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Early and 1-year postsurgical stability and its factors in patients with complicated skeletal Class III malocclusion treated by conventional and surgery-first approach: A prospective cohort study

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Introduction: This study aimed to compare postsurgical stability between conventional (CSA) and surgery-first (SFA) approaches and investigate its prognostic factors in patients with a skeletal Class III extraction. **Methods:** Twenty and 19 patients treated with LeFort I osteotomy and bilateral sagittal split ramus osteotomy (BSSRO) with premolar extraction were enrolled in SFA and CSA groups, respectively. Serial cone-beam computed tomography images obtained before surgery, immediately after surgery (T1), 3 months after surgery, and 12 months after surgery were used for 3-dimensional quantitative analysis. The condyle was segmented for analyzing volumetric changes. Repeated measures analysis of variance, independent *t* test, and chi-square test were used to compare time-course and intergroup differences. Pearson and Kendall correlation and multivariate linear regression analyses were used to explore prognostic factors affecting skeletal stability. **Results:** In both CSA and SFA, postsurgical relapse mainly occurred in the mandible sagittal and vertical dimensions and during the first 3 months after surgery. Stability in SFA was significantly less than that in CSA. Intraoperatively, inferolateral condylar displacement with proximal segment inwards, clockwise rotation, and return movements after surgery were observed regardless of the treatment approach. The condylar volume remained stable over time. Multivariate regression analysis showed that posterior vertical dimension (VD) at T1 (-1.63 mm), surgical amount of mandibular setback (-10.33 mm), surgical condylar downwards displacement (-1.28 mm), and anterior overjet at T1 (6.43 mm) were the most important predictors of early mandibular relapse ($r^2 = 0.593$). **Conclusions:** The risk of early relapse could be reduced by controlling the anterior, middle, and posterior constraints provided by the prediction model. (Am J Orthod Dentofacial Orthop 2023;164:728-40)

Postsurgical relapse has been the major concern in correcting a skeletal Class III malocclusion. The conventional surgery approach (CSA) is well known to provide stable and satisfactory treatment outcomes, consisting of 12-24 months of presurgical orthodontic decompensation, orthognathic surgery, and 5-11

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months of postsurgical orthodontic adjustment. However, this approach often involves an extended treatment duration, progressive facial profile deterioration, worsening dental function, and considerable discomfort in the presurgical orthodontic stage. The surgery-first approach (SFA) has recently been proposed as a 2-stage treatment omitting presurgical orthodontic treatment.[1] This alternative approach has substantially shortened the treatment duration and immediately improved the facial profile. Nevertheless, postsurgical relapse with the SFA is still the subject of heated debate because inconsistent results have been reported because of patient characteristic bias.[2]

In addition to the timing of surgery, the result of mandibular setback (MS) itself is potentially unstable, even with rigid fixation.[3] The challenge of postsurgical stability after mandibular setback surgery is multifactorial. The multiple factors include the amount of MS, condylar resorption, intraoperative displacement of the proximal segment (PS), and occlusal instability after surgery.[4-7]

Malposition of the PS during surgery has been reported to be one of the primary factors responsible for postsurgical relapse and is especially associated with early postoperative relapse.[5-11] The mandible setback procedure using bilateral sagittal split ramus osteotomy (BSSRO) can push the PS of the mandible posteroinferiorly during surgery. The PS can also be intentionally rotated clockwise to level the inferior border of the mandible and avoid bony irregularity, whereas the action of the masticatory muscles and temporomandibular ligament may counterclockwise rotate the entire mandible afterward, causing postsurgical early relapse.[12-14] Long-term skeletal relapse may be related to condylar resorption.[15-18]

In contrast, several studies have indicated that the extent of MS is the major factor related to relapse. A positive correlation between the clockwise rotation (CWR) of the PS during surgery and MS has been reported.[4,12] Batbold et al[4] proposed that the CWR of the PS during surgery was caused by the vertical bone step (VBS) between the PS and distal segment produced directly by the MS, which was the effect rather than the cause; the VBS can prolong the ptertgomasseteric sling, which causes the CWR of the PS.

In addition, previous studies have also emphasized that the instability of occlusion after surgery caused by premature occlusal contact, particularly in SFA, is related to a strong likelihood of more severe postsurgical mandibular forward movement.[19,20] Based on the clinical impression, the increased vertical dimension (VD) and wide anterior overjet (OJ) are often associated with surgical occlusion in patients treated by SFA. As the VD increases, the amount of MS during surgery will no longer be a determining factor of the final MS of the mandible, making the treatment outcome less predictable.[7]

The most common components of adult skeletal Class III malocclusion are the retrusive maxilla and protrusive mandible.[21] Therefore, these patients are often treated by 2-jaw surgery, including LeFort I osteotomy and BSSRO. In most clinical patients, at least maxillary bilateral premolar extraction is required for dental alignment and appropriate decompensation. However, there is little understanding of such complex malocclusions that have undergone SFA treatment. Moreover, SFA needs to take full advantage of postsurgical metabolic acceleration to accelerate tooth movement. It is better to perform orthodontic adjustment immediately after surgery, especially in the first 3 months.[22] At this time, the skeletal bone is still in the preliminary stage of healing. However, little attention has been given to skeletal stability in the early postsurgical period. Furthermore, few studies have comprehensively evaluated the importance and combined effects of prognostic factors on postsurgical stability.

Therefore, the purpose of this prospective cohort study using cone-beam computed tomography (CBCT) images in adult patients with skeletal Class III malocclusion treated by either the CSA or SFA approach coupled with maxillary premolar extraction is to compare (1) the 3-dimensional (3D) skeletal stability during the early postsurgical period (3 months) and at 12 months, (2) the condyle volume changes, (3) the time-course 3D displacement of the PS, and (4) the prognostic factors related to postsurgical stability.

METHODS

Patients and groups

To address the study aims, we implemented a prospective cohort study performed between June 2018 and August 2022. The study population included patients with skeletal Class III malocclusion in the Departments of Orthognathic Surgery and Orthodontics at Peking University School and Hospital of Stomatology. The study was approved by the Institutional Review Board (PKUSSIRB-2018401183). Patient inclusion criteria were (1) adult patients aged ≥18 years, (2) skeletal Class III malocclusion, (3) treated by 2-jaw surgery (LeFort I osteotomy with or without segmental osteotomy and BSSRO with or without genioplasty) with maxillary bilateral premolar extraction, and (4) potential for SFA based on the presurgical simulation of the dental cast model and determined by all the authors involved in

Table I. Patient baseline characteristics in SFA and CSA groups

Characteristics	*SFA*	*CSA*	P *value*
Age (y)	23.39 ± 3.74	24.94 ± 5.26	0.295†
Gender (n)	males, 11; females, 9	males, 7; females, 12	0.341‡
Presurgical skeletal deformities (mm)			
A-VRP	9.77 ± 2.92	9.70 ± 2.13	0.931†
A-HRP	31.07 ± 5.79	32.10 ± 4.42	0.538†
A-MSP	0.81 ± 0.70	0.96 ± 0.88	0.553†
B-VRP	18.46 ± 5.33	17.57 ± 4.69	0.585†
B-HRP	70.67 ± 5.83	70.99 ± 8.27	0.891†
B-MSP	3.00 ± 2.68	3.09 ± 2.76	0.935†
Surgical amount (mm)			
ΔA-VRP	3.98 ± 1.62	3.61 ± 1.31	0.442†
ΔA-HRP	−0.81 ± 2.29	−0.62 ± 1.89	0.774†
ΔA-MSP	0.99 ± 0.83	0.93 ± 0.65	0.799†
ΔB-VRP	−8.86 ± 3.27	−8.35 ± 3.27	0.628†
ΔB-HRP	−2.15 ± 2.63	−0.53 ± 3.66	0.119†
ΔB-MSP	2.48 ± 1.91	2.08 ± 2.45	0.568†

Note. Data are presented as the mean ± standard deviation. See Table II for the definition of landmarks.
SFA, surgery-first approach; *CSA*, conventional surgery approach.
†Independent *t* test; ‡Pearson chi-square test.

this study. The exclusion criteria were (1) congenital craniofacial anomalies, (2) a history of temporomandibular joint and occlusal muscle disorders or severe periodontitis, and (3) received orthodontic treatment in other hospitals. Patient grouping was based on joint assessment by the orthodontist and orthognathic surgeons and patient willingness. The sample size was determined by sample size software PASS (version 15.0; NCSS, LLC, Kaysville, Utah) using the noninferiority tests for the difference between 2 means modules.[23] The primary outcome index was the mandibular postsurgical sagittal relapse at B point. A minimum sample size of 19 subjects per group was required on the basis of the results of the pilot study (conducted by Z.P.Y.), with a power of 0.8, a significance level of 0.05, and a negative noninferiority margin of −0.2.

Thirty-nine patients were involved in this prospective study: 20 SFA patients (11 males, 9 females; mean age, 23.39 ± 3.74 years) and 19 CSA patients (7 males, 12 females; mean age, 24.94 ± 5.26 years). The patient baseline characteristics are summarized in Table I. Analysis of group homogeneity regarding age, sex, initial skeletal deformities, and amount of surgery showed that the 2 groups exhibited an acceptable degree of homogeneity.

Surgical procedures

All patients in both groups underwent 2-jaw orthognathic surgery. The routine procedures of LeFort I osteotomy and BSSRO were performed. In brief, after maxillary downfracture, the maxilla was further mobilized and advanced. After intermaxillary fixation with an intermediate occlusal splint, the maxillomandibular complex was repositioned to its predetermined position and fixed with rigid fixation at the piriform aperture and zygomatic buttress. The modified BSSRO was performed with rigid fixation by sliding plates or miniplates[24] after manually manipulating the condyle into the most appropriate location in the glenoid fossa as determined by the surgeon's palpation. Patients underwent genioplasty as needed.

In the SFA group, the surgery was performed by 2 surgeons (Z.L.L. and X.J.L.). Bracket bonding was performed 1 week before surgery, and a nickel-titanium archwire was placed the day before. Intraoperatively, before surgical incisions, 8 transmucosal 2.0 mm miniscrews were placed for subsequent intermaxillary fixation with intermediate and final splints in place, and bilateral maxillary first premolars were extracted. Nine out of 20 patients underwent maxillary segmental osteotomy to correct the transverse discrepancy and reduce the anterior OJ. Orthodontics was begun 2-3 weeks after surgery by 1 orthodontist (R.P.J.), and the follow-up interval was once every 2-3 weeks within 6 months after surgery.

In group CSA, the orthodontic treatments were conducted by 10 orthodontists, and the surgery was performed by 3 surgeons (Z.L.L., B.Y., and X.X.W.). Postoperative orthodontics was begun 3 months after surgery. The doctors involved in the treatment all have >15 years of treatment experience.

CBCT data acquisition and 3D measurements

To assess the postsurgical stability and PS displacement, serial CBCT images (i-CAT FLX; Imaging Sciences International, Hatfield, Pa; 120 kVp, 5 mA, 3 mGy, 16 × 13-cm field of view, 0.3 voxel size) were obtained at 4 specific points of time: ≤1 week before surgery (T0), and ≤1 week immediately after surgery (T1), 3 months after surgery (T2), and 12 months after surgery (T3). CBCT images were collected in digital imaging and communications in medicine format.

1. Reference plane and superimposition

The CBCT images were imported into Dolphin 3D Imaging software (version 11.8; Dolphin Imaging and Management Solutions, Chatsworth, Calif). On T0 images, as depicted in Figure 1, the Frankfort horizontal plane passing through the bilateral orbitales and the right porion was set as the horizontal reference plane (HRP), and its perpendicular plane passing through 2 central landmarks of the nasion (N) and basion (Ba)

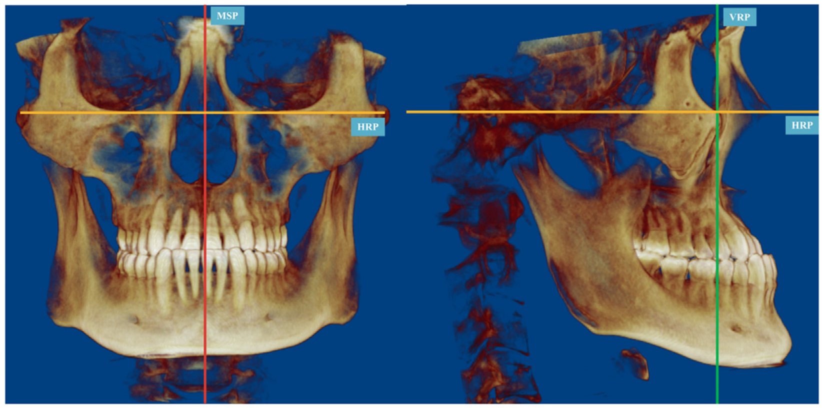

Fig 1. The reference plane used in this study was constructed in Dolphin 3D Imaging software. *MSP*, midsagittal plane.

points were set as the midsagittal plane.[25] A plane vertical to both HRP and midsagittal plane and passing through the right orbitale was set as a coronal plane, namely the vertical reference plane (VRP) in anteroposterior view. The T1, T2, and T3 CBCT images were superimposed onto the T0 image by voxel-based registration using the cranial base as a reference to minimize the accumulated error of repeated establishment of reference planes. All the measurements were done under the same reference planes (T0).

2. Measurement of condylar displacement

Condylar linear and angular measurements were measured by calculating landmarks, whereas condylar translational and rotational displacements were obtained by calculating the difference in measurements at different time points. Landmark identification was processed in Dolphin 3D Imaging software. To quantify the linear measurement, a 3D coordinate system was set (x, mesial [+] and lateral [−]; y, superior [+] and inferior [−]; z, anterior [+] and posterior [−]). To describe rotational changes, 3 angles were used with x, y, and z-coordinates corresponding to yaw, roll, and pitch, respectively. Landmarks and the measurements used in the study are defined in Table II. The landmarks are also depicted in Figure 2, and the angular measurements of PS are demonstrated in Figure 3.

3. Measurement of condylar volume (CV)

To assess the time-course condylar volume (CV), the 3D model containing condylar neck notch, coronoid process, and sigmoid notch as nonchanging anatomic structures was first segmented using the open-source software ITK-SNAP 3.8.0 (www.itksnap.org), and imported into the open-source software 3D Slicer (version 5.0.3; www.3dslicer.org) as surface model for superimposition (Fig 4). Subsequently, the condylar segmentation was performed. The definition of the condyle was described in an earlier study.[17] The CV was measured at 3-time points (T0, T2, and T3).

To test the intraobserver reliability of the measurements, 10 patients ($10 \times 4 = 40$ images) were randomly selected 2 weeks after the data collection, whose serial CBCT images were reoriented, followed by the reference planes reestablishment, the landmarks relocation, and the condylar resegmentation and reregistration. To test the interobserver reliability, 5 patients ($5 \times 4 = 20$ images) were randomly selected and remeasured by 2 observers (Y.R.J. and J.L.P.). Measurement errors were calculated using the method of moments estimator[26] and the intraclass correlation coefficient. All the intraclass correlation coefficients were >0.95, and measurement errors were within an acceptable range (Supplementary Tables I and II).

Statistical analysis

A descriptive analysis of the study variables was done, calculating the mean, standard deviation, and 95% confidence intervals for all the continuous variables. A Shapiro-Wilk test was used to determine the distribution normality of all variables. Noted that if the absolute value of kurtosis was ≤10 and the absolute value of skewness was ≤3, it was also acceptable to be normally distributed.

Repeated measures analysis of variance was used to compare the time-course skeletal and PS changes between SFA and CSA. Mauchly's sphericity test was used to confirm sphericity, and the Greenhouse-Geisser correction was applied to the P values when the values were rejected in the sphericity test. For multiple

Table II. Definition of landmarks and measurements

Variables	*Definition*	*Bilateral*
Landmarks		
C-lat	The most lateral point of the condyle head	
C-mes	The most mesial point of the condyle head	
C	The midpoint of the C-lat and C-mes	√
Co	The most superior point of the condyle head	√
Sn	The most inferior point of the sigmoid notch	√
Cp	Tip of coronoid process	√
B	The innermost point on the contour of the mandible between the incisor and bony chin	
A	The innermost point on the contour of the maxilla between the incisor and anterior nasal spine	
U1c	The midpoint of the maxillary first incisor edge	√
L1c	The midpoint of the mandibular first incisor edge	√
U6c	The point of the maxillary first molar mesial buccal cusp	√
L6c	The point of the mandibular first molar mesial buccal cusp	√
Skeletal measurements		
B-VRP (mm)	The distance of B to the vertical reference plane	
B-HRP (mm)	The distance of B to the horizontal reference plane	
B-MSP (mm)	The distance of B to the midsagittal plane	
A-VRP (mm)	The distance of A to the vertical reference plane	
A-HRP (mm)	The distance of A to the horizontal reference plane	
A-MSP (mm)	The distance of A to the midsagittal plane	
PS measurements		
C-VRP (mm)	The distance of C to the vertical reference plane	√
C-HRP (mm)	The distance of C to the horizontal reference plane	√
C-MSP (mm)	The distance of C to the midsagittal plane	√
Yaw (°)	The angle between the Co and Cp connection and the HRP in the axial view	√
Roll (°)	The angle between the Co and Sn connection and the horizontal plane in the coronal view	√
Pitch (°)	The angle between the Co and Cp connection and the HRP in the sagittal view	√
CV (mm^3)	The volume of the condyle head	√
Dental measurements		
OJ (mm)	The mean sagittal distance between U1c and L1c	
VD (mm)	The vertical distance between the U6c and L6c	√

comparisons, the least significant difference was applied. Independent *t* tests and chi-square tests were used to compare intergroup differences. Pearson correlation and Kendall's coefficients were estimated to assess the degree of linear association between potential parameters and the amount of mandibular relapse and were used further for variable selection. Multivariate linear regression analysis with backward elimination explored factors influencing mandibular postsurgical stability. For all statistical analyses, $P < 0.05$ was considered significant.

RESULTS

The time-course 3D postsurgical skeletal changes are summarized in Table III. In SFA, a considerable amount of mandibular sagittal and vertical relapse occurred within the first 3 months after surgery and then gradually occurred less frequently over the 12-month postoperative period (R3 > R12'; $P < 0.05$). However, in CSA, no significant recurrences were observed in both sagittal and vertical dimensions at 3 months (T2 - T1) and 3 to 12 months (T3 - T1), respectively (R3 = R12'; $P > 0.05$). In both groups, rapid and major relapses occurred within the first 3 months after surgery.

The amount of mandibular vertical reduction at point B was significantly greater in SFA than in CSA at both 3 months and 12 months postsurgery (ΔB-HRP, $P_{R3} < 0.001$ and $P_{R12} = 0.008$). However, the difference in the mandibular sagittal relapse between the 2 groups was only significant at 3 months postsurgery (ΔB-VRP, $P_{R3} = 0.013$).

The stability of the maxilla and mandible transversal positions was clinically acceptable after surgery over time, with no significant difference between the 2 groups.

As summarized in Table IV, the CV of the SFA group was significantly larger than that of the CSA group at all

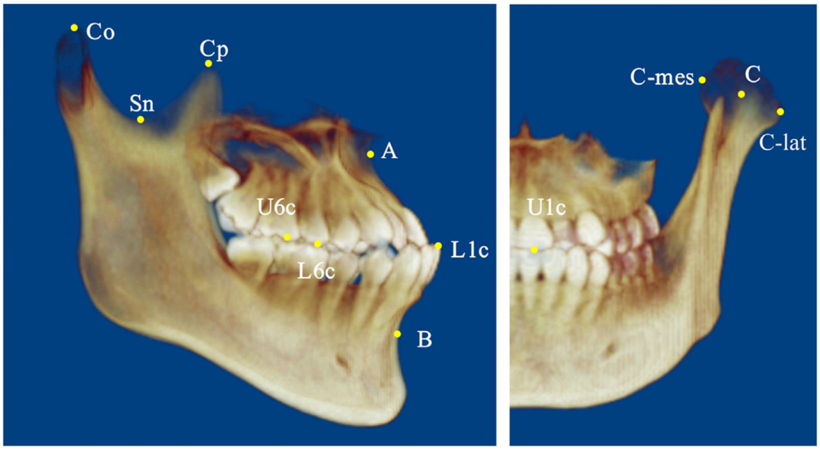

Fig 2. Landmarks used in this study were identified using Dolphin 3D Imaging software.

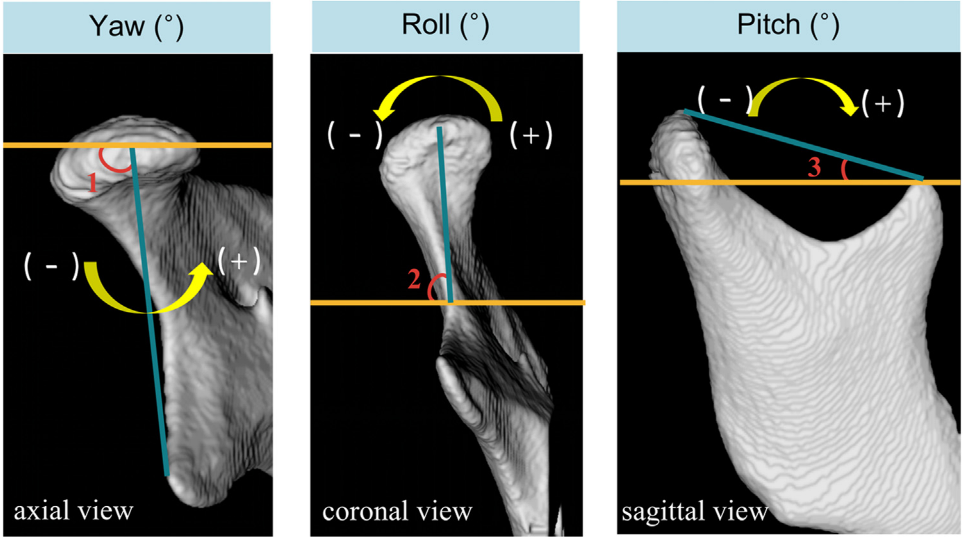

Fig 3. Angular measurements of the PS were used in this study. Yaw: +, inward; −, outward; Roll: +, superior; −, inferior; Pitch: +, clockwise; −, counterclockwise.

3-time points before and after surgery (P_M = 0.021). However, there was no significant difference in CV over time (P_T = 0.840).

The time-course linear and angular displacements of PS are summarized in Table V. In general, similar patterns of PS displacement were observed between the 2 groups.

For the surgery-related displacement, the condyle showed inferior (SFA, −0.94 ± 0.70 mm; CSA, −1.04 ± 0.66 mm) and lateral (SFA, −0.93 ± 0.89 mm; CSA, −0.79 ± 0.73 mm) displacement in both groups. The condyle was displaced posteriorly by −0.08 ± 0.69 mm in the SFA group and anteriorly by 0.25 ± 0.67 mm in the CSA group, although these differences were not statistically significant. Moreover, an apparent intraoperative rotation of PS occurred in both groups. An equal amount of CWR (SFA, 3.97° ± 1.88°; CSA, 2.83° ± 2.10°) and inferior rotation (SFA, −3.38° ± 2.01°; CSA, −1.37° ± 2.38°) of the PS were observed. In contrast, the inwards rotation of the PS was significantly greater in the SFA group than in the CSA group (SFA, 5.25° ± 1.99°; CSA, 3.56° ± 2.93°; *P* = 0.041).

The PS tended to return to its original position after surgery, mainly occurring within 3 months after surgery and remaining relatively stable during the subsequent 12 months after surgery (P3 = P12 in most pairwise

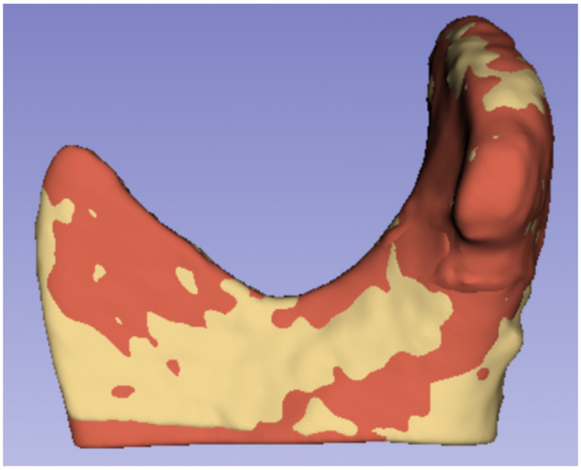

Fig 4. Superimposition of nonchanging anatomic structures for condyle segmentation.

comparisons by least significant difference as $P > 0.05$). Furthermore, the PS continued to rotate counterclockwise in both groups during the 12 months after surgery.

As summarized in Table VI, there was a significantly strong correlation between the CWR of PS and ΔB-VRP during surgery ($r = -0.828$; $P < 0.001$). Nevertheless, other dimensions of the intraoperative displacement of PS showed no significant correlation with the amount of MS. In addition, both surgically related (T1 − T0) ΔB-HRP ($r = 0.629$; $P < 0.001$) and ΔOJ ($r = -0.689$; $P < 0.001$) were significantly moderately correlated with ΔB-VRP during surgery.

The surgical mode, VD at T0 and T1, OJ at T1 and T1 − T0, C-VRP and C-HRP at T1 − T0, and B-VRP and B-HRP at T1 − T0 showed significantly weak to moderate correlations with early relapse of the mandible in the sagittal plane (B-VRP at T2 − T1).

After Pearson correlation analysis and collinearity analysis (Table VI), the surgical mode, variables of VD at T0, amount of MS and intraoperatively condylar sagittal and VD, and VD and OJ at T1 were input into the multivariate linear regression. The amount of MS and condylar vertical displacement, VD, and OJ at T1 were finally selected as parameters. Wider VD and larger OJ at T1, greater inferior displacement of the condyle during surgery, and greater MS were significantly correlated with more postsurgical sagittal relapse of the mandible at the early stage ($r^2 = 0.593$; Table VII). However, the surgical mode was not included in the final equation model, suggesting that it was not a determinant of early relapse.

To account for the measurement error of 0.25 mm, we further divided the sample into postsurgical stable (ΔB-VRP at T2 − T1 ≤1.50 mm; n = 19) and unstable groups (ΔB-VRP at T2 − T1 ≥2.00 mm; n = 15).

In Table VIII, the stable group showed a mean MS of 7.47 mm, an intraoperative condylar vertical displacement of −0.71 mm, a postoperative OJ of 3.90 mm, and a postoperative VD of −0.46 mm. In contrast, the unstable group showed a mean MS of 10.33 mm, an intraoperative condylar vertical displacement of −1.28 mm, a postoperative OJ of 6.43 mm, and a postoperative VD of −1.63 mm. The comparison results showed that all prognostic factors were significantly different between the 2 groups.

DISCUSSION

With increasing attention to the SFA, many surgeons and orthodontists have begun to apply this technique in complex malocclusions. However, there are still few evidence-based reports on this complicated situation. Among them, whether the postsurgical stability of SFA is comparable to that of CSA needs to be discussed first. Furthermore, by exploring factors affecting postsurgical stability, a method predicting the timing of surgery was established.

Previous studies commonly use two-dimensional cephalometric analysis, which has inherent limitations regarding accurately assessing bilateral structures and mediolateral movements. In recent years, more studies have introduced CBCT for comprehensive 3D analysis, which provides accurate linear and angular measurements and permits superimposition before and after surgery.

A certain degree of skeletal relapse is inevitable after orthognathic surgery,[11] regardless of the approaches applied. In particular, MS is regarded as the most problematic movement, with a high relapse tendency.[3] In this prospective cohort study, we found that the 3D position of the maxillary and the mandibular transverse position after surgery were clinically stable in both the CSA and SFA groups. However, the mandible moved anterosuperiorly after surgery. Relapse mainly occurred within the first 3 months after surgery. According to previous studies, the SFA relapse was greater than that in CSA,[27] and the difference was significant at T2. In addition, the results of this study suggested that surgeons and orthodontists should pay more attention to managing the first 3 months after surgery, regardless of CSA or SFA.

The changes in the position of the PS could be seen in all dimensions—x, y, z, yaw, roll, and pitch. In this study, we found that most condyles in both the SFA and CSA approaches moved lateral-inferiorly after surgery, and most PSs rotated anteriorly, inwards, and inferiorly after

Table III. Comparison of postsurgical skeletal changes (mm) between SFA and CSA groups

	T2 postsurgical relapse (R3: T2 − T1)			*T3 Postoperative relapse (R12’: T3 − T2)*			*T3: Postoperative total relapse (R12: T3 − T1)*			
Variables	*SFA (n = 20)*	*CSA (n = 19)*	P *value*	*SFA (n = 20)*	*CSA (n = 19)*	P *value*	*SFA (n = 20)*	*CSA (n = 19)*	P *value*	*RM ANOVA*
B-VRP	2.32 ± 1.67	1.15 ± 1.02	0.013*	0.31 ± 0.72	0.59 ± 0.65	0.206	2.63 ± 1.71	1.75 ± 1.20	0.071	T: *P* <0.001*; M: *P* = 0.071; T – M: *P* = 0.007*; SFA: R3 = R12 > R12’; CSA: R3 = R12’<R12; R3: SFA > CSA; R12’: SFA = CSA; R12: SFA = CSA
B-HRP	2.85 ± 1.51	1.22 ± 0.96	<0.001*	1.02 ± 1.44	1.02 ± 1.25	0.990	3.88 ± 1.85	2.24 ± 1.78	0.008*	T: *P* <0.001*; M: *P* = 0.008*; T – M: *P* = 0.003*; SFA: R12’ < R3 < R12; CSA: R3 = R12’ < R12; R3: SFA > CSA; R12’: SFA = CSA; R12: SFA > CSA
B-MSP	−0.30 ± 1.09	−0.42 ± 0.96	0.732	0.05 ± 1.09	−0.02 ± 0.60	0.806	−0.43 ± 1.09	−0.25 ± 1.21	0.623	T: *P* = 0.107; M: *P* = 0.623; T – M: *P* = 0.896
A-VRP	−0.46 ± 0.52	−0.25 ± 0.90	0.372	−0.57 ± 0.45	−0.40 ± 0.71	0.395	−1.03 ± 0.73	−0.65 ± 0.80	0.135	T: *P* = 0.006*; M: *P* = 0.135; T – M: *P* = 0.616; T: R3 = R12’ > R12
A-HRP	−0.07 ± 1.83	−0.00 ± 1.23	0.890	0.38 ± 1.73	−0.28 ± 1.09	0.164	0.31 ± 1.32	−0.28 ± 1.69	0.230	T: *P* = 0.887; M: *P* = 0.230: T – M: *P* = 0.388
A-MSP	−0.26 ± 0.36	−0.07 ± 0.25	0.052	0.12 ± 0.35	−0.03 ± 0.49	0.665	−0.14 ± 0.55	−0.10 ± 0.43	0.712	T: *P* = 0.019*; M: *P* = 0.803; T – M: *P* = 0.100; T: R3 = R12 < R12’

Note. Data are presented as the mean ± standard deviation. See Table II for the definition of landmarks.
SFA, surgery-first approach; *CSA*, conventional surgery approach; *T*, Time; *M*, Surgical mode; *R*, Relapse; *RM ANOVA*, repeated measures analysis of variance.
*Statistically significant difference with a significance level of 5%.

Table IV. Comparison of time-course CV (mm^3) between SFA and CSA groups

T0			*T2*			*T3*			
SFA	*CSA*	P *value*	*SFA*	*CSA*	P *value*	*SFA*	*CSA*	P *value*	*RM ANOVA*
2384.07 ± 411.81	2017.52 ± 491.83	0.016*	2378.81 ± 446.69	2026.82 ± 480.49	0.023*	2380.47 ± 431.20	2037.92 ± 500.86	0.028*	T: $P = 0.840$; M: $P = 0.021$*; T – M: $P = 0.718$; M: SFA > CSA

Note. Data are presented as the mean ± standard deviation. See Table II for the definition of landmarks.
SFA, surgery-first approach; *CSA*, conventional surgery approach; *RM ANOVA*, repeated measures analysis of variance; *T*, Time; *M*, Surgical mode.
*$P < 0.05$.

surgery, which aligns with previous studies.[12,19,28] In both groups, a tendency to return to the primary position was observed at T2 and stabilization at T3 in most patients, except for the angular changes regarding the pitch direction. Comparisons between SFA and CSA suggest that the intraoperative and postoperative changes in the condylar position in all dimensions after BSSRO are equivalent regardless of the timing of surgery.[29,30] In this study, only the intraoperative inwards rotation of the PS was significantly greater in SFA than in CSA. Torque compression between the contact point of the PS and the distal segment occurred during the fixation procedure of BSSRO, causing a certain degree of transversal displacement and rotation of the PS.[31] However, neither our study (Table VI) nor a previous study by Angle et al[32] found clinically important associations between the transverse displacement of the proximal segments and mandibular sagittal relapse.

Previous studies have suggested that the CWR of the PS was significantly positively correlated with the extent of MS.[4,12] This study confirms this correlation at a strong level ($r = -0.828$; $P < 0.001$). Surgeons can intentionally rotate the CWR of PS to avoid VBS in the mandibular inferior border; this intentional rotation can improve the bone contact between the 2 mandibular segments.[13] The rebound of stretched masticatory muscles and temporomandibular joint ligament would later counterclockwise rotate the PS and bring the entire mandible forward. Therefore, Yang et al[13] suggested maintaining the VBS for more stable results. However, in a study by Batbold et al,[4] the VBS was directly affected by the amount of MS, and the development and resolution of VBS affected postsurgical stability. The CWR of the PS might unintentionally result from the backward force of soft tissue (such as the elongation of the pterygomasseteric sling).[4,10,11] This implies that the CWR of the PS is, to some extent, an inevitable side effect of the MS.

In this study, we found that both sagittal and vertical displacements of the condyle during surgery were not correlated with the extent of MS but were significantly correlated with early relapse. Furthermore, the amount of downward condylar displacement at surgery is one of the important factors determining the amount of early relapse of the mandible (Table VII). Manipulation of the PS during BSSRO may cause intraarticular edema and result in inferior displacement of the condyle. The posteroinferior displacement of the condyle would further elongate the masticatory muscles and temporomandibular joint ligament. Postsurgical recovery movement of the condyle resulting from the rebound of masticatory muscles and ligaments, resorption of edema, and removal of the splint induces early skeletal relapse.[12] In a prospective cohort study, Spinelli et al[33]

Table V. Comparison of proximal segments translational (mm) and angular (°) changes between SFA and CSA groups

	Surgical changes (S0: T1 − T0)			*3 Mo postsurgical changes (P3: T2 − T1)*			*1 Y postoperative changes (P12: T3 − T1)*			
Variable	*SFA (n = 20)*	*CSA (n = 19)*	P *value*	*SFA (n = 20)*	*CSA (n = 19)*	P *value*	*SFA (n = 20)*	*CSA (n = 19)*	P *value*	*RM ANOVA*
C-VRP	−0.04 ± 0.72	0.25 ± 0.67	0.191	0.04 ± 0.58	−0.25 ± 0.73	0.181	0.05 ± 0.89	−0.18 ± 0.68	0.356	T: *P* = 0.040* M: *P* = 0.533 T – M: *P* = 0.202 T: S0 < P3=P12
C-HRP	−0.94 ± 0.70	−1.04 ± 0.66	0.668	0.71 ± 0.69	1.04 ± 0.76	0.159	0.89 ± 0.86	0.91 ± 0.73	0.957	T: *P* <0.001* M: *P* = 0.888 T – M: *P* = 0.338 T: S0 < P3 = P12
C-MSP	−0.93 ± 0.89	−0.79 ± 0.73	0.592	0.71 ± 0.94	0.90 ± 0.54	0.427	0.78 ± 0.51	1.05 ± 0.81	0.207	T: *P* <0.001* M: *P* = 0.012* T – M: *P* = 0.898 T: S0 < P3 = P12; M: SFA < CSA
Yaw	5.25 ± 1.99	3.56 ± 2.93	0.041*	−2.38 ± 3.52	−1.45 ± 1.36	0.290	−2.21 ± 3.81	−1.93 ± 3.06	0.800	T: *P* <0.001* M: *P* = 0.745 T – M: *P* = 0.165 T: S0 < P3 = P12
Roll	−3.38 ± 2.01	−1.37 ± 2.38	0.942	0.66 ± 1.57	0.69 ± 2.33	0.953	0.90 ± 2.28	0.44 ± 2.09	0.184	T: *P* <0.001* M: *P* = 0. 152 T – M: *P* = 0.068 T: S0 < P3 = P12
Pitch	3.97 ± 1.88	3.72 ± 2.27	0.708	−1.89 ± 1.28	−1.54 ± 1.39	0.410	−2.83 ± 1.54	−2.26 ± 2.12	0.344	T: *P* <0.001* M: *P* = 0.500 T – M: *P* = 0.468 T: S0 > P3 > P12

Note. Data are presented as the mean ± standard deviation. See Table II for the definition of landmarks. Translational changes: lateral (−); superior (+); anterior (+); Rotational changes: inferior (−); anterior (+); inwards (+).
SFA, surgery-first approach; *CSA*, conventional surgery approach; *S*, Intraoperative changes; *RM ANOVA*, repeated measures analysis of variance; *T*, Time; *M*, Surgical mode.
*Statistically significant difference with a significance level of 5%.

Table VI. Correlation between ΔB-VRP and other measurements

Variables		*ΔB−VRP (T1 − T0)*			*ΔB−VRP (T2 − T1)*	
Surgical mode		−0.068			0.294[*,†]	
CV (mm^3)		−0.161			0.313	
	T0	*T1*	*T1 − T0*	*T0*	*T1*	*T1 − T0*
PS						
C-VRP (mm)	−0.047	−0.088	0.240	0.154	0.216	−0.381[*,‡]
C-HRP (mm)	−0.209	−0.214	−0.114	0.095	0.031	0.324[*,‡]
C-MSP (mm)	−0.241	−0.258	0.057	0.278	0.309	−0.108
Yaw (°)	0.048	−0.052	0.129	−0.094	−0.118	0.037
Roll (°)	−0.032	−0.081	−0.091	−0.255	−0.255	−0.007
Pitch (°)	0.270	0.024	−0.828[**,‡]	0.093	0.214	0.408[**,‡]
Bimaxilla						
B-VRP (mm)	−0.696[**,‡]	0.033		0.314	−0.101	−0.497[**,‡]
B-HRP (mm)	0.310	0.027	0.629[**,‡]	−0.081	0.051	−0.399[*,‡]
B-MSP (mm)	0.441[**,‡]	−0.110	0.413[**,‡]	−0.309	−0.003	−0.264
A-VRP (mm)	−0.362	−0.318[*]	−0.008	0.219	0.100	0.087
A-HRP (mm)	0.010	−0.067	0.287	−0.186	0.095	−0.136
A-MSP (mm)	−0.053	0.068	0.121	−0.020	−0.035	−0.149
Dental						
OJ (mm)	0.476[**,‡]	−0.201	−0.689[**,‡]	0.013	0.505[**,‡]	0.370[*,‡]
VD (mm)	0.161	0.306	0.144	−0.347[*,‡]	−0.599[**,‡]	−0.260

Note. See Table II for the definition of measurements.
[†]Significance determined using Kendall's correlation test; [‡]Significance determined using Pearson correlation test; *$P < 0.05$; **$P < 0.001$.

Table VII. Multivariate linear regression analysis with backward elimination for early mandibular sagittal relapse (ΔB-VRP: T2 − T1)

Variables	*Unstandardized coefficients*	*Standardized coefficients β*	P *value*
B-VRP (T1 − T0)	−0.137	−0.297	0.015
C-HRP (T1 − T0)	0.601	0.269	0.020
OJ (T1)	0.140	0.252	0.050
VD (T1)	−0.457	−0.385	0.005

Note. See Table II for the definition of landmarks. $R^2 = 0.593$, $F = 12.386$ level of significance for elimination was set at 0.05.

Table VIII. Independent *t* test to compare the selected factors in postsurgical stable and unstable groups

Variables	*Stable (n = 19)*	*Unstable (n = 15)*	P *value*
B-VRP (T1-T0)	−7.47 ± 3.50	−10.33 ± 2.29	0.010
C-HRP (T1-T0)	−0.71 ± 0.68	−1.28 ± 0.60	0.013
OJ (T1)	3.90 ± 1.79	6.43 ± 3.16	0.012
VD (T1)	−0.46 ± 0.87	−1.63 ± 1.43	0.011

Note. Data are presented as the mean ± standard deviation. See Table II for the definition of landmarks.

suggested that piezoosteotomy could substantially reduce intraoperative blood loss, postoperative swelling, and nerve impairment compared with the traditional saw technique.[33] Further studies are needed to investigate whether piezoosteotomy can reduce intraoperative PS displacement and postsurgical relapse.

In this study, we found no significant difference in the CV over time, although there were significant differences between the 2 groups (Table IV). In addition, the presurgical CV had a moderate but insignificant correlation with the amount of MS or postsurgical early relapse (Table VI). Adaptive condylar remodeling is a common phenomenon after orthognathic surgery. Abotaleb et al[16] demonstrated a weak to moderate correlation between the postsurgical displacement of the PS and postsurgical condylar remodeling. Nevertheless, Dicker et al[34] suggested that neither muscle traction nor condylar rotations were responsible for progressive condylar resorption. A multivariate regression analysis by Xi et al[18] indicated that presurgical CV and postsurgical CV reduction were prognostic factors for postsurgical relapse. However, If the adaptive capacity of the temporomandibular joint is within the physiological limits, progressive condylar resorption may not occur.

The multivariate regression analysis in this study suggested that the amount of MS and downward displacement of the condyle at surgery and the OJ and VD at T1 were important prognostic factors in postsurgical early relapse of the mandible in the sagittal plane. The regression model explained 59.3% of the variance ($r^2 = 0.593$; Table VII). Among them, VD was the most important prognostic factor, and the amount of MS was the second most important factor. This is in line with results reported by Lee et al,[7] who emphasized that the increase in VD after surgery would make the surgical result less predictable.

Furthermore, this regression model summarized the anterior, middle, and posterior constraints that affect the early stability of the mandible and could be used as a tool to decide the timing of surgery. The postoperative stability is more predictable when the amount of MS is <7.5 mm, the vertical position of the condyles is relatively stable during surgery, the OJ is <3.9 mm and the VD increases little after surgery (Table VIII). For surgery with a mandible retraction of >10 mm, maintaining a VD of ≤0.5 mm is beneficial for more stable results. Otherwise, it is advisable to perform partial preoperative orthodontics to eliminate occlusal interference and decompensate the anterior teeth or perform anterior maxillary anterior segmental osteotomy to reduce the OJ to at least 3.9 mm after surgery and perform minimally invasive surgery.

Other studies have also recommended extending the usage of the occlusal splint, applying a chincup, or using bone anchorage for intermaxillary Class III elasticity to control postsurgical relapse.[20] However, postoperative patient management is not a part of this study because there are differences between the 2 approaches in the timing of postoperative orthodontic treatment and the method of orthodontic adjustment that are not conducive to studying generalizability. Further studies should be conducted to continue investigating how postoperative orthodontic management could control relapse.

The limitation of this cohort study is the mixed inclusion of subjects with or without mandibular asymmetry, although the average deviation level of both groups was not more than severe deviation. The asymmetric BSSRO is complicated in the distal placement, which can differ between the deviated and the nondeviated sides.[35] In addition, there may be different changes in condyle position between the 2 sides after surgery.[36] In this study, we did not investigate the asymmetry of the displacement and remodeling of the bilateral PS and their respective effects on postsurgical stability. In the future, targeted clinical comparative studies of patients with mandibular asymmetry will be performed.

CONCLUSIONS

For the patients involved in this study, the postsurgical relapse in patients with skeletal Class III malocclusion who underwent 2-jaw surgery and premolar extraction mainly occurred in the sagittal and vertical dimensions of the mandible and the first 3 months after surgery, regardless of CSA or SFA. The SFA resulted in substantially less stable results than those in CSA. Both groups possessed similar patterns of PS displacement and a stable CV. Immediate postsurgical VD, surgical amount of MS, surgical condylar downwards displacement, and immediate postsurgical OJ are the most important predictors of early mandibular stability.

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AUTHOR CREDIT STATEMENT

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SUPPLEMENTARY DATA

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