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Changes in occlusal force and contact area after extraction of premolars in orthodontic treatment: 2-year follow-up

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감사의 글

교정의사의 길을 열어주시고 오늘에 이르기까지 부족한 저를 지도해주신 김경호 교수님께 깊이 머리 숙여 감사드립니다. 또한 바쁘신 와중에도 논문을 살펴주시고 세심한 지도를 베풀어주신 유형석 교수님과 김의성 교수님, 허종기 교수님, 최윤정 교수님께 진심으로 감사드립니다. 무한한 가르침을 주신 박영철 교수님, 백형선 교수님, 황충주 교수님, 이기준 교수님, 정주령 교수님, 차정열 교수님, 황순신 교수님, 최성환 교수님께도 이 기회를 빌어 심심한 감사의 마음을 표합니다.

수련기간 동안 항상 든든한 보탬이 되어준 동기 김종희 선생과 꼭 필요한 조언을 아낌없이 해주신 하영돈 선생님, 백의선 선생님, 신철홍 선생님, 모자란 선배를 잘 따라준 노윤정, 정석진, 송주언, 이준구 선생, 치과의사의 길로 인도해주신 장기완 교수님과 삼촌이자 선배이신 이준학 선생님께도 지면을 통해 감사의 인사를 전합니다.

거인의 어깨가 되어주신 아버지와 늘 헌신적인 사랑으로 제 삶을 응원해주신 어머니, 늘 바쁜 사위를 챙겨주시고 지지해주신 처가댁 식구들과 든든한 형 같은 내 동생 서경이, 그리고 논문을 쓰는 동안 책상에 나란히 앉아 함께 해준 아내 최혜리에게 진심으로 감사하고 사랑한다는 말을 전하고 싶습니다.

2018년 6월

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Changes in occlusal force and contact area after extraction of premolars in orthodontic treatment: 2–year follow–up

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(Directed by Professor Kyung–Ho Kim, D.D.S., M.S., Ph.D.)

This study aims to evaluate the changes in occlusal contact area and force after orthodontic treatment accompanied with premolar extraction. Female patients who completed orthodontic camouflage treatment were categorized into non–extraction group (n = 36), two maxillary premolar extraction group (n = 18), and four premolar extraction group (n = 31) and measured for occlusal function before, immediately after, and 2 years after orthodontic treatment. Patients with mandibular prognathism treated with intraoral vertical ramus osteotomy, as well as Le Fort I osteotomy as necessary, were categorized into male non–extraction (n = 45), male two maxillary premolar extraction (n = 23),

female non-extraction (n = 31), and female two maxillary premolar extraction groups (n = 29) and measured for the occlusal function before treatment, 1 month after orthognathic surgery, immediately after orthodontic treatment, and 2 years after orthodontic treatment. Occlusal function was measured by asking the subjects to bite the pressure-sensitive sheet at maximal strength. The measured values were analyzed using linear mixed model and Bonferroni post hoc test.

1. In female patients who underwent orthodontic camouflage treatment, there was no between-group difference in the occlusal contact area and force in each treatment period, and pattern of change ($P > 0.05$).

2. In female patients who underwent orthodontic camouflage treatment, the occlusal contact area and force at 2 years after the completion of orthodontic treatment recovered to the level prior to orthodontic treatment in the non-extraction group and the two maxillary premolar extraction group ($P > 0.05$), but the occlusal contact area in the four premolar extraction group were significantly smaller at 2 years after orthodontic treatment compared to before orthodontic treatment ($P < 0.05$).

3. In patients with mandibular prognathism treated with surgical-orthodontic treatment, the pattern of changes in occlusal force and occlusal contact area did not show a significant difference between groups in both male and female patients ($P > 0.05$).

4. In patients who received surgical-orthodontic treatment for mandibular prognathism, there was no significant difference between groups in occlusal contact area and force by treatment period in both male and female patients ($P > 0.05$), except after orthodontic treatment in male patients. In male patients, the occlusal contact area in the extraction group

was significantly greater than in the non−extraction group after the completion of orthodontic treatment ($P < 0.05$).

Among female patients who underwent orthodontic camouflage treatment, non−extraction group and two maxillary premolar extraction group recovered to pre−treatment level of occlusal force at 2 years after orthodontic treatment. In patients with mandibular prognathism treated with intraoral vertical ramus osteotomy, maxillary premolar extraction during presurgical orthodontic treatment did not cause significant difference in the changes in occlusal function 2 years after orthognathic treatment.

Key words : Premolar extraction, Long−term retention, Occlusal contact area, Occlusal force

Part I

Changes in occlusal force and contact area after orthodontic treatment with extraction of premolars: 2-year follow-up

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I. Introduction

The goal of orthodontic treatment is to achieve functional occlusion and an aesthetic profile, with stable results in the long term (Haydar et al., 1992). For patients with severe crowding or lip protrusion, the orthodontist may include an extraction protocol in the treatment plan. Although a decision to include extractions and the tooth to be extracted may differ depending on the case, the most common choice is the first premolar (Janson et al., 2014; Proffit, 1994). Extractions are often unavoidable, and the procedure used and number of teeth extracted have substantial effects on the duration of treatment and outcome, including aesthetics and occlusion (Vig et al., 1990).

Masticatory performance is primarily determined by the teeth, masticatory muscles, and jaw movement (Lepley et al., 2011). Orthodontists can play a role in improving masticatory function by aligning the teeth. Recovery of such function can be evaluated by assessing factors affecting occlusal contact, such as occlusal contact points, occlusal contact area, and distribution of occlusal contact (Imamura et al., 2015). According to Owens et al., a wider occlusal contact area helps with grinding of food, and a wider posterior contact area is crucial for masticatory function (Owens et al., 2002).

Occlusal function in patients treated by extraction of varying numbers of teeth has been investigated using dental casts (Cansunar and Uysal, 2014). However, this method combined with the peer assessment rating index and the American Board of Orthodontics objective grading system is only useful for static evaluation (Lee and Lee, 2016). One study suggested possible discrepancies between results from dental casts and the actual occlusal contact during functional occlusion (Gazit and Lieberman, 1985).

The Dental Prescale system® (Fuji Film Corp., Tokyo, Japan) has been widely used to evaluate occlusal contact area and force due to its simplicity and objectivity (Ando et al., 2009; Hidaka et al., 1999; Okiyama et al., 2003), but the scope of the research using this system has been limited to post-treatment changes during short-term follow-up over 1 year without consideration of pre-treatment records (Choi et al., 2010). Similar studies either included patients treated with extraction only (Sultana et al., 2002) or included only a small number of patients (Makino et al., 2014).

This is a 2-year follow-up study with the purpose of evaluating changes in occlusal contact area and force in non-extraction, two maxillary premolar extraction, and four premolar extraction cases. Measurements were taken before, immediately after, and 2 years after treatment with a fixed orthodontic appliance. The effects of premolar extractions on changes in occlusal function were assessed.

II. Materials and Methods

A. Subjects

Patients treated with a fixed appliance in the Department of Orthodontics at Gangnam Severance Dental Hospital, between June 2008 and September 2013 were considered for the study. The subjects were included if they met the following criteria: female sex; age <40 years; eruption of second molars completed to occlusion before treatment; no missing teeth; no extraction except for third molars, two maxillary premolar extractions, or four premolar extractions, with one premolar extraction per quadrant; and no temporomandibular joint disorder or record of orthognathic surgery.

Eligible subjects were divided into a non−extraction group (non−ext, n = 36), a two maxillary premolar extraction group (2−ext, n = 18), and a four premolar extraction group (4−ext, n = 31). Cephalometric measurements for all subjects before and after treatment are shown in Table I−1. The subjects were randomly assigned to three orthodontists who each had at least 10 years of clinical experience. Ethical approval for this study was obtained from the Institutional Review Board of Gangnam Severance Hospital, Yonsei University (IRB No. 3−2016−0203).

Table I−1. Subject number, age and cephalometric measurements before and after treatment[a]

	Non−ext (n = 36)		4−ext (n = 31)		2−ext (n = 18)		*P* value	
	Pre−Tx	Post−Tx	Pre−Tx	Post−Tx	Pre−Tx	Post−Tx	Pre−Tx	Post−Tx
Age (y)	20.3±8.1	22.2±7.9	20.2±6.0	22.5±6.0	19.0±5.2	21.3±5.1	0.808	0.818
Treatment period (mo)	23.0±7.1[w]		28.1±7.5[x]		27.7±7.8		0.012*	
SNA (°)	81.0±2.7	81.1±2.7	81.0±3.4	80.9±3.5	81.5±2.5	81.1±2.3	0.79	0.788
SNB (°)	78.3±3.5	78.4±3.6	77.4±4.2	77.1±4.2	76.0±2.6	75.8±2.5	0.09	0.051
ANB (°)	2.6±2.5[w]	2.6±2.5[y]	3.5±2.4	3.8±2.2	5.5±2.5[x]	5.3±2.3[z]	0.001**	0.001**
APDI	84.7±6.5	84.4±6.3	82.3±5.4	81.4±4.8	80.9±7.2	80.5±6.5	0.083	0.033*
SN to MP (°)	35.1±6.2	35.1±6.8	38.9±8.4	38.6±8.7	38.7±6.1	39.6±6.4	0.063	0.063
Gonial angle (°)	119.6±7.8	119.6±8.5	121.7±7.2	120.8±7.2	122.5±6.6	122.1±6.8	0.34	0.485
Bjork sum (°)	395.1±6.2	395.8±6.9	398.9±8.4	398.6±8.7	398.7±6.1	399.5±6.4	0.063	0.148
ODI	72.6±8.6	71.9±10.0	69.1±5.4[w]	71.6±6.5	76.0±10.1[x]	74.2±8.6	0.016*	0.557

[a] non−ext, non−extraction group; 4−ext, extraction of two maxillary and two mandibular premolars; 2−ext, extraction of two maxillary premolars; APDI, Anteroposterior Dysplasia Index; ODI, Overbite Depth Index.
*$P < 0.05$; **$P < 0.01$; Scheffe post hoc test, w < x, y < z

B. Measurement of occlusal contact area and force

Occlusal contact area and force were determined before the orthodontic treatment (Pre−Tx), right after the fixed appliance was removed (Post−Tx), and 2 years after the removal (2Y after Tx). The evaluation of occlusal contact area and force was performed as reported in the literature (Choi et al., 2010). Out of four pressure−sensitive sheets different in size (Dental Prescale® 50H, type R, Fuji Film Corp., Tokyo, Japan), one that best fits the arch of each subject was selected to ensure the complete coverage of the occlusal contact area with the sheet. The subjects were asked to bite the pressure−sensitive sheet with maximal clenching force for five seconds in a natural head position. Then, the pressure−sensitive sheets were read out with a CCD camera (Occluzer® FPD 707, Fuji Film Corp., Tokyo, Japan) to determine the occlusal contact area and force with the resolutions of 0.1 mm^2 and 0.1 N, respectively.

C. Skeletal pattern analysis

A lateral cephalometric radiograph in the maximum intercuspal position was recorded using PMPROMAX (Planmeca, Helsinki, Finland) for each subject at their first visit. All the measurement was carrie out using V−ceph 3.5 (CyberMed, Seoul, Korea) with a resolution of 0.1° (angular) and 0.01 mm (linear).

D. Statistical analysis

The average and standard deviation of the cephalometric measurements before the treatment were calculated. One-way ANOVA was used to test the statistical significance of the cephalometric measurements, and post-hoc tests were performed using the Scheffe's method. A linear mixed model was used to test the variations of occlusal contact area and force in each group during the study period and compare them among the three groups. The mandibular plane angle and gonial angle, which were shown to affect occlusal contact area and force in previous studies, were designated as covariates (Yoon et al., 2010). The post-hoc test for the linear mixed model was carried out using the Bonferroni test. All statistical analysis was performed using SPSS version 21.0 (IBM Corp., Armonk, NY, USA).

III. Results

The intraexaminer correlation coefficient of skeletal pattern analysis was 0.89 (95% confidence interval 0.87–0.91), indicating high repeatability of the measurements.

There was no significant difference in occlusal contact area or force between the three groups before treatment ($P > 0.05$, Table I–2 and Table I–3). In all groups, the Post–Tx occlusal contact area and force were significantly lower than the Pre–Tx values but increased 2 years later (Figure I–1 and Figure I–2). There was no significant difference in measurements between the three groups for any period of observation and the tendency to recover occlusal contact area and force was similar during the 2 years ($P > 0.05$, Table I–2 and Table I–3).

In all three groups, the Post–Tx occlusal contact areas were significantly smaller than the corresponding Pre–Tx values ($P < 0.05$). However, after 2 years, the occlusal contact area had increased significantly ($P < 0.05$) and there was no significant difference between the Pre–Tx and 2Y after Tx values ($P > 0.05$), except in the 4–ext group, in which the occlusal contact area failed to reach the Pre–Tx level even 2 years later ($P < 0.05$, Table I–2).

Like the occlusal contact area, the occlusal force increased significantly during 2 years of follow–up ($P < 0.05$) following an initial decrease after treatment ($P < 0.05$), and no significant differences were found between Pre−Tx and 2Y after Tx in any of the three groups ($P > 0.05$, Table I−3).

Table I−2. Time−dependent estimated mean, standard error, and P value for occlusal contact area using a linear mixed model (unit: mm^2)[a]

Time \ Group	Estimated mean[b] (SE)			Overall P value
	Non−ext (n = 36)	4−ext (n = 31)	2−ext (n = 18)	
Pre−Tx	11.5(1.0)[x]	12.9(1.1)[x]	10.6(1.6)[x]	Group: 0.451
Post−Tx	6.4(0.5)[y]	4.8(0.6)[y]	5.0(0.8)[y]	Time: < 0.001***
2Y after Tx	10.7(0.8)[x]	9.4(0.8)[z]	8.9(1.4)[x]	Group X Time: 0.397

[a] SE, standard error; non−ext, non−extraction group; 4−ext, extraction of two maxillary and two mandibular premolars; 2−ext, extraction of two maxillary premolars; Tx, treatment.
[b] Estimated means with different superscript letters are significantly different in each group ($P < 0.05$).
*** $P < 0.001$.

Table I−3. Time−dependent estimated mean, standard error, and *P* value for occlusal force using a linear mixed model (unit: N)[a]

Time \ Group	Estimated mean[b] (SE)			Overall *P* value
	Non−ext (n = 36)	4−ext (n = 31)	2−ext (n = 18)	
Pre−Tx	434.1(35.0)[y]	462.8(37.8)[y]	409.2(54.0)[y]	Group: 0.671
Post−Tx	289.5(23.6)[z]	229.5(25.5)[z]	250.8(33.4)[z]	Time: < 0.001***
2Y after Tx	425.2(30.8)[y]	384.3(33.2)[y]	405.0(56.5)[y]	Group X Time: 0.582

[a] SE, standard error; non−ext, non−extraction group; 4−ext, extraction of two maxillary and two mandibular premolars; 2−ext, extraction of two maxillary premolars; Tx, treatment.
[b] Estimated means with different superscript letters are significantly different in each group ($P < 0.05$).
*** $P < 0.001$.

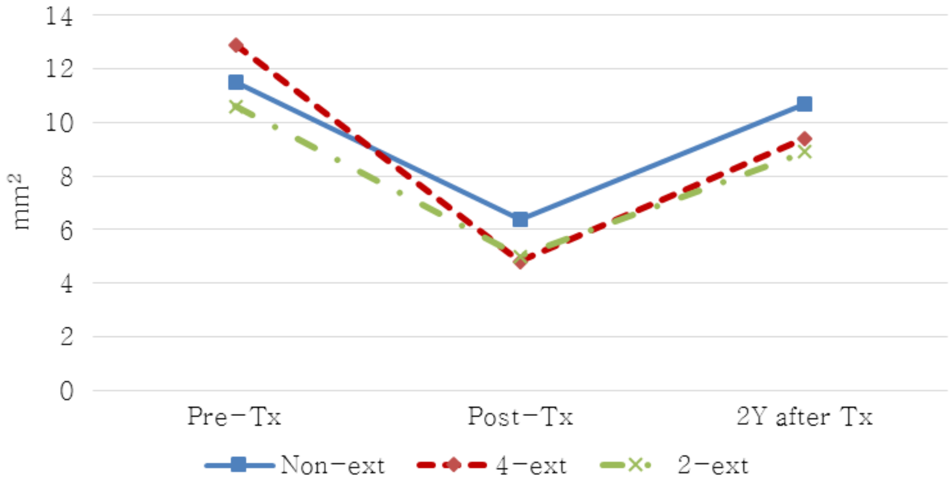

Fig. I-1 Changes in occlusal contact area based on extraction

Non-ext, non-extraction group; 4-ext, extraction of two maxillary and two mandibular premolars; 2-ext, extraction of two maxillary premolars; Tx, treatment.

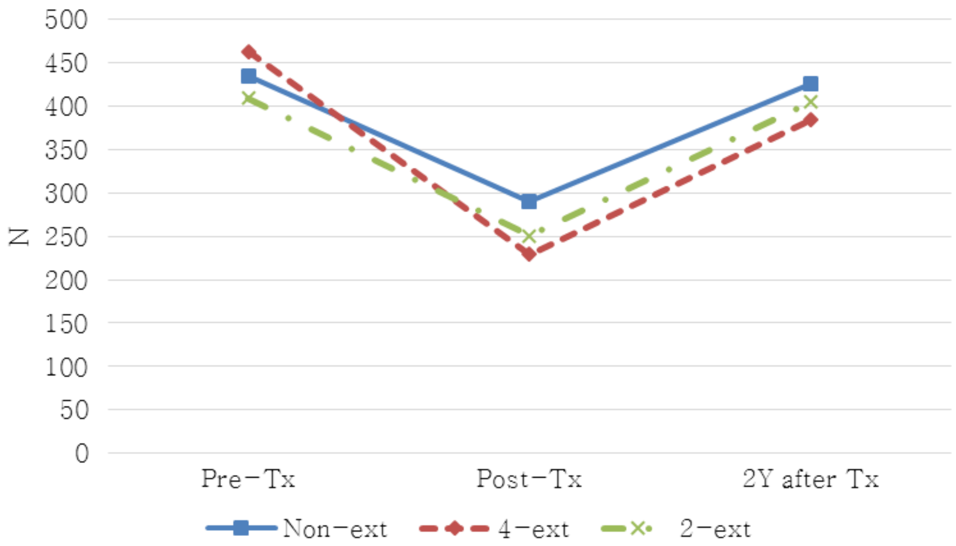

Fig. I−2 Changes in occlusal force based on extraction

Non−ext, non−extraction group; 4−ext, extraction of two maxillary and two mandibular premolars; 2−ext, extraction of two maxillary premolars; Tx, treatment.

IV. Discussion

The Dental Prescale system use a flexible pressure−sensitive sheet of 97 ㎛ thickness. Occlusion by a patient forms marks representing occlusal contact points, and then the film is scanned for analysis. A horseshoe−shape pressure−sensitive sheet is made of two layers of polyethylene terephthalate (PET) films. Developing solution and color−inducing microcapsules are distributed in each of the two layers. When pressure above 5 MPa is applied, the microcapsules bursts and the released colorless dye reacts with the developing solution, forming red−colored marks. The color density is proportional to the pressure applied. The occlusal contact points recorded on the film is read out with a scanner equipped with a CCD camera to determine the pressured area and force. The Dental Prescale system is not dependent on the examiner’s proficiency and offers a simple and objective quantification method for measuring occlusal contact area and force (Ando et al., 2009). Alternatively, the T−scan system (Tekscan Inc., Boston, Mass.) is also commonly used to evaluate occlusal performance. The T−scan is equipped with a horseshoe−shape senor converting pressure into an electric signal to determine occlusal contact area and force. Unfortunately, the T−scan system is not suitable to determine absolute occlusal force (Cerna et al., 2015). Also, the inflexibility of the T−scan system induce a shift of mandible (Sadamori et al., 2007).

In a previous study using an identical method, the occlusal contact area and force were larger in the male than female patients and the occlusal contact area was larger in the patients aged 40 years or older (Yoon et al., 2010). Based on these results, the subjects of this study was limited to the female patients under the age of 40 years. Besides, taking into account previous studies suggesting a correlation between vertical skeletal pattern and occlusal force and contact area, mandibular plane angle and gonial angle were incorporate into the linear mixed model as covariates (Kitafusa, 2004; Yoon et al., 2010). Because anteroposterior jaw relationship has no significant impact on occlusal contact area and force, it was not considered as a covariate (Lee et al., 2015; Watanabe and Abrão, 2012; Yoon et al., 2010). Patients with the temporomandibular joint disorder often show reduced masticatory function and therefore excluded in this study (Sato et al., 1999).

Before the treatment, no correlation was found between extraction protocol and occlusal contact area and force. However, in a comparison of skeletal pattern among the groups, two maxillary premolar extraction protocol was more frequently performed in the skeletal Class II patients based on the ANB. Although this observation was not statistically significant, it was also found in the anteroposterior dysplasia index (APDI). This result is consistent with previous studies reporting that the occlusal success rate was higher in the 2-ext group than that in 4-ext and non-extraction groups for Class II malocclusion patients

(Janson et al., 2004; Janson et al., 2007). The lower overbite depth index in the 4−ext group might be associated with the “drawbridge principle” used to treat the patients with open bite (Janson et al., 2006).

Regardless of the extraction treatment, and the number of extracted teeth, in all measurements, there were no statistically significant differences in occlusal contact area and force among the three groups. Similarly, the changes of occlusal contact area and force overtime were equivalent in all groups. The Post−Tx occlusal contact area and force were reduced to the approximately half of the Pre−Tx and this trend was also found in a study using a three−dimensional digital model (Lee et al., 2015). The major factors affecting occlusal contact area include erosion, attrition, temporomandibular joint, tooth age, type and severity of malocclusion, habitual posture, location of tooth, tooth type, chewing and time of day (Ehrlich and Taicher, 1981; Yurkstas and Manly, 1949). The Post−Tx occlusal contact area and force gradually recover the normal level over time through “settling”, regardless of extraction procedure and the type of malocclusion (Saito et al., 2002; Sultana et al., 2002). However, the 2Y after Tx occlusal contact area and force in the non−extraction group were 425.2 mm^2 and 10.8 N, respectively which were still lower than the average occlusal contact area (24.2 mm^2) and occlusal force (744.5 N) of normal occlusion patients (Yoon et al., 2010). This result suggests that, different from the results obtained in 1−year follow–up study (Choi et al., 2010), the recovery to normal occlusion takes more than 2 years after orthodontic treatment.

In all groups, occlusal function was recovered after 2 years following the initial impairment right after the treatment, except the 4–ext group in which the occlusal contact area failed to achieve a complete recovery. According to Sultana et al., the occlusal contact area of the mandibular premolars is 1.0 – 1.4 mm^2, accounting for 8.4 – 17.5 % of the total occlusal contact area (Sultana et al., 2002). In previous studies where only post–treatment occlusal function was followed up, no significant differences between four premolar extraction and non–extraction group was found at each measurement point, and accordingly, the association of reduction of occlusal contact area with premolar extraction was concluded to be clinically insignificant (Choi et al., 2010). However, the 2Y after Tx occlusal contact area in the 4–ext group was significantly reduced compared to the Pre–Tx occlusal contact area. Considering occlusal contact area has a larger impact on masticatory performance than occlusal force (Lepley et al., 2011), this result suggest that the orthodontic treatment with four premolar extractions could impair the occlusal function. In an assessment of occlusal contact using the American Board of Orthodontics objective grading system, the score for four premolar extractions was lower than that of two maxillary premolar extraction (Cansunar and Uysal, 2014).

Although the Pre−Tx occlusal contact area and force in the 2−ext group were lower than those in the 4−ext group, 2Y after Tx values were higher in the 2−ext group than in the 4−ext group. This result supports the results suggested in studies based on the peer assessment rating index and American Board of Orthodontics objective grading system where the two maxillary premolar extraction protocol showed a higher success rate for the treatment of the patients with skeletal Class II malocclusion than the four premolar extraction protocol (Cansunar and Uysal, 2014). Jason et al. also reported that the treatment period is shorter when two maxillary premolar extraction protocol was chosen over four premolar extraction protocol (Janson et al., 2007). This result reflects the recent trend of increasing two maxillary premolar extraction procedure (Janson et al., 2014).

The Dental Prescale system used in this study to assess the changes in occlusal function pre−and post−orthodontic treatment is not affected by the oral temperature, humidity, and the velocity and duration to press (Noguchi et al., 1983; Suzuki et al., 1994). In addition, this method is validated to be reproducible in the maximum intercuspal position, allowing for objective and quantitative determination of occlusal contact area and force (Imamura et al., 2015; Matsui et al., 1996). However, the thickness of the pressure−sensitive sheet (97 ㎛) can prevent part of actual contact (< 50 ㎛) and near contact (50−350 ㎛) during mastication from being recorded (Gurdsapsri et al., 2000; Owens et al., 2002; Razdolsky et al., 1989; Sakaguchi et al., 1994; Yurkstas and Manly, 1949). Furthermore, pressure above 5 MPa is required to mark contact points on the film, and the measured values can deviate from the actual occlusal force and contact area. Together, these factors can cause significant errors and may explain the 10−fold larger occlusal contact area determined using a three−dimensional model (Lee et al., 2015). With a spatial resolution of 0.25 X 0.25 mm^2 of the CCD camera, the contact points smaller than the spatial resolution cannot be accurately represented (Kwon et al., 2006).

In summary, the variation in occlusal function was investigated through 2−year post−treatment follow−up study by determining occlusal contact area and force. Based on this study, in addition to dentition, facial form, patients' cooperation, and bone age, occlusal function also should be taken into account in extraction decision (Dardengo et al., 2016). Extended long−term studies would be necessary to determine the course of the recovery after orthodontic treatment base on the results of this study.

V. Conclusion

Evaluation of occlusal contact area and force using the Dental Prescale system revealed a tendency for occlusal function to recover to its initial value after 2 years of observation despite premolar extraction. However, the occlusal contact area may not be fully regained during this time if four premolar extraction is performed. Therefore, long-term occlusal function should be considered when contemplating premolar extraction during orthodontic treatment. A recovery period of more than 2 years may be required to achieve normal occlusal function after treatment.

Part II

Changes in occlusal force and contact area after intraoral vertical ramus osteotomy with and without extraction of maxillary premolars: 2-year follow-up

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I. Introduction

The major purpose of surgical-orthodontic treatment is facial profile, occlusion, and the normalization of occlusal function (Johnston et al., 2006; Kim and Oh, 1997). Skeletal Class III patients undergo the deterioration of occlusal function due to cross bite, poor intercuspation, and weaker capacity of the jaw musculation (Islam et al., 2017). Some researches showed that patients with Class III malocclusion have lower chewing efficiency than patients with Class I and II malocclusion (Bae et al., 2017; English et al., 2002). According to Jung (Jung, 2012), 23.6% of domestic orthodontic patients are Class III malocclusion patients and the rate of orthodontic treatment with surgery for patients with Class III malocclusion has been increasing for the last 10 years due to the development of surgical technique and increases in the demand for facial aesthetics (Lee et al., 2016).

In the presurgical orthodontic treatment, factors related to maxillary premolar extraction are aesthetic, function, amount of crowding of the upper jaw, maxillary incisor inclination, transverse problem of the maxilla, and degree of skeletal correction possible with surgery (Collins and Poulton, 1996; Jacobs and Sinclair, 1983; Kim et al., 2013; Kim and Park, 2014; Lee et al., 2006; Ohkubo et al., 2014; Proffit et al., 2003). The maxillary premolars are often extracted for orthognathic surgery in skeletal Class III patients. Sabri reported that the relative difficulty of the retraction of maxilla during Le Fort I surgery could be overcome by the extraction of the maxillary premolars, and Johnston et al. recounted that ANB values for a patient on Class III orthognathic surgery show an ideal angle when a premolars are extracted in contrast with the non-extraction of premolars (Johnston et al., 2006; Sabri, 2006).

There are several measures to evaluate occlusal function but the maximum occlusal force is recognized as the index which estimates the efficiency of dentition and masticatory muscle (Islam et al., 2017). Particularly, the Dental Prescale system® (Fuji Film Corp., Tokyo, Japan) is widely used for the evaluation of occlusal function after surgery because it can collectively measure the ability of the periodontium which supports the contraction of the masticatory muscle, occlusal condition and activity of masticatory muscle (Choi et al., 2014; Harada et al., 2000; Harada et al., 2003; Kobayashi et al., 1993; Nakata et al., 2007; Ohkura et al., 2001; Ueki et al., 2007; Yamashita et al., 2011).

Even though many previous researches analyzed the occlusal force and contact area to evaluate the recovery of occlusal function after orthognathic surgery in skeletal Class III patients, only factors such as surgical methods (Ueki et al., 2007), asymmetry (Moroi et al., 2015), maxillary surgery experience (Choi et al., 2014) were tested without considering maxillary premolar extraction (Ellis et al., 1996; Iwase et al., 2006; Ohkura et al., 2001; Throckmorton et al., 1996; Trawitzki et al., 2010). Therefore, this study was set to test the null hypothesis wherein premolar extraction during the presurgical orthodontic treatment has no influence on the occlusal contact area and force after the orthognathic surgery in prognathic patients.

II. Materials and Methods

This study was approved by Institution of Research review Board of the Gangnam Severance Hospital, Yonsei University (No. 3-2018-0030).

A. Subjects

In this retrospective study, 582 patients diagnosed with skeletal Class III malocclusion among 2,888 patients treated at the Department of Orthodontics, Gangnam Severance Dental Hospital, Yonsei University from 2008 to 2015 were reviewed. Among the 338 patients who underwent orthognathic surgery with orthodontic treatment, 128 patients who met the following criteria were included: patients who did not undergo extraction during presurgical orthodontic treatment except third molars or had only two maxillary premolars extracted; patients without missing tooth except third molar; patients with menton deviation less than 5 mm; patients without temporomandibular joint disorders; patients who did not experience sagittal split ramus osteotomy, arthroplasty, and temporomandibular joint reconstruction during the surgery; patients without systemic disease; patients without dentofacial deformities such as cleft lip/palate etc. Subjects were classified into male (n = 68) and female (n = 60) according to gender. Male and female were classified into the extraction group and the non-extraction group (male non−ext, n = 45; male ext, n = 23; female non−ext, n = 31; female ext, n = 29) (Table II−1).

Table II−1. Demographic features of the study subjects.

	Male	Female	Total
Non−ext	45	31	76
Ext	23	29	52
Total	68	60	128

Non−ext, nonextraction group; ext, extraction of two maxillary premolars.

All subjects received the orthodontic treatment after they were randomly assigned to three orthodontists who had more than 10 years of experience. After all study subjects received the presurgical orthodontic treatment by using fixed appliances, the mandibular setback was performed through intraoral vertical ramus osteotomy (IVRO) either with or without Le Fort I osteotomy. All surgeries were performed in Department of Oral and Maxillofacial Surgery, Gangnam Severance Dental Hospital and the postoperative physiotherapy with elastic traction was performed for 2 weeks after an average of 2 weeks of intermaxillary fixation. After the postsurgical orthodontic treatment, a fixed retainer was applied on the lingual surface from canine to canine for the dental arch treated without extraction, and from premolar to premolar for the arch treated with premolar extraction.

B. Measurements

The measurement of the occlusal contact area and force was performed at before treatment (Pre−Tx), 1 month after surgery (Post−Op), immediately after postsurgical orthodontic treatment (Post−Tx), and 2 years later (2Y after Tx). The evaluation of occlusal contact area and force was performed in the same way used in Part I. It was checked whether all occlusal surfaces are covered by an appropriate size of pressure−sensitive sheet (Dental Prescale 50H, type R, Fuji Film Corp., Tokyo Japan). Before the measurement, the maximum intercuspal position was explained to all subjects and they were told to bite for 5 seconds at maximum strength without any head support on natural head position. Then, the pressure−sensitive sheets were read out with a CCD camera (Occluzer® FPD 707, Fuji Film Corp., Tokyo, Japan) to measure the occlusal contact area with the resolutions of 0.1 mm^2 and occlusal force with the resolutions of 0.1 N.

C. Skeletal and dental pattern analysis

All patients underwent lateral cephalometric radiograph at the maximum intercuspal position using PMPROMAX (Planmeca, Helsinki, Finland) during their first visit. The measurement of lateral cephalometric radiograph was done by 0.1° (angular) and 0.01 mm (linear) using V−ceph 5.5 (CyberMed, Seoul, Korea). Skeletal Class was classified based on ANB angle and skeletal Class III was defined if the ANB angle is below 0 degree (Kim et al., 2001). Facial asymmetry was defined as the case where the menton was deviated from the facial midline by more than 5 mm on the postero−anterior cephalometric radiograph using the method of Haraguchi (Haraguchi et al., 2002). The amount of crowding was defined by using the segmental method of Proffit et al., and the space required for crowding relief and leveling in maxillary dental casts were calculated (Proffit et al., 2006).

D. Statistical analysis

All statistical analyses used SPSS version 21.0 (IBM Corp., Armonk, NY, USA) and the level of significance was 5% for the test. The average and standard deviation of study subjects' age before the treatment, treatment period, and cephalometric measurements were calculated. Also, a statistical significance test between two groups by using an independent sample t−test was carried out. The linear mixed model was used to compare groups in each period and to test changes in occlusal contact area and force based on the time flow in each group. The changes in mandibular plane angle and body length which showed a positive correlation with postsurgical occlusal force were handled as covariates (Kim and Oh, 1997). Bonferroni test was used to perform the post hoc test of linear mixed model.

III. Results

A. Cephalometric measurements and cast analysis before treatment

The result which was made by comparing the age, the lateral and postero−anterior cephalometric radiograph, and analysis of maxillary dental cast before the orthodontic treatment can be found on Table II−2. When two maxillary premolars were extracted during the presurgical orthodontic treatment, the treatment period was significantly increased compared to the treatment without extraction in both sexes ($P < 0.001$). In both male and female, the U1 to SN angle and the amount of crowding were significantly greater in patients who underwent maxillary premolar extraction than those who did not ($P < 0.01$).

Table II-2. Subject age, cephalometric measurements and maxillary cast analysis before treatment

measurements	Male (n = 68)		*P* Value	Female (n = 60)		*P* Value
	Non-ext (n=45)	Ext (n=23)		Non-ext (n=31)	Ext (n=29)	
Age (y)	21.6±3.9	20.9±2.2	0.212	21.5±4.5	20.3±4.7	0.312
Treatment period (mo)	22.4±6.1	28.5±7.7	<0.001***	22.6±6.5	30.0±6.6	<0.001***
SNA (°)	82.0±3.3	82.7±4.7	0.470	80.7±3.0	80.9±3.3	0.765
SNB (°)	85.2±4.0	86.3±5.2	0.322	83.0±3.3	83.3±4.0	0.808
ANB (°)	−3.2±2.4	−3.6±2.0	0.467	−2.4±1.7	−2.4±1.7	0.868
SN to MP (°)	33.3±6.7	31.6±6.3	0.334	36.3±5.8	36.8±5.7	0.755
Gonial angle (°)	125.3±5.9	125.0±7.9	0.859	126.1±7.6	126.1±6.3	0.996
Bjork sum (°)	393.1±6.4	391.6±6.3	0.379	396.3±5.7	397.0±5.4	0.614
Body length (mm)	84.2±6.5	85.0±7.4	0.659	80.5±4.3	81.3±4.0	0.543
ODI	58.4±7.5	58.4±6.4	0.992	59.2±5.7	58.7±5.6	0.735
APDI	98.0±6.0	99.4±6.8	0.372	96.5±4.7	95.7±5.7	0.532
Overjet (mm)	−2.8±2.8	−1.8±1.7	0.126	−1.1±2.6	−1.0±3.1	0.844
Overbite (mm)	0.4±2.1	−0.1±2.4	0.465	0.1±1.6	−0.1±2.4	0.729
Asymmetry (mm)	2.4±1.3	2.4±1.5	0.995	2.4±1.5	2.0±1.4	0.262
U1 to SN (°)	112.1±6.4	117.5±8.3	0.004**	109.1±6.2	114.6±5.5	<0.001***
Crowding (mm)	0.5±1.4	2.5±2.7	<0.001***	0.9±1.0	3.7±3.6	<0.001***

[a] non-ext, nonextraction group; ext, extraction of two maxillary premolars; ODI, overbite depth index; body length, gonion-menton; asymmetry, menton deviation from facial midline; U1, maxillary incisor; SN, sella-nasion.
** $P < 0.01$; *** $P < 0.001$.

B. Changes of occlusal contact area and force in male patients

There was no significant difference in the occlusal contact area and force between the ext group and the non−ext group in male patients ($P > 0.05$, Table II−3 and Table II−4). In both groups, the occlusal contact area and force decreased significantly after the initiation of orthodontic treatment ($P < 0.05$) and decreased to the lowest level immediately after surgery, and returned again to the initial level 2 years after postsurgical orthodontic treatment (Figure II−1 and Figure II−2). In both groups, the measured values at each time period were significantly different from those before and after ($P < 0.05$). However, there was no significant difference in the change pattern between the two groups ($P > 0.05$). There was no significant difference in the occlusal force between the groups at all time points ($P > 0.05$). In the occlusal contact area, however, post−Tx values were significantly higher in the ext group than in the non−ext group ($P < 0.05$, Table II−3). The cephalometric measurements had no influence on the occlusal contact area and the force ($P > 0.05$).

Table II−3. Time−dependent estimated mean, standard error, and *P* value for occlusal contact area using a linear mixed model in male patients (mm^2)[a]

Time \ Group	Estimated mean[b] (SE)		Overall *P* value
	Male non−ext (n=45)	Male ext (n=23)	
Pre−Tx	11.3(0.7)[w]	13.3(0.9)[w]	Group: 0.489 Time: < 0.001*** Group × Time: 0.110 SN to MP: 0.087 Body length: 0.353
Post−Op	1.7(0.6)[x]	1.4(0.9)[x]	
Post−Tx	5.1(0.7)[y]	6.5(0.9)[z]	
2Y after Tx	11.1(0.7)[w]	10.0(1.1)[w]	

[a] SE, standard error; non−ext, nonextraction group; ext, extraction of two maxillary premolars; Tx, treatment; Op, operation.
[b] Estimated means with different superscript letters are significantly different in each group ($P < 0.05$).
*** $P < 0.001$.

Table II−4. Time−dependent estimated mean, standard error, and *P* value for occlusal force using a linear mixed model in male patients (N)[a]

Time \ Group	Estimated mean[b] (SE)		Overall *P* value
	Male non−ext (n=45)	Male ext (n=23)	
Pre−Tx	442.6(24.2)[x]	507.1(33.6)[x]	Group: 0.392 Time: < 0.001*** Group × Time: 0.232 SN to MP: 0.211 Body length: 0.987
Post−Op	91.6(23.7)[y]	83.5(33.9)[y]	
Post−Tx	266.6(23.8)[z]	319.5(33.4)[z]	
2Y after Tx	456.9(27.1)[x]	444.4(38.6)[x]	

[a] SE, standard error; non−ext, nonextraction group; ext, extraction of two maxillary premolars; Tx, treatment; Op, operation.
[b] Estimated means with different superscript letters are significantly different in each group ($P < 0.05$).
*** $P < 0.001$.

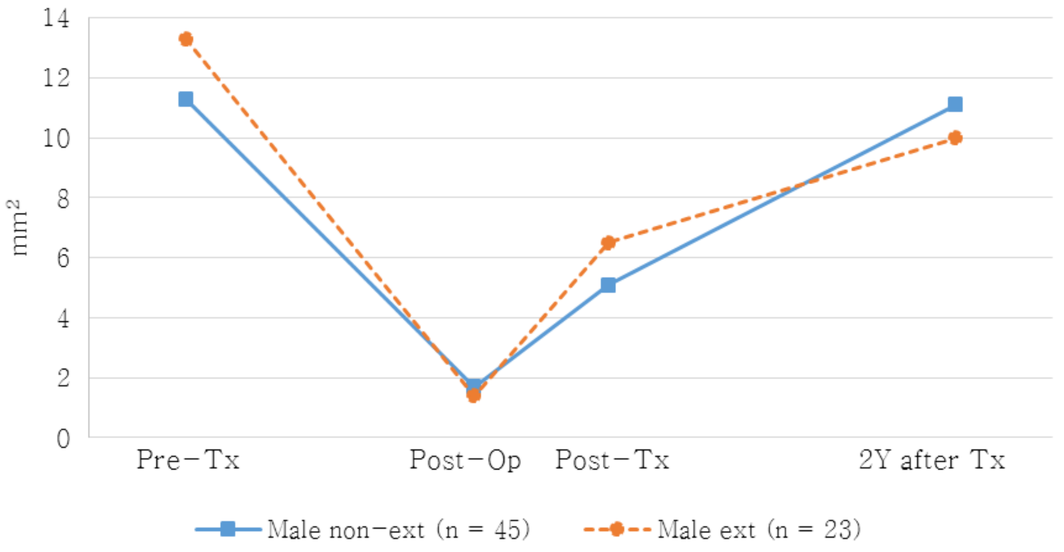

Fig. II-1 Changes in occlusal contact area in male patients

Non-ext, non-extraction group; ext, extraction of two maxillary premolars; Tx, treatment.

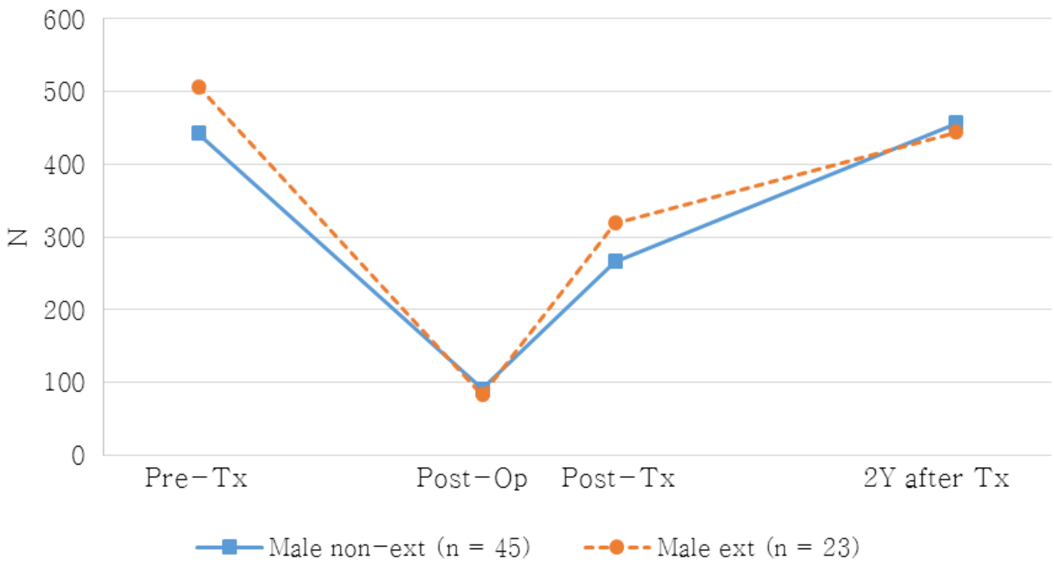

Fig. II−2 Changes in occlusal force in male patients

Non−ext, non−extraction group; ext, extraction of two maxillary premolars; Tx, treatment.

C. Changes of occlusal contact area and force in female patients

Even in women, there was no statistically significant difference in the occlusal contact area and force between the ext group and non−ext group ($P > 0.05$, Table II−5 and Table II−6). In both groups, the occlusal contact area and force decreased significantly at the beginning of orthodontic treatment, with the lowest value recorded immediately after surgery ($P < 0.05$, Figure II−3 and Figure II−4). Afterwards, both significantly increased ($P < 0.05$) and returned to the initial level two years after the end of treatment. Changes in the occlusal contact area and force over time in the two groups did not show any significant difference ($P > 0.05$). In addition, there was no significant difference between the groups at all time points ($P > 0.05$). Changes in the occlusal contact area and force in female indicated that the SN to MP angle has a positive regression coefficient ($P < 0.05$).

Table II-5. Time-dependent estimated mean, standard error, and *P* value for occlusal contact area using a linear mixed model in female patients (mm^2)[a]

Time \ Group	Estimated mean[b] (SE)		Overall *P* value
	Female non-ext (n=31)	Female ext (n=29)	
Pre-Tx	9.6(0.6)[x]	7.8(0.5)[x]	Group: 0.125 Time: < 0.001*** Group × Time: 0.083 SN to MP: 0.044* Body length: 1.000
Post-Op	0.9(0.5)[y]	1.3(0.6)[y]	
Post-Tx	4.4(0.5)[z]	4.2(0.5)[z]	
2Y after Tx	9.3(0.6)[x]	7.9(0.6)[x]	

[a] SE, standard error; non-ext, nonextraction group; ext, extraction of two maxillary premolars; Tx, treatment; Op, operation.
[b] Estimated means with different superscript letters are significantly different in each group ($P < 0.05$).
* $P < 0.05$; *** $P < 0.001$.

Table II-6. Time-dependent estimated mean, standard error, and *P* value for occlusal force using a linear mixed model in female patients (N)[a]

Time \ Group	Estimated mean[b] (SE)		Overall *P* value
	Female non-ext (n=31)	Female ext (n=29)	
Pre-Tx	371.2(22.0)[x]	297.2(21.4)[x]	Group: 0.128 Time: < 0.001*** Group × Time: 0.075 SN to MP: 0.030* Body length: 0.760
Post-Op	49.8(20.3)[y]	70.1(22.4)[y]	
Post-Tx	235.5(20.0)[z]	213.6(20.7)[z]	
2Y after Tx	396.1(23.4)[x]	351.1(23.9)[x]	

[a] SE, standard error; non-ext, nonextraction group; ext, extraction of two maxillary premolars; Tx, treatment; Op, operation.
[b] Estimated means with different superscript letters are significantly different in each group ($P < 0.05$).
* $P < 0.05$; *** $P < 0.001$.

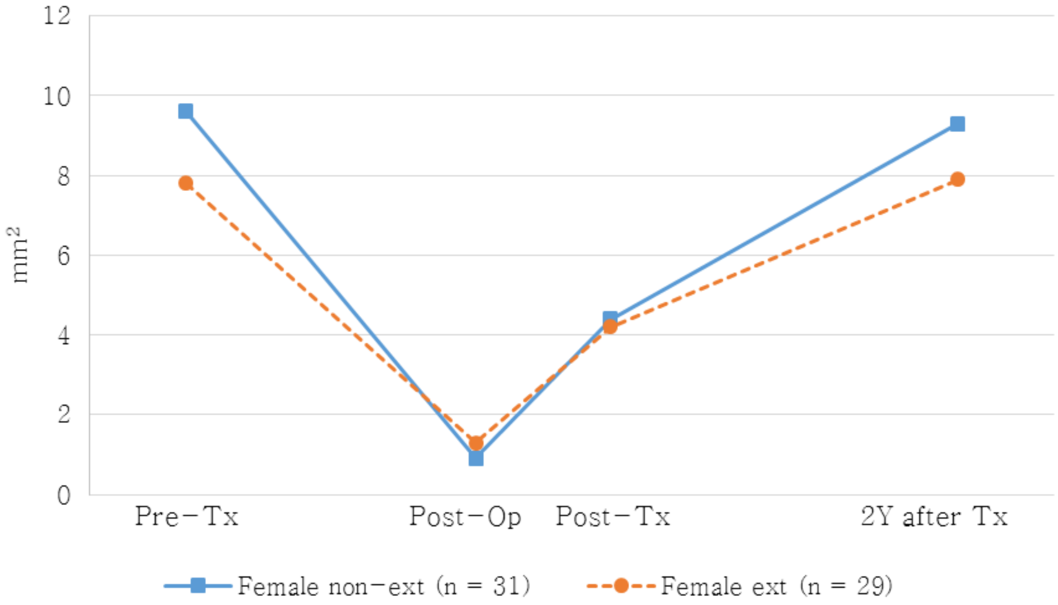

Fig. II−3 Changes in occlusal contact area in female patients

Non−ext, non−extraction group; ext, extraction of two maxillary premolars; Tx, treatment.

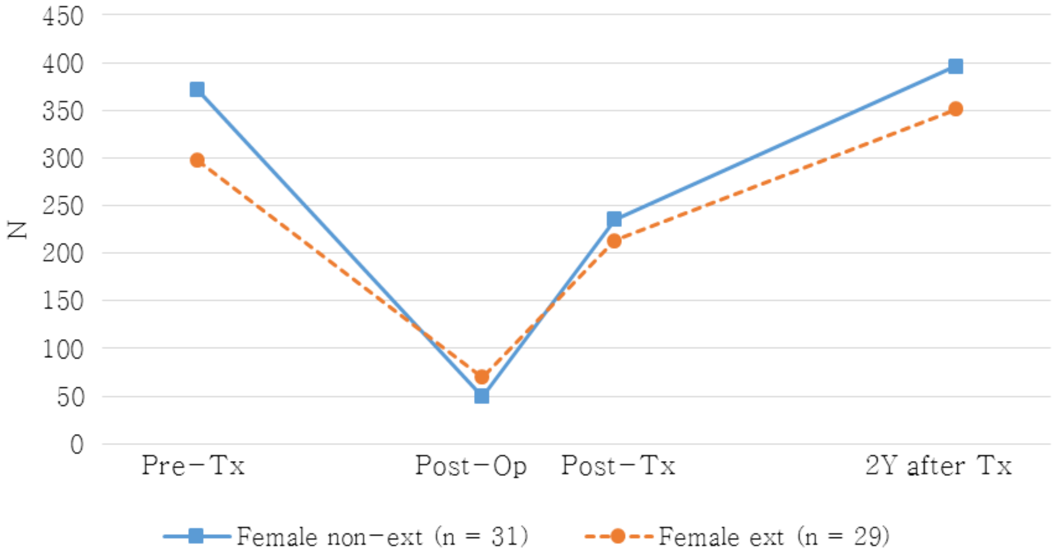

Fig. II-4 Changes in occlusal force in female patients

Non-ext, non-extraction group; ext, extraction of two maxillary premolars; Tx, treatment.

IV. Discussion

The pressure-sensitive sheet was developed by Fuji Photo Film Co. (Tokyo, Japan) in 1977 for industrial use. In 1978, Hirasawa et al. announced that it can be used for bite pressure and occlusal balance measurement (Hirasawa et al., 1978). Dental Prescale was used for various researches related to orthodontic treatment to evaluate the occlusal function (Choi et al., 2010; Kitafusa, 2004; Sultana et al., 2002; Yawaka et al., 2004; Yoon et al., 2010). Because the pressure-sensitive sheet is thin (97㎛) and does not cause the mandibular shift, it can well reproduce the masticatory force of intercuspal position. Also, it is useful for the purpose of comparison of the research values on a large scale because the time for the occlusal measurement is short and it is marked as an objective numerical value (Park et al., 2012).

In particular, Dental Prescale which evaluated the occlusal function after orthognathic surgery was used in various researches, so it is documented that the surgery method, maxillary surgery, and amount of mandibular setback have no influence on the changes in occlusal force and contact area after the surgery (Choi et al., 2014; Harada et al., 2000; Iwase et al., 2006; Moroi et al., 2015; Nakata et al., 2007; Ueki et al., 2007; Ueki et al., 2009). In a study that evaluated occlusal function over time in patients with mandibular prognathism in the same protocol, Choi et al. showed that occlusal contact area and force decreased to the lowest level immediately after surgery regardless of maxillary operation and the patient recovered the function at the initial level 2 years after the end of treatment (Choi et al., 2014). The author obtained the result in which the extraction has no influence on the changes in occlusal contact area and force through a longitudinal study a year after the completion of orthodontic treatment (Choi et al., 2010). However, according to 2 years of follow-up study, premolar extraction can affect the changes in the occlusal contact area after orthodontic treatment (Yoon et al., 2017). Therefore, this study was conducted for surgical patients.

Factors known to affect occlusal contact area and force include age, gender, vertical skeletal pattern, temporomandibular joint disorder, dental state, and facial asymmetry (Koc et al., 2010; Kogawa et al., 2006; Thomas et al., 1995; Yoon et al., 2010). The subjects of this study consisted of an age group (18-34 years old) who showed no significant difference in occlusal contact area and force. Considering that male's bite force is significantly larger than female, male and female were divided and compared according to whether they had extraction of maxillary premolars or not. Patients were excluded if they have temporomandibular joint disorder, a missing tooth or severe facial asymmetry. In the case of mandibular prognathism, it has already been reported that maxillary surgery has no effect on occlusal contact area and force so, it is not considered in the classification of groups (Choi et al., 2014; Ueki et al., 2007).

In the presurgical orthodontic treatment of a patient with mandibular prognathism, the maxillary premolar is often extracted for dental decompensation, and it affects changes in the inclination of maxillary incisor, width and inclination of maxillary molar, and total airway volume (Kim and Park, 2014; Lee et al., 2006; Ohkubo et al., 2014). In the study, the angle of maxillary incisors was significantly larger in the ext group than in the non-ext group in both male and female ($P <$ 0.01). In addition, the amount of crowding in maxilla was significantly higher in the ext group than in the non-ext group ($P < 0.001$), indicating that the extraction of maxillary premolars is useful for dental decompensation in patients with mandibular prognathism (Tabrizi et al., 2016). Meanwhile the treatment duration was significantly increased when the maxillary premolar was extracted ($P <$ 0.001). Therefore, if there is a restriction on the treatment period, the posterior impaction of the maxilla instead of the extraction of maxillary premolars could be considered (Kim and Baek, 2013; Lee et al., 2016).

In this study, 2 years of follow-up was conducted by classifying the group based on maxillary premolar extraction. The extraction had no significant influence on the aspect of changes in occlusal contact area and force and the null hypothesis is acceptable ($P > 0.05$). When the maxillary premolar was extracted during the presurgical orthodontic treatment, the occlusal contact area and force were tend to be lower 2 years after the completion of orthognathic treatment.

However, because it did not show any significant difference ($P > 0.05$), this aspect is the same as the result of Part I. Unlike other results, the occlusal contact area immediately after orthodontic treatment in male patients showed a significant difference between the two groups ($P < 0.05$). This result may be due to the fact that male are known to restore their occlusal function more rapidly after surgery (Ohkura et al., 2001) and the extraction group had a longer duration of postsurgical treatment (8.6 ± 4.6 months) than the non−extraction group (7.3 ± 3.1 months).

Kim and Oh reported that changes in mandibular plane angle and body length positively correlate with postoperative occlusal force after mandibular setback surgery (Kim and Oh, 1997). Therefore, in this study, changes in mandibular plane angle and body length were used as covariates in statistical analysis using linear mixed model, but the use of covariates did not cause any difference in the statistical results. In male patients, cephalometric measurements did not affect changes in occlusal contact area and force ($P > 0.05$), but in female patients, the changes in mandibular plane angle had a positive regression coefficient in changes in the occlusal contact area and force ($P < 0.05$). There are conflicting results regarding the relationship between occlusal contact area and force and cephalometric measurements after orthognathic surgery. Previous studies did not distinguish male and female, and thus, additional research depending on gender is needed to examine the correlation between occlusal force and cephalometric measurements (Choi et al., 2014; Kim and Oh, 1997; Throckmorton and Ellis, 2001).

Factors which affect the occlusal force after orthognathic surgery for patients with prognathism are changes in muscle, occlusal contact area, tooth sensitivity, periodontium, mandibular movement, temporomandibular joint, intermaxillary fixation period, and skeletal morphology (Dal Pont, 1961; Ellis et al., 1996; Kim and Oh, 1997). In the study which used electromyography, it was reported that masseter and temporalis muscle recover to the normal level 8 months after the orthognathic surgery (Ingervall et al., 1979; Raustia and Oikarinen, 1994). This means that the electrical activity of the muscle of mastication reaches the normal level faster than the occlusal contact area and force. Harada et al. advocated that the restoration of occlusal contact area and force after the surgery is more relevant with orthodontic treatment than the electrical activity of the muscle (Harada et al., 2000; Iwase et al., 2006). If a female patient among the study subjects was compared with a study subject in part I, the female patient showed a similar level of occlusal force and contact area 2 years after the completion of orthodontic treatment regardless of the surgery ($P > 0.05$, data are not shown).

In the study which evaluated the occlusal force by using a 15 mm transducer after surgery in skeletal Class III patients, it is reported that the occlusal force reach the normal level 2 to 3 years after the orthognathic surgery (Ellis et al., 1996). However, when Dental Prescale was used for the evaluation, the occlusal force did not reach the normal level after 2 years and this could be a result of the difference in the measurement method (Choi et al., 2014; Islam et al., 2017; Iwase et al., 2006; Ohkura et al., 2001). Some authors reported that it needs 3 to 4 years for the occlusal force after the orthognathic surgery to reach a similar level of a normal occlusion (Ellis et al., 1996; Yamashita et al., 2011). In this study, the measured result at 2 years after the completion of treatment did not attained the normal level of occlusion, so it would need more than 2 years of long-term follow-up study. Also, as mentioned by lwase et al., the adjustment of occlusion could be considered to improve weak occlusal force after surgery (Iwase et al., 1998).

Patients with mandibular prognathism have fewer occlusal contact than patients with normal occlusion and it is expected that the occlusal force is increased due to the increases in the occlusal contact after the surgery. Two factors which mainly contribute to the occlusal force are the strength made by the masticatory muscle and the length of moment arm. However, it is thought that the formation of the accurate occlusion after orthognathic surgery has a greater influence on the occlusal function because the effect of mechanical change due to the surgery is minor (Iwase et al., 1998; Proffit et al., 1989; Throckmorton et al., 1995; Ueki et al., 2007). Therefore, an orthodontist should make a full effort for a tight occlusion to avoid the relapse after orthognathic surgery and the fast recovery of the occlusal function.

V. Conclusion

The extraction of maxillary premolars has no significant influence on the occlusal contact area and force after 2-year follow-up of the orthognathic treatment with IVRO in skeletal Class III patients. Therefore, the orthodontist should include maxillary premolar extraction in the plan for presurgical orthodontic treatments if it is necessary to resolve dental compensation and skeletal discrepancy. In addition, further follow-up studies are needed to assess recovery in normal functionality in patients with mandibular prognathism after orthognathic surgery.

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국 문 요 약

소구치 발치를 동반한 교정치료 후 교합기능 변화: 2년 추적

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윤우강

본 연구는 소구치 발치를 동반한 교정치료 후 교합면적과 교합력의 변화를 평가하고자 하였다. 절충치료를 완료한 여성 환자를 비발치군 (n = 36)과 상악 2개 소구치 발치군 (n = 18), 상하악 4개 소구치 발치군 (n = 31)으로 분류하였으며, 교정치료 전, 교정치료 직후, 교정치료 종료 2년 후의 교합기능을 측정하였다. 구내 하악지 수직 골절단술 및 필요 시 상악의 Le Fort I osteotomy를 동반하여 치료한 하악전돌증 환자는 남자 비발치군 (n = 45), 남자 상악 2개 소구치 발치군 (n = 23), 여자 비발치군 (n = 31), 여자 상악 2개 소구치 발치군 (n = 29)으로 분류하였으며, 교정치료 전, 악교정수술 1달 후, 교정치료 직후, 교정치료 종료 2년 후의 교합기능을 측정하였다. 교합기능은 연구 대상자들에게 자연두부위에서 감압지를 최대 근력으로 교합하게 한 후 감압지를 분석하여 측정하였으며, 측정된 자료를 선형혼합모형과 Bonferroni 사후검정을 이용하여 다음과 같은 결과를 얻었다.

1. 절충치료를 시행한 여성환자에서 각 시기별 교합면적과 교합력 및 변화양상은 군간의 차이가 없었다 ($P > 0.05$).

2. 절충치료를 시행한 여성환자에서 비발치군과 상악 2개 소구치 발치군의 교합면적과 교합력은 교정치료 종료 2년 후 교정치료 전 수준을 회복하였으나 ($P > 0.05$), 상하악 4개 소구치 발치군의 교합면적은 교정치료 2년후에도 교정치료 전보다 유의하게 낮았다 ($P < 0.05$).

3. 악교정수술을 동반하여 교정치료를 받은 하악전돌증 환자에서 시간의 흐름에 따른 교합력과 교합면적의 변화양상은 남녀 모두 군간의 유의한 차이를 보이지 않았다 ($P > 0.05$).

4. 악교정수술을 동반한 교정치료를 받은 하악전돌증 환자에서 남성의 교정치료 후 시기를 제외하고는 남녀에서 모두 각 시기별 교합면적과 교합력의 군간의 유의한 차이가 발견되지 않았으나 ($P > 0.05$), 남성의 경우 교정치료 직후 발치군의 교합면적이 비발치군보다 유의하게 크게 나타났다 ($P < 0.05$).

절충치료를 받은 여성 환자들 중 상하악 4개 소구치 발치군을 제외한 비발치군과 상악 2개 소구치 발치군은 교정치료 2년 후 교정치료 전 수준의 교합력을 회복하였다. 구내 하악지 수직 골절단술을 동반하여 치료한 하악전돌증 환자에서 술전교정 시 상악 소구치 발치여부는 악교정치료 2년 후까지의 추적연구에서 교합기능의 변화에 유의한 차이를 야기하지 않았다.

핵심되는 말 : 소구치 발치, 장기간 연구, 교합면적, 교합력