter (Fig 6). Ostectomy of VBS of DS is performed with this trimming line mark after splitting, but before fixation of PS and DS for ease of access. Additionally, angle shaving can be done to make the mandibular border become more continuous (Fig 6). This ostectomy may reduce the need for maxillary posterior impaction or orthodontic intrusion of the posterior teeth in the aspect of reducing VBS during a mandibular setback. A stent to mark border trimming line can be designed and fabricated by using a 3-dimensional simulation of surgery. This simulation and the use of CAD/CAM surgical splint also can help analyze bony interferences between proximal and distal segments35 and may improve the accuracy of surgery.36 The effect of VBS trimming on the relapse of mandibular setback needs to be studied in the future.

V. CONCLUSIONS

VBS occurs naturally when the mandible is setback with BSSRO along the occlusal plane because of the angular difference between the occlusal plane and the mandibular plane. The relapse of mandibular setback was correlated with the amount of VBS that was caused by surgery and also with the amount of mandibular setback. This VBS was partly resolved by the CCW rotation of the mandible causing a relapse of mandibular setback. To reduce this relapse of mandibular setback, minimizing the development of VBS during surgery is recommended.

REFERENCES

1. Celar AG, Freudenthaler JW, Schneider B. Cephalometric differentiation between vertical and horizontal malocclusions in 122 Europeans using the Denture Frame Analysis and standard measurements. Differentiation between vertical and horizontal malocclusion. J Orofac Orthop 1999;60:195–204.

2. Abeltins A, Jakobsone G, Urtane I, Bigestans A. The stability of bilateral sagittal ramus osteotomy and vertical ramus osteotomy after bimaxillary correction of class III malocclusion. J Craniomaxillofac Surg 2011;39:583–7.

3. Ayoub AF, Millett DT, Hasan S. Evaluation of skeletal stability following surgical correction of mandibular prognathism. Br J Oral Maxillofac Surg 2000;38:305–11.

4. Chou JIC, Fong HJ, Kuang SH, Gi LY, Hwang FY, Lai YC, Chang RCS, Kao SY. A retrospective analysis of the stability and relapse of soft and hard tissue change after bilateral sagittal split osteotomy for mandibular setback of 64 Taiwanese patients. J Oral Maxillofac Surg 2005;63:355–61.

5. Franco JE, Van Sickels JE, Thrash WJ. Factors contributing to relapse in rigidly fixed mandibular setbacks. J Oral Maxillofac Surg 1989;47:451–6.

6. Jakobsone G, Stenvik A, Sandvik L, Espeland L. Three-year follow-up of bimaxillary surgery to correct skeletal Class III malocclusion: Stability and risk factors for relapse. Am J Orthod Dentofacial Orthop 2011;139:80–9.

7. Lee NK, Kim YK, Yun PY, Kim JW. Evaluation of post-surgical relapse after mandibular setback surgery with minimal orthodontic preparation. J Craniomaxillofac Surg 2013;41:47–51.

8. Politi M, Costa F, Cian R, Polini F, Robiony M. Stability of skeletal class III malocclusion after combined maxillary and mandibular procedures: rigid internal fixation versus wire osteosynthesis of the mandible. J Oral Maxillofac Surg 2004;62:169–81.

9. Proffit WR, Turvey TA, Phillips C. The hierarchy of stability and predictability in orthognathic surgery with rigid fixation: an update and extension. Head Face Med 2007;3:21.

10. Yang HJ, Hwang SJ. Contributing factors to intraoperative clockwise rotation of the proximal segment as a relapse factor after mandibular setback with sagittal split ramus osteotomy. J Craniomaxillofac Surg 2014;42:e57–63.

11. Komori E, Aigase K, Sugisaki M, Tanabe H. Cause of early skeletal relapse after mandibular setback. Am J Orthod Dentofacial Orthop 1989;95:29–36.

12. Mobarak KA, Krogstad O, Espeland L, Lyberg T. Long-term stability of mandibular setback surgery: a follow-up of 80 bilateral sagittal split osteotomy patients. Int J Adult Orthodon Orthognath Surg 2000;15:83–95.

13. Moldez MA, Sugawara J, Umemori M, Mitani H, Kawamura H. Long-term dentofacial stability after bimaxillary surgery in skeletal Class III open bite patients. Int J Adult Orthodon Orthognath Surg 2000;15:309–19.

14. Cho HJ. Long-Term Stability of Surgical Mandibular Setback. Angle Orthod 2007;77:851–6.

15. Han JJ, Yang HJ, Lee SJ, Hwang SJ. Relapse after SSRO for mandibular setback movement in relation to the amount of mandibular setback and intraoperative clockwise rotation of the proximal segment. J Craniomaxillofac Surg 2014;42:811–5.

16. Kim CH, Lee JH, Cho JY, Lee JH, Kim KW. Skeletal stability after simultaneous mandibular

angle resection and sagittal split ramus osteotomy for correction of mandible prognathism. J Oral Maxillofac Surg 2007;65:192–7.

17. You KH, Lee KJ, Lee SH, Baik HS. Three-dimensional computed tomography analysis of mandibular morphology in patients with facial asymmetry and mandibular prognathism. Am J Orthod Dentofac Orthop 2010;138:540.e1-8.

18. Lee JS, Xi T, Kwon TG. Three-dimensional analysis of mandibular condyle position in patients with deviated mandibular prognathism. Int J Oral Maxillofac Surg 2017;46:1052–8.

19. Dahlberg G. Statistical methods for medical and biological students. London: George Allen & Unwin Ltd.; 1940. p. 122-32.

20. De Villa GH, Huang CS, Chen PKT, Chen YR. Bilateral sagittal split osteotomy for correction of mandibular prognathism: long-term results. J Oral Maxillofac Surg 2005;63:1584–92.

21. Chen KJ, Chen YC, Cheng JH, Chen CM, Tseng YC. Factors related to skeletal relapse in the two-jaw surgery treatment of mandibular prognathism. J Stomatol Oral Maxillofac Surg 2018;119:113–7.

22. Choi TH, Kim SH, Yun PY, Kim YK, Lee NK. Factors related to relapse after mandibular setback surgery with minimal presurgical orthodontics. J Oral Maxillofac Surg 2019;77:1072.e1-9.

23. Park YH, Seo JH, Yang IH, Choi JY, Lee JH, Kim MJ, Baek SH. What are the contributing factors for postsurgical relapse after two-jaw surgery in patients with cleft lip and palate. J Craniofac Surg 2017;28:1071–7.

24. Takahara N, Kimura A, Tomomatsu N, Nakakuki K, Yoda T. Does the amount of mandibular setback during bimaxillary surgery correlate with the degree of surgical relapse. Oral Surg Oral

Med Oral Pathol Oral Radiol 2020;129:447–52.

25. Han JJ, Jung S, Park HJ, Oh HK, Kook MS. Evaluation of postoperative mandibular positional changes after mandibular setback surgery in a surgery-first approach: isolated mandibular surgery versus bimaxillary surgery. J Oral Maxillofac Surg 2019;77:181.e1-12.

26. Kim MS, Lim SH, Jeong SR, Park JH. Maxillary molar intrusion and transverse decompensation to enable mandibular single-jaw surgery with rotational setback and transverse shift for a patient with mandibular prognathism and asymmetry. Am J Orthod Dentofacial Orthop 2020;157:818–31.

27. Park HS, Kim JY, Kwon TG. Occlusal plane change after intrusion of maxillary posterior teeth by microimplants to avoid maxillary surgery with skeletal Class III orthognathic surgery. Am J Orthod Dentofacial Orthop 2010;138:631–40.

28. Choi SH, Yoo HJ, Lee JY, Jung YS, Choi JW, Lee KJ. Stability of pre-orthodontic orthognathic surgery depending on mandibular surgical techniques: SSRO vs IVRO. J Craniomaxillofac Surg 2016;44:1209–15.

29. Yoshioka I, Khanal A, Tominaga K, Horie A, Furuta N, Fukuda J. Vertical ramus versus sagittal split osteotomies: comparison of stability after mandibular setback. J Oral Maxillofac Surg 2008;66:1138–44.

30. Jung HD, Jung YS, Kim SY, Kim DW, Park HS. Postoperative stability following bilateral intraoral vertical ramus osteotomy based on amount of setback. Br J Oral Maxillofac Surg 2013;51:822–6.

31. Kung AYH, Leung YY. Stability of intraoral vertical ramus osteotomies for mandibular setback: a longitudinal study. Int J Oral Maxillofac Surg 2018;47:152–9.

32. Lee KT, Lai SST, Wu JH, Lee HE, Chen CM. Correlation between the change of gonial region and skeletal relapse after intraoral vertical ramus osteotomy for correction of mandibular prognathism. J Craniofac Surg 2011;22:818–21.

33. Nihara J, Takeyama M, Takayama Y, Mutoh Y, Saito I. Postoperative changes in mandibular prognathism surgically treated by intraoral vertical ramus osteotomy. Int J Oral Maxillofac Surg 2013;421:62–70.

34. Choi SH, Kang DY, Cha JY, Jung YS, Yu HS, Park HS, Hwang CY. Major factors contributing to anterior and posterior relapse after intraoral vertical ramus osteotomy. J Craniomaxillofac Surg 2016;44:413–20.

35. VallsOntañón A, AscencioPadilla RDJ, VelaLasagabaster A, Sada-Malumbres A, Haas-Junior OL, Masià-Gridilla J, Hernández-Alfaro F. Relevance of 3D virtual planning in predicting bony interferences between distal and proximal fragments after sagittal split osteotomy. Int J Oral Maxillofac Surg 2020;49:1020–8.

36. Hong M, Kim MJ, Shin HJ, Cho HJ, Baek SH. Three-dimensional surgical accuracy between virtually planned and actual surgical movements of the maxilla in two-jaw orthognathic surgery. Korean J Orthod 2020;50:293–303.

Tables

Table I. Definitions of landmarks

Landmark	Definition
Condylion (Cd)	The most superior point of the condylar head
Coronion (Cor)	The most superior point of the coronoid process[17]
Corpus left (CL)	The left contact point of a tangent to the inferior border of the mandible
Ramus down (RD)	The lower contact point of a tangent to the posterior border of the ramus and condyle
Vertical bony step (VBS)	The vertical distance between the PS and DS along a line between the first and second molars and 95° to the molar occlusal plane which is constructed by the mesiobuccal cusp tip of mandibular first molar and the distobuccal cusp tip of mandibular second molar[10]
Pogonion (Pog)	The most anterior midpoint on the symphysis[17,18]
Menton (Me)	The most inferior midpoint on the symphysis[17,18]

Table II. Analysis of measurement error

Reference point	T1-T0		T2-T1	
	Dahlberg	**ICC**	**Dahlberg**	**ICC**
Proximal segment				
Cd-Y (mm)	0.11	0.99	0.15	0.99
Cor-Y (mm)	0.09	1.00	0.13	1.00
CL-Y (mm)	0.31	1.00	0.25	0.99
RD-Z (mm)	0.20	1.00	0.13	1.00
PS rotation (°)	0.42	1.00	1.07	0.89
Distal segment				
VBS (mm)	0.14	1.00	0.16	1.00
Pog-Z (mm)	0.22	1.00	0.21	1.00
Me-Y (mm)	0.11	1.00	0.11	1.00
Symphysis rotation (°)	0.23	1.00	0.05	0.98
DS rotation (°)			1.19	0.87

-Y, change of y coordinate; -Z, change of z coordinate; PS, Proximal segment; DS, Distal segment; Dahlberg formula, $S = \sqrt{\Sigma d^2/2n}$ (d, the difference between remeasured values; n, the number of double measurements); ICC, intraclass correlation coefficient; T0, pretreatment; T1, postsurgery; T2, posttreatment.

See Table I for the abbreviations of landmarks.

Table III. Summary of changes between different time points

	T1-T0	T2-T1	Relapse rate (%)	T2-T0
	Mean ± SD	Mean ± SD		Mean ± SD
Proximal segment				
Cd-Y (mm)	-0.7 ± 0.7***	0.2 ± 1.2	33	-0.5 ± 1.0**^{w}
Cor-Y (mm)	-1.8 ± 1.5***	1.9 ± 1.0***	106	0.1 ± 1.4
CL-Y (mm)	-1.7 ± 2.2***^{w}	2.5 ± 2.2***	154	0.9 ± 2.4
RD-Z (mm)	-2.0 ± 1.9***	2.2 ± 1.6***	110	0.2 ± 1.8
PS rotation (°)	2.2 ± 2.8***	-2.8 ± 2.1***	129	-0.6 ± 3.1
Distal segment				
VBS (mm)	-5.6 ± 2.6***	3.9 ± 1.7***	70	-1.6 ± 2.2***
Pog-Z (mm)	-11.9 ± 4.7***^{w}	3.4 ± 1.9***	29	-8.5 ± 3.8***
Me-Y (mm)	-0.3 ± 2.0	2.0 ± 1.2***	587	1.7 ± 1.6***
Symphysis rotation (°)	4.2 ± 3.6***	-1.7 ± 1.8***	40	2.5 ± 3.8**
DS rotation (°)		1.2 ± 2.6*		

SD: Standard deviation; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$ with one-sample *t*-test.

*^{w}, $P < 0.05$; **^{w}, $P < 0.01$; ***^{w}, $P < 0.001$ with Wilcoxon signed rank test.

See Tables I and II for the abbreviations.

Table IV. Correlations between VBS and other movements during T1-T0

		VBS (T1-T0)		VBS (T2-T1)	
		r (ρ)	*P*	*r (ρ)*	*P*
Proximal segment	Cd-Y (mm)	0.00	0.985	0.04	0.841
	Cor-Y (mm)	0.45	0.012*	0.60	0.000***
	CL-Y (mm)	-0.16	0.399	0.14	0.457
	RD-Z (mm)	0.47	0.009**	0.55	0.002**
	PS rotation (°)	-0.42	0.022*	-0.26	0.167
Distal segment	Pog-Z (mm)	0.61	0.000***s	0.73	0.000***
	Me-Y (mm)	0.45	0.012*	0.83	0.000***
	Symphysis rotation (°)	-0.28	0.139	-0.45	0.012*
	DS rotation (°)			-0.10	0.597

*, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$ with Pearson's correlation test; *r*, Pearson's correlation coefficient; *s, $P < 0.05$; **s, $P < 0.01$; ***s, $P < 0.001$ with Spearman's correlation test; *ρ*, Spearman's rank correlation coefficient.

See Tables I and II for the abbreviations.

Table V. Correlation between PS rotation with other variables

	PS rotation			
	T1-T0		T2-T1	
	r (*ρ*)	*P*	*r* (*ρ*)	*P*
Cd-Y	-0.19	0.322	-0.01	0.975
Cor-Y	-0.87	0.000***	-0.29	0.119
CL-Y	-0.33	0.075	0.10	0.591
RD-Z	-0.92	0.000***	-0.76	0.000***
VBS	-0.42	0.022*	-0.26	0.167
Pog-Z	-0.27	0.152	-0.16	0.402
Symphysis rotation	0.21	0.258	0.16	0.392
DS rotation			-0.72	0.000***

*, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$ with Pearson's correlation test; *r*, Pearson's correlation coefficient; $*^{s}$, $P < 0.05$; $**^{s}$, $P < 0.01$; $***^{s}$, $P < 0.001$ with Spearman's correlation test; *ρ*, Spearman's rank correlation coefficient.

See Tables I and II for the abbreviations.

Table VI. Correlation between Pog-Z (T2-T1) with other variables

	Pog-Z (T2-T1)			
	T1-T0		T2-T1	
	r (ρ)	*P*	*r (ρ)*	*P*
Cor-Y	-0.41	0.024*	0.33	0.079
CL-Y	0.09	0.636	-0.03	0.896
RD-Z	-0.43	0.019*	0.39	0.032*
PS rotation	0.38	0.036*	-0.16	0.402
VBS	-0.58	0.001***	0.73	0.000***
Pog-Z	-0.66	0.000***s		
Symphysis rotation	0.40	0.031*	-0.78	0.000***
DS rotation			-0.41	0.024*

*, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$ with Pearson's correlation test; *r*, Pearson's correlation coefficient; *s, $P < 0.05$; **s, $P < 0.01$; ***s, $P < 0.001$ with Spearman's correlation test; *ρ*, Spearman's rank correlation coefficient.

See Tables I and II for the abbreviations of landmarks.

Figures

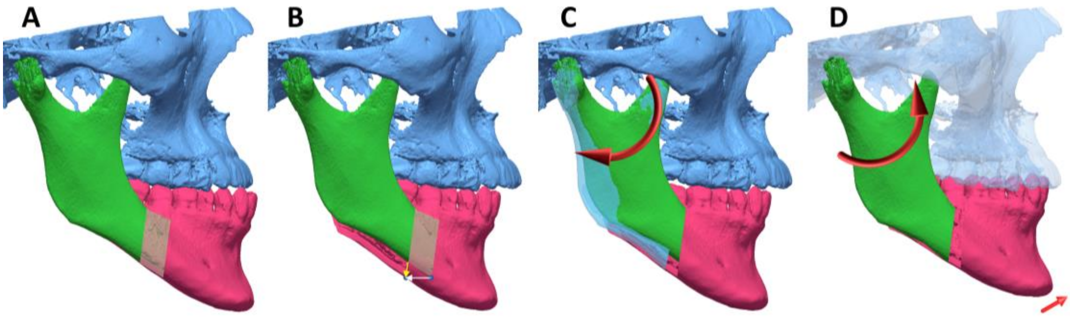


Fig 1. Illustration of the development of vertical bony step (VBS) during a mandibular setback. **A,** After osteotomy; **B,** 10 mm of mandibular setback (white arrow) along the occlusal plane caused 6.3 mm of VBS (yellow arrow) at the vertical osteotomy site; **C,** Proximal segment rotates clockwise (transparent blue) when the surgeon levels the lower borders of proximal and distal segments of mandible; **D,** Proximal segment rotates counterclockwise into the pretreatment position during postsurgical orthodontic treatment, causing a partial relapse of the mandibular setback and premature contact of anterior teeth. The occlusomandibular plane angle was 22˚ in this patient.

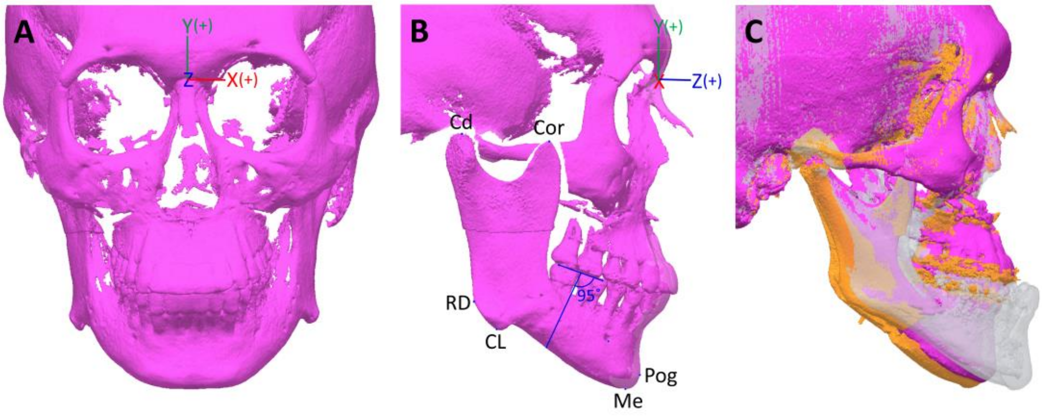


Fig 2. Landmarks and coordinate system used in the measurements of 3D models from CBCT. **A,** Coordinate system; **B,** Landmarks and coordinate system; **C,** Superimposition of 3D models at T0 (transparent gray), T1 (orange), and T2 (pink). See Table I for the abbreviations of landmarks.

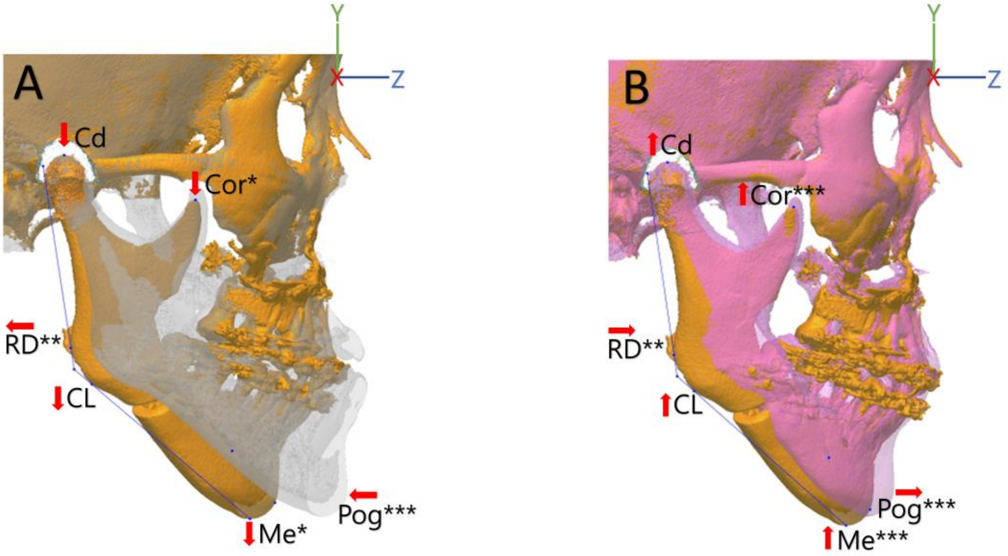


Fig 3. Illustration of surgical changes and relapse changes of landmarks. **A,** Surgical movement (T1-T0); **B,** Relapse movement (T2-T1), T0 (transparent gray), T1 (orange), and T2 (pink). See Table I for the abbreviations of landmarks.

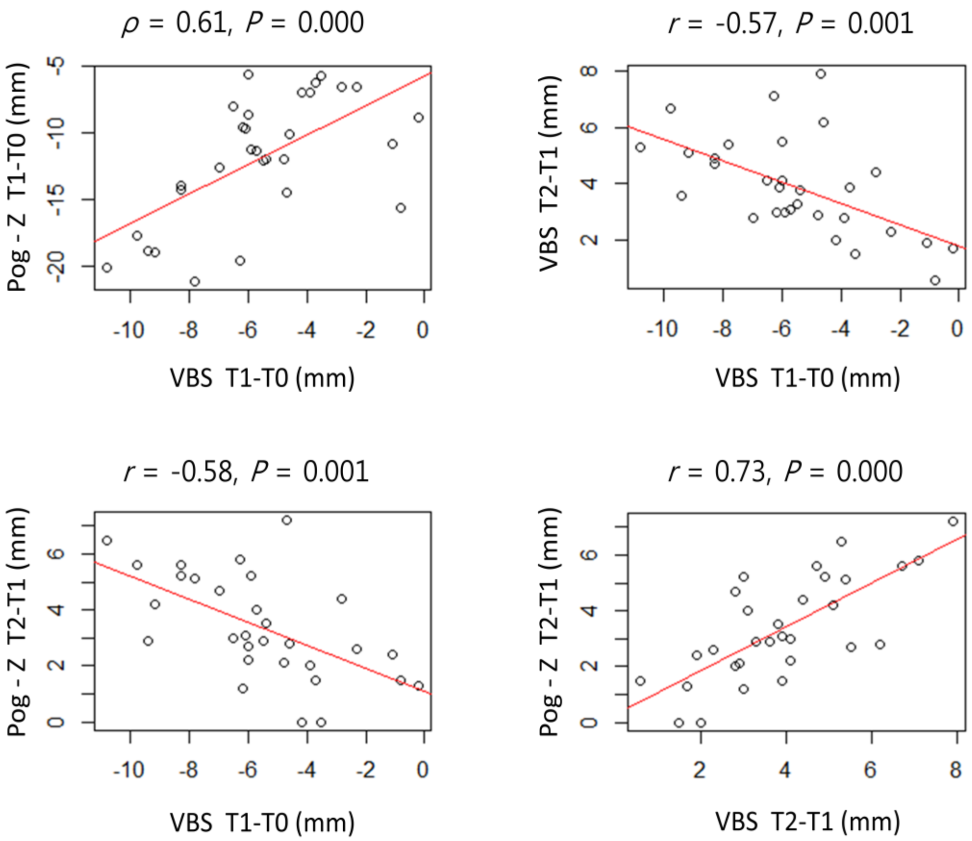
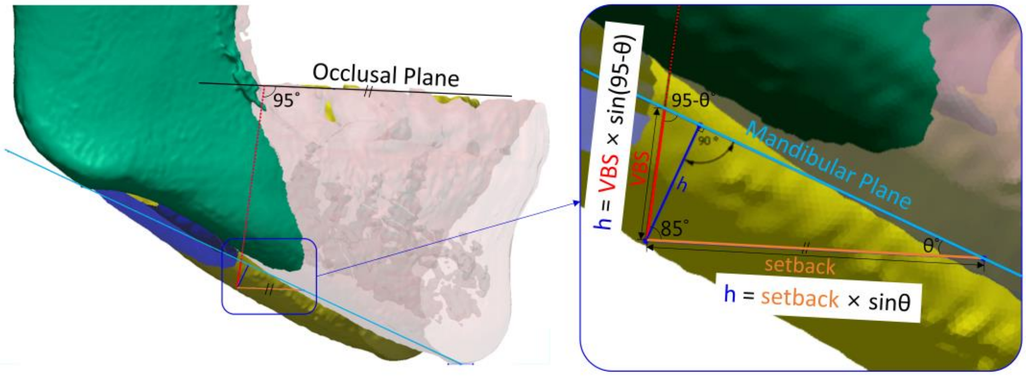


Fig 4. Correlation scatterplots between variables. See Tables I and II for the abbreviations of landmarks.



θ = occlusomandibular plane angle, h = setback × sinθ = VBS × sin(95-θ)

∴ VBS = setback × sinθ/sin(95-θ)

Fig 5. Illustration of the prediction of VBS using trigonometric functions when a mandible is setback along the occlusal plane, and an osteotomy is made along the 95˚ angle to the occlusal plane of mandibular first and second molars.

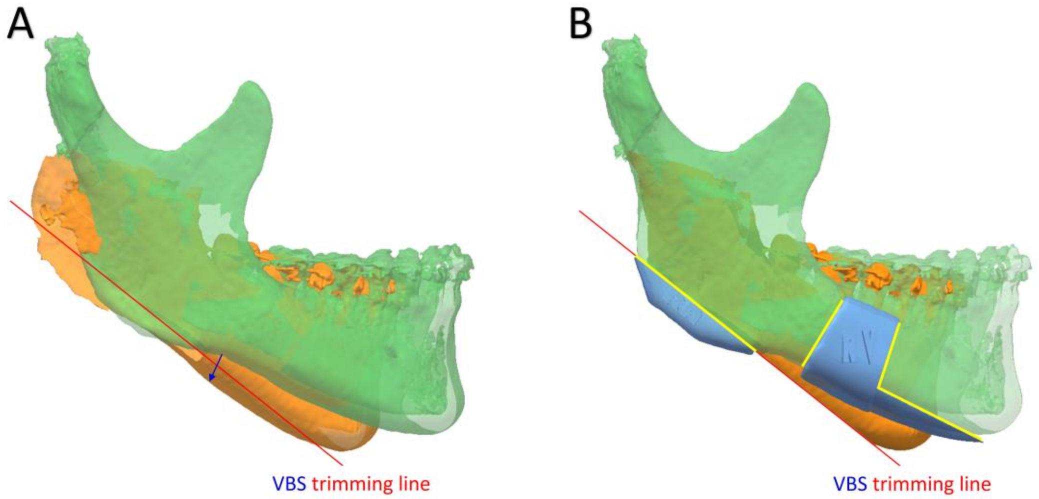


Fig 6. Ostectomy of VBS. **A,** Mandibular setback caused VBS (blue arrow), and trimming of mandibular border and mandibular angle was needed to make a flat mandibular plane (red line); **B,** Surgical guides (blue) were fabricated to mark the ostectomy lines (yellow) before splitting. Ostectomy along this mark is performed after splitting. The half-transparent green color shows presurgery, and orange color shows the distal segment after surgery.