The Relationship between Chewing Patterns and Displacement of the Proximal Bone Fragment and Morphological Changes in Condyle after Sagittal Split Ramus Osteotomy

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Introduction

Sagittal split ramus osteotomy (SSRO) is widely used for surgical orthodontic treatment of patients with jaw deformity. Imamura reported that changes in the mandible after SSRO included external and superior displacement of the proximal bone fragment within a short timeframe after SSRO, which induced the external, superior and internal rotation of condyle, resulting in bone remodeling from external to anterosuperior of condyle (1). Svetlana et al reported that condyle was repositioned and remodeled within the glenoid fossa from 3 months to 1 year after SSRO (2). On the other hand, Suzuki et al investigated postoperative changes in chewing patterns and reported that the occlusal relationship of the molars and the change in chewing patterns after SSRO for patients with facial asymmetry and jaw deformity affected the long-term stability and reversion of the mandibular position (3). Furthermore, Kai et al examined mandibular changes after SSRO and reported that these changes may be due to factors such as postoperative occlusion, muscle position, morphology of condyle and the glenoid.

Keywords:
sagittal split ramus osteotomy, proximal bone fragment, chewing patterns, remodeling

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Abstract

After sagittal split ramus osteotomy (SSRO), morphologic change of the condylar head of mandible due to displacement of the proximal bone fragment have been reported.

This study investigated the relationship between chewing patterns and mandibular displacement of the proximal bone fragment and morphological changes in condyle before and after SSRO in patients with mandibular prognathism with lateral deviation. Bilateral Lp (the most lateral point of condyle) had anterior and internal rotation movement, while bilateral An (antegonial notch) had posterosuperior movement. On the affected side, An changed medially, while on the unaffected side An changed externally, and there was no significant difference between the affected side and the unaffected side. In terms of chewing patterns, At 6 month after SSRO approximately half the patients had changed from Crossover pattern (C pattern), Reverse pattern (R pattern) to Normal pattern (N pattern) on both the affected side and the unaffected side. Crossbites were seen in the N pattern and R, C pattern on the affected side in 100% and 84.5% of cases and on the unaffected side in 33.3% and 41.4% of cases respectively. Remodeling occurred on the surface of condyle with displacement of proximal bone fragment. In the N pattern there was reductional bony change in the anteromedial direction, and additional bony change in the posterolateral direction, while in the R, C pattern there was additional bony change in the anteromedial direction and reductional bony change in the posterolateral direction. Differences in remodeling were seen on both sides due to different chewing patterns.
fossa, the mandibular position and jaw movement (4).

Based on the aforementioned findings, morphological changes of the mandible proximal bone fragment and condyle, as well as changes in the chewing patterns, may occur after SSRO. However, there are no studies that have investigated the relationship of these changes. This study aimed to investigate the relationship between chewing patterns and displacement of the proximal bone fragment and morphological changes in condyle before and after SSRO in patients with mandibular prognathism with lateral deviation.

Materials and Methods

Subjects

The subjects were 29 patients (14 males, 15 females, mean age 27.9 ± 6.8 years old) (only SSRO: n=17, SSRO and Le Fort I osteotomy: n=12) with mandibular prognathism with lateral deviation diagnosed as jaw deformity by the Division of Orthodontics at Nihon University Matsudo Dental Hospital, who underwent SSRO. The criteria for lateral deviation was a ≥ 4.0mm deviation of Menton (Me) relative to the facial midline. The exclusion criteria were the following:

1) patients who had previously received orthodontic treatment
2) patients with dental prostheses, dental caries, or missing teeth
3) patients with a congenital deformity or syndrome, or previous trauma
4) patients with temporomandibular joint pain or temporomandibular joint dysfunction

This study was approved by the Ethics Committee of Nihon University’s School of Dentistry at Matsudo (approval no.: EC 17-003).

Measuring method

1 Cephalometric analysis

Subjects were selected from the outer cephalogram taken at the first visit. First, skeletal class III (ANB < 1°) was selected from the outer cephalogram. Next, a straight line connecting the crista galli (NC) and anterior nasal spine (ANS) was set from the frontal cephalogram as the midline (Line-A). Me midline was selected with a deviation of 4.0mm or more (Fig. 1).

2 Reconstructing 3D-CT image

CT images acquired before SSRO (BO) and 6 months after SSRO (AO) were used. The images were obtained using an Aquilion 64 CT scanner (Toshiba Medical Systems, Tokyo, Japan) at this hospital. The imaging parameters were as follows: tube voltage, 120 kV; tube current, 100 mA; field of view, 240 mm × 240 mm; and slice thickness, 1 mm. The scanning range was from the forehead to the chin. The position of the patient’s head was set using a positioning laser. The longitudinal axis of the beam was the front of the face, and the horizontal axis of the beam was a plane connecting the tragia and left orbit. Occlusion was imaged at the maximal intercuspal position, with the lips gently closed. After image acquisition, the acquired CT data were imported and converted to the digital imaging and communications in medicine (DICOM) format and then to the standard triangulated language (STL) format using DICOM viewer software (OsiriX, Newton Graphics, Hokkaido, Japan). Data were thresholded using 3D volume rendering software (Artec Studio 9, Artec 3D, Luxembourg City, Luxembourg). The skull and mandible were rendered, and 3D-CT images were reconstructed.

3 Definition of the spatial coordinate system for the 3D CT image

Standard coordinates were set for 3D image data in the STL format using 3D image analysis software.
The coordinates were based on the upper margin of the porions (Po) of the left and right external auditory canals and the right infraorbital margin orbitale (Or) on maxillofacial skeletal 3D-CT images. The plane defined by the Po on both the left and right sides and the Or served as the Frankfurter horizontal (FH) plane (defined here as the axial plane). The plane passing through the Po on both the left and right sides and perpendicular to the axial plane served as the coronal plane. The plane passing through the center of the Po on the left and right sides and perpendicular to the axial plane served as the sagittal plane. A straight line passing through the Po on the left and right sides served as the X-axis. A straight line passing through the origin and perpendicular to the X-axis served as the Z-axis (Fig. 2).

4 Measurement of changes in the proximal bone fragment and condyle

The measurement method was based on the method of Imamura (1). 3D-CT images at BO and AO were overlaid, and the extent of changes in the proximal fragment and condyle was measured.

In order to measure the extent of changes in the proximal fragment, 3D-CT images of the chin were overlaid in 3D image analysis software (Body-Rugle, Medic Engineering, Kyoto, Japan) using the least squares method.
The software used an algorithm based on mutual information in a region to calculate the optimal position. The most lateral point of condyle (Lp), coronoid process (Cp), and antegonial notch (An) served as the landmarks for the proximal fragment, and the extent of displacement was determined on the coordinate axes (Fig. 3). In addition a line connecting from the base of the vomer to the midpoint of clivus of the sphenoid is defined as a median sagittal line (line-B). The angle crossing Lp-Mp (the most medial point) of mandibular condyle was measured as Axial Condylar angle (Affected side:-θ Unaffected: θ) (Fig. 4).

5 Analysis of chewing pattern

The Gnatho-Hexagraph III (GC Corporation, Tokyo, Japan) was used to measure masticatory movement. The measurement method was based on the method of Suzuki (3). A mandibular clutch was placed on the subject’s mandibular anterior teeth. The patient was then instructed to relax in a seated position; the patient’s head was not immobilized. Once FH plane was horizontal, a head frame and a facebow were attached. The upper margin of the external acoustic meatus on each side constituted a reference plane. The upper margin of each external acoustic meatus and the inferior margin of the left orbit constituted FH plane. The mandibular condyles, the mesiobuccal cusp of the mandibular first molars, and the point of contact between the mandibular central incisors served as measurement points. The patients were instructed to freely chew the chewing gum. Once the gum softened, the subject was instructed to start at the maximal intercuspal position and chew the gum on each side for 30 seconds. This chewing movement was recorded. The test food used was a piece (1.5 g) of normal chewing gum (100% xylitol chewing gum; Oral Care, Tokyo, Japan). Chewing was analyzed at the mandibular incisal point, and a total of 10 chewing strokes (strokes 5–14) on the dominant chewing side were analyzed. The chewing pattern was classified as Normal pattern (N pattern) (from centric occlusion, the mandible moves downward and then laterally toward the chewing side or the nonchewing side, before returning to centric occlusion along a concave, convex, or linear path). The chewing pattern was based on a total of 10 chewing strokes (strokes 5–14). The chewing patterns was classified as Normal pattern (N pattern) (from centric occlusion, the mandible moves downward and then laterally toward the chewing side or the nonchewing side, before returning to centric occlusion along a concave, convex, or linear path). Reversed pattern (R pattern) (the reverse of normal chewing; the mandible moves laterally first before moving downward and then returning to centric occlusion. In the crossover pattern, the mandible moves slightly laterally, downward, slightly laterally again, and then returns to centric occlusion.

Fig. 5. Chewing pattern classification

CO, Centric occlusion. In the normal pattern, from centric occlusion, the mandible moves downward and then laterally toward the chewing side or the nonchewing side, before returning to centric occlusion along a concave, convex, or linear path. In the reverse pattern, the reverse of normal chewing, the mandible moves laterally first before moving downward and then returning to centric occlusion. In the crossover pattern, the mandible moves slightly laterally, downward, slightly laterally again, and then returns to centric occlusion.
first before moving downward and then returning to centric occlusion), or Crossover pattern (C pattern) (the mandible moves slightly laterally, downward, slightly laterally again, and then returns to centric occlusion) (Fig. 5).

6 Molar crossbite

In BO, the buccolingual covering of the first molar was confirmed on the affected side and the unaffected side. The occlusion was classified into the following two groups; normal bite and crossbite (Fig. 7).

7 Measurement of remodeling amount of condyle

Remodeling at BO and AO was compared, and sites where remodeling had occurred were determined. Lp and Mp of condyle from the axial plane served as the long axis, and a straight line perpendicular to that axis was divided into 3 equal sections. Sections were divided into 9 areas: Anteromedial (A), Antero-middle (B), Anterolateral (C), Medial (D), Middle (E), Lateral (F), Posteromedial (G), Posteromiddle (H), and Posterolateral (I) (Fig. 6). In addition each area was divided into 1–9 subareas, a central point was set in each subarea, and the remodeling amount at that position was measured. The average val-
ue of 9 subareas was used as the representative value for the area (Fig. 6).

8 Statistical analysis
Displacement of proximal bone fragment on affected side and unaffected side were compared using the Mann-Whitney’s U test, remodeling amount of condyle were compared using the Mann-Whitney’s U test.

9 Reproducibility of measurement
Based on the method of Dahlberg (5), the significance of the error related to the measurement method was evaluated. To assess the significance of the error involved in the 3DCT measurement methods, the authors re-assessed a series of 29 subjects two months after the initial measurements were taken.

Results
Reproducibility of measurement
In measuring patient data, the coefficients of variation of cephalogram measurement, the coordinate value and remodeling amount measurement were 0.55-2.27%, 0.61-2.30% and 0.54-2.12%, respectively. The values showed good reproducibility.

Extent of subject deviation and the amount of mandibular setback
The mean from Line-A to Me deviation was 6.3±2.8 mm. The mean amount of mandibular setback with SSRO was 4.1±2.5 mm on the affected side and 7.4±3.1 mm on the unaffected side, indicating a significant difference (P < 0.01).

Displacement of proximal bone fragment
After SSRO, displacement of proximal bone fragment from BO to AO were as follows: On the affected side An changed 1.5 mm externally, 1.4 mm superiorly and 1.2 mm posteriorly, Lp changed 0.7 mm anteriorly, and condyle had a 4.1° internal rotation. On the unaffected side An changed 2.5 mm medially, 1.9 mm superiorly and 2.0 mm posteriorly, Lp changed 0.5 mm anteriorly, and condyle had a 4.3° internal rotation. Bilateral Lp had anterior and internal rotation movement, while bilateral An had posterolateral movement. On the affected side, An changed medially, while on the unaffected side An changed externally, and there was no significant difference between the affected side and the unaffected side (P > 0.05) (Table 1).

When we also compared the changes based on the chewing patterns, on the affected side, the N pattern and R, C pattern had the following respective changes: An changed 0.2 mm, 1.5 mm externally, 1.6 mm, 1.3 mm superiorly, and 0.8 mm, 1.0 mm posteriorly, Lp changed 0.6 mm, 0.7 mm anteriorly, while condyle had a 4.1° and 3.8° internal rotation. On the unaffected side, the N pattern and R, C pattern had the following respective changes: An changed 3.1 mm, 2.4 mm medially, 2.2 mm, 1.5 mm superiorly, and 2.7 mm, 1.2 mm posteriorly, Lp changed

|                     | X |      | Y |      | Z |      | θ |      |
|---------------------|---|------|---|------|---|------|---|------|
|                      | Mean S.D. | Mean S.D. | Mean S.D. | Mean S.D. | Mean S.D. |
| **Affected side**    | Lp | -0.1 | 1.3 | 0.1 | 1.1 | 0.7 | 0.6 |
|                     | Cp | -1.9 | 2.8 | -0.3 | 1.6 | -0.3 | 0.9 |
|                     | An | -1.5 | 2.7 | 1.4 | 1.8 | -1.2 | 3.1 |
|                     | condylar angle | | | | | 4.1 | 4.1 |
| **Unaffected side**  | Lp | 0.2  | 1.4 | 0.1  | 1.2 | 0.5 | 0.6 |
|                     | Cp | 1.7  | 2.1 | -0.3 | 2.3 | -0.3 | 0.7 |
|                     | An | -2.5 | 2.1 | 1.9 | 2.3 | -2.0 | 4.3 |
|                     | condylar angle | | | | | -4.3 | 5.1 |

(0.05)

Table 1. Amount of displacement of proximal bone fragment and axial condylar angle between BO and AO

BO: before operation, AO: after operation
Lp: the most lateral point of condyle Cp: coronoid process An: antegonial notch
Condylar angle: angle between Lp-Mp and line-B
0.2 mm, 0.8 mm anteriorly, while condyle had a 4.5° and 5.0° internal rotation. In the N pattern and R, C pattern on the affected side the An X axis only was 0.2 mm and 2.4 mm respectively (P < 0.05), indicating a significant difference (Table 2).

Changes in chewing pattern and presence or absence of a molar crossbite

In terms of chewing patterns, at BO 3 out of 29 people were N pattern (10.0%) and 26 people were R, C pattern (90.0%) on the affected side. At AO 12 people were N pattern (41.0%) and 17 people were R, C pattern (59.0%). Between BO and AO 10 people changed from R, C pattern to N pattern and 1 person changed from N pattern to R, C pattern.

At BO 3 out of 29 people were N pattern (10.0%) and 26 people were R, C pattern (90.0%) on the unaffected side. At AO 15 people were N pattern (52.0%) and 14 people were R, C pattern (48.0%). Between BO and AO 12 people changed from R, C pattern to N pattern and no people changed from N pattern to R, C pattern.

At AO approximately half the patients had changed from R, C pattern to N pattern on both the affected side and the unaffected side, but the remaining half were still R, C pattern. Only one person had changed from N pattern to R, C pattern at AO.

Regarding the presence or absences of molar crossbite, on the affected side 3 (100%) of the N pattern patients and 22 (84.5%) of the R, C pattern patients had a crossbite. On the unaffected side 1 (33.3%) of the N pattern patients and 12 (41.4%) of the R, C pattern patients had a crossbite.

Extent and distribution of remodeling of condyle

At AO there was no significant difference in the extent of remodeling on the affected side and the unaffected side (Table 3). When we compared the affected side, the unaffected side and the chewing patterns, there was a significant difference in the A, B, F, H areas of the affected side (P < 0.05) and a significant difference in the A, B, G, H, I areas of the unaffected side (P < 0.01) (Table 4) (Fig. 8).

### Table 2. Comparison between normal pattern and reverse / crossover pattern of proximal bone fragment and axial condylar angle between BO and AO

|                  | N pattern |                  | R, C pattern |                  |
|------------------|-----------|------------------|--------------|------------------|
|                  | X Mean S.D. | Y Mean S.D. | Z Mean S.D. | θ Mean S.D.     | X Mean S.D. | Y Mean S.D. | Z Mean S.D. | θ Mean S.D.     |
| Affected side    | Lp        | -0.5            | 0.8          | 0.6             | 0.6           | 0.2          | 1.5          | 0.0             | 1.4             | 0.7             | 0.6             |
|                  | Cp        | -2.5            | 1.5          | -0.6            | 1.5           | -0.3         | 0.8          | -1.5           | 3.2             | -0.1           | 1.7             | -0.3           | 0.8             |
|                  | An        | -0.2            | 1.9          | 1.6             | 2.0           | -0.8         | 2.6          | -2.4           | 2.8             | 1.3           | 1.7             | -1.0           | 3.3             |

Condylar angle: angle between Lp-Mp and line-B

Unaffected side: Lp: the most lateral point of condyle Cp: coronoid process An: antegonial notch

Normal pattern: N pattern Reverse pattern: R pattern Crossover pattern: C pattern

Mann-Whitney’s U test P<0.05:* BO: before operation, AO: after operation

### Table 3. Mean change remodeling amount of condyle in each area between BO and AO

|                  | Affected | Unaffected |
|------------------|----------|------------|
|                  | Mean S.D. | Mean S.D.  |
| A                 | -0.1     | 0.0        |
| B                 | -0.1     | 0.0        |
| C                 | 0.1      | 0.1        |
| D                 | -0.3     | -0.2       |
| E                 | -0.1     | -0.1       |
| F                 | 0.0      | 0.2        |
| G                 | -0.2     | 0.1        |
| H                 | 0.0      | 0.0        |
| I                 | 0.0      | 0.0        |

BO: before operation, AO: after operation

A: Anteromedial  B: Antero-middle  C:Anterolateral  D: Medial  E: Middle  F: Lateral  G: Posteromedial  H: Posteromiddle  I: Posterolateral
Discussion

This study investigated displacement of proximal bone fragment in patients with facial asymmetry and a displacement of ≥ 4.0 mm, and found a significant difference in the amount of mandibular setback on the affected side and unaffected side, but there was no significant difference in the displacement of proximal bone fragment. However, Seung et al. (6–8) reported that patients with asymmetric mandibular setback had asymmetric changes in proximal bone fragments on the affected side and the unaffected side. On the other hand, while Jeong et al. (9, 10) reported that the proximal bone fragment changed in a clockwise direction, Suzuki et al. (6, 11) reported that the proximal bone fragment changed in a counterclockwise direction. Thus, while there are a number of studies that have observed displacement of proximal bone fragments after SSRO in patients with mandibular prognathism, there is no consistent view on the direction of
change. However, a commonly reported phenomenon in many studies is that after disarticulation resection of the mandible a plate is fixed to press the proximal bone fragment in place, but then the proximal bone fragment changes, causing internal rotation of condyle (7, 9–12). Svetlana et al. (2, 9, 12–15) reported that they found no significant difference in the amount of mandibular setback and displacement of the proximal bone fragment between symmetrical and asymmetrical cases, therefore, the direction of displacement of the proximal bone fragment when the plate is fixed in place is thought to determine whether condyle will move clockwise or counterclockwise. Jeong et al. (9) trimmed the bone fragment during plate fixing and reported that reducing the steps enabled control of displacement of the proximal bone fragment. Ueki et al. (16) reported that displacement of the proximal bone fragment could be suppressed by fixing the bone fragment with curved plates. Based on these reports, it is important that surgeons fix the plate after reducing the gap between the proximal and distal bone fragments as much as possible, thereby reducing displacement of the proximal bone fragment.

In terms of changes in chewing patterns, crossbite was seen at BO on the affected side in 100% of N patterns and 84.5% of R, C patterns, and 33.3% and 41.4% respectively on the unaffected side, indicating that chewing patterns were seen more often in R, C patterns. Suzuki et al. (3, 17, 18) reported that there tended to be a high probability of R pattern on the crossbite side in patients with molar crossbite. Similarly, Tomonari et al. (19) investigated the relationship between molar overlap and chewing patterns and found that the crossbite chewing patterns was consistent with reports indicating that the opening and closing paths were reversed, reporting that many crossbites were found on the affected side. However, despite half the crossbites being on the unaffected side, R, C patterns are common on this side also; thus, it seems to be a characteristic of mandibular prognathism.

At AO, approximately half of both the affected side and unaffected side had changed to N pattern. This differs from the report by Suzuki et al. (3, 17, 20–22) in similar patients, where many had changed to N pattern one year after surgery. Therefore, even if the mandibular asymmetry is removed, and the molar crossbite is improved, the chewing patterns does not always change to N pattern; thus, there seems to be little correlation with the presence or absence of crossbite at BO. However, Suzuki et al. (3) observed long-term changes in chewing patterns for more than one year. The measurements in this study were taken at 6 months, and are still in the process of changing; therefore, further changes may be seen in the future.

Regarding remodeling of condyle and changes in the proximal bone fragment (Lp), the position of condyle in the glenoid fossa changed after SSRO, and remodeling may be triggered by excessive mechanical stress on condyle (1, 23–25). That is, depending on the position of the proximal bone fragment, it is thought that a reductional bony change occurs with small distances between the glenoid fossa and condyle, while additional bony change occurs with large distances (1, 13, 23, 26). This response is assumed to be an adaptive response to stabilize condyle within the glenoid fossa. The results of this study showed that on both sides the bone fragment had posterosuperior deviation, while condyle deviated anteriorly and also had internal rotation, and there was remodeling of condyle. However, there were no noticeable trends in the distribution of remodeling, in a comparison of the affected side and the unaffected side.

Next, we compared the affected side, the unaffected side and chewing patterns and did not find a significant difference in deviation of the proximal bone fragment, but there was a difference in the distribution of remodeling. In the N pattern there was reductional bony change in the anteromedial direction (A, B areas), and additional bony change in the posterolateral direction (F, G, H, I areas). The R, C pattern was the opposite, with additional bony change in the anteromedial direction (A, B areas) and reductional bony change in the posterolateral direction (F, G, H, I areas). There were areas with different amounts of remodeling on both sides due to differences in the chewing patterns. In the N pattern, remodeling occurs as an adaptation to the anterosuperior deviation and internal rotation of the proximal bone fragment (Lp), so it is assumed that condyle is in a normal position within the glenoid fossa. However, in the R, C pattern, remodeling does not occur as an adaptation to deviation of the proximal bone fragment; thus, it is assumed that condyle is in an unstable position within the glenoid fossa. Suzuki et al. (3) found that in occlusal stability after surgical ortho-
dontic treatment. R, C pattern had more reversion than N pattern, and reported that the cause was related to differences in the shape of condyle. Differences in chewing patterns after SSRO cause changes in remodeling, and are thought to affect reversion. During mastication, N pattern is a gliding pattern mastication, and mainly involves lateral movement of the lateral pterygoid muscle attached to condyle. R, C pattern is a chopping pattern mastication and mainly involves a hinge movement by the masseter muscle attached to the mandibular angle (27), and the differences in N pattern and R, C pattern are assumed to be due to different masticatory muscles performing the movement of mastication. The gliding pattern has a wide masticatory path and actively moves the lateral pterygoid muscles (28). For this reason, N pattern has more remodeling, which is performed more accurately than R, C pattern. Chujo (29) et al. reported that masticatory function can be recovered at an early stage with gum training after SSRO. It is suggested that gum training will lead to early occlusal stability and prevent reversion by acquiring an N-pattern chewing patterns at an early stage and promote remodeling of condyle.

**Conclusion**

After SSRO for patients with mandibular prognathism, the following findings were shown that

1. The proximal bone fragment had posterosuperior deviation of An and anterior deviation of Lp, and there was internal rotation of condyle on both the affected side and the unaffected side.
2. At AO approximately half the chewing patterns were N pattern and half were R, C pattern. Crossbites were seen in the N pattern and R, C pattern on the affected side in 100% and 84.5% of cases and on the unaffected side in 33.3% and 41.4% of cases respectively.
3. Remodeling occurred on the surface of condyle with displacement of proximal bone fragment. In the N pattern there was reductional bony change in the anteromedial direction, and additional bony change in the posterolateral direction, while in the R, C pattern there was additional bony change in the anteromedial direction and reductional bony change in the posterolateral direction. Differences in remodeling were seen on both sides due to different chewing patterns.

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