1. Title

Comparison of bite force and occlusal contact area between the deviated and non-deviated sides after intraoral vertical ramus osteotomy in skeletal Class III patients with mandibular asymmetry: two-year follow-up

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ABSTRACT

Objectives: The objectives of this study were to compare the time-dependent changes in occlusal contact area (OCA) and the bite force (BF) between deviated side and non-deviated side in mandibular prognathic patients with mandibular asymmetry before and after orthognathic surgery, and to investigate the factors associated with the changes in OCA and BF on each side. **Methods**: The sample consisted of 66 patients (32 men and 34 women; range 15-36 years) with facial asymmetry who underwent 2-jaw orthognathic surgery. OCA and BF were taken before presurgical orthodontic treatment, within 1 month before surgery, and at 1 month, 3 months, 6 months, 1 year, and 2 years after surgery. OCA and BF were measured using the Dental Prescale System. **Results**: The OCA and BF decreased gradually before surgery and then increased after surgery on both sides. The OCA and BF were significantly larger on the deviated side than on the non-deviated side before surgery, and there was no difference after surgery. According to the linear mixed-effect model, only the changes in the mandibular plane angle showed a significant effect on the OCA and BF ($p<0.05$). **Conclusions**: There was a difference in the amount of the OCA and BF between the deviated and non-deviated sides before surgery. The change in mandibular plane angle affects the change, especially on the non-deviated side, during the observation period.

Keywords: Asymmetry, Class III orthognathic surgery, bite force, occlusal contact area

INTRODUCTION

Facial asymmetry can cause esthetic and functional problems in patients in the form of dentofacial deformity. Therefore, patients with facial asymmetry seek orthognathic surgery.[1,2] Baily et al.[1] reported that more than one-third of the patients who visited the Dentofacial Clinic of the University of North Carolina had facial asymmetry. Anistoroaei et al.[3] investigated the prevalence of facial asymmetry in orthodontic clinics before treatment and found that 13.8% of the patients had facial asymmetry. Facial symmetry occurs in the order of the chin area (74 %–75%), the midface (36%), and the upper face (5%).[1,2] Growth modification, orthodontic treatment, and orthognathic surgery are the alternative treatments for facial asymmetry. The treatment method was selected based on the patient's age and the severity of the deformity.

The objectives of orthognathic surgery are to improve jaw function and enhance facial appearance. It is difficult to evaluate the jaw function quantitatively. Currently, a simple method using a thin pressure-sensitive sheet is widely used to measure the occlusal contact area (OCA) and bite force (BF). Since the launch of the device, many studies have been conducted to observe the changes in OCA and BF as an evaluation index of masticatory efficiency before and after orthognathic surgery in patients with mandibular prognathism.[4-18] The typical results of several previous studies were as follows: (1) the OCA and BF were improved after surgery; (2) the absolute values of the OCA and BF after surgery were still lower than those of the control group.[7,8,10,11,13,17,18] The above studies were conducted on patients with facial symmetry, and few studies have observed the difference between deviated and non-deviated sides in those with asymmetry. Goto et al.[15] carried out a study in patients with skeletal asymmetry to investigate masticatory function differences between the deviated and non-deviated sides. They also compared the parameters in the asymmetry group with those in the symmetric control group. They found that OCA and BF were greater on the deviated side than on the non-deviated side. Both the OCA and BF were smaller in the patient group than in the control group. Moroi et al.[19] compared the postoperative changes between asymmetric and symmetric groups. Both groups showed postoperative improvement in the OCA and BF. These studies did not compare the differences between the deviated and non-deviated sides.

The objectives of this study were as follows: (1) to observe the time-dependent changes in OCA and BF on the deviated and non-deviated sides in mandibular prognathic patients with mandibular asymmetry, and (2) to investigate the factors associated with the changes in OCA and BF on each side. The first hypothesis was that there would be no difference in the OCA and BF between the deviated and non-deviated sides in all observation periods. The second hypothesis is that no skeletal variables affect the time-dependent changes in OCA and BF between the deviated and non-deviated sides.

MATERIALS AND METHODS

Subjects

The study sample was selected from patients diagnosed with skeletal Class III malocclusion and who visited Gangnam Severance Dental Hospital for orthognathic surgery. A posteroanterior cephalogram was used to divide the study samples. Patients whose chin deviated by more than 3 mm from the midline were deemed to have facial asymmetry. Additional inclusion criteria were the absence of previous orthodontic treatment, missing teeth except for the third molars, temporomandibular disorder, systemic diseases, cleft lip and palate, and craniofacial deformity. The sample consisted of 66 patients (32 men and 34 women; range 15-36 years) with facial asymmetry. The completion of the mandibular growth was confirmed by hand-wrist X-ray film. This prospective study was approved by the Gangnam Severance Hospital Institutional Review Board (No. 3-2015-0196), and all participants signed an informed consent agreement.

The pre- and post-surgical orthodontic treatments were performed with fixed appliances and performed by one orthodontist in the same hospital. Orthognathic surgery was performed by a single surgeon. The patients underwent intraoral vertical ramus osteotomy (IVRO) with Le Fort I osteotomy. The duration of maxillomandibular fixation (MMF) was approximately 2 weeks. The duration of the pre- and post-surgical orthodontics were 11.4 months (range 9.2-15.5 months) and 7.6 months (range 5.3-12.8 months), respectively.

Measurements

Lateral and posteroanterior cephalograms were taken before surgery (T0), 1 month (T2), and 2 years after surgery (T6) for skeletal analysis. OCA and BF were taken before presurgical orthodontic treatment (T0), within 1 month before surgery (T1), at 1 month (T2), 3 months (T3), 6 months (T4), 1 year (T5), and 2 years (T6) after surgery. OCA and BF were measured using the Dental Prescale System (FujiFilm Corp., Tokyo, Japan) (Figure 1). The device consists of a pressure-sensitive sheet and an analysis apparatus (Occluzer FPD-707). The accuracy and reliability of this device have been examined in previous studies.[12,16,20] Before recording the measurements, all subjects were seated upright in an unsupported headrest and practiced clenching in the intercuspal position. The pressure-sensitive sheet was placed between the maxillary and mandibular teeth, and the center of the sheet coincided with the facial midline. The patient was instructed to bite the sheet forcefully during maximum intercuspation for 5 seconds. The sheets were scanned and analyzed using an analysis apparatus. The maximum occlusal pressure (unit, MPa), average occlusal pressure (unit, MPa), OCA (unit, mm^2), and BF (unit, Newton) were displayed on the screen. The scanning procedures were performed by one examiner. Twenty sheets were randomly selected and re-analyzed by the same examiner at 2-week intervals. An Intra-examiner error was evaluated using the intraclass correlation coefficient (ICC). The ICC values for the OCA and BF (97 %–99%) indicated good intra-examiner reliability. At T0, each patient was tested twice, and a paired t-test was performed. As a result, there was no statistically significant difference ($P>0.05$); therefore, after the T1 period, each patient was tested once.

Statistical analysis

The measured data were described as means and standard errors. Lateral cephalometric measurements were performed at T0, T2, and T7 (Table 1). A linear mixed model (LLM) was applied to compare the measurements of OCA and BF over time. This method considers both within-subject and between-subject variabilities. The Bonferroni post hoc test was applied to correct for type I errors related to multiple comparisons. A linear mixed model with random intercept was fitted with participants as a random effect to test for significant changes in the measurements. Among several cephalometric measurements, changes in the mandibular plane angle, mandibular body length, and chin deviation were selected as variables. The paired t-test was used to compare the difference in the measured values of OCA and BF between the deviated side and non-deviated side at each time point, and the amount of change at each time point was also compared. The significance level was set at $p < 0.05$. SPSS software ver.25 (IBM Corp., Armonk, NY, USA) was used for all statistical analyses.

RESULTS

The chin deviation decreased after the surgery (Table 1). The OCA and BF decreased gradually before surgery and then increased after surgery on both sides. The OCA on both sides and the BF on the deviated side recovered to its initial state 2 years after surgery. Otherwise, the BF on the non-deviated side was restored to its original state 1 year after surgery, and thereafter, it was found to be increased (Table 2).

The OCA and BF were significantly larger on the deviated side than on the non-deviated side before surgery (T0), and the difference was more significant after pre-orthodontic treatment (T1). There was no difference after surgery (T2-T6) (Table 3, Figure 2).

The difference in change at each observation time point on the deviated and non-deviated was evaluated (Table 4, Figure 3). The patterns of change were similar for each side. Most changes were observed during the pre-surgical orthodontic period (T1-T0). The difference between the deviated and non-deviated sides was observed only at T2-T1. After surgery, there were many changes during the first 3 months (T3-T2), and after that, the amount of change decreased and gradually increased again (T6-T5) on both sides.

According to the linear mixed-effect model, the OCA and BF of both sides showed statistically significant differences ($p<0.0001$) at each time point. Only the changes in the mandibular plane angle (ΔSN to MP) showed a significant effect on the OCA and BF ($p<0.05$). The mandibular body length and the amount of chin deviation did not affect the OCA and BF ($p>0.05$). When comparing the deviated and non-deviated sides, the BF of the non-deviated side was more affected by the change in mandibular plane angle in the multivariable analysis (Table 5).

DISCUSSION

The OCA and BF decreased during the presurgical orthodontic period and 1 month after surgery, and gradually increased after surgery (Figure 2). The pattern of changes in OCA and BF over time was similar in the deviated and non-deviated sides. Many studies have reported time-dependent changes in the OCA and BF in patients undergoing orthognathic surgery. In all studies, the OCA and BF gradually decreased until 4-6 weeks post-surgical period and then steadily increased from 2-3 years after surgery, same with our findings.[7-9,11,13] Although the OCA and BF increased more than the initial level, the final values of the OCA and BF were still lower than that of the standard group like in previous studies.[5,13,17] The average OCA and BF in the Korean normal occlusion group were 24.2 ± 8.2 mm^2 and 744.5 ± 262.6 N, respectively.[20] Choi et al.[17] examined the OCA and BF in skeletal Class III patients who underwent orthognathic surgery. The patients showed smaller OCA and BF than the standard occlusion group before surgery and at the end of the observational period (2 years after surgery). The measured values were similar to those obtained in our study.

When comparing the deviated and non-deviated sides, the deviated side had a larger OCA and higher BF than the non-deviated side at T0 and T1, and no differences were observed after surgery (Figure 2). Goto et al.[15] reported that the occlusal balance shifted to the deviated side in patients with asymmetry. The causes of these differences may be due to the difference in the musculoskeletal system on each side and/or the difference in dental compensation pattern. However, they found that the morphology and orientation of the muscles did not show a linear correlation but a complex correlation with the BF.

Goto et al.[21] investigated the size and orientation of the masticatory muscles, such as the masseter, medial, and lateral pterygoid muscles in patients with mandibular asymmetry using magnetic resonance imaging. On the deviated side, the length of the masseter muscle was shorter, the volume was smaller, and it was placed more vertically in the frontal view and more forward directed in the sagittal view. The difference in the orientation and morphology of the muscles might cause different dental compensation on the deviated and non-deviated sides. After two-jaw orthognathic surgery, Lee and Yu[22] also evaluated the masseter muscle morphology by computed tomographic images in skeletal Class III patients with facial asymmetry. They found a difference in the muscle orientation but not in the thickness and width of the masseter muscles between the deviated and non-deviated sides before surgery. Muscle orientation was closely related to the position of the gonion and the zygomatic arch. Therefore, when skeletal asymmetry was corrected after surgery, the muscle orientation showed no difference between the two sides. Iodice et al.[23] performed a systematic review to investigate the association between unilateral posterior crossbite (UPCB) and muscle asymmetry. The papers, which used electromyography (EMG) to measure muscle activities, were selected. They found that the UPCB was related to asymmetric EMG activities of the masticatory muscles. However, it could not be concluded that there is a clear correlation between UPCB and skeletal asymmetry due to insufficient evidence.

More occlusal contacts on the deviated side could indicate that compensatory tooth movement was more evident on the deviated side than on the non-deviated side. Kim et al.[24] observed the pattern of dental compensation in patients with facial asymmetry and compared the deviated and non-deviated sides. There was more buccolingual tipping movement on the deviated side and more vertical changes on the non-deviated side. They explained that buccolingual dental compensation was related to the difference in the mandibular body length, and the vertical dental compensation was related to the ramus length and inclination difference. In addition, the more the menton deviated from the center, the more vertical extrusion appeared on the non-deviated side. Kim et al.[25] observed short-term changes in mandibular movement and chewing patterns in skeletal Class III adult patients with facial asymmetry. They found that the patients recovered their muscle activity and mandibular movement to their presurgical level 7–8 months after surgery. However, the asymmetric muscle activity between the deviated and non-deviated sides was maintained 7–8 months after surgery. Although this asymmetric muscle activity remained, it did not appear to have an asymmetric effect on the OCA and BF in our study.

The deviated side showed larger OCA and BF than the non-deviated side before surgery. The amount of change in OCA and BF was similar on both sides during the presurgical orthodontic period (T1-T0), but it increased significantly on the deviated side within 1 month before and 1 month after surgery (T2-T1), and there was no difference between the two sides 1 month after surgery. Muscle weakness and atrophy due to maxillomandibular fixation are thought to be the leading causes of this decrease in OCA and BF.[6] After two months, there was a large amount of change. Regional acceleratory phenomenon (RAP) could be one of the reasons for this change after surgery. The average duration of RAP on the bone is known to be 4-6 months.[26] In our study, the amount of change was large immediately after surgery and decreased after 3 months of surgery. The RAP might have lasted about 3 months in our samples.

The BF on the non-deviated side reached its original level 1 year after surgery and increased further thereafter, whereas the OCA and BF on the deviated side recovered to their initial level 2 years after surgery. Moroi et al.[19] had reported that the asymmetry group showed delayed recovery. The duration of BF recovery to the preoperative level is known to be within 3 months.[8,17,18] The magnitude of BF is positively correlated with the muscular environment, such as the thickness of the masseter muscle.[27] This result showed that muscular rehabilitation was slower in patients with facial asymmetry than in those with symmetry. It is inferred that muscular function was the major factor in recovering BF rather than OCA. Because BF recovers before OCA, it can be inferred that the BF by the muscle affects the occlusal seating.

In our study, the change in the mandibular plane angle (ΔSN-MP) only affected the time-dependent changes in BF among other skeletal variables, and it affected the non-deviated side more than the deviated side. This seems to be related to the fact that dental compensation occurs more vertically on the non-deviated side. No skeletal variables affected the time-dependent changes in OCA. This result was in accordance with previous studies showing that skeletal patterns were not the primary factor affecting BF.[17,20]

Based on these results, the first hypothesis was rejected that there would be no difference between the deviated and non-deviated sides during the entire observation period. There was a difference in the OCA and BF between the deviated and non-deviated sides before surgery. The second hypothesis was rejected. The change in mandibular plane angle affects the change, especially on the non-deviated side, during the observation period. There are several limitations to this study. First, the samples were not classified according to their vertical facial pattern. Previous studies have shown that vertical facial patterns are closely related to occlusal function.[28-30] In addition, the vertical facial pattern after surgery may also affect the OCA and BF. Second, the difference in the dental problems, such as crowding, spacing, between the deviated and non-deviated was not considered. The severity of dental problems could affect the rehabilitation of masticatory function.[30] In our study, the amount of arch length discrepancy (ALD) in the maxilla and mandible was 1.01 ± 2.32 mm and 1.12 ± 1.89 mm, respectively. Since it was not severe, the amount of ALD was not considered when selecting the sample. In the future, studies on patients with various skeletal patterns should be conducted. Besides, it is recommended to consider EMG to evaluate the role of the muscles.

CONCLUSION

There was no significant difference in the pattern of change in the OCA and BF between the deviated and non-deviated sides. The OCA and BF were larger on the deviated side than on the non-deviated side before surgery, and no differences were observed after surgery. There was a significant difference in the amount of change over time in the deviated and non-deviated sides only between 1 month before and after surgery. The BF on the non-deviated side recovered to its original state 1 year after the surgery, and the BF on the deviated side and OCA 2 years after surgery. The change in mandibular plane angle affected the time-dependent change in BF and the OCA.

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LEGENDS FOR ILLUSTRATIONS

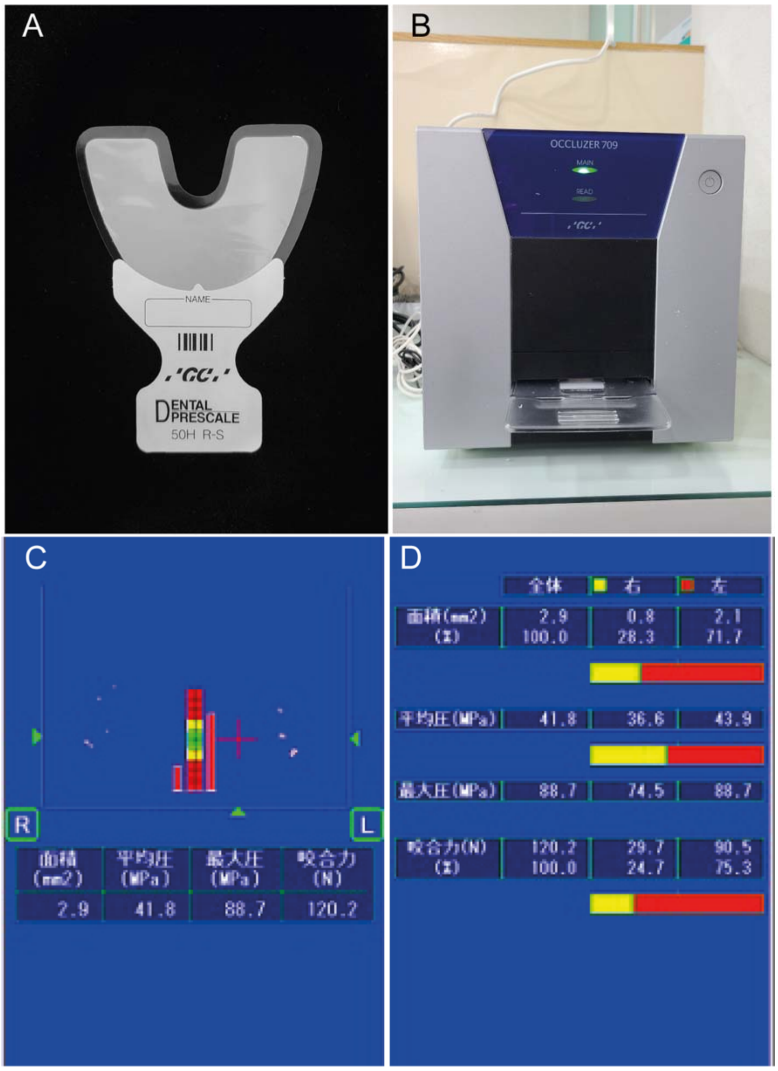


Figure 1. The Dental Prescale System (FujiFilm Corp., Tokyo, Japan) **A,** Pressure-sensitive sheet (50H, type R-L) **B,** The image scanner (Occluzer FPD-707) **C, D**, An example of the results of the bite force and occlusal contact area. The results are presented on the screen comparing the left and the right sides.

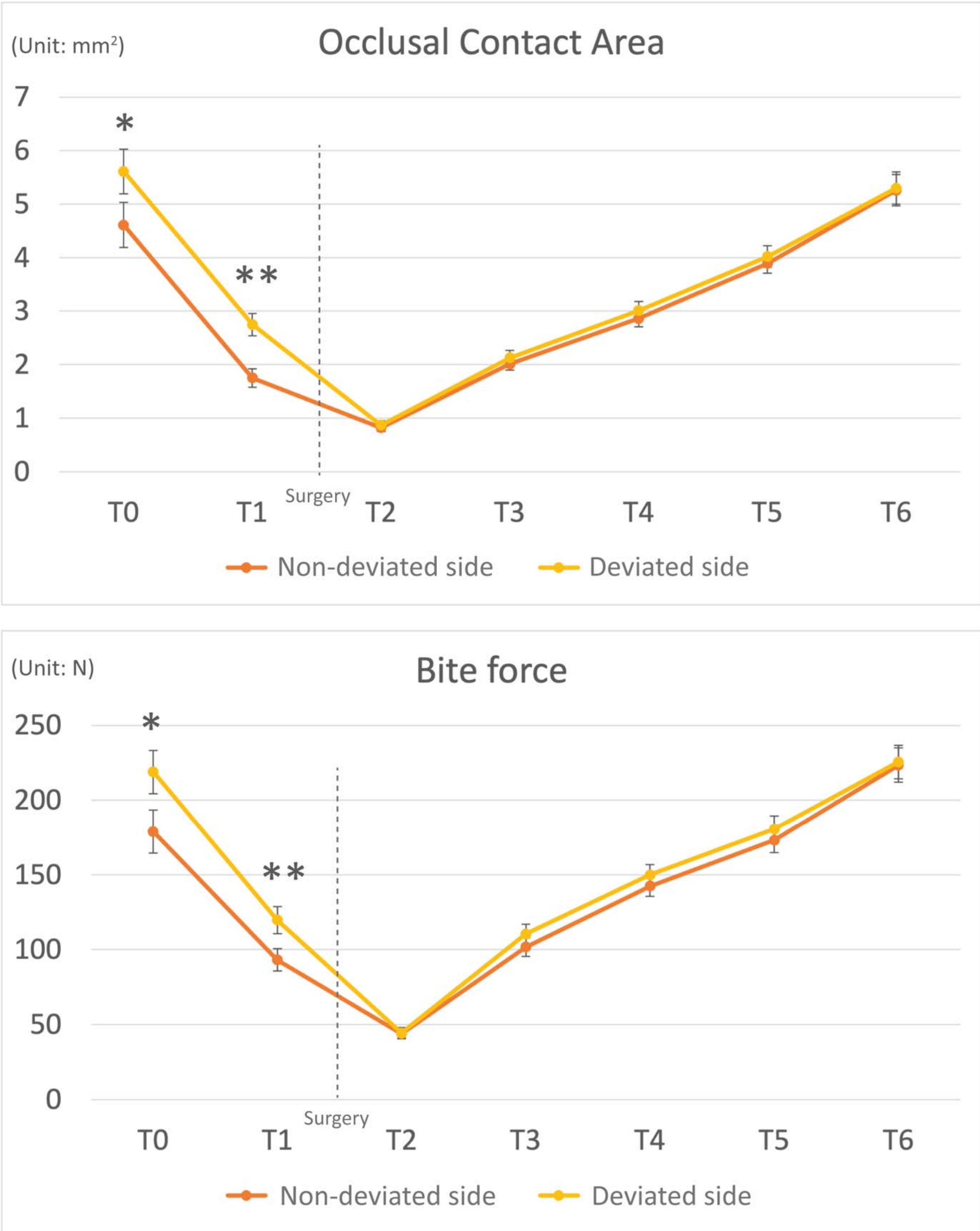
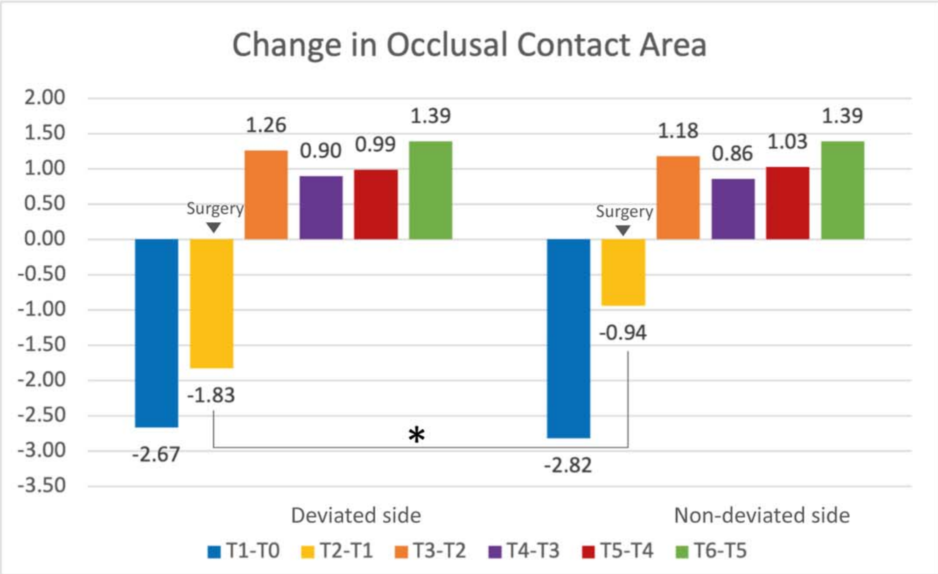


Figure 2. Comparison of the occlusal contact area and bite force between deviated side and non-deviated side at each time point.

T0, before starting orthodontic treatment; T1, 1 month pre-surgery; T2, T3, T4, T5, and T6 indicate 1, 3, 6, 12, and 24 months post-surgery, respectively. The dashed line indicates the time when surgery was performed. The vertical bars indicate the 95% confidence intervals. * $p<0.05$, ** $p<0.01$



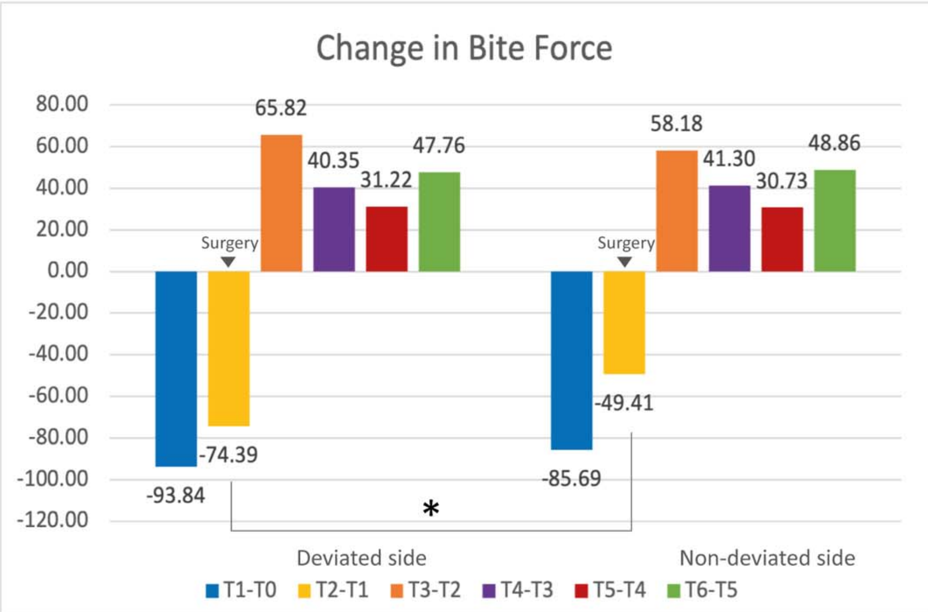


Figure 3. Comparison of the amount of change in occlusal contact area and bite force between deviated side and non-deviated side between each time point.
T0, before starting orthodontic treatment; T1, 1-month pre-surgery; T2, T3, T4, T5, and T6 indicate 1, 3, 6, 12, and 24 months post-surgery, respectively. The time indicated by an inverted triangle is when surgery is performed.
* $p<0.05$

Table 1. Cephalometric measurements of the study subjects.

	Time		
	T0	T2	T6
SNA (°)	81.3 ± 3.6	83.4 ± 4.0	83.0 ± 3.8
SNB (°)	85.5 ± 10.8	79.5 ± 3.9	79.1 ± 3.8
ANB (°)	-3.1 ± 2.6	3.9 ± 0.1	3.9 ± 0.1
SN to MP (°)	35.3 ± 5.9	37.2 ± 5.3	38.6 ± 6.0
Body length (mm)	80.5 ± 4.8	74.6 ± 4.1	73.0 ± 3.9
Chin deviation (mm)	6.0 ± 3.4	1.8 ± 0.8	2.0 ± 1.0

SNA, Sella-nasion-A point; SNA, Sella-nasion-B point; ANB, A point-Nasion-B point; SN, sella-nasion; MP, mandibular plane

Table 2. Time-dependent changes in the occlusal contact area and the bite force in deviated side and non-deviated side.

			T0	T1	T2	T3	T4	T5	T6	p-value†
Occlusal contact area (Unit: mm^2)	Deviated side	Mean (SE)	5.61 (0.24)	2.75 (0.25)	0.89 (0.24)	2.11 (0.24)	3.01 (0.24)	4.01 (0.24)	5.32 (0.25)	0.001
			A	BC	D	B	C	E	A	
	Non-deviated side	Mean (SE)	4.61 (0.22)	1.74 (0.23)	0.83 (0.22)	1.99 (0.22)	2.86 (0.22)	3.88 (0.22)	5.26 (0.24)	0.001
			AB	C	D	C	E	B	A	
Bite force (Unit: N)	Deviated side	Mean (SE)	219.02 (9.06)	119.67 (9.54)	44.50 (9.17)	109.71 (9.11)	150.02 (9.06)	180.40 (9.17)	225.53 (9.6)	0.001
			A	BC	D	B	CE	E	A	
	Non-deviated side	Mean (SE)	179.00 (8.71)	92.59 (9.18)	43.82 (8.82)	101.17 (8.76)	142.46 (8.71)	172.86 (8.82)	223.29 (9.25)	0.001
			A	B	C	B	D	AD	E	

† Comparison among the timing of different measurements for bite force and occlusal contact area with adjustment for age and sex, using a linear mixed model. The letters indicate the Bonferroni post hoc results, with the different letters representing statistically significant differences ($P<0.05$).

Table 3. Comparison of the occlusal contact area and bite force between deviated side and non-deviated side on each time point.

			T0	T1	T2	T3	T4	T5	T6
Occlusal contact area (Unit: mm^2)	Deviated side	Mean (SE)	5.61 (0.42)	2.75 (0.21)	0.87 (0.08)	2.13 (0.14)	3.01 (0.17)	4.02 (0.20)	5.30 (0.30)
	Non-deviated side	Mean (SE)	4.61 (0.42)	1.75 (0.17)	0.82 (0.07)	2.01 (0.11)	2.86 (0.15)	3.89 (0.18)	5.26 (0.29)
	p-value†		<0.05	<0.05	NS	NS	NS	NS	NS
Bite force (Unit: N)	Deviated side	Mean (SE)	218.92 (14.47)	119.82 (9.07)	44.44 (3.71)	110.51(6.57)	149.93 (7.01)	180.72 (8.84)	225.63 (11.20)
	Non-deviated side	Mean (SE)	178.99 (14.44)	93.16 (7.45)	43.93 (3.45)	101.79 (6.11)	142.46 (6.89)	173.19 (8.43)	223.48 (11.42)
	p-value†		<0.05	<0.05	NS	NS	NS	NS	NS

T0, before treatment; T1, within 1 month before surgery; T2, T3, T4, T5, T6 indicate 1, 3, 6, 12 and 24 months after surgery, respectively; SE, standard error; NS, not significant

† Comparison between the deviated side and non-deviated side for the occlusal contact area and bite force, using a paired t-test

Table 4. Comparison of the change of the occlusal contact area and bite force between deviated side and non-deviated side on each time point.

period			T1-T0	T2-T1	T3-T2	T4-T3	T5-T4	T6-T5
Occlusal contact area (Unit: mm^2)	Deviated side	Mean (SE)	-2.67 (0.38)	-1.83 (0.22)	1.26 (0.16)	0.90 (0.12)	0.99 (0.11)	1.39 (0.17)
	Non-deviated side	Mean (SE)	-2.82 (0.37)	-0.94 (0.19)	1.18 (0.11)	0.86 (0.11)	1.03 (0.11)	1.39 (0.17)
	p value		NS	<0.05	NS	NS	NS	NS
Bite force (Unit: N)	Deviated side	Mean (SE)	-93.84 (12.51)	-74.39 (9.45)	65.82 (6.28)	40.35 (5.7)	31.22 (6.19)	47.76 (9.82)
	Non-deviated side	Mean (SE)	-85.69 (12.52)	-49.61 (8.16)	58.18 (5.34)	41.30 (5.67)	30.73 (5.88)	48.86 (8.7)
	p value		NS	<0.05	NS	NS	NS	NS

T0, before treatment; T1, within 1 month before surgery; T2, T3, T4, T5, T6 indicate 1, 3, 6, 12 and 24 months after surgery, respectively; SE, standard error

† Comparison between the deviated side and non-deviatied side for the change of the occlusal contact area and bite force, using a paired t-test

Table 5. P-values for the correlation coefficients using linear mixed effect models showing factors affecting time-dependent changes in bite force and occlusal contact area.

Side	Variable	Bite force		Occlusal contat area	
		Univariable	Multivariable	Univariable	Multivariable
Deviated side	Occlusal contact area	<0.0001	<0.0001		
	Bite force			<0.0001	<0.0001
	Time	0.0002	<0.0001	0.0702	0.0001
	Sex	0.2717	0.2141	0.6594	0.2482
	Age	0.8673	0.2583	0.8752	0.4184
	Chin deviation	0.2143	0.1882	0.5791	0.2831
	ΔSN-MP	0.0089	0.0543	0.0603	0.3671
	ΔBody Length	0.2673	0.3411	0.5367	0.2337
Non-deviated side	Occlusal contact area	<0.0001	<0.0001		
	Bite force			<0.0001	<0.0001
	Time	<0.0001	<0.0001	<0.0001	0.0102
	Sex	0.0819	0.4609	0.1035	0.7949
	Age	0.3981	0.3471	0.8063	0.2808
	Chin deviation	0.2987	0.8710	0.4653	0.0867
	ΔSN-MP	0.0407	0.0196	0.1356	0.7521
	ΔBody Length	0.0638	0.5186	0.1742	0.9495

SN, sella-nasion; MP, mandibular plane