



Changes in cross-sectional measurements of masseter, medial pterygoid muscles, ramus, condyle and occlusal force after bi-maxillary surgery

Akihiro Takayama, Koichiro Ueki*, Akinori Moroi, Takamitsu Tsutsui, Yuki Saito, Momoko Sato, Kunio Yoshizawa

Department of Oral and Maxillofacial Surgery, (Head: Prof. Dr. K Ueki), Division of Medicine, Interdisciplinary Graduate School, University of Yamanashi, 1110 Shimokato, Chuo-shi, Yamanashi, 409-3898, Japan



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ABSTRACT

Purpose: The purpose of this study was to examine changes in masseter and medial pterygoid muscles, ramus, condyle and occlusal force after bi-maxillary surgery in class II and III patients.

Subjects and methods: The subjects were 42 patients (84 sides) who underwent sagittal split ramus osteotomy with Le Fort I osteotomy (21 class II cases: mandibular advancement and 21 class III cases: mandibular setback). The cross-sectional measurements of the masseter and medial pterygoid muscles, ramus and condyle were measured in horizontal plane images by computed tomography (CT), before and 1 year after the operation. Occlusal force and contact area were also recorded before and 1 year after the operation.

Results: Preoperatively, class II was significantly larger than class III in masseter width ($P = 0.0068$), masseter area ($P < 0.0001$) and medial pterygoid length ($P < 0.0001$). However, class II was significantly smaller than class III in medial pterygoid width ($P < 0.0001$). After 1 year, class II was significantly smaller than class III in masseter length ($P = 0.0017$). Class II was still larger than class III in medial pterygoid area after 1 year ($P = 0.0343$). Class II was significantly larger than class III in condylar angle pre-operatively ($P < 0.0001$) and after 1 year ($P = 0.0006$). After 1 year, class II decreased significantly more than class III in condylar thickness ($P = 0.0020$), condylar width ($P < 0.0001$) and condylar area ($P < 0.0001$).

Conclusion: This study suggested that changes in the cross-sectional measurements of masseter and medial pterygoid muscles and the condyle differed between class II and class III patients, although occlusal force did not significantly change 1 year after surgery in both groups.

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1. Introduction

In orthognathic surgery, it is important to establish skeletal stability. Changes in skeletal stability and occlusion can induce changes in the masticatory force vectors and occlusal force.

The relationship between masticatory muscles and maxillofacial morphology has been studied. Many studies on facial growth pattern concluded that subjects with strong mandibular muscles have wider and shorter facial dimension (Benington et al., 1999; Chan et al., 2008; Hannam and Wood, 1989; Kitai et al., 2002;

Kubota et al., 1998). Furthermore, previous studies suggested that the cross-sectional area and thickness of masticatory muscles are significantly correlated with biting force and the properties of facial morphology (Ingervall, 1976; Ingervall and Bitsanis, 1987; Proffit and Fields, 1983; Ringqvist, 1973; Sassouni, 1969; Throckmorton et al., 2000).

The pterygo-masseter sling, consisting of masseter and medial pterygoid muscles, plays an important role in the masticatory function and can be strongly related to occlusal force (Hunt et al., 2006). As such, studies regarding the measurements of masseter and medial pterygoid muscles in patients with jaw deformity from the direction and cross-sectional images obtained by computed tomography (CT) and magnetic resonance imaging (MRI) have been

* Corresponding author. Fax: +81 55 273 8210.

E-mail address: kueki@yamanashi.ac.jp (K. Ueki).

reported (Beukes et al., 2013; Dicker et al., 2012; Dicker et al., 2015; Lee et al., 2012; Trawitzki et al., 2011; Zepa et al., 2009).

Several studies that dealt with occlusal force have reported that patients with jaw deformity have lower bite force value than normal occlusion subjects (Harada et al., 2000; Iwase et al., 2006; Ohkura et al., 2001; Throckmorton et al., 1996; Van Der Braber et al., 2006; Zarrinkelk et al., 1996).

However, only one study examined the relationship between cross sectional area of masseter and medial pterygoid muscles and realistic occlusal force in class III patients (Ueki et al., 2009). There is no study that describes both data of cross-sectional area of the masticatory muscles by CT and the realistic occlusal force in class II retrognathic patients, although the relationship between morphology and function is very important for integrating various information on how much muscle force reflects the occlusal force. Furthermore, when mechanical stress in the maxillo-facial region is assumed, condyle and ramus morphology should be included.

Therefore, the purpose of this study was to examine changes in masseter and medial pterygoid muscles, ramus, condyle and occlusal force after bi-maxillary surgery in class II and III patients.

2. Material and methods

The subjects consisted of 42 Japanese female patients (84 sides) with jaw deformities diagnosed as skeletal classes II and III, to exclude the gender difference. This was a retrospective factorial cohort study and informed consent was obtained from the patients.

Conventional lateral cephalometric measurements were analyzed pre- and post-operatively, according to previous reports (Iguchi et al., 2017; Ueki et al., 2017). All 42 patients underwent sagittal split ramus osteotomy with Le Fort I osteotomy. Twenty one class II cases were mandibular advancement and 21 class III cases were mandibular setback performed by the method reported previously (Ueki et al., 2017).

A high-speed, advantage-type CT generator (Aquilion One; Toshiba Medical Systems Corp, Tochigi, Japan) was used, similar to the method reported previously (Iguchi et al., 2017). CT measurements were performed using a similar method reported previously (Ueki et al., 2009). The RL line was determined as the line between the most anterior points of the bilateral auricles at the plane parallel to the FH plane. Multi planner reconstruction can be

established in the software such that the arbitrary plane can be moved parallel to the plane in which the RL line was determined. The horizontal plane above the mandibular foramen parallel to the FH plane was identified on the right and left sides, and the masseter and medial pterygoid muscles, and ramus were measured in each side preoperatively and at 1 year postoperative. Condyle was measured on each side in the plane parallel to FH where maximum area of the condyle was recognized (Simplant[®], Materialise, Leuven, Belgium) and (Image J[®], National Institutes of Health, ML, USA) the items listed below (Ueki et al., 2009).

- 1) Ramus area: Square of ramus
- 2) Ramus length: The distance between the most anterior point and most posterior point of the ramus
- 3) Ramus width: The thickest distance of the ramus parallel to the RL line
- 4) Masseter area: Square of masseter muscle
- 5) Masseter length: The distance between the most anterior point and most posterior point of the masseter muscle
- 6) Masseter width: The thickest distance of the masseter muscle parallel to the RL line
- 7) Medial pterygoid area
- 8) Medial pterygoid length
- 9) Medial pterygoid width
- 10) Condylar angle: the angle between the LR line and the line of the most medial point and most lateral point of the condyle
- 11) Condylar thickness: the thickest distance perpendicular to the condylar length in the plane parallel to FH where maximum area of condyle was recognized
- 12) Condylar width: The distance between the most medial point and most lateral point of the condyle
- 13) Condylar area: Area of condyle in the plane parallel to FH where maximum area of condyle was recognized
- 14) Masseter vertical length: The distance between the gonion point and the most superior point on the coronoid process on the 2 dimensional lateral view in each side, from the reconstructed 3D image.
- 15) Masseter direction angle: The angle between the masseter vertical length line and the FH plane on the 2 dimensional lateral view in each side, from the reconstructed 3D image (Figs. 1 and 2).

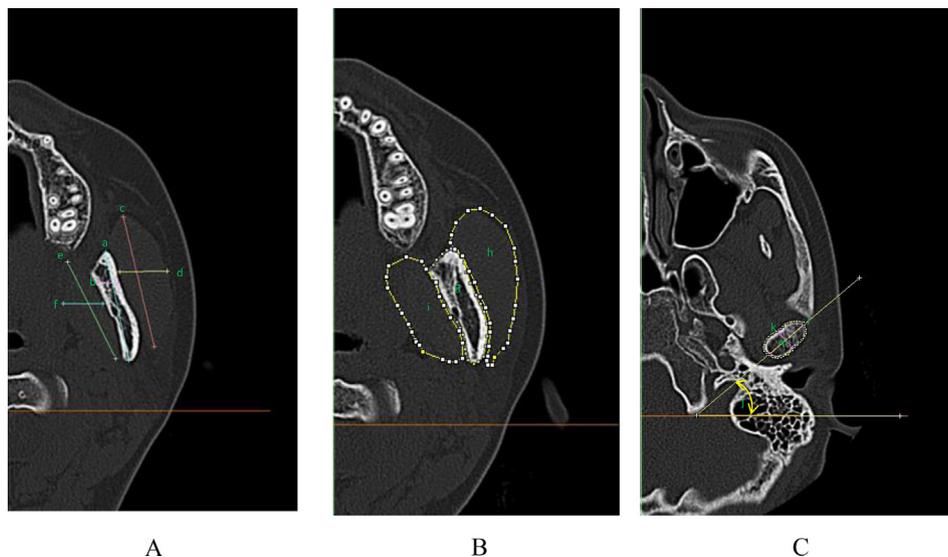


Fig. 1. Horizontal CT image of ramus and condyle. A: a) Ramus length, b) Ramus width, c) Masseter length, d) Masseter width, e) Medial pterygoid length, f) Medial pterygoid width, B: g) Ramus area, h) Masseter area, i) Medial pterygoid area, C: j) Condylar angle, k) Condylar thickness, l) Condylar width, m) Condylar area.

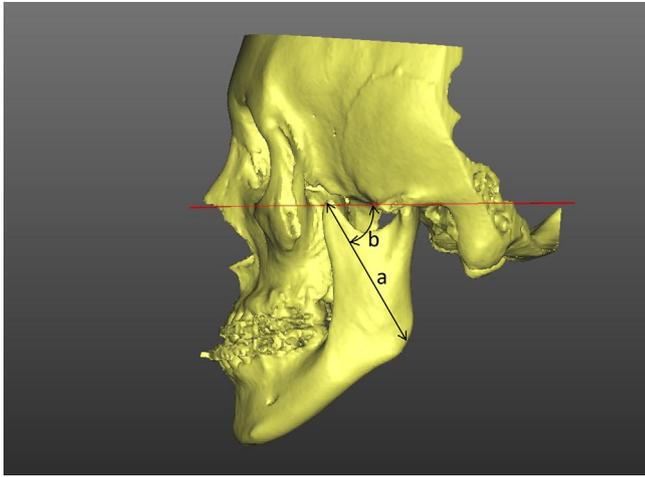


Fig. 2. Lateral view of the 3D-CT. a) Masseter vertical length, b) Masseter angle direction.

Furthermore, occlusal force and contact area were recorded preoperatively and at 1 year post-operatively, using the Dental Prescale System[®] according to a previous study (Ueki et al., 2009).

2.1. Statistical analysis

Pre-operative and post-operative values were compared by a paired t-test, and the comparison between classes II and III was performed using a non-paired t-test with SPSS (SPSS Japan Inc., Tokyo, Japan). Differences were considered significant at $p < 0.05$.

3. Results

3.1. CT measurements

In class III, ramus area ($P < 0.0001$), ramus length ($P = 0.0054$), ramus width ($P < 0.0001$), masseter length ($P = 0.0122$), med pterygoid area ($P = 0.0021$) and med pterygoid length ($P = 0.0092$) increased significantly after 1 year. In class II, the area ($P = 0.0003$) and width of the masseter muscle ($P < 0.0001$) decreased significantly, while ramus length ($P = 0.0171$), masseter length ($P = 0.0107$) and med pterygoid width ($P < 0.0001$) increased significantly after 1 year (Table 1).

Preoperatively, class II was significantly larger than class III in ramus area ($P = 0.0050$), ramus width ($P = 0.0089$), masseter width ($P = 0.0068$), med pterygoid area ($P < 0.0001$) and med pterygoid length ($P < 0.0001$). However, class II was significantly smaller than class III in med pterygoid width ($P < 0.0001$). After 1 year, class II was significantly smaller than class III in the length of masseter

muscle ($P = 0.0017$). Class II remained larger than class III in ramus width ($P = 0.0408$), and the square of medial pterygoid muscle after 1 year ($P = 0.0343$) (Table 1).

In class III, condylar area ($P = 0.0181$) and masseter vertical length ($P = 0.0001$) increased significantly after 1 year. However, there was no difference in the condylar angle, thickness and width. In contrast, in class II, condylar angle ($P = 0.0369$), condylar width ($P = 0.0001$), and masseter vertical length ($P = 0.0191$) decreased significantly after 1 year (Table 2).

Class II was significantly larger than class III in condylar angle pre-operatively ($P < 0.0001$) and after 1 year ($P = 0.0006$), and class II was significantly smaller than class III in masseter direction angle pre-operatively ($P < 0.0001$) and after 1 year ($P = 0.0006$). After 1 year, class II was significantly smaller than class III in condylar thickness ($P = 0.0020$), condylar width ($P < 0.0001$), and condylar area ($P < 0.0001$). After 1 year, class II was significantly larger than class III in masseter vertical length ($P = 0.0005$), although there was no significant difference between classes II and III pre-operatively (Table 2).

3.2. Cephalometric analysis

There were significant differences between classes II and III in SNB ($P < 0.0001$), Mandibular plane angle ($P = 0.0007$), and Overjet ($P < 0.0001$), pre-operatively. There were significant differences between classes II and III in SNB post-operatively ($P = 0.0142$) (Table 3).

3.3. Occlusal force and contact area

There was no significant difference between pre- and post-operative values in both classes II and III. Furthermore, there was no significant difference between classes II and III preoperatively and at 1 year post-operative (Table 3).

4. Discussion

When mechanical stress in the maxillo-facial region is calculated using a mathematical model, the force generated by the masticatory muscles, occlusal force and stress on the condyle are required in order to determine the equations. Although stress on the condyle and masticatory muscle force cannot be measured directly, occlusal force alone can be measured directly with a device. Therefore, it is very important to integrate the morphological data such as masseter and medial pterygoid muscles, ramus and condyle and the functional data such as occlusal force before and after orthognathic surgery.

Many studies using the Dental Prescale System[®] (Fujifilm Corp., Tokyo Japan) or T Scan System (Iwase et al., 2006) that have evaluated the change of occlusal force and contact are on class III mandibular prognathism patients before and after orthognathic

Table 1
Result of CT measurements in ramus region.

			Ramus area (cm ²)	Ramus length (mm)	Ramus width (mm)	Masseter area (cm ²)	Masseter length (mm)	Masseter width (mm)	Med. pterygoid area (cm ²)	Med. pterygoid length (mm)	Med. pterygoid width (mm)
Class III	Pre-operation	Mean	2.3 ^{a,c}	28.1 ^a	9.6 ^{a,c}	3.4	36.2 ^a	10.3 ^c	2.5 ^{a,c}	24.4 ^{a,c}	12.5 ^c
		SD	0.4	3.2	1.5	0.4	3.3	1.6	0.3	1.7	1.5
	After 1 year	Mean	2.7 ^a	26.7 ^a	11.7 ^{a,d}	3.6	38.0 ^{a,d}	10.1	2.7 ^{a,d}	26.0 ^a	12.1
		SD	0.4	3.9	1.8	1.2	4.0	1.4	0.5	3.6	1.5
Class II	Pre-operation	Mean	2.6 ^c	27.3 ^b	10.5 ^c	3.6 ^b	34.6 ^b	11.3 ^{b,c}	3.0 ^c	27.0 ^c	11.2 ^{b,c}
		SD	0.4	3.2	1.7	0.5	4.0	1.7	0.4	2.9	1.2
	After 1 year	Mean	2.6	28.1 ^b	10.9 ^d	3.4 ^b	35.4 ^{b,d}	9.7 ^b	2.9 ^d	27.3	12.3 ^b
		SD	0.4	3.4	1.3	0.5	3.2	1.3	0.4	2.8	1.6

SD indicates standard deviation. Same letters indicate a significant difference at $P < 0.05$.

Table 2
Result of CT measurement in the condyle and lateral view.

			Condylar angle (Degree)	Condylar thickness (mm)	Condylar width (mm)	Condylar area (cm ²)	Masseter vertical length (mm)	Masseter direction angle (Degree)
Class III	Pre-operation	Mean	19.5 ^c	6.9	16.6	1.2 ^a	64.5 ^a	69.2 ^c
		SD	7.5	0.9	1.6	0.2	6.3	7.3
	After 1 year	Mean	19.7 ^d	7.1 ^d	16.8 ^d	1.2 ^{a,d}	59.6 ^{a,d}	69.8 ^d
		SD	7.0	1.1	2.1	0.2	4.9	7.2
Class II	Pre-operation	Mean	30.8 ^{b,c}	6.8	15.6 ^b	1.0	65.9 ^b	64.1 ^c
		SD	11.3	4.9	2.2	0.3	5.4	5.9
	After 1 year	Mean	27.3 ^{b,d}	6.0 ^d	14.7 ^{b,d}	1.0 ^d	64.1 ^{b,d}	65.3 ^d
		SD	11.9	1.9	2.2	0.3	6.3	4.0

SD indicates standard deviation. Same letters indicate a significant difference at $P < 0.05$.

Table 3
Result of cephalometric analysis and occlusal force.

			SNA (degree)	SNB (degree)	Mandibular plane angle (Degree)	Gonial angle (Degree)	Overjet (mm)	Overbite (mm)	Occlusal Force (N)	Contact Area (mm ²)
Class III	Pre-operation	Mean	81.5	82.6 ^{a,c}	32.7 ^c	131.0	-3.6 ^{a,c}	-1.5 ^a	310.8	6.8
		SD	3.0	3.6	6.5	7.3	3.7	2.8	221.3	5.4
	1 year after	Mean	80.9	79.7 ^{a,d}	33.4	129.4	2.8 ^a	1.0 ^a	250.1	5.1
		SD	5.4	4.7	9.3	8.9	1.2	0.9	128.8	2.9
Class II	Pre-operation	Mean	81.7	75.1 ^c	38.8 ^c	128.5	6.5 ^{b,c}	-2.7 ^b	225.4	5.0
		SD	3.5	3.0	4.7	6.5	3.0	3.7	145.2	3.5
	1 year after	Mean	80.7	75.9 ^d	38.1	130.1	2.6 ^b	0.9 ^b	233.7	4.9
		SD	5.4	5.1	8.5	7.5	1.2	0.8	99.7	2.3

SD indicates standard deviation. Same letters indicate a significant difference at $P < 0.05$.

surgery. The reason for that is treatment for class III patients predominates in Japan and South Korea (Choi et al., 2014; Harada et al., 2003; Iwase et al., 1998; Iwase et al., 2006; Nakata et al., 2007; Kato et al., 2012; Nagai et al., 2001; Ueki et al., 2007; Ueki et al., 2009; Yamashita et al., 2007; Yamashita et al., 2011). The Dental Prescale System[®] can measure occlusal force and contact area at maximum intercuspation by the whole maxillo-mandibular dentition with pressure sensitive sheets and a computer analysis. The previous studies have suggested similar trends in the occlusal force after orthognathic surgery. In that, immediately after surgery, occlusal force decreased to minimal values. By 8 weeks to 6 months after surgery, occlusal force improved, and recovered or exceeded the pre-operative values. By 2 years post-surgery, occlusal force continues to increase, however it does not reach that of the controls (Choi et al., 2014; Iwase et al., 2006; Nakata et al., 2007; Yamashita et al., 2011). By 3–4 years post-surgery, occlusal force can reach the control levels (Ohkura et al., 2001; Yamashita et al., 2011).

On the other hand, there is no report on the measurement of occlusal force at the maximum intercuspation using pressure sensitive sheets after orthognathic surgery for class II mandibular retrognathic patients. Moreover, studies on occlusal force in the retrognathic patients are fewer, compared with those on prognathic patients. Zarrinkelk et al. (1996) measured bite force at eight tooth positions using a dual-arm bite transducer with tapered ends. Throckmorton and Ellis (2001) reported that unilateral isometric bite force measurements were made using a bite force transducer with ends covered with polypropylene tubing and opened to 15 mm. They suggested that bite force increased significantly after surgery, approaching normal values within 2 years. Van den Braber et al. (2004, 2006) measured bite force using a bite fork with 2 force transducers in each side, and concluded that surgical correction of mandibular retrognathism improved bite force after 5 surgeries, but it remained impaired when compared with controls. Trawitzki et al. (2011) evaluated maximal isometric bite force using a digital gnathodynamometer, and suggested that there was no significant difference in the maximal isometric bite force between classes II and III. However, these devices cannot measure occlusal force at

maximum intercuspation, at one time. Therefore, these data of retrognathism patients could not be compared with the data that dealt with occlusal force of mandibular prognathism cases using the Dental Prescale System[®]. Since the results of this study are values of measurements performed by the Dental Prescale System[®] for retrognathism class II patients, comparison between classes II and III could be done objectively.

Some studies that evaluated the cross-sectional morphology of masticatory muscles in class III patients before and after orthognathic surgery have been reported (Katsumata et al., 2004; Lee et al., 2012; Trawitzki et al., 2011; Ueki et al., 2009), however only a few studies in class II patients could be found (Dicker et al., 2007; Zepa et al., 2009). Katsumata et al. (2004) reported that 3 months after surgery there was a significant reduction in the trans-sectional area of the masseter, and it tended to return to the pre-operative values after 6 months to 1 year, with CT. Trawitzki et al. (2011) concluded that masseter muscle thickness increased significantly after 3 years in class III patients as revealed by ultrasonographic evaluation. The study on class II mandibular advancement surgery by Dicker et al. (2007) showed that there was a significant reduction in the cross-sectional area and volume of the masseter and medial pterygoid muscles based on a magnetic resonance image (MRI) evaluation after advancement bilateral SSRO in both patients with a short and long face. Zepa et al. (2009) assessed three-dimensional musculoskeletal features in both class II and III patients with MRI and CT, and showed that all mandibular and medial pterygoid measurements were higher in class III, and that all masseter variables were higher in class III.

In our previous retrospective longitudinal study that evaluated both the morphology and function (masticatory muscle and occlusal force) in class III patients with CT, we reported that masseter muscle area did not change, but occlusal force increased and there were positive correlations between occlusal force and masseter width, and contact area and masseter width pre-operative, even though there was no difference after 1 year (Ueki et al., 2009). This further study has an advantage that masticatory muscle including masseter and medial pterygoid muscles and

ramus and condyle and occlusal force are measured longitudinally for both class II and III patients.

The results of cephalometric analysis showed that distribution of the two groups was valid and that the skeletal morphology in class II and III patients could be altered accurately by orthognathic surgery.

In this study, post-operative increase in ramus area and width, post-operative decrease in ramus length that was found after class III setback surgery, and post-operative increase in ramus length that was found in class II advancement surgery were consistent with the findings in our previous study (Ueki et al., 2018). Regarding masticatory muscles, masseter area and length showed a tendency of increase after 1 year post-surgery in the class III patients; however masseter area and width decreased after 1 year in the class II patients. Medial pterygoid area and length increased after 1 year in the class III patients, and medial pterygoid area showed a decrease tendency in the class II patients. However, medial pterygoid width increased after 1 year while masseter width decreased in the class II patients. The change in ramus length seemed to reflect the changes in masseter and medial pterygoid lengths in both class II and III patients. The change in ramus area also seemed to reflect the changes in masseter and medial pterygoid area in the class III patients. However, masseter and medial pterygoid areas showed a decreased tendency, in spite of a slight increase in ramus area in class II. These findings suggested that there were differences in the post-operative change in masseter and medial pterygoid muscles between advancement and setback surgeries.

Regarding cross-sectional measurement of the condyle, condylar horizontal angle in class II is known to be larger than that in class III (Fernandez Sanroman et al., 1998). This study also showed a similar tendency. Post-operative increase in change of the condylar angle in class II suggested that inference between the posterior site of the distal segment and anterior site of the proximal segment was one of the causes. However, the post-operative condylar angle in class II came closer to the condylar angle of the normal skeletal and occlusion. Condylar area increased after 1 year in the class III patients, in contrast, condylar thickness and width and area decreased 1 year after surgery in class II. This suggested that condylar resorption or volume reduction of condyle occurred in the class II patients. A previous study showed that condylar square on the lateral view significantly decreased after 1 year post-surgery in both classes II and III, however, the incidence ratio of reduction was larger in class II (Iguchi et al., 2017). Significant decreases in masseter vertical length in both classes II and III suggested shortening of the ramus after surgery. These causes might be ramus height reduction by condylar resorption or volume reduction in class II, and by setback including ramus area in class III. The difference in masseter direction angle suggested that the proximal segment of class III rotated clockwise and that of class II rotated counter-clockwise. When the findings were summarized, height of condyle was considered to have decreased and condylar area increased after surgery in class III, while both condylar height and area decreased in class II. The post-operative increase in condylar area in class III might be an adaptive change to compensate for the condylar height reduction. On the other hand, occlusal force and contact area did not change significantly after 1 year in both classes II and III in this study. Furthermore, there were no significant correlations between the cross-sectional measurements of masticatory muscles and occlusal force. Therefore, this study could not prove whether the increase in the mechanical stress on the condyle was a causal factor of the condylar resorption or volume reduction. Although the force on the condyle and disc might increase in early period after surgery, it was considered that the occlusal force could not be related to the force in the TMJ. Otherwise, condylar

resorption might not be caused by this mechanism. However, larger sample sizes of class II and III with a long-term follow up period will be necessary to obtain much more information.

5. Conclusion

This study suggested that changes in the cross-sectional measurements of masseter and medial pterygoid muscles and the condyle differed between the class II and class III patients. However, occlusal force did not change significantly 1 year after surgery in both groups.

Ethical approval

This study was performed according to the Declaration of Helsinki, and was approved by the Ethical committee of the University of Yamanashi.

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None.

Conflicts of interest

None declared.

Offprint request

Not required.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jcms.2018.11.036>.

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