Stability of Clockwise Rotation of The Maxillary Occlusal Plane By Two-Jaw Surgery In Patients With Skeletal Class III Malocclusion

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Abstract

Introduction: To investigate the post-surgical stability of clockwise rotation of the maxillary occlusal plane (MXOP) after Le Fort I osteotomy for posterior impaction and advancement in skeletal Class III patients who had undergone two-jaw orthognathic surgery (2J-OGS).

Materials and methods: Sample set consisted of 46 patients [18 males and 28 females]. Using lateral cephalograms taken at the initial (T0), before 2J-OGS (T1), after (T2), and at debonding (T3), The amount of MXOP change (criterion: 2° in Δ MXOP between T2-T3) was used to assign patients to Group1[G1, high relapse, 3.09°] or Group2 [G2, low relapse, -0.99°]. Statistical analyses were then performed.

Results: Compared to G2, G1 exhibited more severe skeletal Class III relationships and a flatter MXOP at T0, a greater increase in Δ ANB, and more clockwise rotation of Δ MXOP and Δ FMA during T1-T2, as well as a greater decrease in Δ ANB, higher counterclockwise rotation of Δ MXOP, and upward movement of U1 during T2-T3. Regression analysis resulted in formulation of the following equation: $MXOP(\Delta T2-T3) = -0.37 \times MXOP(\Delta T1-T2) - 0.43$.

Conclusions: The higher the clockwise rotation of the MXOP during 2J-OGS in skeletal Class III patients, the greater the relapse (counterclockwise rotation) in the MXOP.

Introduction

Orthognathic surgery (OGS) is performed to improve facial aesthetics and occlusal function by resolving severe dentofacial discrepancies. Several previous studies reported a hierarchy in post-surgical stability according to the surgical movement types of OGS¹⁻⁴. Al-Delayme et al⁵ suggested that the main cause of post-surgical relapse of the mandible might be counter-clockwise (CCW) rotation of the proximal segment in patients who had undergone both one-jaw OGS (1J-OGS) and two-jaw OGS (2J-OGS). Cho⁶ reported that the amount of post-surgical relapse in 2J-OGS increased as did the amount of clockwise (CW) rotation of the proximal segment of the mandible during surgery. Although several previous studies^{4,5,7} have compared post-surgical stability between 1J-OGS and 2J-OGS, there is no consensus among studies whether the post-surgical stabilities of 1J-OGS and 2J-OGS are significantly different. Furthermore, Chemello et al⁸ investigated post-surgical stability of CW and CCW rotation of the occlusal plane in patients that had undergone 2J-OGS. However, they did not include skeletal Class III patients in their sample.

To optimize facial aesthetics and occlusal function, Arnett and Gunson⁹ emphasized the importance of the maxillary occlusal plane (MXOP). Furthermore, CW rotation of the MXOP in patients with skeletal Class III malocclusion has been reported to have aesthetic advantages^{10,11}. Posterior impaction of the maxilla in patients with skeletal Class III malocclusion can increase the amount of mandibular setback with CW rotation^{12,13}. However, how posterior impaction of the maxilla affects the stability of the MXOP change is still unknown. In addition, some patients with skeletal Class III malocclusion require advancement of the maxilla as well as posterior impaction of the maxilla^{14,15}.

Although diverse aspects of surgical stability have been examined^{1-5,7,16,17}, these studies have focused primarily on comparison of the difference between 1J-OGS and 2J-OGS. Therefore, when considering the stability of MXOP changes in 2J-OGS, the following study design should be used: (1) to increase sample homogeneity, the sample should be limited to 2J-OGS cases in which metal plates and mono-cortical screws have been employed for fixation of the osteotomized segments; (2) assessment of the post-surgical stability of the maxilla and MXOP should include linear changes as well as angular changes¹⁸; and (3) the follow-up period for 2J-OGS patients should be confined to 1 year after surgery^{4,5}.

As mentioned before, determination of the MXOP is critical to achieve pleasing midface facial esthetics and occlusal function, including incisal guidance¹⁸. However, no study to date has quantitatively evaluated the stability of the MXOP change in 2J-OGS in patients with skeletal Class III malocclusion. Therefore, our purpose in this study was to investigate the post-surgical stability of CW rotation of the MXOP after Le Fort I osteotomy for posterior impaction and advancement in patients with skeletal Class III malocclusion who had undergone 2J-OGS.

Materials And Methods

Subjects

The initial sample comprised 212 Korean adult patients with skeletal class III malocclusion who had undergone surgical orthodontic treatment and 2J-OGS at Seoul National University Dental University Hospital, Seoul or Ajou University Dental Hospital, Suwon, Gyeonggi province, Republic of Korea from 2006 to 2017.

Inclusion criteria were (1) patients who had undergone Le Fort I osteotomy for advancement and posterior impaction with or without anterior elongation of the maxilla and bilateral sagittal split osteotomy (BSSO) in the mandible; (2) patients who had more than one degree of MXOP change after Le Fort I osteotomy; and (3) rigid fixation (RF) with a metal plate and mono-cortical screws for fixation of the osteotomized bony segments; (4) patients for whom photographs and lateral cephalograms were taken at the initial visit (T0), at least 1 month before 2J-OGS (T1), at least 1 month after 2J-OGS (T2), and at debonding (T3); and (5) patients who were treated by faculty orthodontists with more than 30 years of experience (SHB and YHK). Exclusion criteria were (1) patients who had cleft lip and/or palate or congenital craniofacial deformities; (2) patients who had a history of trauma in the craniofacial area; and (3) patients who had severe facial asymmetry (more than 5 mm of menton deviation). The study design followed the Declaration of Helsinki principles and was approved by SNUDH and Ajou University Hospital.

As a result, 46 patients (18 males and 28 females) were selected as final subjects. Proffit et al¹⁹ suggested that post-surgical changes more than 2 mm or 2 degrees could be considered clinically significant. Therefore, in the present study, according to the amount of MXOP change between T2 and T3 stages

[criteria: 2° in Δ MXOP between T2-T3 [MXOP(Δ T2-T3)], subjects were divided into Group 1 (high relapse, n=22, 13 males and 9 females; 17 extraction and 5 non-extraction cases; mean age, 20.1 years at T0, 21.6 years at T1, 21.8 years at T2, 22.9 years at T3; MXOP(Δ T2-T3), $-3.1^\circ \pm 0.9^\circ$) and Group 2 (low relapse, n=24, 15 males and 9 females; 14 extraction and 10 non-extraction; mean age, 21.1 years at T0, 23.0 years at T1, 23.2 years at T2, 24.3 years at T3; MXOP(Δ T2-T3), $-1.0^\circ \pm 0.6^\circ$). The differences between the two groups at each stage are summarized in Table 1.

This retrospective cohort study was reviewed and approved by the Institutional Review Board (IRB) of Seoul National University Dental Hospital (SNUDH) (ER18002) and Ajou University Hospital (IRB no.: AJIRB-MED-MDB-21-255). The requirement for patient consent was waived by the IRB Committee of Seoul National University Dental Hospital (SNUDH) (ER18002) and Ajou University Hospital (IRB no.: AJIRB-MED-MDB-21-255).

Landmarks and variables used in this study

Definitions of landmarks and linear and angular variables are presented in Figures 1 and 2. Especially, Changes in the most anterior and inferior point of the maxillary rigid plate angle between T2 and T3 stages (Δ APP) were measured to quantify skeletal relapse of the maxilla using best-fit superimposition in the two lateral cephalograms. Landmark identification and measurement of variables were performed by a single operator (SYK).

Sample size determination

Power analyses were performed using mean and standard deviation (SD) values of the angulation of MXOP postsurgical change from Wolford and colleagues' 1994 study²⁰ (mean, 0.6° and SD 1.5°). The R program (ver. 4.0.3, Vienna, Austria) suggested 21 as the minimum sample size.

Reliability test

To assess intra-examiner reliability, all variables from 20 randomly selected subjects were evaluated again one month later by the same investigator (SYK). Since there was no significant difference between the first and second measurements according to paired t-tests, the first set of variables was used in further statistical analyses.

Statistical analyses

Shapiro-Wilk test was conducted to evaluate the normality of each variable. One-way analysis of variance (ANOVA), Kruskal-Wallis Test, Tukey post-hoc analysis, paired t-test, Wilcoxon signed rank sum test, independent t-test, Mann-Whitney U test, correlation analysis, and simple regression analysis were performed. All statistical analyses were performed using the R program (Ver. 4.0.3). A p-value of less than 0.05 was considered statistically significant.

Results

Table 2 described Comparison of Group 1 and Group 2 at each stage. When compared to Group 2 at T0, Group 1 presented with more severe skeletal Class III relationships (ANB, -4.9° vs -2.4° , $P<0.01$), a more prognathic maxilla (SNA, 79.9° vs 77.8° , $P<0.05$), a more prognathic mandible (SNB, 84.7° vs 80.1° , $P<0.01$; Pog to N-perp, 10.1 mm vs 6.9 mm, $P<0.05$), a more forward position of the maxillary incisor and first molar (U1_x, 67.6 mm vs 61.8 mm; U6_x, 37.0 mm vs 33.3 mm; all $P<0.05$), and more labial inclination of the maxillary incisor (U1 to FH, 121.5° vs 114.6° ; $P<0.05$). However, Group 1 presented with a flatter MXOP than Group 2 (10.6° vs 15.3° , $P<0.01$), which implied that a higher amount of posterior impaction of the maxilla was required in Group 1 than Group 2.

At T1, compared to Group 2, Group 1 still presented with more severe skeletal Class III relationships (ANB, -5.3° vs -2.0° , $P<0.01$) and a more forward position of the maxillary incisor and maxillary first molar; U1_x, 65.0 mm vs 60.7 mm, $P<0.05$; U6_x, 38.0 mm vs 33.4 mm, $P<0.01$). Although the difference was not statistically significant, Group 1 presented with a flatter MXOP than Group 2 (11.9° vs 15.6°). An increase in MXOP from 10.6° to 11.9° in Group 1 might have occurred due to intrusion of the maxillary molars using miniscrews during pre-surgical orthodontic treatment. However, there was no significant difference in MXOP in Group 2 (15.3° to 15.5°) during pre-surgical orthodontic treatment.

At T2, SNA, SNB, ANB, FMA, U1 to FH, and IMPA were similar between the two groups. In addition, there was no significant difference in MXOP between the two groups (16.5° vs 18.4°). At T3, although there was no difference in ANB, FMA, U1 to FH, and IMPA between the two groups, MXOP showed a significant difference between Group 1 and Group 2 (13.4° vs 17.4° , $P<0.05$). Surgical changes (Δ T1-T2) were the forward movement of Point A (Δ A-x, 4.0 mm, Δ A-N perp, 3.2 mm, all $P<0.05$) and the backward movement of Pog (Δ Pog-N perp, 11.5 mm, $P<0.001$). SNB decreased significantly (Δ SNB, 5.8° , $P<0.001$) and ANB increased significantly (Δ ANB, 8.0° , $P<0.001$). Due to posterior impaction of the maxilla by surgery (Δ PNS-y, 3.6 mm, $P<0.01$; Δ U6-y, 2.3 mm, $P>0.05$), CW rotation of the MXOP occurred (Δ MXOP, 4.6° , $P<0.01$).

There were no significant changes in cephalometric variables except CCW rotation of the MXOP (Δ MXOP, -3.1° , $P<0.05$) and a decrease in ANB (Δ ANB, -1.7° , $P<0.001$) and the Δ APP angle (-1.7° , $P<0.001$) post-surgically (Δ T2-T3). Since the Δ APP angle represents skeletal changes of the maxilla, these results imply CCW relapse during the post-operative treatment period.

Net changes (Δ T1-T3) were the forward movement of Point A (Δ A-x, 3.5 mm, $P<0.05$) and the backward movement of Pog (Δ Pog-N perp, 9.9 mm, $P<0.01$). SNB decreased significantly (Δ SNB, 4.7° , $P<0.01$) and ANB increased significantly (Δ ANB, 6.3° , $P<0.001$). Despite posterior impaction of the maxilla by surgery (Δ PNS-y, 2.8 mm, $P<0.01$), the amount of maxillary molar and CW rotation of the MXOP was not significantly different pre- and post-surgery (Δ U6-y, 0.6 mm; Δ MXOP, 1.5° ; all $P>0.05$).

In Group 2, there was no significant forward movement of Point A pre- and post-surgery (Δ T1-T2; Δ A-x, 2.3 mm, Δ A-N perp, 0.8 mm, all $P>0.05$). However, there was significant backward movement of Pog (Δ Pog-N perp, 8.1 mm, $P<0.001$). SNB decreased (Δ SNB, 3.9° , $P<0.01$) and ANB increased (Δ ANB, 4.7° , $P<0.001$). CW rotation of the MXOP occurred (2.9° , $P<0.01$) as a result of upward movement of PNS (Δ PNS-y, 3.3 mm, $P<0.001$) and U6-y (Δ PNS-y, 2.2 mm, $P>0.05$).

Post-surgery ($\Delta T2-T3$), there were no significant change in any cephalometric variables. There was no significant change in ΔAPP angle (-0.7° , $P=0.1001$), suggesting no significant post-surgical relapse of the maxilla. The net change ($\Delta T1-T3$) was backward movement of Pog ($\Delta Pog-N$ perp, 6.9 mm, $P<0.01$). Additionally, SNB decreased significantly (ΔSNB , 3.3° , $P<0.01$) and ANB increased significantly (ΔANB , 3.4° , $P<0.001$). Due to posterior impaction of the maxilla by surgery ($\Delta PNS-y$, 3.4 mm, $P<0.001$) and U6-y ($\Delta U6-y$, 1.0 mm, $P>0.05$), significant CW rotation of the MXOP was observed ($\Delta MXOP$, 1.9° , $P<0.05$). There were no significant differences in dental decompensation of the maxillary and mandibular incisors between the two groups pre-surgically ($\Delta T0-T1$). More forward movement of Point A (ΔSNA , 0.6 vs -0.8 , $P<0.05$; $\Delta A-N$ per, 1.5 mm vs -0.5 mm, $P<0.01$) and more backward movement of Pog ($\Delta Pog-N$ per, 2.3 mm vs 0.0 mm, $P<0.05$) were observed in Group 2 than Group 1. After surgery ($\Delta T1-T2$), Group 1 showed more forward movement of Point A (ΔSNA , 2.2° vs 0.8° , $P<0.05$; $\Delta A-N$ perp, 3.2 mm vs 0.8 mm, $P<0.01$; $\Delta A-x$, 4.0 mm vs 2.3 mm, $P<0.01$) and backward movement with CW rotation of the mandible (ΔSNB , -5.8° vs 3.9° ; $\Delta Pog-N$ perp, -11.5 mm vs -8.1 mm; ΔFMA , 2.4° vs 0.4° , all $P<0.05$) than Group 2, resulting in an increase in ANB (8.0° vs 4.7° , $P<0.01$). Due to more CW rotation of the MXOP in Group 1 (4.6° vs 2.9° , $P<0.01$), there was more linguoversion of the maxillary incisors in Group 1 than Group 2 (U1 to FH, 4.2° vs 0.1° , $P<0.05$). Post-surgically ($\Delta T2-T3$), Group 1 showed more of a decrease in ANB (-1.7° vs -1.3° , $P<0.05$), labioversion of the maxillary incisors (U1 to FH, 3.7° vs 0.8° , $P<0.01$), and linguoversion of the mandibular incisors (IMPA, -1.7° vs 0.8° , $P<0.05$) than Group 2. Group 1 exhibited more CCW rotation of the MXOP (-3.1° vs -1.0° , $P<0.001$) and upward movement of the maxillary incisors (U1_y, -1.1 mm vs 0.1 mm, $P<0.05$) than Group 2. Since there were no differences in the amount of downward movement of U6-y (1.7 mm vs 1.2 mm, $P>0.05$) and PNS-y (0.8 mm vs -0.1 mm, $P>0.05$) between the two groups, the greater CCW rotation of the MXOP that occurred in Group 1 might have been induced by upward movement of the maxillary incisor (U1_y). The differences in the amount by which MXOP decreased in the two groups (from 16.5° to 13.4° in Group 1 and from 18.4° to 17.3° in Group 2).

Table 2 demonstrated the comparison of Group 1 and Group 2 at each stage. When compared to Group 2 at T0, Group 1 presented with more severe skeletal Class III relationships (ANB, -4.9° vs -2.4° , $P<0.01$), a more prognathic maxilla (SNA, 79.9° vs 77.8° , $P<0.05$), a more prognathic mandible (SNB, 84.7° vs 80.1° , $P<0.01$; Pog to N-perp, 10.1 mm vs 6.9 mm, $P<0.05$), a more forward position of the maxillary incisor and first molar (U1_x, 67.6 mm vs 61.8 mm; U6_x, 37.0 mm vs 33.3 mm; all $P<0.05$), and more labial inclination of the maxillary incisor (U1 to FH, 121.5° vs 114.6° ; $P<0.05$). However, Group 1 presented with a flatter MXOP than Group 2 (10.6° vs 15.3° , $P<0.01$), which implied that a higher amount of posterior impaction of the maxilla was required in Group 1 than Group 2.

At T1, compared to Group 2, Group 1 still presented with more severe skeletal Class III relationships (ANB, -5.3° vs -2.0° , $P<0.01$) and a more forward position of the maxillary incisor and maxillary first molar; U1_x, 65.0 mm vs 60.7 mm, $P<0.05$; U6_x, 38.0 mm vs 33.4 mm, $P<0.01$). Although the difference was not statistically significant, Group 1 presented with a flatter MXOP than Group 2 (11.9° vs 15.6°). An increase in MXOP from 10.6° to 11.9° in Group 1 might have occurred due to intrusion of the maxillary molars using miniscrews during pre-surgical orthodontic treatment. However, there was no significant difference in MXOP in Group 2 (15.3° to 15.5°) during pre-surgical orthodontic treatment.

At T2, SNA, SNB, ANB, FMA, U1 to FH, and IMPA were similar between the two groups. In addition, there was no significant difference in MXOP between the two groups (16.5° vs 18.4°).

At T3, although there was no difference in ANB, FMA, U1 to FH, and IMPA between the two groups, MXOP showed a significant difference between Group 1 and Group 2 (13.4° vs 17.4° , $P<0.05$).

Table 3 presented Changes in Group 1. Surgical changes ($\Delta T1-T2$) were the forward movement of Point A ($\Delta A-x$, 4.0 mm, $\Delta A-N$ perp, 3.2 mm, all $P<0.05$) and the backward movement of Pog ($\Delta Pog-N$ perp, 11.5 mm, $P<0.001$). SNB decreased significantly (ΔSNB , 5.8° , $P<0.001$) and ANB increased significantly (ΔANB , 8.0° , $P<0.001$). Due to posterior impaction of the maxilla by surgery ($\Delta PNS-y$, 3.6 mm, $P<0.01$; $\Delta U6-y$, 2.3 mm, $P>0.05$), CW rotation of the MXOP occurred ($\Delta MXOP$, 4.6° , $P<0.01$).

There were no significant changes in cephalometric variables except CCW rotation of the MXOP ($\Delta MXOP$, -3.1° , $P<0.05$) and a decrease in ANB (ΔANB , -1.7° , $P<0.001$) and the ΔAPP angle (-1.7° , $P<0.001$) post-surgically ($\Delta T2-T3$). Since the ΔAPP angle represents skeletal changes of the maxilla, these results imply CCW relapse during the post-operative treatment period.

Net changes ($\Delta T1-T3$) were the forward movement of Point A ($\Delta A-x$, 3.5 mm, $P<0.05$) and the backward movement of Pog ($\Delta Pog-N$ perp, 9.9 mm, $P<0.01$). SNB decreased significantly (ΔSNB , 4.7° , $P<0.01$) and ANB increased significantly (ΔANB , 6.3° , $P<0.001$). Despite posterior impaction of the maxilla by surgery ($\Delta PNS-y$, 2.8 mm, $P<0.01$), the amount of maxillary molar and CW rotation of the MXOP was not significantly different pre- and post-surgery ($\Delta U6-y$, 0.6 mm; $\Delta MXOP$, 1.5° ; all $P>0.05$).

Table 4 indicated Changes in Group 2. In Group 2, there was no significant forward movement of Point A pre- and post-surgery ($\Delta T1-T2$; $\Delta A-x$, 2.3 mm, $\Delta A-N$ perp, 0.8 mm, all $P>0.05$). However, there was significant backward movement of Pog ($\Delta Pog-N$ perp, 8.1 mm, $P<0.001$). SNB decreased (ΔSNB , 3.9° , $P<0.01$) and ANB increased (ΔANB , 4.7° , $P<0.001$). CW rotation of the MXOP occurred (2.9° , $P<0.01$) as a result of upward movement of PNS ($\Delta PNS-y$, 3.3 mm, $P<0.001$) and U6-y ($\Delta PNS-y$, 2.2 mm, $P>0.05$).

Post-surgery ($\Delta T2-T3$), there were no significant change in any cephalometric variables. There was no significant change in ΔAPP angle (-0.7° , $P=0.1001$), suggesting no significant post-surgical relapse of the maxilla.

The net change ($\Delta T1-T3$) was backward movement of Pog ($\Delta Pog-N$ perp, 6.9 mm, $P<0.01$). Additionally, SNB decreased significantly (ΔSNB , 3.3° , $P<0.01$) and ANB increased significantly (ΔANB , 3.4° , $P<0.001$). Due to posterior impaction of the maxilla by surgery ($\Delta PNS-y$, 3.4 mm, $P<0.001$) and U6-y ($\Delta U6-y$, 1.0 mm, $P>0.05$), significant CW rotation of the MXOP was observed ($\Delta MXOP$, 1.9° , $P<0.05$).

Table 5 displayed the comparison of the amount of change between the two groups. There were no significant differences in dental decompensation of the maxillary and mandibular incisors between the two groups pre-surgically ($\Delta T0-T1$). More forward movement of Point A (ΔSNA , 0.6 vs -0.8 , $P<0.05$; $\Delta A-N$ per, 1.5 mm vs -0.5 mm, $P<0.01$) and more backward movement of Pog ($\Delta Pog-N$ per, 2.3 mm vs 0.0 mm, $P<0.05$) were observed in Group 2 than Group 1.

After surgery ($\Delta T1-T2$), Group 1 showed more forward movement of Point A (ΔSNA , 2.2° vs 0.8° , $P < 0.05$; $\Delta A-N$ perp, 3.2 mm vs 0.8 mm, $P < 0.01$; ΔA_x , 4.0 mm vs 2.3 mm, $P < 0.01$) and backward movement with CW rotation of the mandible (ΔSNB , -5.8° vs 3.9° ; $\Delta Pog-N$ perp, -11.5 mm vs -8.1 mm; ΔFMA , 2.4° vs 0.4° , all $P < 0.05$) than Group 2, resulting in an increase in ANB (8.0° vs 4.7° , $P < 0.01$). Due to more CW rotation of the MXOP in Group 1 (4.6° vs 2.9° , $P < 0.01$), there was more linguoversion of the maxillary incisors in Group 1 than Group 2 (U1 to FH, 4.2° vs 0.1° , $P < 0.05$).

Post-surgically ($\Delta T2-T3$), Group 1 showed more of a decrease in ANB (-1.7° vs -1.3° , $P < 0.05$), labioversion of the maxillary incisors (U1 to FH, 3.7° vs 0.8° , $P < 0.01$), and linguoversion of the mandibular incisors (IMPA, -1.7° vs 0.8° , $P < 0.05$) than Group 2. Group 1 exhibited more CCW rotation of the MXOP (-3.1° vs -1.0° , $P < 0.001$) and upward movement of the maxillary incisors (U1_y, -1.1 mm vs 0.1 mm, $P < 0.05$) than Group 2. Since there were no differences in the amount of downward movement of U6-y (1.7 mm vs 1.2 mm, $P > 0.05$) and PNS-y (0.8 mm vs -0.1 mm, $P > 0.05$) between the two groups, the greater CCW rotation of the MXOP that occurred in Group 1 might have been induced by upward movement of the maxillary incisor (U1_y). The differences in the amount by which MXOP decreased in the two groups (from 16.5° to 13.4° in Group 1 and from 18.4° to 17.3° in Group 2) indicated that post-surgical stability differed according to the amount of MXOP change.

Correlations analyses were performed (Table 6) between the amount of post-surgical relapse ($T2-T3$) and the amount of surgical change ($T1-T2$). There was a significant negative correlation between ($\Delta T1-T2$) and ($\Delta T2-T3$) in PNS_x (all $P < 0.001$) and U1_y ($P < 0.001$ and $P < 0.01$) in both groups. In Group 1, there was a significant negative correlation between ($\Delta T1-T2$) and ($\Delta T2-T3$) in A_x, PNS_y, and U6_y ($P < 0.05$, $P < 0.01$, $P < 0.05$). However, in Group 2, the only significant negative correlations between ($\Delta T1-T2$) and ($\Delta T2-T3$) were in U1_x ($P < 0.01$).

There were significant negative correlations between ($\Delta T1-T2$) and ($\Delta T2-T3$) in SNB ($P < 0.01$ and $P < 0.05$) in both groups. In Group 1, there was a significant negative correlation between ($\Delta T1-T2$) and ($\Delta T2-T3$) in Pog-N perp ($P < 0.05$). In Group 2, there were significant negative correlations between ($\Delta T1-T2$) and ($\Delta T2-T3$) in A-N perp ($P < 0.01$) and ANB ($P < 0.05$).

Although Group 2 did not exhibit a significant correlation between ($\Delta T1-T2$) and ($\Delta T2-T3$) in MXOP ($r = -0.1713$, $P > 0.05$), there was a significant negative correlation between ($\Delta T1-T2$) and ($\Delta T2-T3$) in MXOP ($r = -0.7517$, $P < 0.001$). Simple regression analysis in Group 1 generated the following formula: $MXOP(\Delta T2-T3) = [-0.37 \times MXOP(\Delta T1-T2)] - 0.43$. This formula indicates that when greater CW rotation of the MXOP is planned in 2J-OGS in skeletal Class III patients, approximately 37% MXOP relapse with CCW rotation is likely to occur.

Discussion

In terms of the hierarchy of surgical stability, Bailey et al¹ reported that upward and forward movements of the maxilla are stable in addition to upward movement of the maxilla combined with forward movement of the mandible and forward movement of the maxilla accompanied with backward movement of the mandible with rigid fixation; by contrast, downward movement and expansion of the maxilla are regarded as problematic movements. However, Hass et al² stated that the maxilla presented with less surgical stability than the mandible based on a systematic review. Bharti et al²¹ reported significant relapse (30%) in the SNA after 2J-OGS. Dowling et al.²² calculated 24% relapse at point A, which was correlated with the amount of advancement of the maxilla. In the present study, Group 1 showed stable surgical outcomes with the exceptions of ANB, ΔAPP , and MxOP. The hierarchy of surgical stability therefore remains controversial.

Factors affecting MxOP can be divided into skeletal and dental components. In the present study, skeletal factors were APP, A_y, and PNS_y, while dental factors comprised U1_y and U6_y. During $T2-T3$, the ΔAPP difference between G1 and G2 was significant (Table 5, $\Delta T2-T3$, G1: -1.72 vs G2: -0.67 , $p < 0.001$), signifying that skeletal relapse occurred more in G1 than G2. With regards to dentition, a significant difference in U1_y was discovered between G1 and G2 (Table 5, $T2-T3$, G1: -1.1 vs G2: 0.1 , $p < 0.0109$), indicating that in G1, the maxillary incisors intruded more than in Group 2. The measurements A_y, PNS_y, and U6_y showed no significant differences between the two groups.

PNS_y was significantly different between $\Delta T2$ and $T3$ in Group 1 (Tables 3 4, G1: -1.72), while other variables were stable within groups over this time period. Consistent with our findings, Dowling²² reported that the PNS vertical position moved downward (0.4 mm, $0.01 < P < 0.05$) from 1 week after surgery to 3 years after surgery. Overall, MxOP relapse appears to arise mainly as a result of instability of the maxillary anterior teeth and skeletal PNS downward movement embodied by ΔAPP . Therefore, maxillary intrusion is associated with labioversion.

There were significant differences between G1 and G2 in the inclination of the maxillary incisors during post-surgical treatment between the two groups ($\Delta T2-T3$, Table 5; G1: 3.66 vs G2: 0.82 , $p = 0.0079$). There was also a significant difference in mandibular incisors between the two groups (Table 5, $\Delta T2-T3$, G1: -1.68 vs G2: 0.80 , $p = 0.0079$). Literature indicates that a change in the inclination of the incisors indicates unstable surgical outcomes. Troy²³ suggested that the amount of surgical correction was limited by the degree of incisor decomposition in pre-orthodontic treatment. Attainment of a positive OJ with insufficient decompensation of the incisors results in compensation. In the current study, we demonstrated that the changes in U1FH in G1 were 121.5° (T0), 118.38° (T1), 114.23° (T2), and 117.89° (T3), respectively. The position of the preoperative maxillary incisors was close to the normal position. Although normal inclination was attained during surgery through CW rotation of the MXOP (Table 2, T2 stage), this was unstable in G1 and the incisor inclination moved back to the preoperative inclination (T1). These findings are incongruent with Troy's reasoning that decompensation is the primary reason for incisor instability. The disagreement may be due to the preoperative direction of the maxillary incisors. Troy²³ reported that the inclination of the maxillary incisors was slightly increased (U1 to SN: $108.9^\circ \rightarrow 109.6^\circ$) during pre-operative orthodontic treatment while in the current study, both groups presented with retroclination and almost normal inclination was attained after surgery (Tables 2 and 3). In G1, the maxillary incisors showed significant labial inclination (Table 5). This implies that achievement of incisor decompensation may not be the primary factor determining final inclination, thus the amount of MXOP change during surgery should be evaluated to assess maxillary incisor stability. Baek²⁴ emphasized the importance of preoperative decompensation rather than surgical movement of the maxilla in terms of stability, suggesting that surgical correction of the inclination of the maxillary incisors is of limited utility. Interestingly, in a study that

used the surgery-first approach (SFA), maxillary incisor inclination was normalized with CW rotation of the maxilla (U1 to SN, 114°→108°). However, during post-operative orthodontic treatment, the labial inclination of the maxillary incisors increased to 114° while IMPA was maintained, and the authors suggested that it would be prudent to use class III mechanics after surgery²⁵. Taken together, a surgical treatment plan to normalize the inclination of the upper incisors depending on the amount of change in MXOP after surgery should be carefully designed to minimize relapse. Burstone reported that when incisors were labially inclined, this was accompanied by “pseudointrusion”²⁶. Thus, it can be inferred that labioversion of the maxillary incisors during post-operative treatment decreases the MXOP.

Since Proffit et al¹⁹ considered more than 2° of relapse clinically significant, the regression formula obtained in this study $MXOP(\Delta T2-T3) = [-0.37 \times MXOP(\Delta T1-T2)] - 0.43$ suggests that 4.2° CW rotation of MXOP is a relevant cut-off value for high versus low surgical relapse. A high relapse tendency after CW rotation of the MXOP could be managed by intrusion of the maxillary molars using miniscrews and elastomeric chains. In addition, clinicians should be careful to use long-term Class III elastics during post-surgical orthodontic treatment. If Class III elastics are used, they can be connected from miniscrews installed at the buccal attached gingiva of the maxillary molar area to hooks in the mandibular archwire. Maxillary incisor position can also be managed by selective grinding of the anterior part of the wafer (Baek, 2010)²⁵. An example of high relapse of the MXOP (CW rotation of the MXOP after 2J-OGS and CCW rotational relapse of the MXOP after 2J-OGS) is provided in Figure 3.

Conclusion

The greater the amount of CW rotation of the MXOP during 2J-OGS in skeletal Class III patients, the greater the relapse (CCW rotation) of the MXOP. Therefore, the amount of surgical change of the MXOP should be carefully planned and monitored to take post-surgical relapse into consideration.

Declarations

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Availability of data and materials

The data supporting the study can be obtained directly from the authors.

Ethics approval and consent to participate

This retrospective cohort study was reviewed and approved by the Institutional Review Board (IRB) of Seoul National University Dental Hospital (SNUDH) (ERI18002) and Ajou University Hospital (IRB no.: AJIRB-MED-MDB-21-255). The requirement for patient consent was waived by the IRB Committee of Seoul National University Dental Hospital (SNUDH) (ERI18002) and Ajou University Hospital (IRB no.: AJIRB-MED-MDB-21-255).

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

With the submission of this manuscript I would like to undertake that

- All authors of this research paper have directly participated in the planning, execution, or analysis of this study.
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- The research is original. There are no directly related manuscripts published or unpublished, by any authors of this paper.
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The individual role of each author was as follows

- Soon-young Kang: collection of data, analysis of data, interpretation of data, construction of manuscript
- Young Ho Kim : conception and design of the article
- Seung-Hak Baek : collection of data, conception and design of the article
- Dong Woo Kim : collection of data, conception and design of the article
- Jeong Won Shin: conception and design of the article
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References

1. Bailey, L. T. J., Cevidanes, L. H. & Proffit, W. R. Stability and predictability of orthognathic surgery. *American Journal of Orthodontics and Dentofacial Orthopedics* **126**, 273–277 (2004).
2. Junior, O. H. *et al.* Hierarchy of surgical stability in orthognathic surgery: overview of systematic reviews. *International journal of oral and maxillofacial surgery* **48**, 1415–1433 (2019).
3. Proffit, W., Turvey, T. & Phillips, C. Orthognathic surgery: a hierarchy of stability. *The International journal of adult orthodontics and orthognathic surgery* **11**, 191–204 (1996).
4. Proffit, W. R., Turvey, T. A. & Phillips, C. The hierarchy of stability and predictability in orthognathic surgery with rigid fixation: an update and extension. *Head & face medicine* **3**, 1–11 (2007).
5. Al-Delayme, R., Al-Khen, M., Hamdoon, Z. & Jerjes, W. Skeletal and dental relapses after skeletal class III deformity correction surgery: single-jaw versus double-jaw procedures. *Oral surgery, oral medicine, oral pathology and oral radiology* **115**, 466–472 (2013).
6. Cho, H. J. Long-term stability of surgical mandibular setback. *The Angle Orthodontist* **77**, 851–856 (2007).
7. Rizk, M. Z., Torgersbråten, N., Mohammed, H., Franzen, T. J. & Vandevska-Radunovic, V. Stability of single-jaw vs two-jaw surgery following the correction of skeletal class III malocclusion: A systematic review and meta-analysis. *Orthodontics & Craniofacial Research* **24**, 314–327 (2021).
8. Chemello, P. D., Wolford, L. M. & Buschang, P. H. Occlusal plane alteration in orthognathic surgery—part II: long-term stability of results. *American Journal of Orthodontics and Dentofacial Orthopedics* **106**, 434–440 (1994).
9. Arnett, G. W. & Gunson, M. J. Facial planning for orthodontists and oral surgeons. *American Journal of Orthodontics and Dentofacial Orthopedics* **126**, 290–295 (2004).
10. Choi, J. W. & Jeong, W. S. Occlusal plane altering 2 jaw surgery based on the clockwised rotational surgery-first orthognathic approach. *Plastic and Reconstructive Surgery Global Open* **5** (2017).
11. Lee, T. S. & Park, S. Clockwise rotation of the occlusal plane for aesthetic purposes by double jaw surgery without orthodontic treatment. *Plastic and reconstructive surgery* **144**, 1010e–1013e (2019).
12. Steinhäuser, S., Richter, U., Richter, F., Bill, J. & Rudzki-Janson, I. Profile changes following maxillary impaction and autorotation of the mandible. *Journal of Orofacial Orthopedics/Fortschritte der Kieferorthopädie* **69**, 31–41 (2008).
13. Togawa, R., Iino, S. & Miyawaki, S. Skeletal Class III and open bite treated with bilateral sagittal split osteotomy and molar intrusion using titanium screws. *The angle orthodontist* **80**, 1176–1184 (2010).
14. Choi, J.-Y., Choi, J.-P. & Baek, S.-H. Surgical accuracy of maxillary repositioning according to type of surgical movement in two-jaw surgery. *The Angle Orthodontist* **79**, 306–311 (2009).
15. Park, J. U. & Baik, S. Classification of Angle Class III malocclusion and its treatment modalities. *International Journal of Adult Orthodontics and Orthognathic Surgery* **16**, 19–29 (2001).
16. Junior, O. H. *et al.* Stability and surgical complications in segmental Le Fort I osteotomy: a systematic review. *International journal of oral and maxillofacial surgery* **46**, 1071–1087 (2017).
17. Raposo, R., Peleteiro, B., Paço, M. & Pinho, T. Orthodontic camouflage versus orthodontic-orthognathic surgical treatment in class II malocclusion: a systematic review and meta-analysis. *International journal of oral and maxillofacial surgery* **47**, 445–455 (2018).
18. Baek, S.-H., Ahn, H.-W., Yang, S.-D. & Choi, J.-Y. Establishing the customized occlusal plane in systemized surgical treatment objectives of class III. *Journal of Craniofacial Surgery* **22**, 1708–1713 (2011).
19. Proffit, W. R., Bailey, L. T. J., Phillips, C. & Turvey, T. A. Long-term stability of surgical open-bite correction by Le Fort I osteotomy. *The Angle Orthodontist* **70**, 112–117 (2000).
20. Wolford, L. M., Chemello, P. D. & Hilliard, F. Occlusal plane alteration in orthognathic surgery—Part I: Effects on function and esthetics. *American Journal of Orthodontics and Dentofacial Orthopedics* **106**, 304–316 (1994).

21. Bharti, D. *et al.* Evaluation Of Relapse In Orthognathic Surgery: An Original Research. *European Journal of Molecular & Clinical Medicine* **7**, 3210–3215 (2020).
22. Dowling, P. A., Espeland, L., Sandvik, L., Mobarak, K. A. & Hogevoid, H. E. LeFort I maxillary advancement: 3-year stability and risk factors for relapse. *American journal of orthodontics and dentofacial orthopedics* **128**, 560–567 (2005).
23. Troy, B. A., Shanker, S., Fields, H. W., Vig, K. & Johnston, W. Comparison of incisor inclination in patients with Class III malocclusion treated with orthognathic surgery or orthodontic camouflage. *American Journal of Orthodontics and Dentofacial Orthopedics* **135**, 146. e141-146. e149 (2009).
24. Kim, D.-K. & Baek, S.-H. Change in maxillary incisor inclination during surgical-orthodontic treatment of skeletal Class III malocclusion: comparison of extraction and nonextraction of the maxillary first premolars. *American Journal of Orthodontics and Dentofacial Orthopedics* **143**, 324–335 (2013).
25. Baek, S.-H., Ahn, H.-W., Kwon, Y.-H. & Choi, J.-Y. Surgery-first approach in skeletal class III malocclusion treated with 2-jaw surgery: evaluation of surgical movement and postoperative orthodontic treatment. *Journal of Craniofacial Surgery* **21**, 332–338 (2010).
26. Burstone, C. R. Deep overbite correction by intrusion. *American journal of orthodontics* **72**, 1–22 (1977).

Tables

Table 2 is available in the Supplementary Files section

Table 1. Demographic data.

Variables		Group 1 (n=22)	Group 2 (n=24)	P value
Age (years)	T0 ^a	20.06 ± 3.74	21.11 ± 3.54	0.2519
	T1 ^a	21.61 ± 3.75	23.04 ± 3.41	0.0857
	T2 ^a	21.84 ± 3.81	23.21 ± 3.42	0.0968
	T3 ^a	22.85 ± 3.89	24.29 ± 3.70	0.1180
Sex ^b		13 males and 9 females	15 males and 9 females	0.8129
Amount of MXOP change between T2 and T3 stages [MXOP(ΔT2-T3)] ^a		-3.09° ± 0.92°	-0.99° ± 0.57°	<0.001***
Extraction in the maxillary arch ^b		17 extractions and 5 non-extractions	14 extractions and 10 non-extractions	0.1711

^a Mann-Whitney U test was performed.

^b Chi-square test was performed.

T0, initial visit; T1, at least 1 month before two-jaw surgery; T2, at least 1 month after two-jaw surgery; T3, debonding; (-) value in MXOP(ΔT2-T3), backward and upward movement and counter-clockwise (CCW) rotation; *, P<0.05; **, P<0.01; ***, P<0.001

Table 3. Amount of change in the linear and angular variables in Group 1.

Variables			Δ T1-T2 (surgical change)			Δ T2-T3 (post-surgical change)			Δ T1-T3 (net change)		
			Mean	SD	p-value	Mean	SD	p-value	Mean	SD	p-value
Linear	sagittal	A-x (mm) ^a	+3.96	2.12	0.0179 ^{a*}	-0.43	1.01	0.7937 ^a	+3.53	1.81	0.0339 ^{a*}
		PNS-x (mm) ^a	+1.27	4.04	0.1407 ^a	+1.39	4.18	0.1112 ^a	+2.67	1.93	0.0074 ^{a**}
		U1-x (mm) ^a	+2.54	3.02	0.1942 ^a	+0.57	1.50	0.7644 ^a	+3.11	3.06	0.1194 ^a
		U6-x (mm) ^a	+3.04	3.16	0.0590 ^a	-0.06	1.49	0.9712 ^a	+2.98	2.93	0.0714 ^a
	vertical	A-y (mm) ^a	+0.28	1.57	0.5386 ^a	-0.69	1.43	0.0938 ^a	-0.41	1.67	0.3210 ^a
		PNS-y (mm)	-3.57	2.68	0.0020 ^{b**}	+0.79	1.52	0.5308 ^a	-2.78	2.25	0.0327 ^{b*}
		U1-y (mm) ^a	+0.18	2.40	0.9062 ^a	-1.14	1.99	0.1039 ^a	-0.92	1.84	0.6177 ^a
		U6-y (mm) ^a	-2.29	1.49	0.0933 ^a	+1.72	3.11	0.0792 ^a	-0.57	3.06	0.1436 ^a
	A-N perp (mm) ^a		+3.21	2.83	0.0174 ^{a*}	-1.41	1.81	0.3077 ^a	+1.80	3.07	0.1778 ^a
	Pog-N perp (mm)		-11.54	5.65	0.0002 ^{b***}	+1.62	3.15	0.4581 ^a	-9.92	5.02	0.0014 ^{b**}
Angular	MxOP (°) ^a		+4.60	1.91	0.0056 ^{a**}	-3.09	0.92	0.0474 ^{a*}	+1.51	1.37	0.3532 ^a
	Δ APP angle (°) ^a		N/A	N/A	N/A	-1.72	0.66	<0.001 ^{***}	N/A	N/A	N/A
	SNA (°) ^a		+2.19	2.14	0.0745 ^a	-0.61	1.16	0.5927 ^a	+1.57	2.36	0.2047 ^a
	SNB (°)		-5.78	3.48	0.0008 ^{b***}	+1.11	0.87	0.3252 ^a	-4.67	3.01	0.0025 ^{a**}
	ANB (°)		+7.97	3.54	<0.001 ^{b***}	-1.71	0.86	0.0002 ^{b***}	+6.26	3.45	<0.001 ^{b***}
	FMA (°)		+2.42	3.97	0.1734 ^b	-0.13	2.40	0.9722 ^b	+2.29	3.39	0.2781 ^b
	U1 to FH (°)		-4.15	6.84	0.4315 ^b	+3.66	4.02	0.0726 ^a	-0.49	8.07	0.2961 ^b
	IMPA (°) ^a		+0.47	5.01	0.8212 ^a	-1.68	3.17	0.4651 ^a	-1.21	6.15	0.5890 ^a

^a Paired t test was used to compare variables.

^b Wilcoxon signed rank sum test was used to compare variables.

SD, standard deviation; T1: 1 month before two-jaw surgery, T2: 1 month after two-jaw surgery, T3: debonding; * P<0.05, ** P<0.01, ***P<0.001, MxOP (maxillary occlusal plane), (+) value indicates forward and downward movement and clockwise (CW) rotation, (-) value indicate backward and upward movement and counter-clockwise (CCW) rotation. In the sagittal plane, a (+) value symbolizes forward movement while (-) indicates backward movement. In the vertical plane, a (+) value symbolizes downward movement while a (-) value indicates upward movement.

Table 4. Amount of change in linear and angular variables in Group 2.

Variables			$\Delta T1-T2$ (surgical change)			$\Delta T2-T3$ (post-surgical change)			$\Delta T1-T3$ (net change)		
			Mean	SD	p-value	Mean	SD	p-value	Mean	SD	p-value
Linear	sagittal	A-x (mm) ^b	+2.29	1.85	0.1122	-0.85	2.15	0.5423	+1.44	2.30	0.3460
		PNS-x (mm) ^a	+2.75	5.31	0.3255	-1.01	6.14	0.9222	+1.74	2.31	0.0771
		U1-x (mm) ^b	+2.32	1.88	0.1560	-0.47	2.36	0.7022	+1.85	2.00	0.3091
		U6-x (mm) ^b	+2.70	2.41	0.0743	-0.68	2.64	0.6186	+2.02	3.24	0.1376
	vertical	A-y (mm) ^b	-1.00	2.43	0.3699	-0.52	1.28	0.5094	-1.52	2.68	0.1492
		PNS-y (mm) ^b	-3.31	1.76	0.0003***	-0.13	1.31	0.7780	-3.44	2.14	0.0001***
		U1-y (mm) ^b	-0.59	2.69	0.6062	+0.07	1.10	0.8680	-0.52	2.21	0.6456
		U6-y (mm) ^b	-2.15	1.96	0.0849	+1.15	2.07	0.3810	-1.00	2.51	0.4520
	A-N perp (mm) ^a		+0.79	2.98	0.5801	-1.00	2.09	0.4443	-0.21	2.55	0.7815
	Pog-N perp (mm) ^a		-8.11	4.38	<0.001***	+1.23	3.45	0.4906	-6.88	5.13	0.0013**
Angular	MxOP (°) ^b		+2.92	1.92	0.0045**	-0.99	0.57	0.2143	+1.93	1.91	0.0287*
	Δ APP angle (°) ^a		N/A	N/A	N/A	-0.67	0.37	0.1001	N/A	N/A	N/A
	SNA (°) ^b		+0.76	2.08	0.4050	-0.70	1.62	0.4050	+0.05	2.05	0.9635
	SNB (°) ^b		-3.89	1.83	0.0023**	+0.56	1.15	0.6805	-3.34	1.58	0.0056**
	ANB (°) ^b		+4.65	2.11	<0.001***	-1.26	1.11	0.0607	+3.39	1.90	<0.001***
	FMA (°) ^b		+0.42	3.69	0.6697	+0.02	2.84	0.9783	+0.44	4.03	0.7280
	U1 to FH (°) ^b		+0.11	4.00	0.8476	+0.82	2.59	0.8048	+0.93	3.70	0.9053
	IMPA (°) ^b		+0.14	3.75	1.0000	+0.80	4.79	0.8048	+0.94	5.41	0.6671

^a Paired t test was used to compare variables.

^b Wilcoxon signed rank sum test was used to compare the variables.

SD, standard deviation; T1: 1 month before two-jaw surgery, T2: 1 month after two-jaw surgery, T3: debonding; * P<0.05, ** P<0.01, ***P<0.001, MxOP (maxillary occlusal plane), (+) value indicates forward and downward movement and clockwise (CW) rotation, (-) value indicates backward and upward movement and counter-clockwise (CCW) rotation. In the sagittal plane, a (+) value symbolizes forward movement while a (-) value indicates backward movement. In the vertical plane, a (+) value symbolizes downward movement while a (-) value indicates upward movement.

Table 5. Comparison of the amount of change between the two groups.

Variables			$\Delta T0-T1$ (pre-surgical orthodontic treatment change)				$\Delta T1-T2$ (surgical change)				$\Delta T2-T3$ (post-surgical change)			
			Group1 (n=22)		Group2 (n=24)		P value		Group1 (n=22)		Group2 (n=24)		P value	
			Mean	SD	Mean	SD			Mean	SD	Mean	SD		
Mean duration (year)			1.55	0.98	+1.96	1.12	0.2217 ^b		+0.23	0.17	+0.17	0.11	0.3532 ^b	
linear	sagittal	A_x (mm)	-0.91	2.08	-0.69	1.66	0.7807 ^b		+3.96	2.12	+2.29	1.85	0.0055 ^{***}	
		PNS_x (mm)	-0.12	1.45	+0.03	1.55	0.7217 ^a		+1.90	4.04	+2.75	2.31	0.8127 ^a	
		U1_x (mm)	-2.58	3.29	-1.44	3.86	0.2900 ^a		+2.54	3.02	+2.32	1.88	0.5362 ^b	
		U6_x (mm)	+0.99	2.86	-0.44	2.19	0.0559 ^a		+3.04	3.16	+2.70	2.41	0.6457 ^a	
	vertical	A_y (mm)	+0.32	1.44	+0.97	1.99	0.1914 ^a		+0.28	1.57	-1.00	2.43	0.0897 ^b	
		PNS_y (mm)	-0.15	0.87	+0.57	2.00	0.1122 ^b		-3.57	2.68	-3.31	1.76	0.7669 ^a	
		U1_y (mm)	-0.14	2.23	+0.33	2.37	0.4894 ^a		+0.22	2.40	-0.59	2.69	0.6443 ^a	
		U6_y (mm)	-0.34	1.60	+0.46	2.05	0.1354 ^a		-2.29	1.49	-2.15	1.96	0.7693 ^a	
	A-N perp (mm)		-0.49	2.30	+1.46	1.63	0.0023 ^{***}		+3.21	2.83	+0.79	2.98	0.0084 ^{***}	
	Pog-N perp (mm)		0.00	3.02	+2.29	3.66	0.0290 ^{a*}		-11.54	5.65	-8.11	4.38	0.0296 ^{a*}	
angular	MxOP (°)		+1.29	2.19	+0.11	2.72	0.1155 ^a		+4.60	1.91	+2.92	1.92	0.0046 ^{***}	
	Δ APP angle (°)		NA	NA	NA	NA	NA		NA	NA	NA	NA	NA	
	SNA (°)		-0.81	1.92	+0.60	1.30	0.0326 ^{b*}		+2.19	2.14	+0.76	2.08	0.0300 ^{a*}	
	SNB (°)		-0.37	1.73	+0.21	0.78	0.2311 ^b		-5.78	3.48	-3.89	1.83	0.0290 ^{b*}	
	ANB (°)		-0.44	1.85	+0.39	1.18	0.0653 ^b		+7.97	3.54	+4.65	2.11	0.0010 ^{b***}	
	FMA (°)		-0.29	1.46	-0.22	1.38	0.4812 ^b		+2.42	3.97	+0.42	3.69	0.0411 ^{b*}	
	U1 to FH (°)		-3.12	9.97	+0.16	10.30	0.4959 ^b		-4.15	6.84	+0.11	4.01	0.0366 ^{b*}	
	IMPA (°)		+5.99	5.60	+4.73	6.96	0.5109 ^a		+0.47	5.01	+0.14	3.75	0.8011 ^a	

^a Independent t test was performed.

^b Mann-Whitney U test was performed.

SD, standard deviation; T1: 1 month before two-jaw surgery, T2: 1 month after two-jaw surgery, T3: debonding; * P<0.05, ** P<0.01, ***P<0.001, MxOP (maxillary occlusal plane), (+) value indicates forward and downward movement and clockwise (CW) rotation, (-) value indicates backward and upward movement and counter-clockwise (CCW) rotation.

Table 6. Correlations between the amount of post-surgical relapse (T2-T3) and the amount of surgical change (T1-T2).

Variables			Group 1 (n=22)		Group 2 (n=24)	
			Pearson Correlation	P value	Pearson Correlation	P value
Linear	sagittal	ΔA_x (mm)	-0.5254	0.0120*	-0.3439	0.1170
		ΔPNS_x (mm)	-0.8904	<0.001***	-0.9286	<0.001***
		$\Delta U1_x$ (mm)	-0.2206	0.3238	-0.5758	0.0050**
		$\Delta U6_x$ (mm)	-0.3816	0.0797	-0.1764	0.4323
	vertical	ΔA_y (mm)	-0.3839	0.0778	-0.0536	0.8128
		ΔPNS_y (mm)	-0.5435	0.0089**	-0.0456	0.8403
		$\Delta U1_y$ (mm)	-0.6619	0.0008***	-0.6011	0.0031**
		$\Delta U6_y$ (mm)	-0.4713	0.0298*	-0.2293	0.3047
	$\Delta A-N$ perp (mm)		-0.1828	0.4156	-0.5399	0.0095**
	$\Delta Pog-N$ perp (mm)		-0.4688	0.0277*	-0.1570	0.4854
Angular	$\Delta MxOP$ (°)		-0.7517	<0.001***	-0.1713	0.4460
	ΔSNA (°)		-0.0770	0.7333	-0.4090	0.0587
	ΔSNB (°)		-0.6345	0.0015**	-0.5210	0.0129*
	ΔANB (°)		-0.2163	0.3336	-0.4414	0.0397*

Pearson correlation test was performed.

*, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$

Figures

Figure 1

Definitions of cephalometric landmarks. S, sella; N, nasion; Or, orbitale; Po, porion; A, point A; B, point B; Pog, pogonion; Me, menton; PNS, posterior nasal spine; U1E, the incisal edge of the maxillary central incisor (U1); L1E, the incisal edge of the mandibular central incisor (L1); U6MBC, the mesiobuccal cusp tip (MBC) of the maxillary first molar; L6MBC, the mesiobuccal cusp tip (MBC) of the mandibular first molar; APP, anterior plate point (the most anterior point of maxillary plates); MxOP, maxillary occlusal plane that is a line joining U1E and U6MBC; Po-APP line, a line joining Po and APP; Horizontal reference plane (HRP), a horizontal plane angulated 7° clockwise to the SN-line passing through Sella; vertical reference plane (VRP), a perpendicular line to the HRP passing through Sella.

Figure 2

Definitions of Linear and Angular measurements. **Linear measurements** : 1. A_x(mm), horizontal distance from point A to VRP. 2. PNS_x(mm), horizontal distance from PNS to VRP. 3. U1_x(mm), horizontal distance from U1E to VRP. 4. U6_x(mm), horizontal distance from U6MBC to VRP. 5. A_y(mm), vertical distance from point A to HRP. 6. PNS_y(mm), vertical distance from PNS to HRP. 7. U1_y(mm), vertical distance from U1E to HRP. 8. U6_y(mm), vertical distance from U6MBC to HRP. 9. B_x(mm), horizontal distance from point B to VRP. 10. Pog_x(mm), horizontal distance from Pog to VRP. 11. L1_x(mm), horizontal distance from L1E to VRP. 12. L6_x(mm), horizontal distance from L6MBC to VRP. 13. B_y(mm), vertical distance from point B to HRP. 14. Pog_y(mm), vertical distance from Pog to HRP. 15. L1_y(mm), vertical distance from L1E to HRP. 16. L6_y(mm), vertical distance from L6MBC to HRP. **Angular measurements** : 17. MxOP angle($^{\circ}$), angle between MxOP and HRP. 18. APP angle($^{\circ}$), angle between Po-APP line and HRP.

Figure 3

A high MXOP relapse case. The surgical movement(left) and relapse pattern(right). T1(black), T2(red), T3(green).

Supplementary Files

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- [Table2.docx](#)