



Original Research

Does postoperative masticatory training for prognathism contribute to functional improvement?

Rio Min^{a,*}, Tomokazu Motohashi^b, Yuichi Shoju^b, Hirohito Kubo^b, Masahiro Nakajima^b^a Graduate School of Dentistry (Second Department of Oral and Maxillofacial Surgery), Osaka Dental University, Osaka, Japan^b Second Department of Oral and Maxillofacial Surgery, Osaka Dental University, Osaka, Japan

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ABSTRACT

Objective: Introduction of postoperative oral rehabilitation has been expected to improve the oral function after orthognathic surgery for mandibular prognathism, but remains uncertain on its efficacy. This study was to clarify what kind of improvement in oral function is associated with postoperative oral rehabilitation.

Methods: 51 patients of mandibular prognathism underwent orthognathic surgery. Gum chewing exercise was introduced in all patients from the third month after surgery. At the fourth month only 12 patients (EG) performed training perfectly and continued till the sixth month, however another group of 12 patients (NEG) quitted training then. The occlusal contact area (OCA), the maximum bite force (MBF), and the chewing ability (CA) were measured at the day before surgery, the first, the third, and the sixth month compared with a control group comprised of 20 normal subjects. The chewing pathway area of EG and NEG were measured using a mandibular movement measurement device. Each measured value was compared by Shapiro-Wilk normality test. Analysis of variance was performed by ANOVA, and multiple comparison test (p Value < 0.05).

Results: OCA and MBF were low significantly at the sixth month after surgery compared to the control group. There was no difference in OCA and MBF at the third month between in EG and in NEG, but CA was improved and the chewing pathway area was higher at the sixth month in EG.

Conclusion: Gum chewing exercise as postoperative oral rehabilitation may restore chewing ability even in a short period of months after orthognathic surgery for mandibular prognathism.

1. Introduction

Sagittal split ramus osteotomy was introduced into Japan in the 1970 s and surgical orthognathic treatment was systemized. In 1990, preoperative orthodontic treatment before surgical correction became covered by public insurance and the number of cases rapidly increased. The age range of patients has recently risen and surgical orthognathic treatment of jaw deformity has become a general treatment method. Surgical orthodontic treatment of jaw deformity aims at functional improvement, such as occlusal function, and facial esthetic improvement including esthetics around the lips. Many studies on not only esthetic improvement but also functional improvement have been performed. Stomatognathic function is generally low in the presence of mandibular prognathism compared with that in persons with normal occlusion and the function temporarily decreases after surgery. The function improves with time, but it has been reported that it has not reached the level in persons with normal

occlusion even after several years [1]. Attempts to improve stomatognathic function within a shorter time by rehabilitation, such as postoperative gum chewing exercise, have been reported [2], but the rehabilitation method of gum chewing exercise was not specifically mentioned.

It has been reported that the chopper type in which the locus of mouth opening and locus of mouth closing of the mastication route overlap is a characteristic of mandibular prognathism [3]. In contrast, the chewing pathway of normal occlusion is simple and regular. Ahlgren et al. [4] mentioned that the teardrop type in which the mouth smoothly opens from centric occlusion toward the working side and then closes to centric occlusion, forming a convex locus, is the most efficient chewing pathway.

In this study, mandibular prognathism patients with performed gum chewing exercise (3 times a day, 10 min after each meal) from 3 to 6 months after surgery, and the occlusal contact area, maximum bite force, amount of glucose discharge induced by gummy candy chewing,

* Correspondence to: 1-5-17 Otemae, Chuo ward, Osaka city, Osaka 540-0008, Japan.

E-mail address: min-r@cc.osaka-dent.ac.jp (R Min).

and the route of mandibular masticatory movement were measured over the time.

2. Subjects and Methods

2.1. Subjects

The subjects were 51 patients (male: 19, female: 32, mean age: 22.9 ± 5.3 years old) who were diagnosed with mandibular prognathism and underwent orthognathic surgery at Second Department of Oral and Maxillofacial Surgery, Osaka Dental University Hospital between October 2018 and August 2020. The details of surgery were: SSRO alone, 28 (male: 10, female: 18, mean age: 22.4 ± 4.9 years old); Le Fort I + SSRO, 23 (male: 10, female: 13, mean age: 23.9 ± 5.9 years old). A control group comprised of 20 subjects with Angle Class I normal occlusion (male: 10, female: 10, mean age: 25.8 ± 3.2 years old) was set.

2.2. Occlusal contact area and maximum bite force

The occlusal contact area (OCA [mm^2]) and maximum bite force (MBF [N]) were measured before surgery and 1, 3, and 6 months after surgery using DENTAL PRESCALE II® (GC Co, Tokyo, Japan). The subjects sat on a chair and the overlapping relationship of maxillomandibular dentition was confirmed in the natural head position. The subjects clenched a PRESCALE sheet with maximum force in the maximal intercuspal position for 3 s. Saliva adhering to the PRESCALE sheet was gently wiped off, the sheet was disinfected by wiping with ethanol for disinfection, and a positioning template and the PRESCALE sheet were set on a scanner (EPSON GT-X830®, SEIKO EPSON Co, Nagano, Japan). Regions with 10 MPa or higher color development on the PRESCALE sheet were selected using bite force analysis software (Bite force analyzing system®, GC Co, Tokyo, Japan) and each region was subjected to calculation.

2.3. Chewing ability

The subjects chewed a glucose-containing gummy candy (Glucoram®, GC Co, Tokyo, Japan) on the habitual chewing side for 20 s. Spit saliva was mixed with 10 mL of water, a sponge brush was soaked in this mixture solution, the solution was applied to a spot of a sensor chip attached to Gluco Sensor GS-II® (GC Co, Tokyo, Japan), and the amount of discharge glucose (Glu (mg/dL)) was measured.

2.4. Measurement of chewing pathway

The frontal movement of the mandibular anterior tooth region in the chewing pathway while chewing the glucose-containing gummy candy for 20 s on the habitual chewing side was drawn using a mandibular movement measurement device, K7 Evaluation system® (Myotronics-Noromed, Inc., Washington, US) [5] (Fig. 1). The measured frontal movement routes were extracted from 10 chewing pathway which were stable from the initiation of chewing and the loop of each chewing was presented as a bitmap image. The area of the frontal chewing pathway in the acquired image was measured as a pixel value using image analysis software, image J® (National Institute of Health, Maryland, US), standardized with $7500 \text{ pixel} = 25 \text{ mm}^2$, and the frontal chewing pathway area (F [mm^2]) was calculated.

2.5. Gum chewing exercise

Chewing exercise was performed for 10 min 3 times a day after each meal from 3 months after surgery using a commercial gum (Xylitol gum®, lime mint flavor, LOTTE Co). The subjects were instructed to record the date with exercise and the frequency and time of exercise on a check sheet. The check sheet was collected 1 month after initiation of

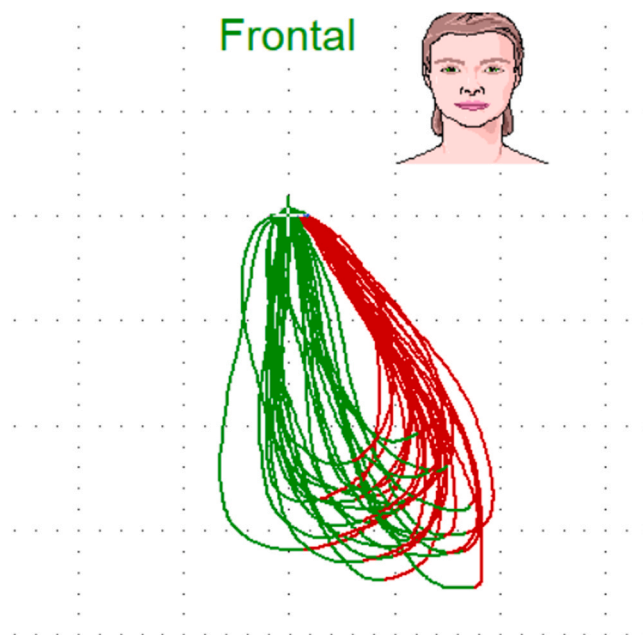


Fig. 1. A sample of frontal chewing pathways drawn with k7 evaluation system.

exercise and the degree of performing exercise (date, frequency, and time) was surveyed. Twelve patients performed 10-minute training 3 times daily, 27 performed 1–2 times a day, and 12 did not perform exercise. The 12 patients who completely performed exercise and 12 patients who did not perform exercise were classified as the Exercise Group (EG) and Non-Exercise Group (NEG), respectively. The 12 patients of the EG were instructed to grind food with the back teeth 4 months after surgery (1 month after initiation of gum chewing exercise) to continue exercise by chewing gum combined with grinding movement largely changing the vertical height and amplitude of the chewing pathway, for which they visually confirmed the locus of mandibular movement on a monitor using a K7 Evaluation System®. The 12 patients of the NEG stopped chewing exercise.

2.6. Statistical analysis of data

Shapiro-Wilk normality test was carried out. Analysis of variance was performed on all data by ANOVA, and multiple comparison test (Tukey test) was performed on those with significant differences. The significance level was set at $p < 0.05$ in all analyses. The relationship between measured values was evaluated based on a 95% confidence interval using regression analysis. The tests were performed using data analysis software, Microsoft Excel 2016.

3. Results

3.1. Occlusal contact area (OCA) and maximum bite force (MBF)

In the control group, the occlusal contact area was $38.1 \pm 11.6 \text{ mm}^2$ in males, $31.6 \pm 10.9 \text{ mm}^2$ in females, and $34.9 \pm 11.7 \text{ mm}^2$ in all. In the mandibular prognathism group before surgery, the area was $10.6 \pm 6.5 \text{ mm}^2$ and this value corresponded to 30% of that in the control group, being significantly smaller. No significant sex difference was noted in the mandibular prognathism group before surgery and the control group. And, no significant surgical procedure was difference between in the mandibular prognathism group. Both surgical groups showed significant differences between preoperative and 3 months postoperatively, and 3 months and 6 months postoperatively. Regarding changes with time in the mandibular prognathism group, OCA decreased to $7.5 \pm 4.2 \text{ mm}^2$ 1 month after surgery and then recovered to $11.3 \pm 5.2 \text{ mm}^2$ 3 months after surgery,

Table 1
Measurements in All categories of Participants (OCA and MBF).

Measurements		OCA[mm2]				MBF[N]			
Characteristics		Pre	PO1M	PO3M	PO6M	Pre	PO1M	PO3M	PO6M
Mandibular Prognathism (n = 51)	SSRO (n = 28)	11.8 ± 7.7	9.4 ± 4.5	13.0 ± 5.4	13.9 ± 4.8	469.4 ± 251.5	284.0 ± 128.0	466.1 ± 182.0	538.4 ± 168.6
	LF1+SSRO (n = 23)	9.2 ± 4.3	5.4 ± 2.4	8.6 ± 3.6	11.2 ± 4.6	451.8 ± 197.2	158.9 ± 67.6	284.7 ± 128.4	412.8 ± 148.6
	Total	10.6 ± 6.5	7.5 ± 4.2	11.3 ± 5.2	12.7 ± 5.0	445.2 ± 230.1	222.5 ± 119.9	394.9 ± 182.1	479.1 ± 165.0
Control Group (n = 20)	Male (n = 10)	38.1 ± 11.6				1360.3 ± 416.2			
	Female (n = 10)	31.6 ± 10.9				1202.1 ± 372.4			
	Total	34.9 ± 11.7				1281.2 ± 402.8			

Mean ± SD, EG: exercise group, NEG:non-exercise group, LF 1Le Fort I, SSRO: sagittal split ramus osteotomy, OCA: occlusal contact area, MBF: maximum bite force.
Mean ± SD *p < 0.05.

being close to the preoperative value, and rose to $12.7 \pm 5.0 \text{ mm}^2$ 6 months after surgery, but it reached only 36% of that of the control group (Table 1, Fig. 2).

By exercise, OCA in the EG was $12.3 \pm 6.1 \text{ mm}^2$ before surgery and 8.4 ± 5.5 , 11.8 ± 6.7 , and $13.7 \pm 6.6 \text{ mm}^2$ at 1, 3, and 6 months after surgery, respectively. In the NEG, OCA was $7.5 \pm 4.4 \text{ mm}^2$ before surgery and 7.8 ± 3.3 , 10.8 ± 2.4 , and $11.8 \pm 3.6 \text{ mm}^2$ at 1, 3, and 6 months after surgery, respectively (Fig. 3).

In the control group, the maximum bite force was $1360.3 \pm 416.2 \text{ N}$ in males, $1202.1 \pm 372.4 \text{ N}$ in females, and $1281.2 \pm 402.8 \text{ N}$ in all. It was $445.2 \pm 230.1 \text{ N}$ in the mandibular prognathism group before surgery and corresponded to 35% of that of the control group, being significantly smaller. No significant sex difference was noted in the mandibular prognathism group before surgery and the control group. Regarding changes with time in the mandibular prognathism group, MBF decreased to $222.5 \pm 119.9 \text{ N}$ 1 month after surgery then rose to 394.9 ± 182.1 and $479.1 \pm 165.0 \text{ N}$ 3 and 6 months after surgery, respectively, but it reached only 37% of that of the control group (Table 1, Fig. 4).

By exercise, MBF in the EG was $486.2 \pm 161.1 \text{ N}$ before surgery and 233.1 ± 156.1 , 404.5 ± 219.3 , and $522.6 \pm 222.5 \text{ N}$ at 1, 3, and 6 months after surgery, respectively. In the NEG, it was $301.6 \pm 92.3 \text{ N}$ before surgery and 221.9 ± 67.1 , 388.1 ± 111.9 , and $451.6 \pm 101.1 \text{ N}$ at 1, 3, and 6 months after surgery, respectively (Fig. 5).

Both bite force and the contact area were slightly higher in the EG than NEG at 6 months after surgery, but these were significantly lower than those in the control group (Figs. 6 and 7).

3.2. Chewing ability

In the control group, the chewing ability was $245.6 \pm 52.0 \text{ mg/dL}$ in males, $224.2 \pm 43.2 \text{ mg/dL}$ in females, and $234.9 \pm 49.0 \text{ mg/dL}$ in all. It was $162.0 \pm 50.5 \text{ mg/dL}$ in the mandibular prognathism group before surgery and corresponded to 68% of that of the control group. There was no significant sex difference in the mandibular prognathism group before surgery or the control group. Regarding changes with time in the mandibular prognathism group, the value at 1 month after surgery was $108.1 \pm 45.3 \text{ mg/dL}$, being lower than the preoperative value, then rose to 167.8 ± 46.3 and $204.9 \pm 50.8 \text{ mg/dL}$ at 3 and 6 months after surgery, respectively, being close to the value in the control group (Table 2, Fig. 8).

By exercise, the chewing ability in the EG was $141.6 \pm 40.6 \text{ mg/dL}$ before surgery and 117.8 ± 47.5 , 168.5 ± 27.1 , and $239.9 \pm 27.1 \text{ mg/dL}$ at 1, 3, and 6 months after surgery, respectively, showing that the value at 6 months was close to that in the control group. In addition, a significant difference was noted between before surgery and 6 months and between 3 and 6 months in the EG (Fig. 9). On the other hand, in the NEG, the chewing ability was $162.5 \pm 45.0 \text{ mg/dL}$ before surgery and 106.3 ± 37.7 , 161.6 ± 40.3 , and $170.4 \pm 36.1 \text{ mg/dL}$ at 1, 3, and 6 months after surgery, respectively, showing no significant difference between before surgery and 6 months and between 3 and 6 months (Fig. 9). At 6 months after surgery, the chewing ability of the EG recovered to a value close to that in the control group, and a significant difference was noted between the NEG and EG and between the NEG and control group (Fig. 10).

3.3. Area of frontal chewing pathway

The pattern of the chewing pathway was teardrop-shaped in many cases in the control group. In the mandibular prognathism group before surgery, the chopper type, in which the mouth opening pathway and closing pathway draw the same locus, was noted in 47 of the 51 patients. In the control group, the area of the pathway was $901.9 \pm 368.3 \text{ mm}^2$ in males, $921.2 \pm 287.0 \text{ mm}^2$ in females, and $911.5 \pm 330.3 \text{ mm}^2$ in all. In the mandibular prognathism group, the

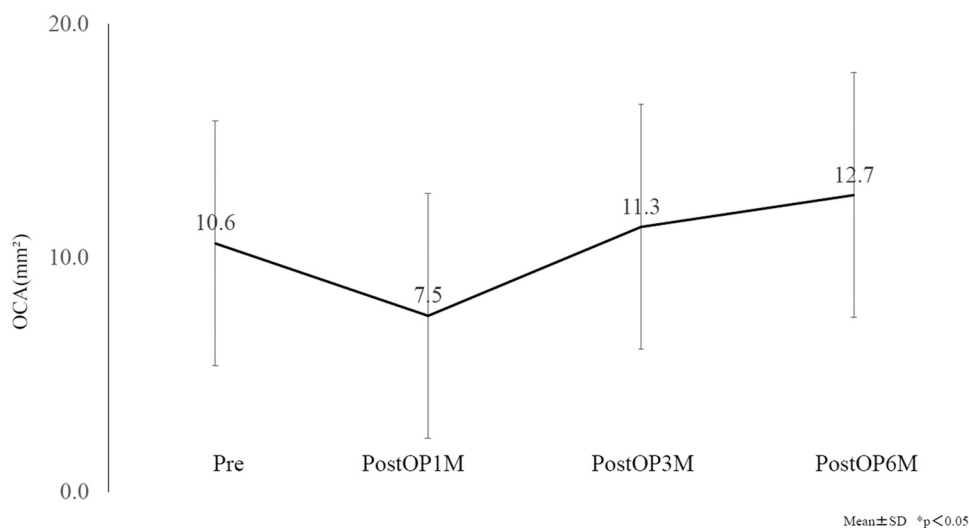


Fig. 2. Changes in occlusal contact area (OCA) during gum chewing exercise after operation.

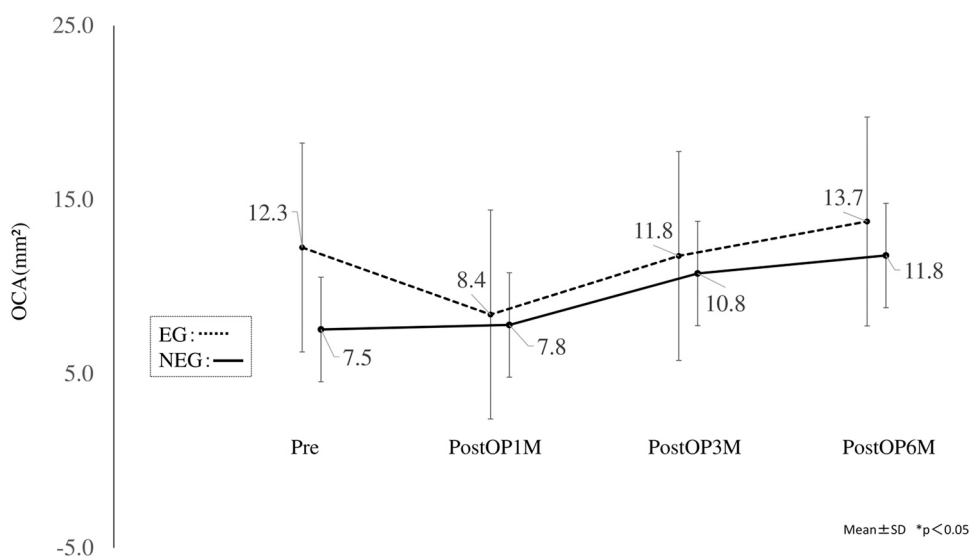


Fig. 3. Changes in occlusal contact area (OCA) by exercise group and non-exercise group over time.

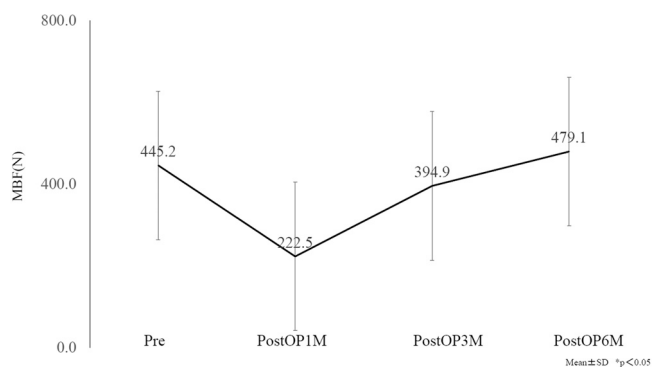


Fig. 4. Changes in maximal bite force (MBF) during gum chewing exercise after operation.

area before surgery was $429.2 \pm 367.6 \text{ mm}^2$ and corresponded to 50% of that of the control group. Regarding changes with time in the mandibular prognathism group, the area slightly increased to $535.0 \pm 408.5 \text{ mm}^2$ at 3 months after surgery and further increased to $721.1 \pm 511.7 \text{ mm}^2$ at 6 months, reaching about 80% of that of the control group (Table 2).

On comparison by exercise, in the EG, the area was $525.2 \pm 322.6 \text{ mm}^2$ before surgery and 681.1 ± 479.3 and $1004.0 \pm 47.8 \text{ mm}^2$ at 3 and 6 months, respectively. In the NEG, the area was $333.3 \pm 270.3 \text{ mm}^2$ before surgery and 388.8 ± 247.6 and $438.1 \pm 251.9 \text{ mm}^2$ at 3 and 6 months, respectively, showing that the area increased with time in both groups. The area of the chewing pathway in EG and NEG increased at 6 months after surgery, but there was no significant difference between over time (Fig. 11). At 6 months after surgery, the value in the EG recovered to a value close to that in the control group and a significant difference was noted between the NEG and EG and between the NEG and control group (Fig. 12).

4. Discussion

4.1. Difference in time-course changes between static occlusal function and dynamic masticatory function

Throckmorton et al. [6,7] reported that the preoperative maximum bite force of patients with mandibular prognathism was half or less than that of subjects with normal occlusion and it took 2–3 years to reach a level of normal occlusion, i.e., even though the occlusal relationship was improved by orthognathic surgery, long-term observation is

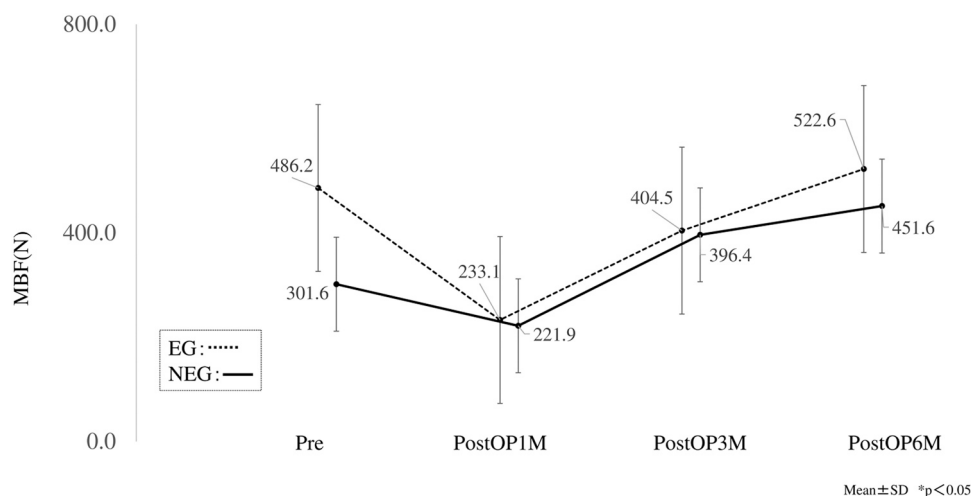


Fig. 5. Changes in maximal bite force (MBF) by exercise group and non-exercise group over time.

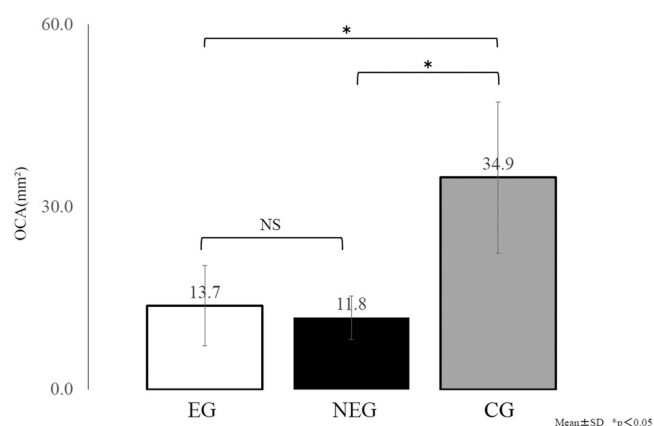


Fig. 6. Comparison in occlusal contact area (OCA) of each group by gum exercise (EG PostOP6M), non-exercise (NEG PostOP6M) and control.

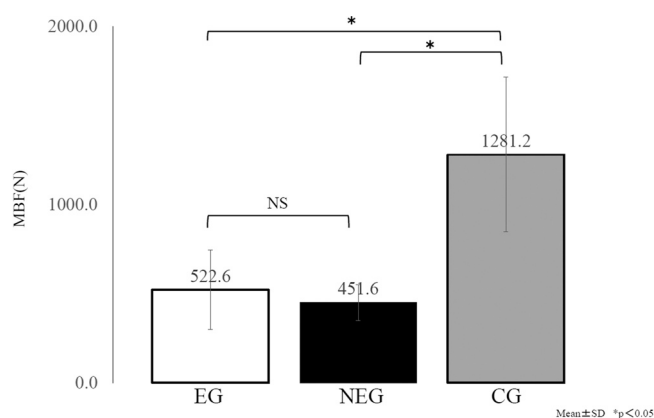


Fig. 7. Comparison in maximal bite force (MBF) of each by gum exercise (EG PostOP6M), non-exercise (NEG PostOP6M) and control.

necessary for increases in the occlusal contact area and maximum bite force. Generally, occlusal function is reduced in mandibular prognathism patients compared with that in persons with normal dentition and it has been reported that although the function improved after surgery, it did not reach the level of subjects with normal dentition [8,9]. In the 51 patients involved in this study, the before surgery occlusal contact area was corresponded to 30% of that of the control group. It decreased 1 month after surgery then recovered to the

preoperative value at 3 months. It further rose at 6 months compared with the preoperative value, but remained 36% of that of the control group. The same tendency was noted in the maximum bite force, i.e., the static mechanical indices of occlusal function; occlusal contact area and maximum bite force, showed a course similar to the previously reported course [10,11]. No significant difference was noted in the occlusal contact area and maximum bite force at 6 months after surgery in each exercise-based group, clarifying that functional rehabilitation; short-term gum chewing exercise, did not have an influence on either index.

On the other hand, since the chewing ability evaluated based on the amount of glucose discharged by gummy candy chewing was evaluated as a result of chewing pathway, this was considered a dynamic mechanical index of masticatory function. The discharged amount in the mandibular prognathism group was corresponding to 68% of that of the control group. It in 1 months after surgery was being decreased from the preoperative value, then significantly increased to 3 and 6 months after surgery, respectively, showing that it improved to a level close to that of the control group.

Based on the above, the result of dynamic masticatory function acquired by short-term gum chewing exercise was different from that of static occlusal function.

4.2. Influence of gum chewing exercise on dynamic masticatory function

The mandibular movement chewing pattern in the frontal view during chewing pathway has been utilized as a method evaluating the dynamic movement of masticatory function [11]. It has been reported that a linear chopper shape in which the locus of the mouth opening and locus of the mouth closing overlap is a characteristic of mandibular prognathism [12] and postoperative changes in mandibular movement are small [13]. We regarded the shape of the chewing pathway formed by single mouth opening and closing as a circle and focused on changes in the circle area induced by changes in the vertical height and amplitude of the chewing pathway. In this study, the chewing pathway pattern was not compared but the area surrounded by the loop of the chewing pathway was compared.

Compared to NEG, EG had slightly higher occlusal contact area and maximum bite force before surgery, but there was no difference in chewing ability. By performing postoperative rehabilitation, improvement of chewing ability was observed in EG. There is no significant difference in occlusal contact area and maximum bite force between EG and NEG due to postoperative rehabilitation. This study suggests that elevated chewing ability may involve not only elevated occlusal contact area and maximum bite force, but also other oral functions such as chewing pathway. Because the area in NEG slightly increased, but the change was

Table 2

Measurements in All categories of Participants (Glu and F).

Measurements		Glu[mg/dl]				F[mm2]		
Characteristics		Pre	PO1M	PO3M	PO6M	Pre	PO3M	PO6M
Mandibular Prognathism (n=51)	SSRO (n=28)	154.8±39.6	117.0±46.1	168.0±47.9	201.0±48.1	511.4±349.9	596.7±453.7	774.4±534.2
	LFI+SSRO (n=23)	170.8±60.2	97.2±41.9	160.0±47.1	209.6±53.5	314.2±201.5	448.5±315.3	646.4±468.2
	Total	162.0±50.5	108.1±45.3	167.8±46.3	204.9±50.8	429.2±367.6	535.0±408.5	721.1±511.7
Control Group (n=20)	Male (n=10)		245.6±52.0				901.9±368.3	
	Female (n=10)		224.2±43.2				921.2±287.0	
	Total		234.9±49.0				911.5±330.3	

Mean ± SD * p<0.05

Mean ± SD, Glu: chewing ability, F: frontal chewing pathway area.

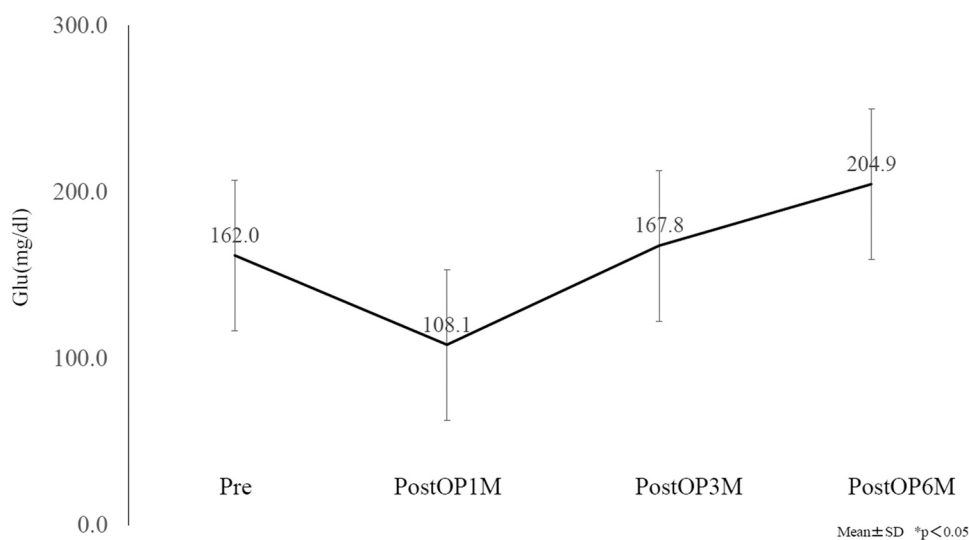
smaller than that in EG. However, in this study, it cannot be denied that EG may have been superior to NEG in oral function before surgery.

Kubota et al. [3] and Pröschel et al. [14] reported that chopper movement with a narrow amplitude was frequently observed in the chewing pathway area pattern in mandibular prognathism patients before surgery and it was converted to grinding movement with a wider amplitude at 6 months after surgery. The large increase the chewing pathway area in the EG was considered an influence of grinding movement combined with gum chewing exercise and it may have resulted from an increase in the vertical and horizontal distances of the chewing pathway.

Regarding the relationship between the chewing ability and mastication movement during chewing a gummy candy, Uesugi et al. [11]

and Flores-Orozco et al. [12] reported that the vertical height and amplitude of the chewing pathway area involved in the favorable chewing ability of adults with normal dentition. Accordingly, the acquisition of grinding movement promoting vertical and horizontal increases in the chewing pathway is expected to improve chewing ability.

Gum chewing exercise is a training method which can be performed relatively easily. It is frequently performed as postoperative oral rehabilitation after orthognathic surgery and its contribution to increases in the activity level of the muscles of mastication and bite force has been reported [2,15,16]. However, in these reports, no specific planned rehabilitation method was proposed for the mandibular mastication movement method of the exercise and it was left to patients who performed exercise. This study suggested that improvement of masticatory

**Fig. 8.** Changes in chewing ability (Glu) during gum chewing exercise after operation.

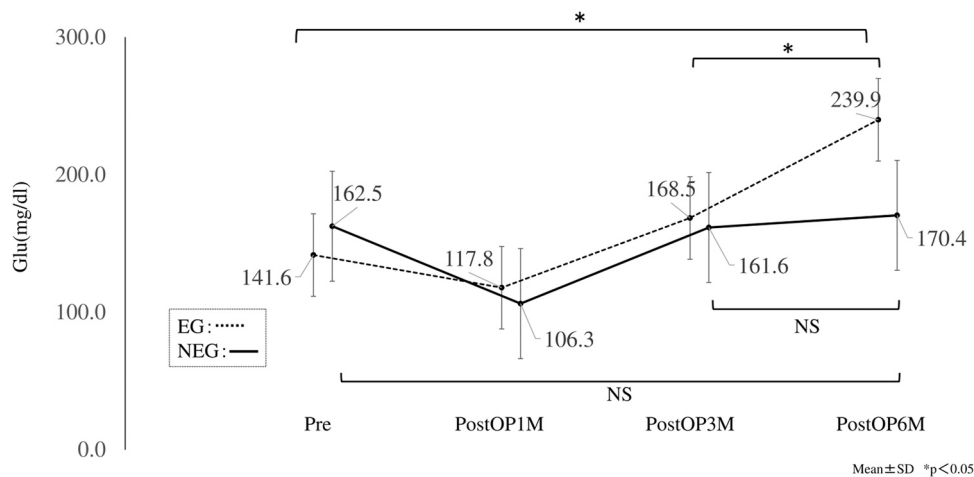


Fig. 9. Changes in chewing ability (Glu) by exercise group(EG) and non-exercise group(NEG) over time.

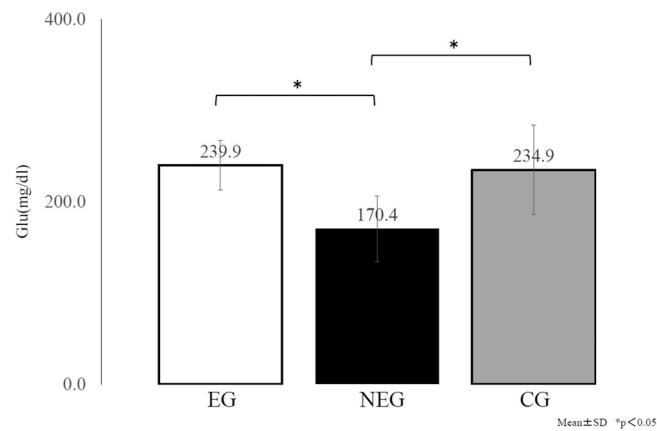


Fig. 10. Comparison in chewing ability (Glu) of each group by gum exercise (EG PostOP6M), non-exercise (NEG PostOP6M) and control.

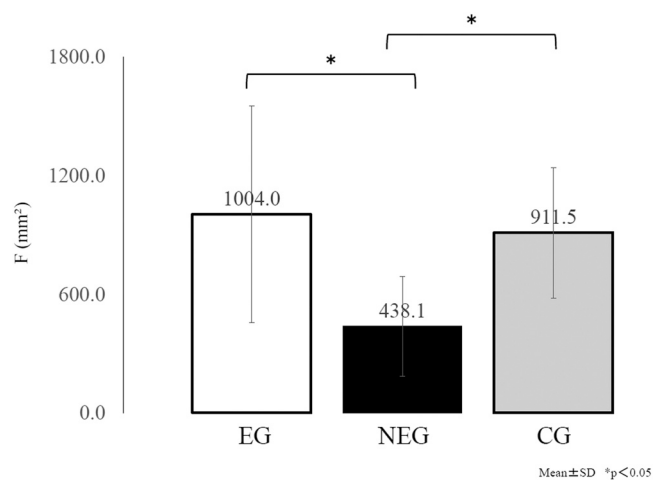


Fig. 12. Comparison in chewing pathway area (F) of each group by gum exercise (EG PostOP6M), non-exercise (NEG PostOP6M) and control.

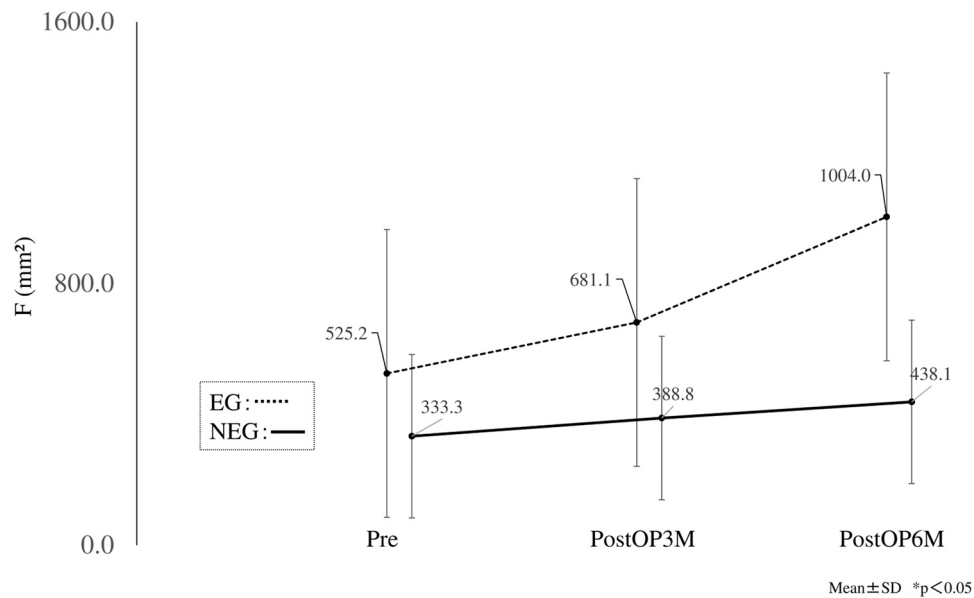


Fig. 11. Changes in chewing pathway area (F) by exercise group(EG) and non-exercise group(NEG) over time.

function can be expected by instruction of grinding movement increasing the amplitude of vertical and horizontal mandibular movement and exercise with visually observing the locus of mandibular movement during gum chewing exercise so as to increase the chewing pathway area and improve masticatory function even though it is intervention by only 2-month short-term exercise. In the future, it is necessary to increase the number of patients and further pursue the effects of postoperative rehabilitation.

5. Conclusion

It was suggested that stability of the chewing pathway can be acquired and chewing ability can be improved by postoperative gum chewing exercise combined with grinding movement after orthognathic surgery widening the chewing pathway vertically and horizontally. Furthermore, the efficiency of postoperative oral rehabilitation after orthognathic surgery may be increased by performing chewing exercise while monitoring the locus so as to increase the chewing pathway area.

Ethical approval

This study was conducted with the approval of the Ethics Committee of Osaka Dental University (Approval No. 110992).

Patient consent

Written patient consent was obtained to publish the clinical dates.

Declaration of Competing Interest

The authors report no declarations of interest.

Acknowledgements

None.

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