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Original Article

# Establishment of a new rehabilitation program using masticatory training food for jaw deformity patients

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## KEYWORDS

Orthognathic surgery;  
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food

**Abstract** *Background/purpose:* Patients with jaw deformities may show a reduction in masticatory function as a result of postoperative hypofunction. This study aimed to establish a novel rehabilitation program using a commercially available masticatory training food for patients with jaw deformities after orthognathic surgery.

*Materials and methods:* Nine patients with mandibular prognathism (the training group: n = 5, and the non-training group: n = 4) and 6 control participants with normal occlusion were included in this study. For the rehabilitation program with masticatory exercise, patients were instructed to chew the training food once a day for 60 days starting from 10 days after the surgery. The effects of the rehabilitation program were assessed by determining the maximum bite force (MBF) and the masticatory performance (MP). Clinical assessments were performed just before orthognathic surgery (Pre) and at 10 days (T0), 1 month (T1), 2 months (T2), and 3 months (T3) after surgery.

*Results:* Compared with the non-training group, the training group showed a trend toward greater recovery amount of MBF from Pre to T3, and a significantly greater recovery amount in MP ( $p < 0.05$ ) from Pre to T3. When the time-series change of MP was evaluated in both groups from T0 to T3, a significant difference was observed in the interaction terms ( $p = 0.03$ ). This result indicates that the effectiveness of the training may be demonstrated by following the postoperative course further.

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*Conclusion:* The rehabilitation using this training food may become a useful method for postoperative hypofunction in patients with jaw deformities.

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## Introduction

Patients with jaw deformities are subject to masticatory disturbance after orthognathic surgery, and these masticatory problems are associated with two major causes: masticatory functional disorder due to malocclusion and hypofunction following orthognathic surgery. Patients with mandibular prognathism and masticatory functional disorder have a smaller occlusal contact area, lower maximum bite force, lower muscle activity, and higher ratio of abnormal chewing strokes to the total chewing strokes in comparison with the corresponding values in control subjects with normal occlusion.<sup>1–5</sup> With respect to the postoperative hypofunction following orthognathic surgery, the bite force and masticatory efficiency at 6 weeks after orthognathic surgery were significantly lower than the corresponding values before surgery, and masticatory function recovered to the presurgical level only after 3 months.<sup>6</sup> Kojo et al.<sup>7</sup> reported that recovery of the postoperative reduction of occlusal force and body weight required approximately 3 and 6 months, respectively. Similarly, restoration to a regular diet required 3 months. The inadequate nutritional state caused by a reduced food intake should be recovered quickly to improve the postoperative prognosis. Therefore, rehabilitation after orthognathic surgery is indicated.

Physical rehabilitation for postoperative hypofunction in patients with jaw deformities has been conducted over the last few decades.<sup>8–13</sup> Storum et al.<sup>9</sup> reported that patients who received physical rehabilitation showed a significantly greater maximal mandibular opening and bite force than patients who did not receive rehabilitation. Teng et al.<sup>11</sup> demonstrated that patients who underwent rehabilitative physiotherapy exhibited more favorable recovery in the range of mandibular motion than those who did not receive training. However, mastication consists of complicated jaw movements. Therefore, rehabilitation with a masticatory exercise using training food is preferable for the recovery of masticatory function. Commercially available masticatory training food (Processlead, Otsuka Pharmaceutical Factory Inc., Tokyo, Japan) has recently been developed for dysphagia rehabilitation in the elderly.<sup>14</sup> We attempted to use this training food in postoperative patients with jaw deformities to accelerate the recovery of masticatory function.

The aim of this study was to establish a rehabilitation program using commercially available masticatory training food after orthognathic surgery in patients with jaw deformities.

## Materials and methods

### Participants

Twelve patients with non-syndromic mandibular prognathism were recruited into this study. All the patients underwent orthognathic surgery at the Tokushima University Hospital. None of the patients had a cleft palate or craniofacial syndrome. They were divided into two groups according to their preference after being explained about the study. The training group consisted of five patients who received the rehabilitation program after surgery (2 males and 3 females; mean age,  $28.4 \pm 7.1$  years) and the non-training group consisted of seven patients who did not receive the rehabilitation program (2 males and 5 females; mean age,  $22.3 \pm 5.7$  years).

Six healthy individuals (2 males and 4 females; mean age,  $25.5 \pm 1.1$  years) were enrolled as the control group. The control group comprised dental school students and staff members at Tokushima University, and the inclusion criteria for enrollment were age over 18 years, no severe malocclusion, no jaw deformities, no functional disorders, and no previous orthodontic treatment. This study was approved by the Ethics Committee of Tokushima University Hospital (Approval No. 3185), and informed consent was obtained from all the participants.

### Measurements of muscle activity, maximum bite force and masticatory performance

Clinical examinations were performed just before orthognathic surgery (Pre) and 10 days (T0), 1 month (T1), 2 months (T2), and 3 months (T3) after the surgery. The muscle activity and maximum bite force could not be recorded at T0 because patients could not clench due to postoperative pain.

Muscle activity was recorded by one examiner with adequate electromyography (EMG) training, using a 4-channel surface electromyograph (K7 Evaluation System; Myotronics-Noromed, Inc., Tukwila, WA, USA) with simultaneous acquisition, common grounding to all channels, and filters of 50 Hz. The muscle activity was expressed in  $\mu\text{V}$  as the root mean square of the amplitude. EMG of the masseter and temporalis muscles was performed bilaterally using bipolar surface electrodes. The skin surface corresponding to the masseter and temporalis muscles was cleaned with alcohol-soaked cotton for the removal of excess oiliness. Special attention was paid to obtain

reproducible recordings. The bipolar surface electrodes were placed on the midpoint of the masseter muscle and the anterior part of the temporalis muscle along the muscle fiber orientation. To obtain a reliable EMG recording, the reliability of signal capitation of each electrode was tested by a noise test software (K7 Program; Myotronics-Noromed, Inc.): only when the software gave the absence of noise (corresponding to the value provided by the software of 0.0), the EMG recording was started.<sup>15</sup> The participants were instructed to clench with maximum effort for 3 s twice, with an interval of 7 s. The mean value of the EMG amplitude was calculated during the median 2 s of the 3-s clenching. The larger mean EMG amplitude measured on each side was regarded as the representative value. The bilateral representative measurements were averaged to calculate the muscle activity value for each individual.

A portable occlusal force gauge (Occlusal Force-meter GM10, Nagano Keiki Co. Ltd., Tokyo, Japan) was used to measure the maximum bite force (MBF). The Frankfort horizontal plane of the subjects was made parallel to the floor. The MBF applied on the both sides first molars were measured twice, and the larger measurement achieved on each side was regarded as a representative. Each measurement was pertained with 30-s intervals. The mean value of bilateral representative measurements was used as the MBF of the individual as the subject's MBF used in the analysis.<sup>16,17</sup>

The masticatory performance (MP) was evaluated according to the dissolved glucose concentration from a cylindrically shaped gummy jelly (diameter, 15 mm; height, 8 mm; weight, 2 g) consisting of 40% maltose, 10% sorbitol, and 5% glucose (GLUCOLUMN; GC Co. Ltd., Tokyo, Japan), based on previous studies.<sup>18,19</sup> Participants were asked to chew the gummy jelly on their habitual chewing side for 20 s. After chewing, participants were instructed to hold 10 mL of distilled water in their mouths. They were then asked to spit out the gummy jelly, distilled water, and saliva into a filter cup. The glucose concentration in the filtrate was measured using a glucose measuring device (GLUCO SENSOR GS-II; GC Co. Ltd.).

## Rehabilitation program

A commercially available masticatory training food (Processlead, 50 g; Otsuka Pharmaceutical Factory Inc., Tokushima, Japan) was used for the masticatory exercise in this study. This chew-and-swallow food is meant to help participants focus on the process of chewing, forming a food mass, and swallowing. For the masticatory exercise, patients were instructed to chew the training food divided into six parts (one of six equal parts, approximately 8 g) by unilateral mastication more than 20 times on each side, perform bilateral natural chewing, and finally swallow; this protocol was performed twice by each participant. This exercise was conducted for approximately 2 min and 30 s, once a day for 60 days, starting from 10 days after the surgery.

## Statistical analysis

The amount of recovery in MBF and MP from Pre to T3 was analyzed using the Mann–Whitney U test. A two-way

repeated measures analysis of variance (ANOVA) was used to examine the interaction effects between time (T0/T1/T2/T3) and training (training group/non-training group). Training was regarded as the inter-individual factor, and time was regarded as the intra-individual factor. A probability of less than 0.05 was considered statistically significant. Data analysis was performed using a statistical software package, Statcel4 (OMS Publishing Inc., Tokyo, Japan), and power analysis of the MP was performed with BellCurve for Excel (Social Survey Research Information Co., Ltd. Tokyo, Japan).

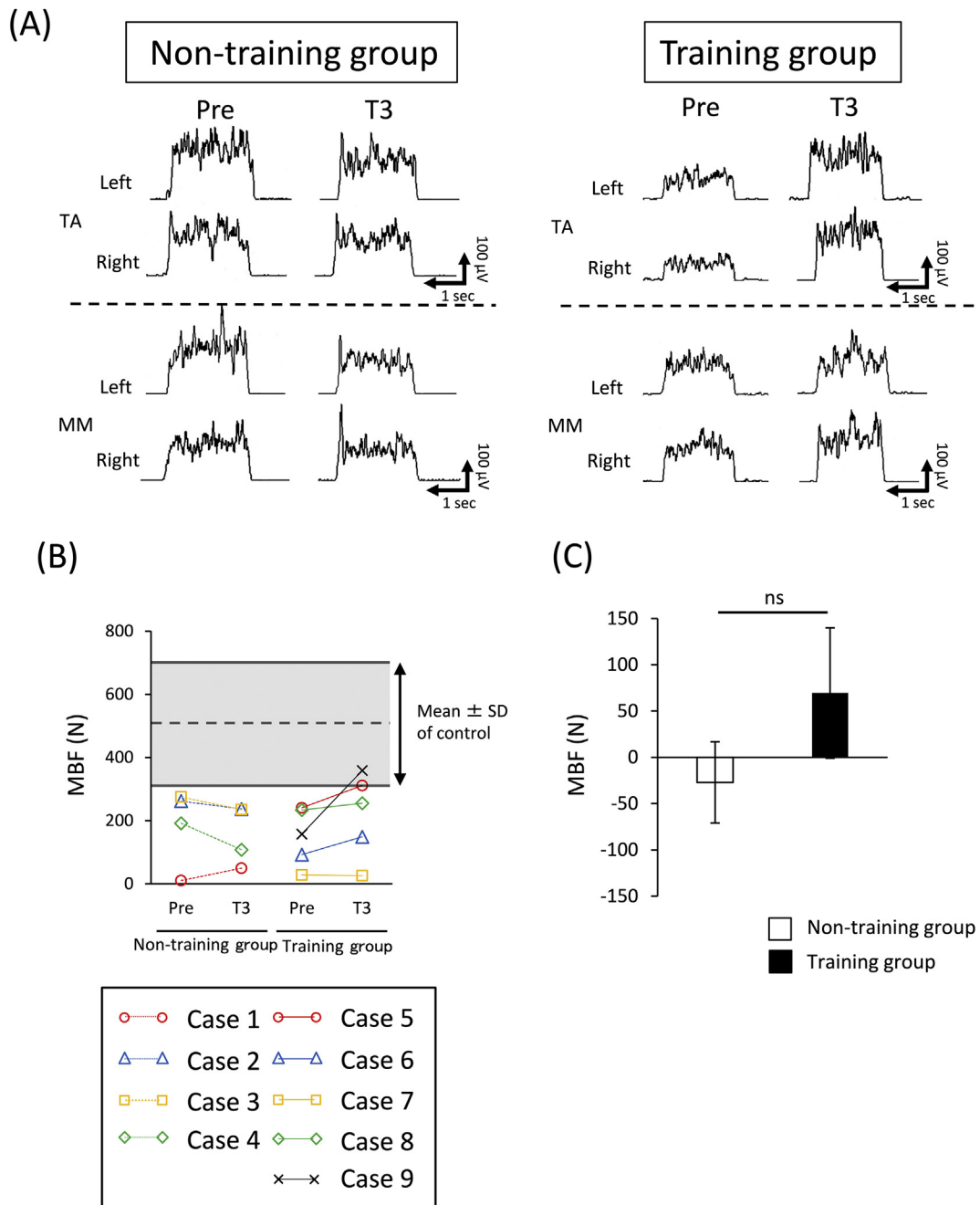
## Results

Of the 12 patients who underwent orthognathic surgery, this study sample consisted of 5 patients in the training group and 4 patients in the non-training group that were recorded the muscle activity, MBF and MP throughout the experimental period. The total sample size used in the present study was 9. In total, 3 patients in the non-training group were excluded because their records did not complete due to the spread of COVID-19.

Fig. 1A shows the representative EMG of the masseter and temporalis muscles during clenching in the non-training and training groups. In this study, we paid much attention to place the electrodes in precise positions and to measure the muscle activities in the same manner in order to obtain reproducible recordings. For the masseter and temporalis muscles of the training group, the amplitude during the 3-s clenching looks to increase from Pre to T3. In the non-training group, it seems that the amplitude even at T3 could not exceed that at Pre, except for that of the right temporalis muscle. However, this result was not used for detailed analysis.

The MBF of the control group was  $507.8 \pm 197.6$  N (Fig. 1B). In the training group, 4 of 5 patients recovered from Pre to T3, while only one of 4 patients in the non-training group recovered from Pre to T3. Fig. 1C shows the amount of MBF recovery from Pre to T3 for each group. The values of the training group were higher than those of the non-training group, but there was no significant difference between the training and non-training groups (Table 1).

The MP value of the control group was  $213.2 \pm 13.5$  mg/dl (Fig. 2A). In the training group, all patients recovered from Pre to T3, while 2 of 4 patients in the non-training group recovered from Pre to T3. Fig. 2B shows the MP for each group of the amount of recovery MP from Pre to T3 for each group. The values of recovery from Pre to T3 was significantly higher in the training group than in the non-training group ( $p < 0.05$ ) (Table 1). To confirm the validity of the sample size in the MP, a power analysis was performed. Power analysis was based on a two-tailed t-test with the significance level of 0.05, a power level of 0.92, and the effect size  $d = \text{difference of means/standard deviation} = 2.67$ . As a result, the total estimated sample size was determined to be 3.2 persons in each group. This indicates that the sample size in this study was appropriate, and that the effect size of the present results was large.



**Figure 1** (A) Representative examples of the time-course amplitude of masseter and temporalis muscles in the non-training and training groups. TA: temporalis muscle, MM: masseter muscle. (B) Individual values of the maximum bite force (MBF) for each group at Pre and T3. (C) Changes in the MBF from Pre to T3. Data are the mean  $\pm$  standard deviation. Shadow area indicates the mean  $\pm$  standard deviation of the control group. ns: no significant difference.

Fig. 3 shows the time-series change in the MP of each group from T0 to T3. All patients in both groups exhibited an increase in the MP value from T0 to T3 (Fig. 3A and B). This implies that the MP can be recovered regardless of the training. We used a two-way repeated measures ANOVA to determine whether statistically significant differences existed among the postoperative training, postoperative time, and MP. As the result, significant interaction between the postoperative training and time was observed ( $p = 0.03$ ) (Table 2).

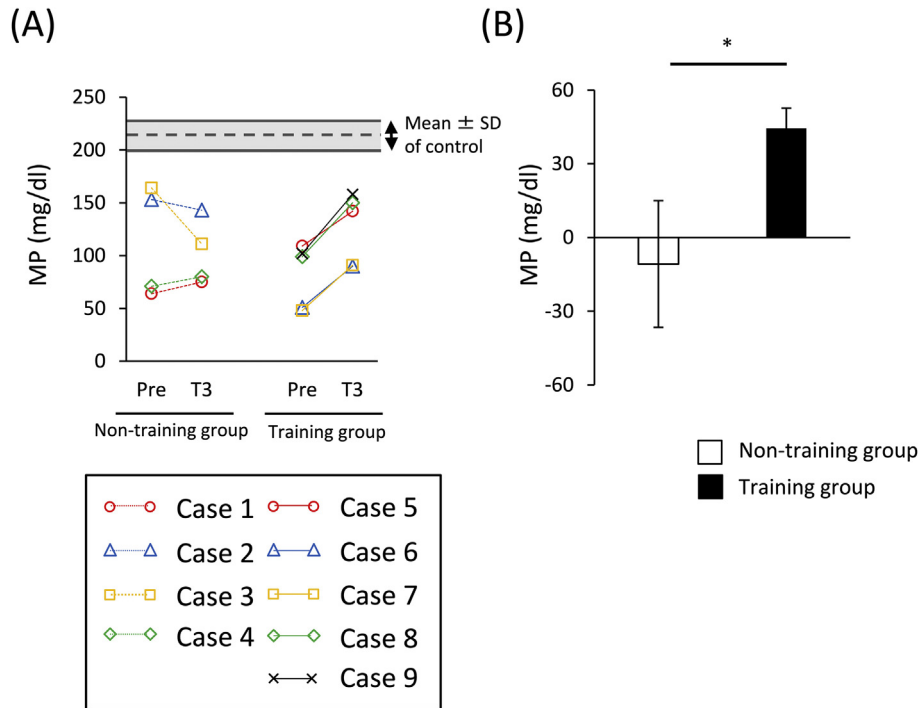
## Discussion

The masticatory function of patients with jaw deformities decreases immediately after orthognathic surgery, and the early recovery of function is important to improve the postoperative prognosis. In this study, we examined the effectiveness of postoperative rehabilitation using a commercially available masticatory training food for the recovery of masticatory function in patients with mandibular prognathism. To the best of our knowledge, this is the

**Table 1** Changes in the maximum bite force (MBF) and the masticatory performance (MP) from Pre to T3.

	MBF		MP	
	Non-training group	Training group	Non-training group	Training group
T3-Pre	-27.1 ± 43.9	69.5 ± 70.5	-10.8 ± 25.7	44.4 ± 8.2
	ns		*	

Pre: before orthognathic surgery, T3: 3 months after the surgery, T3-Pre: the amount of MBF and MP recovery, Data are the mean ± standard deviation. \*:  $p < 0.05$ , ns: no significant difference, tested by Mann-Whitney U–test.

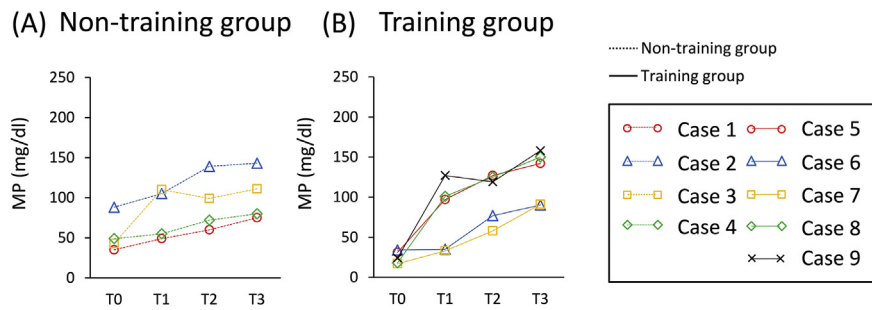


**Figure 2** (A) Individual values of the masticatory performance (MP) for each group at Pre and T3. (B) Changes in the MP from Pre to T3. Data are the mean ± standard deviation. Shadow area indicates the mean ± standard deviation of the control group. \*:  $p < 0.05$ , compared with the non-training and training groups (by Mann–Whitney U test).

first study to assess the effect of a masticatory exercise using training food on patients immediately after orthognathic surgery.

Patients with mandibular prognathism have more negative overjet just before orthognathic surgery by a preoperative orthodontic treatment, compared to those before preoperative orthodontic treatment, and they acquire a normal occlusion by mandibular setback surgery. Patients with skeletal mandibular prognathism are subject to lower bite force and less occlusal contact area than those with normal occlusion even at the beginning of treatment, but preoperatively, the bite force and occlusal contact area are even lower. It is known that masticatory functions more decrease just after orthognathic surgery than those at pre-surgery due to the surgical stress, even though the occlusion is corrected.<sup>6,20–23</sup> As for the postoperative changes, Phillips et al.<sup>20</sup> described the effects of the postsurgical recovery process on the stand points of patients’ quality of

life. Postsurgical sequelae resolved within 7 days after surgery, and most patients resumed their usual activities (i.e., sleeping, routine, and social activities) within 30 days. On the other hand, problems with oral function required longer to recover, and 15% of the patients had difficulty with oral function 2 months after surgery. Iwase et al.<sup>6</sup> reported that the recovery of masticatory efficacy after orthognathic surgery required 3 months, and that there was a weak correlation between masticatory efficiency and bite force.<sup>6</sup> However, the ordinary convalescence after orthognathic surgery appears to be insufficient clinically because the postsurgical recovery of the body weight of the patients required 6 months.<sup>7</sup> Weight loss after orthognathic surgery is a serious problem, since poor nutrition plays an important role in the development of postoperative complications.<sup>24</sup> The nutritional deficiency after surgery causes fat and weight loss, which may lead to poor wound healing and recovery.<sup>21</sup> Thus, postsurgical



**Figure 3** The time-series change in the masticatory performance (MP) of the training (A) and non-training groups (B) from T0 to T3.

**Table 2** Two-way repeated measures ANOVA for the masticatory performance (MP).

	df	Mean square	F	P
Total variation	35			
Inter-individual factor	1	3.61	0.001	0.97
Experimental individual factor	7	3002.91		
Intra-individual factor	3	10 002.55	33.99	<0.01
Interaction term	3	1101.55	3.74	0.03
Error	21	294.31		

df: Degrees of freedom, Total variation = inter-individual factor + experimental individual factor + intra-individual factor + interaction term + error.

masticatory problems may lead to nutrient deficiency and problems with wound healing. Therefore, the establishment of a novel rehabilitation program is indispensable for the early recovery of masticatory function after orthognathic surgery in jaw deformity patients.

Physiotherapy has been reported as an option for the rehabilitation of patients with jaw deformities after surgery, and its effectiveness in early recovery has been proven.<sup>8–13</sup> However, since mastication consists of complicated jaw movements, stretching exercises alone cannot satisfactorily improve masticatory ability. Thus, rehabilitation based on masticatory exercises using training food is preferable. Functional training using a gum-chewing exercise after orthognathic surgery has been reported previously.<sup>25</sup> However, in that study, the gum-chewing exercise was used to improve the masticatory function in jaw deformity patients close to the levels observed in healthy individuals, not for recovery of postoperative hypofunction.

The requirements for training food include an appropriate texture for effective training as well as safety during training. In other words, the training food should be prepared such that it does not cause aspiration during swallowing in patients with functional problems. In this study, we used a commercially available masticatory training food. The usefulness of this training food for dysphagia rehabilitation in the elderly has been recognized.<sup>14</sup> During mastication, this training food forms an easy-to-swallow food mass with a texture similar to that of masticated normal food when swallowed. The hardness and texture of the food are considered to be adequate for patients to masticate and form food boluses 10 days after orthognathic surgery. Patients who undergo orthognathic

surgery are initially put on a liquid diet and introduced to harder foods gradually.<sup>26</sup> For such patients, masticatory exercises using excessively hard food should be avoided for at least 4 months after surgery, because premature mastication of such tough foods may result in inadequate bone healing.<sup>26</sup>

Postoperative problems in masticatory function are attributable to both surgical stress and inadequate adaptation to the corrected occlusion. The rehabilitation program with masticatory exercise using the training food described in the present study appears to promote adaptation to the postoperative occlusion. In this study, when the training effect was evaluated at preoperative and 3 months postoperative, a significant difference in the MP was obtained between the training and the non-training groups (Fig. 2B, Table 1). Therefore, we evaluated the temporal changes of the MP in both groups (Fig. 3A and B). As a result, a significant interaction between postoperative training and time was found (Table 2). This result acknowledges the training effect over time because of the interaction terms. However, it cannot prove the training effect at 3 months postoperatively, and suggests that the effectiveness of the training effect by training foods may be shown by further increasing the follow-up period to 4 and 5 months in the future. From the individual data, it can be inferred that the training effect was also affected by the fact that the training group recovered step by step from the decline in masticatory ability after surgery, while the non-training group showed generally smaller recovery after 2 months following surgery compared to the training group. In addition, it can be considered that the training group started to actively take various foods in their daily life as a side effect of the early mastication training, which resulted in the difference in the effect. However, if the influence of food intake in daily life is also considered, it will be necessary to consider other evaluations such as food intake status in order to evaluate the pure training effect in the future.

However, our study has a number of limitations. Firstly, the results of this study showed that although there was a significant difference in the MP between Pre and T3, no significant difference was found in the MBF. This suggests that the training food used in this study was soft in texture and did not affect the isometric contraction of the masticatory muscles. In other words, since the food for masticatory training in this study can be swallowed only by masticatory movement, we think that the training had the effect on isotonic contraction but not isometric contraction caused by MBF. Therefore, in the future, it will be

necessary to improve the training program according to the changes in recovery, such as increasing the hardness of food step by step and giving instructions to increase the number of chewing. Secondly, the masticatory function levels in patients with jaw deformities are also known to be lower than those in control participants even after surgical orthodontic treatment, and several years are required to improve them to the levels seen in control participants.<sup>1–5</sup> In the present study, the masticatory function of patients in both groups remained inferior to that of the control subjects even at 3 months after surgery. Therefore, although the training in this study may be effective in improving postoperative functional decline, further postoperative functional training protocols including early rehabilitation programs, for instance gum-exercise, are necessary to improve masticatory function in patients with jaw deformities. Finally, there is the limitation of a small sample size. To confirm the validity of results of the present study regarding the recovery amount of masticatory performance (Fig. 2B), power analysis was performed. According to the result of power analysis, a required sample size was 3.2 persons in each group, indicating that the sample size in the present result was appropriate. However, further investigations using much more samples are required to determine the optimal training program for postoperative patients with jaw deformities.

The patients with mandibular prognathism who performed the masticatory exercise after orthognathic surgery showed possibility to recover their MP early compared to those who did not performed the masticatory exercise. Thus, masticatory rehabilitation using training food might be a useful method for improving postoperative hypofunction in patients with jaw deformities.

## Declaration of competing interest

All authors state that there are no conflicts of interest to disclose.

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