

Article

The Effects of Chewing Exercises on Masticatory Function after Surgical Orthodontic Treatment

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Abstract: Recovery of oral function is one of the most important objectives of orthognathic surgery. This study investigated the effects of a chewing exercise on chewing patterns and other oral functions after sagittal split ramus osteotomy (SSRO). Ten subjects performed a chewing exercise. The control group comprised 19 patients. For masticatory function, the masticatory pattern, width, and height were assessed. For oral function, the occlusal, lip closure, and tongue pressure forces were measured. The chewing exercise was started 3 months after SSRO, and was performed for 5 min twice a day for 3 months. The masticatory pattern normalized in 60% of the patients and remained unchanged for the reversed and crossover types in 40% of the patients. In contrast, 21.0% of patients in the control group showed a change to the normal type. This may be a natural adaptation due to the changes in morphology. A more detailed study is needed to determine what does and does not improve with chewing exercise. The masticatory width significantly increased after performing the exercise. For oral function, a significant increase in the occlusal force was observed, with no significant difference in the control group. Chewing exercises immediately after SSRO improve masticatory patterns.

Keywords: chewing exercise; masticatory function; masticatory pattern



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1. Introduction

One of the most important objectives of orthognathic surgery is the recovery of oral function. Numerous investigators have reported on oral function, including masticatory efficiency [1–6], muscle of mastication activity [5,7,8], occlusal force [2,3,9–12], masticatory movement [8,13,14], and occlusal contacts [3,4,10,11,15], following orthognathic surgery. After sagittal split ramus osteotomy (SSRO), the displacement of the proximal bone fragment often causes the condyle to move in the mandibular fossa, affecting the stability of the postoperative orthodontic treatment.

Okada et al. [16] reported that the displacement of bone fragments was compensated by resorption and the addition of the condyle. Furthermore, Kobayashi et al. [4] reported a significant change in masticatory efficiency after orthognathic surgery in patients with skeletal mandibular prognathism. Additionally, the normal chewing pattern showed a change in the condylar position compared with the abnormal chewing pattern. Kubota et al. [17] reported that the masticatory pattern normalizes after surgery for skeletal mandibular prognathism, but the preoperative masticatory movement pattern tends to be retained compared with the control group. This study investigated the effects of a chewing exercise on chewing patterns and other oral functions in patients with skeletal mandibular prognathism after SSRO.

2. Materials and Methods

2.1. Subjects

Eighty-nine patients with skeletal class III, who were not excluded based on the exclusion criteria, were selected from a total of 8625 patients in the clinic. Subsequently, 29 patients fulfilled the inclusion criteria, and 10 of these patients underwent mastication

training. Ten subjects performed the chewing exercise after SSRO (4 men, 6 women; mean age, 27 years and 10 months, skeletal class III SSRO with mandibular setback) and were diagnosed with mandibular prognathism by the Department of Orthodontics, Nihon University, School of Dentistry at Matsudo. The control group comprised 19 patients (10 men, 9 women, with a mean age of 31 years and 9 months), who did not perform the masticatory exercise (skeletal class III SSRO with mandibular setback). The exclusion criteria were as follows: (1) dental caries and missing teeth; (2) syndrome, congenital deformity, or previous trauma; and (3) TMJ pain and dysfunction. The inclusion criteria were as follows: (1) asymmetry with a deviation of less than 4.0 mm from the facial midline; (2) fully erupted permanent dentition (without third molar); (3) needing mandibular setback by SSRO; (4) skeletal class III relationship determined by ANB angle; (5) absence of periodontal disease; and (6) no history of trauma (Figure 1).

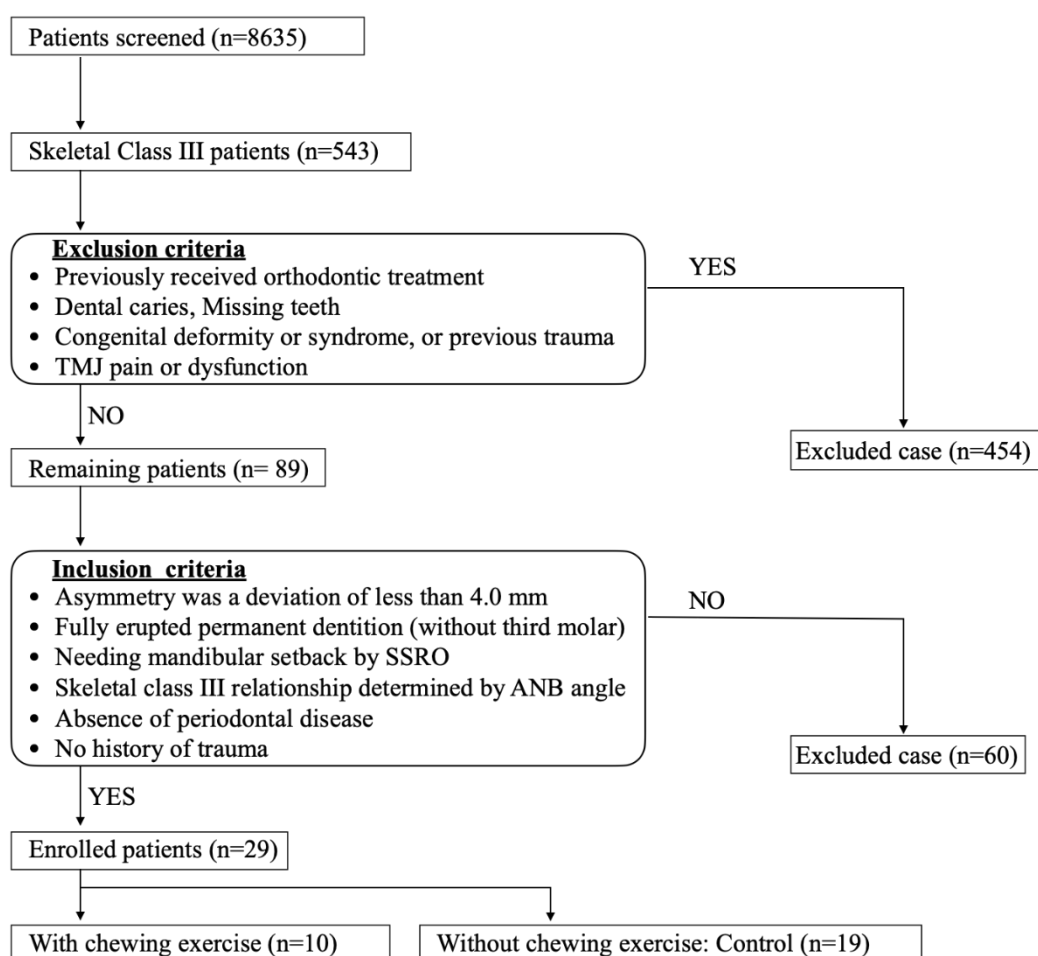


Figure 1. Flowchart of patient enrollment.

All data were taken before SSRO (T1) and 6 months after SSRO (T2). The chewing exercise was started at 3 months after SSRO, which coincides with the timing of bone fragment healing.

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

2.2. Methods of Measurement

2.2.1. Cephalometric Analysis

To investigate the maxillofacial morphology of the patients, lateral cephalograms were taken before SSRO (T1) and 6 months after SSRO (T2). Of the ten items measured through

cephalometry, two were linear and eight were angular (Figure 2 and Table 1); the setback amount was also measured.

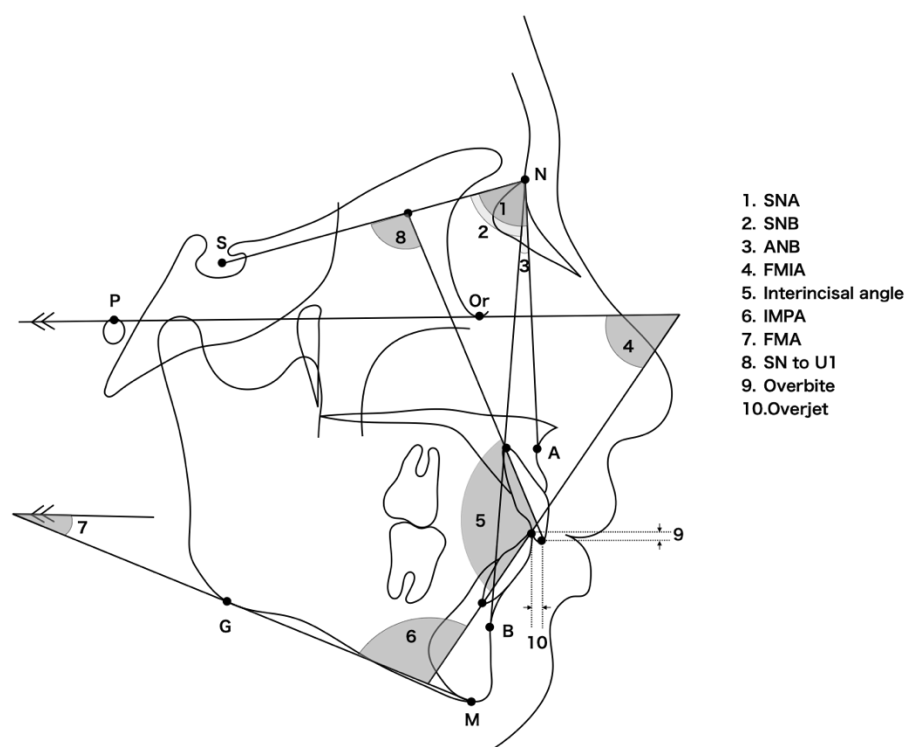


Figure 2. Cephalometric measurements: 1. SNA (degrees), 2. SNB (degrees), 3. ANB (degrees), 4. FMIA (degrees), 5. Interincisal angle (degrees), 6. IMPA (degrees), 7. FMA (degrees), 8. U1—SN (degrees), 9. Overbite (mm), 10. Overjet (mm).

Table 1. Cephalometric measurements.

	Exercise Group (n = 10)				Control Group (n = 19)				Statistical Significance			
	T1		T2		CT1		CT2		<i>p</i> -Value			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	T1-T2	CT1-CT2	T1-CT1	T2-CT2
<i>Angle measurement</i>												
SNA (°)	82.1	3.5	82.2	3.5	80.4	3.5	81.9	3.1	NS	NS	NS	NS
SNB (°)	83.5	4.3	81.1	4.3	80.7	4.1	78.6	3.0	**	**	NS	NS
ANB (°)	−1.5	3.1	1.1	2.4	−0.2	3.8	3.2	3.0	**	**	NS	NS
FMA (°)	30.1	4.8	30.4	4.8	29.8	4.3	30.2	3.9	NS	NS	NS	NS
FMIA (L1 to FH) (°)	65.8	8.5	67.4	7.4	59.3	9.9	60	6.4	NS	NS	NS	NS
IMPA (L1 to MP) (°)	84.2	5.3	82.3	4.7	90.9	9.1	89.7	7.8	NS	NS	NS	NS
U1 to SN (°)	114.9	8.0	112.7	8.9	111.3	8.6	110.3	8.4	NS	NS	NS	NS
Interincisal angle (°)	123.2	7.7	126.1	6.7	117.2	8.1	118.9	8.5	NS	NS	NS	NS
<i>Liner measurement</i>												
Overjet (mm)	−0.1	4.9	3.1	1.9	−3.2	3.6	2.6	2.6	**	**	NS	NS
Overbite (mm)	0.4	1.5	2.0	1.7	0.8	1.0	2.4	1.3	*	**	NS	NS

NS, non-significant. * $p < 0.05$, ** $p < 0.01$.

2.2.2. Three-Dimensional Computed Tomography (3D CT) Analysis

Three-dimensional CT image reconstruction.

The 3D CT scanning method was performed as reported by Imamura [18], and 3DCT images were used at T1 and T2. The images were produced using an Aquilion 64 CT scanner (Toshiba Medical Systems Tokyo, Japan). The image parameters were tube current, 100 mA; tube voltage, 120 kV; slice thickness, 1 mm; field of view, 240 mm × 240 mm. The patient was scanned from the chin to the glabella. A laser was used to stabilize the position of the patient's head. The vertical axis of the laser was the front view and the transverse

axis of the laser was the plane between the tragia and the left side orbit. The occlusion was captured in a centric occlusion position with the lips lightly closed. The CT data were then taken and converted into Digital Imaging and Communications in Medicine (DICOM) format and then into Standard Triangulated Language (STL) format using DICOM software (OsiriX, Newton Graphics, Hokkaido Japan). The data were generated using 3D volume rendering software (Artec Studio 9, Artec 3D, Luxembourg City, Luxembourg). 3DCT image reconstruction was performed after rendering of the cranial and mandibular bones.

Defining the spatial coordinate system (3D CT images).

The standard coordinates of the STL were set using 3D image analysis software (Body-Rugle, Medic Engineering, Kyoto, Japan). On the CT images, the coordinates were determined with reference to the superior border of the right and left external auditory canal poles (Po) and the right inferior orbital border (Or). The Frankfurt horizontal (FH) plane (axial plane) connected the Po and Or on both sides. The Coronal plane was drawn perpendicular to the axial direction through Po on both sides. The sagittal plane was defined as the plane passing through the center of Po from left to right and perpendicular to the axial direction. The X axis was the line defined through the left and right Po. The Y axis was a straight line through the center of the left and right Po and perpendicular to the FH plane. The Z axis (Figure 3) was the line through the origin and perpendicular to the X axis. The left side of the X axis was [+], the top side of the Y axis was [+], and the front side of the Z axis was [+].

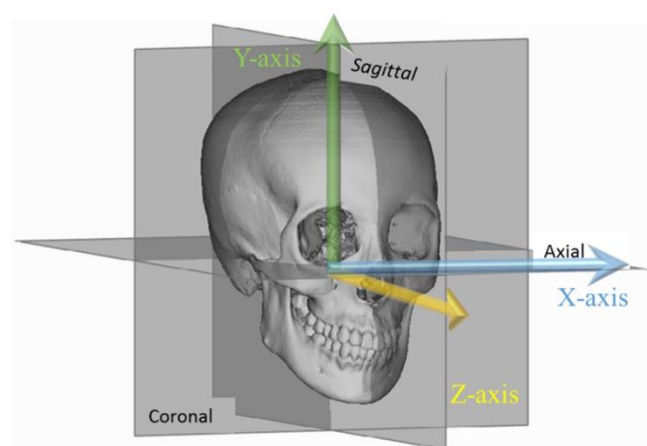


Figure 3. Definition of the coordinate system for the CT image. The X axis was set by the right and left center of porions and orbitales. The Y axis was perpendicular to the X axis and through the right and left porions. The Z axis was perpendicular to the X and Y axes and through the center of the right and left orbitals.

Changes in the position of the proximal bone fragment and condyle.

The method described by Imamura [19] was used. In addition, 3D CT images at T1 and T2 were superimposed to measure changes in the position of the proximal bone fragments and condyle.

To measure changes in the proximal fragment, 3D CT images of the mandible were superimposed by 3D image analysis software (Body-Rugle, Medic Engineering, Kyoto, Japan), using the least squares method. The software calculated the optimal position using an algorithm based on mutual information of each data set, and superimposed T1 and T2. The landmarks of the proximal fragment were the outermost points of the condyle (Lp), the coronoid process (Cp), and the vestibular incision (An), which were set on a coordinate axis. The amount of change in the position was then calculated (Figure 4).

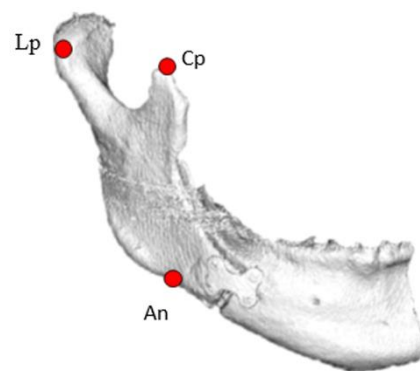


Figure 4. Setting landmarks of proximal bone fragment. Lp: lateral point, Cp: coronoid process, An: antegonial notch.

From the coronal view of the CT image, the midsagittal line (line B) was defined as the line joining the base of the vomer and the midpoint of the clivus of the sphenoid. The axial condylar angle was measured as the angle between Line B and the line crossing Lp-Mp (the most medial point) of the condyle (Figure 5).

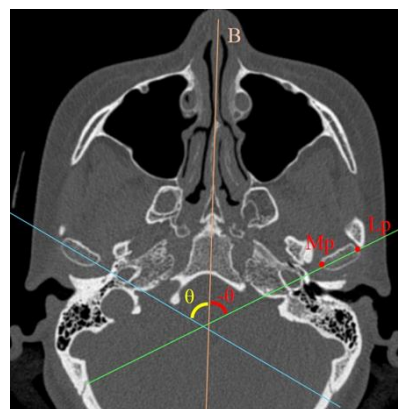


Figure 5. Landmarks, reference line, and angular measurement of condyle on an axial plane.

The median sagittal line (line B) was defined as a line connecting the base of the vomer to the midpoint of the clivus of the sphenoid. The angle crossing the lateral point-medial point of the condyle was measured as the axial condylar angle.

2.2.3. Analysis of Chewing Pattern

The masticatory movements were measured by Gnatho-Hexagraph III (GC Corporation, Tokyo, Japan). The method of measurement was based on the method reported by Suzuki et al. [19]. A mandibular clutch was set on the patient's mandibular anterior incisors. Then, the patient's head was allowed to relax in a sitting position without being fixed. The FH plane was horizontal to the floor of the treatment room, and the headframe and facebow were placed. The reference plane was the bilateral upper edge of the external acoustic meatus. The FH plane was defined as the upper edge of the external auditory meatus and the inferior edge of the left orbit. The measurement points were the mandibular condyle, the mesial buccal cusp of the mandibular first molar, and the contact point of the mandibular central incisor. The patient was instructed to masticate freely with chewing gum. After the gum had softened, the patient was instructed to masticate the gum alternately on one side for 30 s. Masticatory movement was recorded. One piece (1.5 g) of regular chewing gum (100% xylitol chewing gum; Oral Care, Tokyo, Japan) was used for the test. A total of 10 masticatory strokes (strokes 5–14) on the dominant-hand side were analyzed in the masticatory cycle of the mandibular incisor region. The masticatory

patterns were analyzed using software attached to a device measuring jaw movements. The masticatory width and height were calculated based on the average of 10 masticatory cycles. The chewing patterns were classified as follows: a normal pattern (from centric occlusion, the mandible moves downward and then laterally toward the chewing side or the non-chewing side, before returning to centric occlusion along a concave, convex, or linear path); a reversed pattern (R pattern; the reverse of normal chewing; the mandible moves laterally first before moving downward and then returning to centric occlusion); or a crossover pattern (C pattern; the mandible moves slightly laterally, downward, and slightly laterally again and then returns to centric occlusion), as shown in Figures 6 and 7.

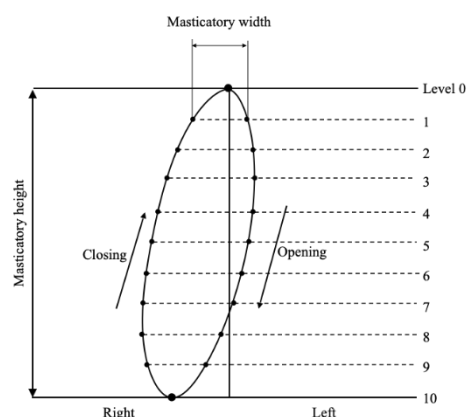


Figure 6. Measurement of the masticatory width and height. With an intercuspal position of 0 and a mean maximum mouth opening position of 10, the opening and closing path distances of the mouth were measured at levels from 1 to 9. The mean value was calculated and used as the masticatory width.

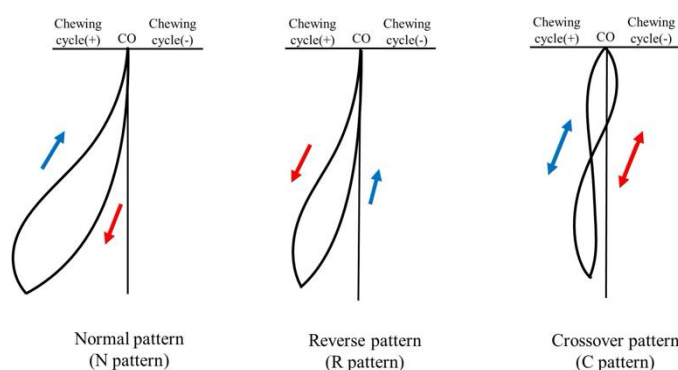


Figure 7. Schematic drawing of a chewing cycle from the frontal view.

A chewing exercise using chewing gum (NOTIME, LOTTE Co. Ltd., Tokyo, Japan) was started 3 months after surgery and was performed for 5 min twice a day for 3 months. The patients recorded the exercise conditions on the check sheets.

2.2.4. Analysis of Oral Function

Occlusal force (OF): An OF meter (GM10, Nagano Keiki Co. Ltd., Tokyo, Japan), as shown in Figure 8, was used to measure the OF. The maximum OFs applied by the left and right first molars were measured twice, and the highest values were recorded for each subject.



Figure 8. Occlusal force measurement. The occlusal force was measured using GM10 (Nagano Keiki Co. Ltd., Tokyo, Japan). The subjects were seated in the Frankfurt horizontal plane parallel to the floor. The sensor was placed in the maxillary first molar, and the occlusal force was measured.

Lip closure force (LCF) was measured using Lip De Cum LDC-110R[®] (Cosmo Instruments Co. Ltd., Tokyo, Japan), shown in Figure 9. The analyzer consists of a sensor with a lip adapter and a digital display [20]. The lip closure force analyzer (Lip De Cum[®]) was set up with a lip holder (Ducklings[®]) placed on the sensor. The lip closure force was measured while the patient was seated (with the FH plane parallel to the floor plane) and was instructed to close the upper and lower lips with maximum force. The LCF was measured three times, and the highest value was recorded for each subject.



Figure 9. Lip closure force measurement. The lip closure force was measured using a Lip de Cum[®] LDC-110R (Cosmo Instruments Co. Ltd., Tokyo, Japan). The subjects were seated with the Frankfurt horizontal plane parallel to the floor. Duckling lip holders were placed between the lips and the maximum lip closure force was measured in the intercuspal position.

Tongue pressure force (TPF): The TPF was measured using a TPM-01 (JMS Co. Ltd., Hiroshima, Japan), as shown in Figure 10. For the measurement of TPF, the patient was instructed to hold the cylinder so that the balloon was placed between the tongue and the anterior region of the palate with the lips closed. Then, three times in one-minute intervals, the patient pressed the balloon against the palate for seven seconds. The measurements were made based on previous reports [21]. The reproducibility of these measurements between sessions was checked before this study. The greatest of the three measurements was taken as the TPF for each patient.



Figure 10. Tongue pressure force measurement. The tongue pressure force was measured using a TPM01 (JMS Co. Ltd., Hiroshima, Japan). The patient sat with the Frankfurt plane parallel to the clinic floor. The balloon was inserted into the mouth, and the patient was instructed to lightly bite down on the hard ring with the upper and lower central incisors, to secure the balloon to the anterior part of the palate.

2.2.5. Statistical Analyses

We performed a sample size calculation using data derived from a preliminary study [22]. On the basis of these results, we calculated the sample size and determined that 10 subjects and 19 controls were required.

To test the intra-inspector reliability, 10 cephalometric films were randomly selected by one person and traced and measured by the inspector twice, two weeks apart [23,24]. The selected cephalometric films were blinded to the patient's name. Each film was then taken and randomized by assigning it to an inspector. Intra-class correlation coefficients (r) were calculated from cephalometric films of T1 and T2 to assess reliability. Confidence intervals of 95% were considered statistically reliable, and the R values calculated for each variable ranged between 0.95 and 1.00. Furthermore, the random error was assessed using the Dahlberg equation, and the measurement error ranged from 0.10 to 0.19. Statistical analyses were performed using the JMP 14 software, SAS for Universities Edition (SAS Institute Inc., Cary, NC, USA). Means and standard deviations were calculated for each cephalometric and oral function value, and are presented in Tables 1 and 2. The Shapiro–Wilk normality test confirmed the normality of the sample distribution in each group (both $p > 0.05$). The Wilcoxon rank-sum test was used to examine the values of T1, T2, and each control group value.

Table 2. Oral function measurements.

	Exercise Group (n = 10)				Control Group (n = 19)				Statistical Significance			
	T1		T2		CT1		CT2		<i>p</i> -Value			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	T1-T2	CT1-C2	T1-C1	T2-C2
<i>Oral function measurements</i>												
Masticatory width (mm)	1.7	0.9	3.0	1.3	1.4	1.0	1.2	0.8	*	NS	NS	**
Masticatory height (mm)	15.2	3.6	15.2	5.1	12	4.9	12.4	4.6	NS	NS	NS	NS
Occlusal force (N)	209.4	98.9	261.5	91.3	204.6	124	222.5	144.8	*	NS	NS	*
Lip closure force (N)	11.4	9.4	8.2	3.0	7.6	3.0	8.5	2.8	NS	NS	NS	NS
Tongue pressure force (Kpa)	27.0	6.2	29.0	5.9	22	13.2	29.6	9.3	NS	NS	NS	NS

NS, non-significant. * $p < 0.05$, ** $p < 0.01$.

3. Results

3.1. Cephalometric Analysis

Analysis of the molar relationship showed bilateral angle class III findings in all patients. The mean preoperative orthodontic treatment period was 2 years and 10 months (control group: 3 years and 3 months), the mean postoperative orthodontic treatment period was 9 months (control group: 8 months), and the mean total orthodontic treatment

period was 3 years and 7 months (control group: 3 years and 11 months). Due to the extraction of the maxillary first premolar in the preoperative orthodontic treatment, the patient's molar relationship changed to angle class II after SSRO. The mean amount of mandibular setback by SSRO was 5.8 ± 4.2 (control: 6.2 ± 5.2) mm, with a difference of less than 2 mm between the left and right sides. The mean ANB angle (derived from the maxilla, nasion, and mandible) in the patient group at T2 did not differ significantly from that of the controls at T2 (Table 1).

3.2. Chewing Cycle and Oral Function Analysis

Chewing cycles were assessed for chewing pattern, masticatory width, and masticatory height. The chewing pattern changed to normal in 60.0% of the patients and did not change in 40.0% of the patients. In the control group, 21.0% changed to normal, and 79.0% did not change from reversed or crossover type (Figure 11). Masticatory width significantly increased, with no significant difference in the control group. Although oral function showed a significant increase in OF, there was no significant difference in LCF and TPF, with no significant difference observed in the control group (Table 2).

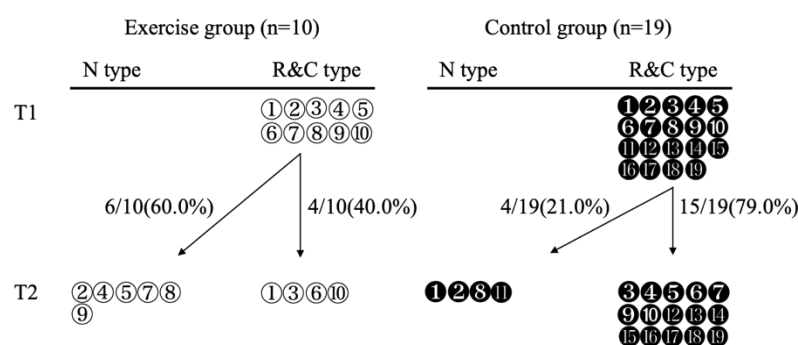


Figure 11. Changes in chewing patterns between T1 and T2.

3.3. Measurement of Changes in Position in the Proximal Bone Fragment and Condyle

The displacement of the proximal bone fragment from T1 to T2 after SSRO is shown in Table 3. The Lp changed by 0.1 externally, superiorly, and anteriorly; Cp changed externally, superiorly by 0.1 mm, and anteriorly by 0.2 mm; and An changed externally by 0.1 mm, superiorly by 0.6 mm, and posteriorly by 0.5 mm. There was no significant difference between the value of each measurement and the control group (Table 3).

Table 3. Comparison between exercise group and control group of proximal bone fragment and axial condylar angle between T1 and T2.

	Exercise Group (n = 10)								Control Group (n = 19)							
	X		Y		Z		θ		X		Y		Z		θ	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Lp (mm)	−0.1	0.4	0.1	0.1	0.1	0.5			−0.2	1.3	0.2	1.0	0.4	0.7		
Cp (mm)	−0.1	0.4	0.1	0.5	0.2	0.6			−0.7	2.3	0.1	2.5	−0.2	0.9		
An (mm)	0.1	0.8	−0.6	3.4	−0.5	2.3			−0.9	2.8	2.4	2.2	−1.9	4.0		
Condylar angle (°)							3.0	1.1							3.0	3.9

Lp: Lateral point Cp: Coronoid process An: Antegonial notch.

4. Discussion

This study evaluated chewing patterns, oral function, and condylar position before and after orthognathic surgery with a chewing exercise in patients with skeletal class III SSRO. SSRO is widely performed for surgical orthodontic treatment of patients with jaw deformities. Imamura [18] reported that changes in the mandible after SSRO included external and superior displacement of the proximal bone fragment within a short timeframe,

which induced the external, superior, and internal rotation of the condyle, resulting in bone remodeling from the external to the anterosuperior condyle. Thus, after SSRO, changes in the proximal bone fragments may cause unpredictable reactions in the mandibular position and occlusion.

Several studies have reported that there were no significant differences between the preoperative chewing cycle duration or peak velocity and the corresponding postoperative values [25,26]. However, Okada et al. [16] reported that after and before orthognathic surgery, the chewing pattern changed in approximately 50% of patients from the narrow type (chopping) to the broader (grinding) type, and the condylar position also changed due to condylar resorption. Furthermore, Kubota et al. [17] reported that the chewing pattern changed from chopping to grinding after SSRO. The results of our study's control group are consistent with those reported previously [16,17]. A previous study suggested that chewing exercises after orthognathic surgery improve masticatory efficiency and bite force [27]. Harzer et al. [28] stated that the setback of the mandible by SSRO improves the activity of the masticatory muscles. It was also reported that improved occlusal contact increases bite force [29]. Our previous study in Japan suggested that a chewing exercise for grown-up children facilitates an increase in oral function and changes in chewing patterns [30]. The results of the present study are similar to those of the previous studies of chewing exercises. The masticatory pattern changed to the normal type in 60% of the patients and remained unchanged from the reversed and crossover type in 40% of the patients. Three of the four patients with no change had a crossbite molar occlusion on their first visit. The results suggest that longer or more demanding chewing exercises are needed to change masticatory movements. In contrast, 21.0% of the patients in the control group showed a change to the normal type. This may be a natural adaptation due to the changes in morphology. A more detailed study is needed to determine what does and what does not improve with chewing exercises.

Okada et al. [16] suggested that patients with a broader chewing pattern after SSRO undergo condylar remodeling. This may be a compensation mechanism for the change in the proximal fragment's position caused by SSRO. Based on the present study's results of the chewing exercise compared with the control group, the chewing exercise group showed a change in chewing pattern to the normal type (broader). In this study, the amount of change in the proximal fragment was less than that reported by Okada et al. because the asymmetry case was excluded, but the proximal fragment moved in a distal rotation around the condyle. The amount of movement of the proximal fragment was less than that of the control group without training, suggesting that the chewing exercise may have affected the adaptation of the proximal fragment to the postoperative position. This result suggests that the purpose of chewing exercise is to adapt the chewing pattern to occlusion and jaw position after SSRO. In clinical practice, it is important to provide chewing exercises to patients who do not adapt chewing patterns to occlusion after SSRO. However, our investigation has a limitation: it did not include long-term follow-ups with sufficient subjects. The control group, which did not conduct the chewing exercise, may have been able to adapt their form and function with a longer follow-up period. In the future, longer-term observations will be made to investigate the remodeling of the condyle after improvement with a chewing exercise.

5. Conclusions

- Chewing patterns change to the normal type in 60% of the patients by performing a chewing exercise after SSRO.
- In the control group with no chewing exercise, 21% of the subjects spontaneously changed to the normal type of mastication.
- Chewing exercises can be useful to normalize masticatory movements after SSRO.

Author Contributions: Conceptualization, S.N. and K.K.; methodology, S.N.; software, K.S.; validation, S.N. and K.K.; formal analysis, S.N.; investigation, S.N.; resources, K.S.; data curation, K.S.; writing—original draft preparation, S.N.; writing—review and editing, S.N.; visualization, S.N.; supervision, K.K.; project administration, K.K. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Ethics Committee of Nihon University School of Dentistry at Matsudo (approval no. EC 17-003).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Conflicts of Interest: The authors declare no conflict of interest.

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