Changes in masticatory performance during the retention period following extraction and non-extraction orthodontic treatment

Song-Hyun Lee

Department of Dentistry
The Graduate School, Yonsei University

Changes in masticatory performance during the retention period following extraction and non-extraction orthodontic treatment

Directed by Professor Kee-Joon Lee

A Doctoral Dissertation
Submitted to the Department of Dentistry
and the Graduate School of Yonsei University
in Partial Fulfillment of the Requirements for the Degree of
Doctor of Philosophy of Dental Science

Song-Hyun Lee

December 2022

This certifies that the Doctoral Dissertation of

Song-Hyun Lee is approved.

Kee-joon Lee

Thesis Supervisor: Kee-Joon Lee

Hyung Seog Yu

Hyung Seog Yu

Yoon Jeong Choi

Yoon Jeong Choi

Jeehwan Kim

Jeehwan Kim

Kyung Seok Hu

Kyung-Seok Hu

The Graduate School

Yonsei University

December 2022

감사의 글

논문을 완성해 나가는 과정은 지금까지 무심코 읽어 왔던 연구문헌들의 깊이와 무게를 깨닫게 하는 과정이었습니다. 지도교수이신 이기준교수님께서는 주제를 주시고 스스로 문제에 대한 해답을 찾게 하곤 하셨습니다. 뵐 때마다 하시는 몇 마디의 말씀과 질문들에 중요한 키 포인트가 있었습니다. 뒤늦게야 깨닫곤 하는 부족한 제자를 끝까지 믿어 주시고 지도해 주신 이기준교수님께 깊이 감사드립니다. 논문의 완성도를 높일 수 있도록 논문의 작성과 심사에 많은 지도편달을 해주신 유형석교수님, 최윤정교수님, 김지환교수님. 허경석교수님께 심심한 감사의 인사를 드립니다. 저에게 교정학의 원리를 가르쳐 주신 황충주교수님, 김경호교수님, 차정열교수님, 정주령교수님, 최성환교수님, 박선형교수님께도 감사드립니다. 대학원을 추천해주시고 지금도 늘 격려해 주고계시는 김희진교수님, 치의학 임상의 기본을 가르쳐 주신 통합치의학과 김기덕교수님, 정복영교수님, 박원서교수님. 방난심교수님께도 이 기회를 빌려 감사의 인사드립니다.

또한 대학원 학업을 전적으로 지지해주시고 배려해주신 하남세브란스치과 심경섭원장님과 실험을 도와준 스텝선생님들께도 감사드리며 특히 바쁜 와중에도 연구를 성심껏 도와준 방미령선생님에게 진심 어린 감사의 마음을 전합니다.

항상 곁에서 응원해주는 사랑하는 아들 진원이와 고향에 계시는 존경하는 아버지, 어머니, 사랑하는 오빠들, 그리고 고마운 많은 분들 생각에 포기하지

않고 논문을 완성할 수 있어서 감사한 마음입니다.

끝으로 고난속에서도 삶의 희망을 잃지 않고 살아갈 수 있도록 힘과 용기를 주시고 믿음의 은혜를 주신 살아 계신 하나님 아버지께 무한한 감사와 영광을 드리면서 이 논문을 바칩니다.

2022년 12월

저자 씀

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Changes in masticatory performance during the retention period following extraction and non-extraction orthodontic treatment

Song-Hyun Lee, D.D.S., M.S.,

Department of Dentistry
The Graduate School, Yonsei University
(Directed by Prof. Kee-Joon Lee, D.D.S., M.S., Ph.D.)

Orthodontic treatment is the process of acquiring an optimal occlusion by modifying the initial malocclusion through space closure after extraction or space gain without extraction using various techniques. The functional benefits of modifying the occlusion while treating malocclusion remain controversial due to the lack of long-term studies evaluating the outcomes after orthodontic treatment.

This study aimed was (1) to evaluate change in masticatory performance (MP) during retention period after extraction and non-extraction orthodontic treatment in adult patients and compare it with the MP in the participants with normal occlusion by measuring the mixing ability (MA) using a two-color chewing gum and (2) to evaluate whether extraction affects the MP after orthodontic treatment.

Adult patients who had completed orthodontic fixed appliance treatment comprised the non-extraction group (mean age 25.33±5.26) and extraction group (mean age 29.14±7.00), and those with normal occlusion(mean age 28.3±6.57) comprised the control group.

Mixing ability (MA), maximum bite force (MBF), and occlusal contact area (OCA)were recorded one week after debonding the fixed appliance, the day when the wrap-around retainer was delivered (T0), 1-month post-treatment(T1), 6 months post-treatment(T2), 1-year post-treatment(T3). MA were measured with two-color chewing gum MA test using ViewGum software, and MBF and OCA were measured using Dental Prescale II system.

The results are follows

1. The MA immediately after orthodontic treatment was lower than that observed in normal occlusion group but showed a time-dependent gradual increase during 1-year retention period ($P<0.01$).
2. The MA at 1-month post-treatment was not significantly different from that in the normal occlusion group ($P>0.05$), but the MBF and OCA at 1-year post-treatment were significantly lower than those in the normal occlusion group ($P<0.01$).
3. The MA showed a significant correlation with the MBF and OCA ($P<0.05$).
4. No significant difference was observed in MA between the non-extraction group and extraction group ($P>0.05$).

In conclusion, the MP immediately after orthodontic treatment in the experimental groups was lower than that in the normal occlusion group but increased gradually over time during the retention period and improved to levels similar to those in the normal occlusion group at 1-month post-treatment. Further, extraction did not affect the MP after orthodontic treatment.

Key word: Orthodontic treatment, masticatory performance, two-color chewing gum mixing ability, extraction and non-extraction, retention period, maximum bite force and occlusal contact area

Changes in masticatory performance during the retention period following extraction and non-extraction orthodontic treatment

Song-Hyun Lee, D.D.S., M.S.,

Department of Dentistry
The Graduate School, Yonsei University
(Directed by Prof. Kee-Joon Lee, D.D.S., M.S., Ph.D.)

I. INTRODUCTION

Orthodontic treatment is the process of acquiring optimal occlusion by modifying the initial malocclusion through space closure after extraction or space gain without extraction using various techniques. Decreased masticatory performance (MP) or impaired chewing efficiency has been reported in patients with dental malocclusion (Bae et al., 2017; Magalhaes et al., 2010; Ngom et al., 2007). Ngom et al.(2007) stated that improving the patient’s chewing function by improving occlusal relationships could be an indication for orthodontic treatment in individuals with occlusal anomalies.

However, the concept that modifying the occlusion to treat malocclusion through extraction and non-extraction has functional benefits remains controversial (English et al., 2002; Gameiro et al., 2017; Henrikson et al., 2009). Few studies have investigated the effect of orthodontic treatment on MP, and their outcomes generated two views. First, the orthodontic treatment improves MP to the level found in normal occlusion. Gameiro et al. (2017) reported that patients with malocclusion had impaired masticatory and swallowing functions, and that their MP following orthodontic treatment was reestablished to that observed in the normal occlusion group. Second, the orthodontic treatment does not significantly improve masticatory efficiency. Henrikson et al.(2009) compared the masticatory efficiency in adolescent girls with class II malocclusion who underwent orthodontic treatment with those having untreated class II malocclusion and normal occlusion and found no significant difference in the two class II groups. Moreover, the masticatory efficiency associated with normal occlusion was better than that in the two class II groups, and the masticatory efficiency at 2 years was greater than that at baseline in all the groups. They attributed the increase in masticatory efficiency in the orthodontic group to the general development and growth of the masticatory system rather than the orthodontic treatment itself. Furthermore, it was reported that surgical correction did not significantly improve MP, which remained poor in comparison with the MP of the normal occlusion group (van den Braber et al., 2006; van den Braber et al., 2005; van den Braber et al., 2004; Zarrinkelk et al., 1995). In particular, van den Braber et al. (2006) concluded that surgical treatment had a positive influence on the MP of patients with mandibular retrognathism 5 years after surgery, which could not be detected 1 year after the surgery. The improvement in MP after orthodontic treatment remains controversial due to the lack of long-term studies evaluating the outcomes after orthodontic treatment.

The bite force and occlusal contact area (OCA) immediately after orthodontic treatment are less than those before treatment; however, they gradually increase during the retention period. Two years after treatment, their values are close to those associated with initial or normal occlusion, and there is no significant difference in the bite force and OCA of non-extraction and extraction patients (Choi et al., 2010; Choi et al., 2014; Sultana et al., 2002; Yoon et al., 2017). Besides, remodeling of soft and hard tissues continues for a long time after the removal of active appliances; therefore, long-term observation of MP following orthodontic treatment is necessary.

To our knowledge, the existing literature does not clarify how MP changes during the retention period. This study aimed (1) to evaluate the changes in MP over time following extraction and non-extraction orthodontic treatment in adult patients and compare it with the MP in the participants with normal occlusion by measuring the mixing ability (MA) using a two-color chewing gum and (2) to evaluate whether extraction affects the MP after orthodontic treatment.

The null hypothesis was that (1) the MP after extraction and non-extraction orthodontic treatment does not change during a 1-year retention period and that (2) there is no difference between the extraction/non-extraction group and the normal occlusion group as well as between the non-extraction and extraction groups.

II. Materials and Methods

1. Participants

Men and women aged 18-48 years were included in the study. The experimental groups comprised patients who had completed orthodontic fixed appliance treatment at the Department of Orthodontics, Yonsei University Dental Hospital, between February 2019 and April 2021.

The inclusion criteria were as follows: Class I canine and molar relationships and good occlusion; for the extraction group, extraction of four premolars, one premolar from each quadrant; absence of temporomandibular joint dysfunction (TMD); and no history of orthognathic surgery. Patients were classified into non-extraction and extraction groups without considering the type of skeletal malocclusion; each group included the same number of men and women. All participants of the experimental groups wore fixed retainers on the lingual surface of the six maxillary and mandibular anterior teeth, and a removable wrap-around retainer in the maxilla was used to allow occlusal settling as dual retention. The fixed retainer was fabricated using a 0.0195-inch dead-soft wire (Respond, Ormco Corp., Orange, CA, USA). The fixed retainer was bonded directly after debonding of the fixed orthodontic appliance. The wrap-around retainer was of the conventional type and delivered 1 week after debonding of the fixed appliance. The same methods and types of retainers were used for participants of both experimental groups. The participants were instructed to wear the removable retainer full-time for the first month, except when eating and brushing teeth. Thereafter, they were instructed to wear it only at night. Their compliance with wearing the removable retainer was assessed at every follow-up. The normal occlusion group comprised the same number of men and women who underwent screening and were found to have normal occlusion from among those who visited the Dental clinic of Hanam for a regular checkup. The inclusion criteria for this group were as follows: bilateral canine and molar Class I relationship; a normal transverse relationship without history of orthodontic treatment; overjet and overbite between 1 and 3 mm; crowding or spacing <2 mm in each jaw; and midline discrepancies <1 mm.

All individuals who satisfied the inclusion criteria were told about the study verbally and in writing. They provided written informed consent prior to participation. This study was approved by the Institutional Review board of Yonsei University dental hospital (IRB 2-2018-0042).

2. Measurements

2-1) Mixing ability

Commercial chewing gums (Hubba-Bubba Tape Gums: Sour Blue Raspberry [azure color] and Seriously Strawberry [pink color], William Wrigley Jr. Company, Chicago) were used to measure MA. The azure and pink color gums were cut in dimensions of 30 mm × 18 mm × 3 mm and manually stacked together. The participants were instructed to sit upright and chew the gums on the preferred chewing side for 5, 10, and 20 cycles. Then, the participants were asked to spit the gums in a transparent plastic bag. To reduce the effect of masticatory muscle fatigue, the participants were given an interval of at least 1 min before chewing each specimen. Each gum was flattened to achieve a thickness of 1 mm by pressing with a stamp having a custom-made milled depression of dimensions 1 mm × 50 mm × 50 mm. The MA was measured by scanning both sides of the flattened gum using an Epson scanner (GT-X830), and the data were assessed using the ViewGum software (2017, dHAL Software; version1.4; Figures 1 and 2). The ViewGum software measures the standard deviation of the hue (SDHue) in a given image. A lower value of the SDHue implies higher MA. These experimental methods are based on those described by Halazonetis et al.(Halazonetis et al., 2013).

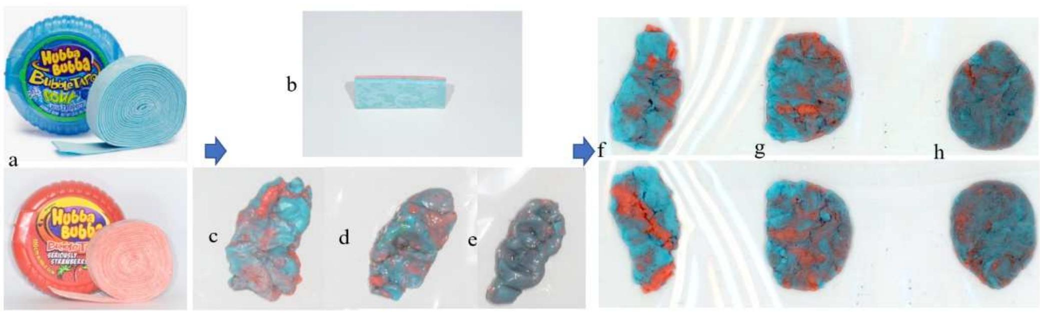

Figure 1. Chewing gum specimens: (a) Hubba-bubba gums; (b) the two-colored chewing gums stuck together; (c-e) chewing gum bloused after 5, 10, and 20 chewing cycles, respectively; (f-h), chewing gum specimens flattened to a 1-mm-thick wafer after 5, 10, and 20 chewing cycles, respectively, and scanned

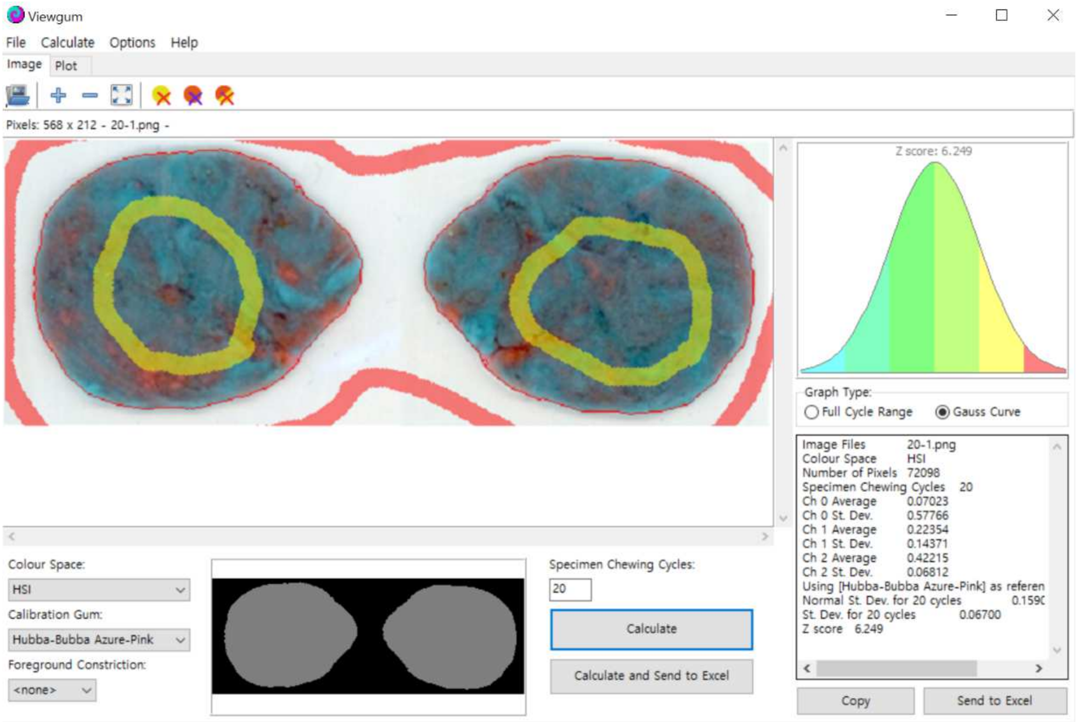

Figure 2. The user interface after importing the scanned images of the flattened gum chewed for 20 cycles in ViewGum software

2-2) Maximum bite force and Occlusal contact area

An appropriately sized pressure-sensitive film (Dental Prescale II System, Fujifilm Corp., Tokyo, Japan) sheet was selected to fit the dental arch of each participant. Then, the participants were instructed to bite on the sheet for approximately 3 s while sitting upright and to exert maximum sustained power, not instantaneous power, when clenching. The MBF and OCA were calculated using an occlusal force analyzing system (GC, Tokyo, Japan; Figure 3).

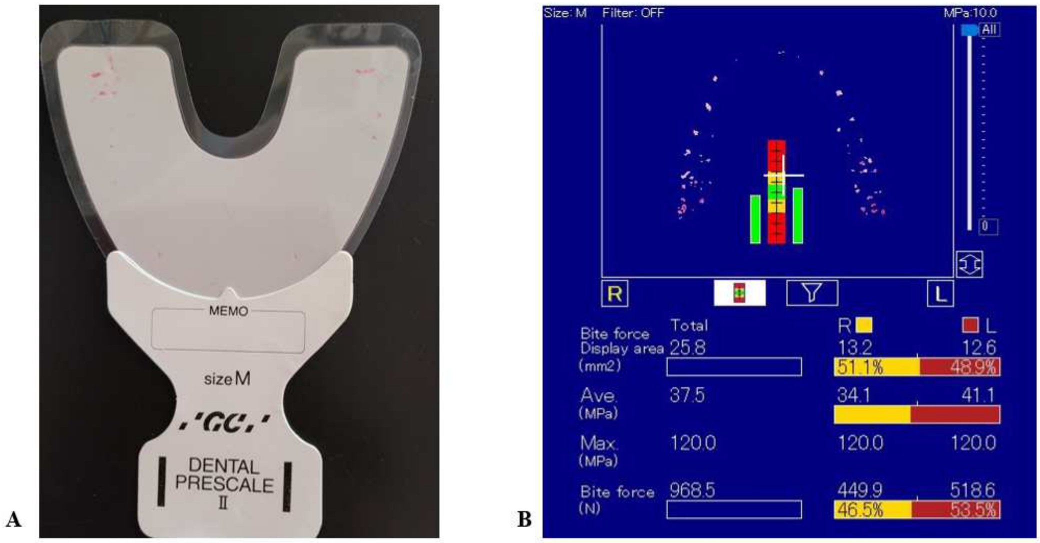

Figure 3. The Dental Prescale II system: A, Pressure-sensitive sheet, B, Scan result

These evaluations were performed by a single investigator one week after debonding the fixed appliance, the day when the wrap-around retainer was delivered, (T0) and after 1 month (T1), 6 months (T2), and 1 year (T3) post-treatment. Post-treatment lateral cephalograms were obtained using Cranex 3+ (Soredex, Helsinki, Finland) in the natural head position and with the bite in centric relation. Cephalometric tracing was digitized using the V-ceph program (Osstem Inc, Seoul, Korea). All lateral cephalometric assessments and measurements were performed by the same investigator. Two weeks after the first tracing, 20 samples were randomly selected and retraced by a single examiner. The intra-class correlation coefficient was greater than 0.94.

3. Statistical analysis

All statistical analyses were performed using SPSS software version 26 (IBM SPSS, Armonk, NY). Using the G*power 3.1 program (Dusseldorf, Germany), we determined that with an experimental group sample size of 32, the analysis would be sufficiently powered, with a significance level of (P value) <0.05, 95% power, and 0.4 effect size. The Shapiro–Wilk test was used to test the variations in MA, MBF, and OCA between the groups. For the analysis of changes in MA, MBF, and OCA between the time-intervals and groups, repeated measures ANOVA was used and the Bonferroni post hoc test was applied to correct for excessive errors related to multiple comparisons. The independent t-test was used to compare between experimental groups and normal occlusion group. The paired t-test was used to compare the MA between chewing cycles. Furthermore, Pearson’s correlation coefficients were calculated to verify the association between the MA, MBF, and OCA. Statistical significance was defined as a probability value of <0.05.

III. Results

1. Participant characteristics

Among all 168 patients aged 18-48 years, 105 were excluded before measurement due to not meeting the inclusion criteria of TMD (n=35), missing teeth (n=12), upper premolar extraction only (n=21), third molar (n=18), orthognathic surgery (n=8), and not agreeing to participate (n=11). Among these, 31 patients were excluded due to incomplete follow-up data, as most did not visit the hospital at the 1-year follow-up (Figure 4). Finally, the non-extraction group comprised nine men and nine women (mean age, 25.33 ± 5.26 years, 28 teeth totally), and the extraction group comprised seven men and seven women (mean age, 29.14 ± 7.00 years, 24 teeth totally). All fixed retainers were appropriately positioned until 1 year, and all patients reported good compliance in wearing the retainers as instructed. The normal occlusion group comprised 10 men and 10 women (mean age, 28.3 ± 6.57 years). Skeletal analysis of the experimental groups after active treatment are presented in Table 1. No difference was observed in the skeletal variables between the non-extraction and extraction groups.

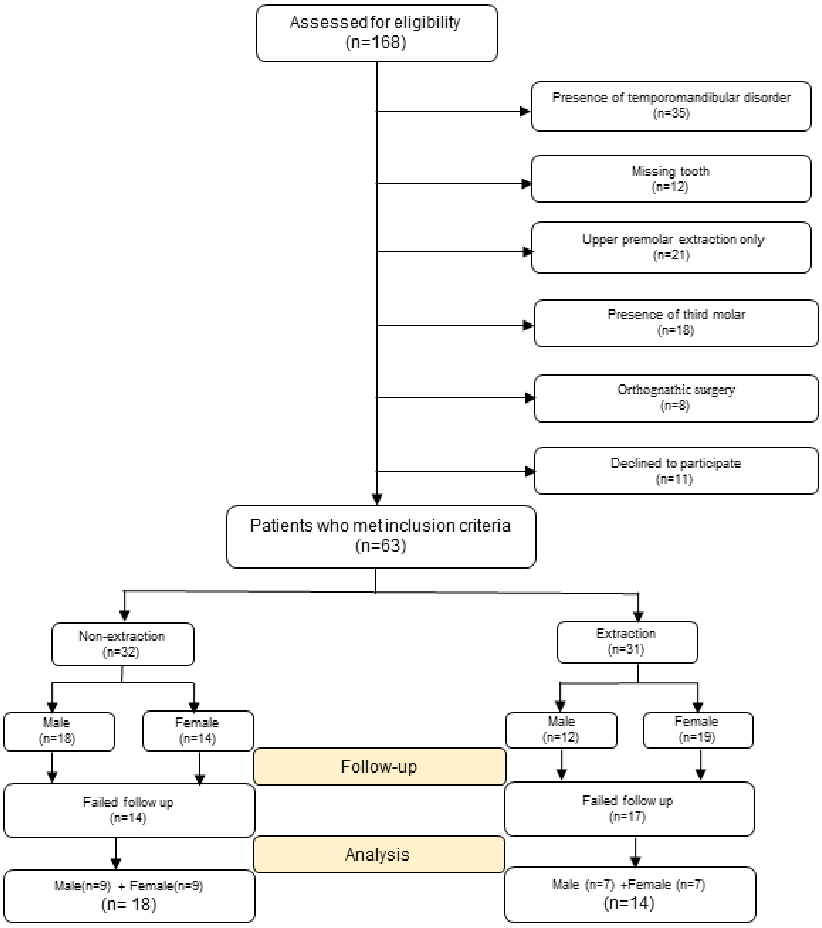

Fig 4. Flow diagram illustrating the process of participant selection and group allocation

Table 1. Participant characteristics

Variable	Non-extraction group (n=18) Mean ± SD	Extraction group (n=14) Mean ± SD	Normal occlusion group(n=20) Mean±SD	*P*-Value
Age (years)	25.33±5.26	29.14±7.00	28.3±6.57	0.190
Treatment duration (months)	23.33±8.91	30.21±9.56	---	0.041*
SNA (deg)	80.67±3.55	80.34±3.09	---	0.663
SNB (deg)	78.18±4.77	77.25±3.39	---	0.543
ANB (deg)	2.68±2.92	3.10±3.04	---	0.696
Gonial angle (deg)	120.62±8.36	121.11±6.82	---	0.861
Bjork sum (deg)	395.56±5.19	398.14±7.61	---	0.263
Mandibular plane angle (deg)	35.53±5.18	38.14±7.62	---	0.257

*$P<0.05$, *P*-value was obtained with independent t-test
Variable of age was compared with one-way ANOVA

2. Changes in the MA during the retention period

One-hundred-and-forty-eight samples for 5, 10, and 20 chewing cycles were obtained from the participants enrolled in the present study. The SDHue at 5, 10, and 20 chewing cycles was analyzed to assess the differences based on the number of chewing cycles. The SDHue showed a significant decrease (P<0.001) as the number of chewing cycles increased (Table 2).

Table 2. Comparison of standard deviation of hue between chewing cycles

	5 cycles	10 cycles	20 cycles
SD Hue (Mean ± SD)	0.85±0.06	0.78±0.08	0.60±0.14
10 cycles	0.0001 *	---	---
20 cycles	0.0001 *	0.0001 *	---

*, $P<0.001$, Paired t-test, Sample size: 148 (the sum of the number of samples obtained from 32 experimental subjects at four time points and the number of samples obtained from 20 subjects with normal occlusion)

Intragroup comparison of the SDHue at 5, 10 cycles revealed insignificant changes in both non-extraction and extraction groups ($P>0.05$). However, the SDHue at 20 cycles showed significant decreases ($P<0.05$) in the non-extraction group at the T0-T3 time interval and in the extraction group at the T0-T1, T0-T2, T0-T3 time intervals (Table 3).

Intergroup comparison of the SDHue at five cycles showed insignificant changes at T0, T1, T2 and T3. ($P>0.05$). SDHue at 10 cycles showed insignificant changes at T1, T2, and T3 ($P>0.05$), but a significant difference was found between the extraction and normal occlusion groups at T0 ($P<0.05$). SDHue at 20 cycles showed insignificant differences between the non-extraction and extraction group, but significant differences ($P<0.05$) were found between the experimental and normal occlusion groups at T0 (Table 4, Figure 5).

3. Changes in the MBF and OCA during the retention period

Intragroup comparison of the MBF revealed significant increases in the non-extraction group at T0-T1, T0-T2, T0-T3, T1-T2, T1-T3 and T2-T3 time intervals and in the extraction group at the T0-T1, T0-T2, T0-T3, and T1-T3 time intervals ($P<0.05$). Intragroup comparison of the OCA revealed significant increases ($P<0.05$) in the non-extraction group at T0-T1, T0-T2, T0-T3, T1-T2, T1-T3, and T2-T3 time intervals and in the extraction group at T0-T3 and T1-T3 time intervals (Table 3).

Intergroup comparison of the MBF and OCA revealed insignificant differences in the non-extraction and extraction groups at the T0, T1, T2, and T3 time periods ($P>0.05$), but significant differences ($P<0.01$) were found between the experimental and normal occlusion groups at T0, T1, T2, and T3 (Table 4, Figure 6, 7).

Table 3. Time-dependent changes in the mixing ability, maximum bite force and occlusal contact area during a 1-year retention period

		Non-extraction group (n=18)						Extraction group (n=14)						Subgroup * Time *P*
		Mean±SD				*P*	Post-hoc	Mean±SD				*P*	Post-hoc	
		T0	T1	T2	T3			T0	T1	T2	T3			
SDHue	5cycles	0.85±0.07	0.86±0.06	0.86±0.07	0.85±0.06	.778	---	0.89±0.04	0.83±0.07	0.83±0.06	0.85±0.05	.052	---	.055
	10cycles	0.79± 0.08	0.78±0.08	0.78±0.09	0.73±0.06	.101	---	0.85±0.09	0.80±0.09	0.75±0.07	0.76±0.07	.056	---	.251
	20cycles	0.70±0.15	0.60±0.14	0.58±0.09	0.55±0.10	.003*	T0-T3	0.76±0.13	0.62±0.13	0.57±0.10	0.57±0.09	.0001*	T0-T1, T0-T2 T0-T3	.461
MBF (N)		619.9± 206.45	751.07± 134.28	931.14± 161.78	1030.54± 209.19	.0001*	T0-T1, T0-T2 T0-T3, T1-T2 T1-T3, T2-T3	577.96± 213.95	722.38± 262.54	795.00± 297.97	968.47± 270.44	.0001*	T0-T1, T0-T2 T0-T3, T1-T3	.449
OCA (mm^2)		19.3±5.28	22.33±4.03	28.29±6.31	31.62±6.08	.0001*	T0-T1, T0-T2 T0-T3, T1-T2 T1-T3, T2-T3	19.89±8.57	22.41± 9.78	24.58±9.35	27.96± 9.09	.0001*	T0-T3, T1-T3	.458

SDHue, Standard deviation of hue; MBF, maximum bite force; OCA, occlusal contact area; T0, baseline; T1, 1 month post-treatment; T2, 6 months post -treatment; T3; 1 year post-treatment.
***P*,** Comparison among the timing of different measurements using the repeated measures ANOVA; **P<0.01*
Post-hoc, time intervals indicate the Bonferroni post hoc results, representing statistically significant difference(p<0.05)

Table 4. Comparison of the mixing ability, maximum bite force and occlusal contact area between the experimental groups and normal occlusion group at every time point

		Non-extraction group (n=18)				Extraction group (n=14)				Normal occlusion group (n=20)
		T0 Mean±SD	T1 Mean±SD	T2 Mean±SD	T3 Mean±SD	T0 Mean±SD	T1 Mean±SD	T2 Mean±SD	T3 Mean±SD	Mean±SD
SDHue	5cycles	0.85±0.07	0.86±0.06	0.86±0.07	0.85±0.06	0.89±0.04	0.83±0.07	0.83±0.06	0.85±0.05	0.85±0.07
	10cycles	0.79±0.08	0.78±0.08	0.78±0.09	0.73±0.06	0.85±0.09*	0.80±0.09	0.75±0.07	0.76±0.07	0.75±0.09
	20cycles	0.70±0.15*	0.60±0.14	0.58±0.09	0.55±0.10	0.76±0.13*	0.62±0.13	0.57±0.10	0.57±0.09	0.53±0.13
MBF (N)		619.9± 206.45*	751.07± 134.28*	931.14± 161.78*	1030.54± 209.19*	577.96± 213.95*	722.38± 262.54*	795.00± 297.97*	968.47± 270.44*	1377.34± 457.08
OCA (mm^2)		19.3±5.28*	22.33±4.03*	28.29±6.31*	31.62±6.08*	19.89±8.57*	22.41±9.78*	24.58±9.35*	27.96±9.09*	46.73±16.89

SDHue, Standard deviation of hue; MBF, maximum bite force; OCA, occlusal contact area;T0, baseline; T1, 1 month post-treatment; T2, 6 months post -treatment; T3; 1 year post-treatment; *$p<0.01$, significant difference with normal occlusion by independent t-test

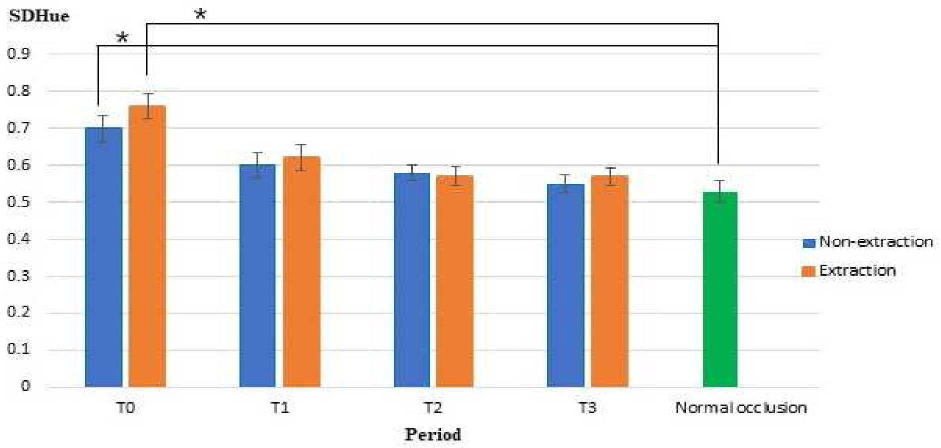

Figure 5. Comparison of Standard deviation of hue between the experimental groups and normal occlusion group, SDHue, standard deviation of hue; T0, baseline; T1, 1month post-treatment; T2, 6 months post-treatment; T3, 1year post-treatment; * $P < 0.01$, comparison with normal occlusion

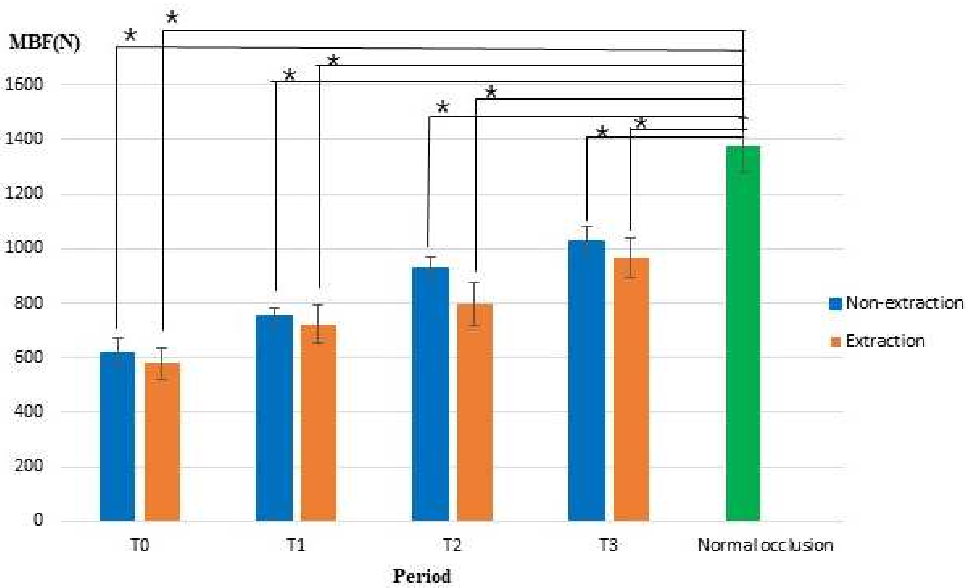

Figure 6. Comparison of the maximum bite force between the experimental groups and normal occlusion group, MBF; maximum bite force; T0, baseline; T1, 1month post-treatment; T2, 6 months post-treatment; T3, 1year post-treatment; *$P<0.01$, comparison with normal occlusion

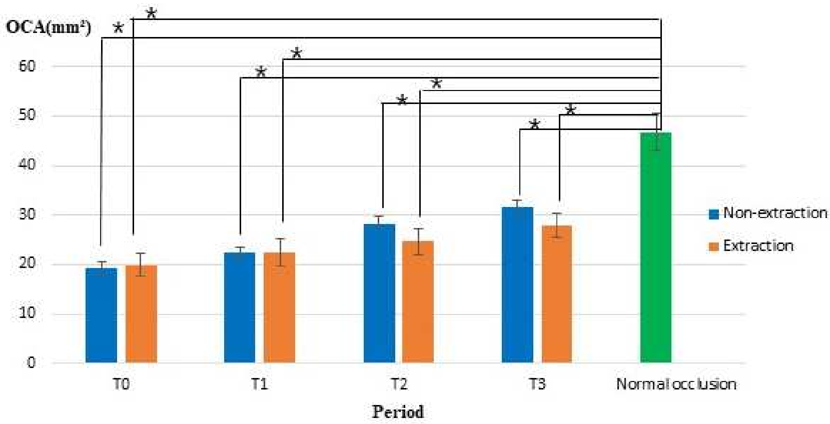

Figure 7. Comparison of the occlusal contact area between the experimental groups and normal occlusion group, OCA, occlusal contact area; T0, baseline; T1, 1month post-treatment; T2, 6 months post-treatment; T3, 1year post-treatment; **P<0.01*, comparison with normal occlusion

4. Correlation between the MA, MBF, and OCA

The correlation coefficient between the SDHue at 5 and 10 chewing cycles and between 10 and 20 chewing cycles were 0.309 and 0.483, respectively (P<0.01). The SDHue at 5 and 10 cycles was not associated with the MBF and OCA (P>0.05). The correlation coefficients between the SDHue at 20 cycles and MBF and between the SDHue at 20 cycles and OCA were -0.382 and -0.350, respectively (Table 5).

Table 5. Pearson's correlation coefficients between standard deviation of hue, maximum bite force and occlusal contact area

	SDHue 5cycles	SDHue 10cycles	SDHue 20cycles	Maximum bite force
SDHue 10cycles	0.309			
SDHue 20cycles	0.203*	0.483**		
Maximum bite force	0.085	-0.159	-0.382**	
Occlusal contact area	0.121	-0.117	-0.350**	0.899**

SDHue, standard deviation of hue; *Indicate statistical significance with Pearson's correlation test (* *P<0.05, **P<0.01);*

IV. Discussion

This study aimed to evaluate the changes in MP in adult patients who had completed orthodontic fixed appliance treatment with extraction or non-extraction during a 1-year retention period. Furthermore, it aimed to compare the MP after orthodontic treatment with that associated with normal occlusion.

Mastication is the first step to digest food and involves breaking down and comminuting, mixing, kneading, and transporting the food bolus into the oropharynx (Bourdiol et al., 2020; van der Bilt et al., 2006).A variety of methods have been used to clinically evaluate the MP. The most conventional method is based on a comminution test, that is, grinding of a test material, which helps evaluate the distribution of particle sizes after a given number of chewing cycles; other methods place emphasis on the bolus formation preparatory to swallowing and evaluate bolus mixing (Halazonetis et al., 2013; Liedberg and Owall, 1995; Prinz, 1999; Schimmel et al., 2007; van der Bilt, 2011). However, the comminution test using the sieving method is messy, time-consuming, and inconvenient in clinical practice; therefore, a variety of other MA tests have been used recently (Aquilanti et al., 2020; Halazonetis et al., 2013; Hama et al., 2014; Kaya et al., 2017; Schimmel et al., 2007; Weijenberg et al., 2013). In this study, the two-color chewing gum MA test using ViewGum software, which can be easily applied in clinical practice, was used to evaluate the MP. It evaluates the degree of mixing of the bolus by measuring the SDHue of the specimen using ViewGum software that quantifies HIS color space (hue, saturation, intensity). Previous studies have reported that this method has good sensitivity and reliability, although its validity should be established (Halazonetis et al., 2013; Kaya et al., 2017; Schimmel et al., 2007; Schimmel et al., 2015; Weijenberg et al., 2013).

To minimize the influence of sex, the same number of male and female participants comprised the experimental and normal occlusion groups. Three specimens were obtained from each participant by asking the participants to chew the gum for 5, 10, and 20 cycles. The SDHue at 5, 10, and 20 chewing cycles was analyzed in a total of 148 samples to assess whether this digital image analysis method showed differences on the basis of the number of chewing cycles. In this study, the SDHue value was found to be larger than that reported in other studies (Halazonetis et al., 2013; Schimmel et al., 2015). According to previous studies, the pink color Hubba-Bubba Tape gum was discontinued (Schimmel et al., 2015), but we were able to purchase it through Coupang apps. It was speculated that the SDHue values obtained in the present study were greater than those obtained in the previous studies because the pink color of the Seriously Strawberry Hubba-Bubba gum used in the current study was darker. The SDHue showed a significant decrease as the number of chewing cycles increased; thus, this digital image analysis method showed differences in the SDHue based on the number of chewing cycles. However, in the two experimental groups, the SDHue value showed no significant change over time at 5 and 10 chewing cycles and was not significantly different from that of the normal occlusion group. On the other hand, the SDHue showed significant changes over time in the two experimental groups, with the greatest difference at 20 chewing cycles. This was in line with the findings of previous studies, according to which 20 chewing cycles were sufficient for extracting valid conclusions for chewing efficiency(Halazonetis et al., 2013; Schimmel et al., 2015). Based on the above results, the MA was evaluated using the specimen obtained after 20 cycles. If the SDHue was large, the MA was considered low, and if the SDHue was small, the MA was considered high.

The MA in the two experimental groups was lower than that in the normal occlusion group immediately after orthodontic treatment when the wrap-around retainer was delivered. In the extraction and non-extraction groups, MA showed a significant increase over time, and at 1-month post-treatment, it had improved to a level not significantly different from that in the normal occlusion group. Furthermore, the mean value of MA at 1-year post-treatment was similar to that in the normal occlusion group. Thus, the first null hypothesis was rejected.

Mastication undergoes a slow reprogramming to adapt to evolving conditions such as orthodontic movements (Bourdiol et al., 2020). The low MA values immediately after orthodontic treatment may be attributed to the time needed to learn a new masticatory praxis enabling the patient to adapt to the new occlusion. Gameiro et al.(2017) reported that non-extraction orthodontic treatment helped improve the MP to the normal occlusion level. Makino et al.(2014) reported that the occlusal force and OCA were lower than those before the orthodontic treatment, but the subjective masticatory ability improved in all patient's post-treatment. In this study, MA at 1-month post-treatment showed no significant difference between the two experimental and normal occlusion groups, which was in line with the above studies (Gameiro et al., 2017; Makino et al., 2014).

On the other hand, we observed no significant difference in the MA between the non-extraction and extraction groups. The post-canine functional tooth units (FTUs) in the non-extraction and extraction groups were 12 and 10, respectively. Hatch et al.(2001) stated that the number of FTUs and bite force influenced MP and that the number of FTUs was the most crucial factor. Many studies have suggested that >20 teeth and >8 FTUs are sufficient to maintain the masticatory function. The results of our study matched with those of Hatch et al. (Hatch et al., 2001); it was shown that the FTU of a premolar was 0.5 and that premolar extraction did not affect the MP after orthodontic treatment. Thus, the second null hypothesis in this study was accepted.

The MBF and OCA showed low values in the non-extraction and extraction groups immediately after orthodontic treatment and a significant increase 1-year post-treatment ($P<0.001$); however, even at 1-year post-treatment, they remained lower than the corresponding values in the normal occlusion group. Based on previous studies, it is expected that two more years would be necessary for the MBF and OCA values to reach the normal occlusion group levels (Yoon et al., 2017). The results of this study showed that at 1-month post-treatment, unlike the MBF and OCA, the MP improved to a level not significantly different from that in the normal occlusion group.

In this study, the correlation between MP, MBF, and OCA was examined by evaluating the changes in MP immediately and at 1 month, 6 months, and 1 year after active orthodontic treatment. The Pearson's correlation coefficient for the association between the MA and MBF and between the MA and OCA was 0.382 and 0.350, respectively ($P<0.01$).

Previous studies reported that various factors, such as occlusal force, OCAs, jaw movement, and characteristics of muscle activity, among others, affect MP (Hatch et al., 2001; Julien et al., 1996; Lepley et al., 2011; Owens et al., 2002; Shiga et al., 2012; Wilding and Lewin, 1994; Wilding and Shaikh, 1997). Although there is a controversy regarding the correlation between MP and occlusal force, OCA, jaw movement, and muscle activity, several studies have reported that the MBF and OCA are the most important factors and that the jaw movement and salivary flow rate play important roles (Julien et al., 1996; Lambrecht, 1965; Lepley et al., 2011). Okiyama et al.(2003) examined the relationship between MP and MBF in dentate individuals using test foods of varying hardness, and found a positive correlation between the two variables, with a lower positive correlation coefficient with soft gummy jelly than with harder ones. In this study, which used gums of a hardness lower than that of jelly, the correlation between the MA and bite force was less than that found in other studies. This result suggests that the function of mixing and kneading foods might not require a high bite force. According to Yoshida et al. (2007), MA assessed using the two-color chewing gum method is expected to correlate more with the mandibular movement parameters than with the bite force. Further research should be conducted to identify the factor that significantly influences the MA.

This study has some limitations. First, although participants of the treatment groups reported good compliance with the removable retainer, the wearing time of the retainers was not measured objectively (for example, using a built-in electronic chip) and may therefore have not been controlled among participants. However, all participants were provided fixed retainers on maxillary and mandibular anterior teeth, and other factors, such as sex, age, skeletal type, and type of retainer were controlled. Thus, not measuring the wearing time of removable retainers may not have significantly affected the results. Second, MA was evaluated in the normal occlusion group only at one time point. In future, prospective studies should ensure that the MA does not change over time in individuals with normal occlusion. Previous studies have reported that age is not related to masticatory performance and that there is no change in the occlusion of individuals with normal occlusion over a short period(Hatch et al., 2001; Kim et al., 2021). Therefore, this limitation does not reduce the merit of the present results. Third, the MP before treatment and the number of chewing cycles that reached saturation were not evaluated. However, many studies have reported significant differences in MP depending on the severity of the malocclusion and the amount of crowding (Bae et al., 2017; Magalhaes et al., 2010; Ngom et al., 2007). The treatment period varies depending on the severity of malocclusion and difficulty of treatment, especially in occlusal conditions that will be different at the initial occlusion before treatment, the variables at the baseline before treatment would not be reliable parameter to compare two groups. Besides, the volume of the gum decreased by 40% at more than 20 chewing cycles (Halazonetis et al., 2013); thus, it must be evaluated whether discernment between the participants at more than 20 cycles is possible. Further research in this regard is therefore necessary.

V. CONCLUSIONS

This study was performed to evaluate the change in masticatoy performance over time in patients completed orthodontic treatment using fixed orthodontic appliances with extraction or non-extraction during 1-year retention period.

The results are as follows:

1. The MA immediately after orthodontic treatment was lower than that observed in normal occlusion group but showed a time-dependent gradual increase during 1-year retention period ($P<0.01$).
2. The MA at 1-month post-treatment was not significantly different from that in the normal occlusion group ($P>0.05$), but the MBF and OCA at 1-year post-treatment were significantly lower than those in the normal occlusion group ($P<0.01$).
3. The MA showed a significant correlation with the MBF and OCA ($P<0.01$).
4. No significant difference was observed in MA between the non-extraction group and extraction group ($P>0.05$).

This study was concluded the MP immediately after orthodontic treatment in the treatment groups was lower than that in the normal occlusion group but increased gradually over time during the retention period and improved to levels similar to that in the normal occlusion group at 1-month post-treatment. Further, extraction did not affect the MP after orthodontic treatment.

REFERENCES

Aquilanti L, Scalise L, Mascitti M, Santarelli A, Napolitano R, Verdenelli L, et al. (2020). A Novel Color-Based Segmentation Method for the Objective Measurement of Human Masticatory Performance. *Applied Sciences-Basel* 10(23).

Bae J, Son WS, Kim SS, Park SB, Kim YI (2017). Comparison of masticatory efficiency according to Angle's classification of malocclusion. *Korean J Orthod* 47(3): 151-157.

Bourdiol P, Hennequin M, Peyron MA, Woda A (2020). Masticatory Adaptation to Occlusal Changes. *Front Physiol* 11: 263.

Choi YJ, Chung CJ, Kim KH (2010). Changes in occlusal force and occlusal contact area after orthodontic treatment. *Korean Journal of Orthodontics*.

Choi YJ, Lim H, Chung CJ, Park KH, Kim KH (2014). Two-year follow-up of changes in bite force and occlusal contact area after intraoral vertical ramus osteotomy with and without Le Fort I osteotomy. *Int J Oral Maxillofac Surg* 43(6): 742-747.

English JD, Buschang PH, Throckmorton GS (2002). Does malocclusion affect masticatory performance? *Angle Orthod* 72(1): 21-27.

Gameiro GH, Magalhaes IB, Szymanski MM, Andrade AS (2017). Is the main goal of mastication achieved after orthodontic treatment? A prospective longitudinal study. *Dental Press J Orthod* 22(3): 72-78.

Halazonetis DJ, Schimmel M, Antonarakis GS, Christou P (2013). Novel software for quantitative evaluation and graphical representation of masticatory efficiency. *J Oral Rehabil* 40(5): 329-335.

Hama Y, Kanazawa M, Minakuchi S, Uchida T, Sasaki Y (2014). Reliability and validity of a quantitative color scale to evaluate masticatory performance using color-changeable chewing gum. *J Med Dent Sci* 61(1): 1-6.

Hatch JP, Shinkai RS, Sakai S, Rugh JD, Paunovich ED (2001). Determinants of masticatory performance in dentate adults. *Arch Oral Biol* 46(7): 641-648.

Henrikson T, Ekberg E, Nilner M (2009). Can orthodontic treatment improve mastication? A controlled, prospective and longitudinal study. *Swed Dent J* 33(2): 59-65.

Julien KC, Buschang PH, Throckmorton GS, Dechow PC (1996). Normal masticatory performance in young adults and children. *Arch Oral Biol* 41(1): 69-75.

Kaya MS, Guclu B, Schimmel M, Akyuz S (2017). Two-colour chewing gum mixing ability test for evaluating masticatory performance in children with mixed dentition: validity and reliability study. *J Oral Rehabil* 44(11): 827-834.

Kim S, Doh RM, Yoo L, Jeong SA, Jung BY (2021) Assessment of age-related changes on masticatory function in a population with normal dentition. Int J Environ Res Public Health 18:6899.

Lambrecht JR (1965). The Influence of Occlusal Contact Area on Chewing Performance. *J Prosthet Dent* 15: 444-450.

Lepley CR, Throckmorton GS, Ceen RF, Buschang PH (2011). Relative contributions of occlusion, maximum bite force, and chewing cycle kinematics to masticatory performance. *Am J Orthod Dentofacial Orthop* 139(5): 606-613.

Liedberg B, Owall B (1995). Oral bolus kneading and shaping measured with chewing gum. *Dysphagia* 10(2): 101-106.

Magalhaes IB, Pereira LJ, Marques LS, Gameiro GH (2010). The influence of malocclusion on masticatory performance. A systematic review. *Angle Orthod* 80(5): 981-987.

Makino E, Nomura M, Motegi E, Iijima Y, Ishii T, Koizumi Y, et al. (2014). Effect of orthodontic treatment on occlusal condition and masticatory function. *Bull Tokyo Dent Coll* 55(4): 185-197.

Ngom PI, Diagne F, Aidara-Tamba AW, Sene A (2007). Relationship between orthodontic anomalies and masticatory function in adults. *Am J Orthod Dentofacial Orthop* 131(2): 216-222.

Okiyama S, Ikebe K, Nokubi T (2003). Association between masticatory performance and maximal occlusal force in young men. *J Oral Rehabil* 30(3): 278-282.

Owens S, Buschang PH, Throckmorton GS, Palmer L, English J (2002). Masticatory performance and areas of occlusal contact and near contact in subjects with normal occlusion and malocclusion. *Am J Orthod Dentofacial Orthop* 121(6): 602-609.

Prinz JF (1999). Quantitative evaluation of the effect of bolus size and number of chewing strokes on the intra-oral mixing of a two-colour chewing gum. *J Oral Rehabil* 26(3): 243-247.

Schimmel M, Christou P, Herrmann F, Muller F (2007). A two-colour chewing gum test for masticatory efficiency: development of different assessment methods. *J Oral Rehabil* 34(9): 671-678.

Schimmel M, Christou P, Miyazaki H, Halazonetis D, Herrmann FR, Muller F (2015). A novel colourimetric technique to assess chewing function using two-coloured specimens: Validation and application. *J Dent* 43(8): 955-964.

Shiga H, Kobayashi Y, Katsuyama H, Yokoyama M, Arakawa I (2012). Gender difference in masticatory performance in dentate adults. *J Prosthodont Res* 56(3): 166-169.

Sultana MH, Yamada K, Hanada K (2002). Changes in occlusal force and occlusal contact area after active orthodontic treatment: a pilot study using pressure-sensitive sheets. *J Oral Rehabil* 29(5): 484-491.

van den Braber W, van der Bilt A, van der Glas H, Rosenberg T, Koole R (2006). The influence of mandibular advancement surgery on oral function in retrognathic patients: a 5-year follow-up study. *J Oral Maxillofac Surg* 64(8): 1237-1240.

van den Braber W, van der Bilt A, van der Glas HW, Bosman F, Rosenberg A, Koole R (2005). The influence of orthognathic surgery on masticatory performance in retrognathic patients. *J Oral Rehabil* 32(4): 237-241.

van den Braber W, van der Glas H, van der Bilt A, Bosman F (2004). Masticatory function in retrognathic patients, before and after mandibular advancement surgery. *J Oral Maxillofac Surg* 62(5): 549-554.

van der Bilt A (2011). Assessment of mastication with implications for oral rehabilitation: a review. *J Oral Rehabil* 38(10): 754-780.

van der Bilt A, Engelen L, Pereira LJ, van der Glas HW, Abbink JH (2006). Oral physiology and mastication. *Physiol Behav* 89(1): 22-27.

Weijenberg RA, Scherder EJ, Visscher CM, Gorissen T, Yoshida E, Lobbezoo F (2013). Two-colour chewing gum mixing ability: digitalisation and spatial heterogeneity analysis. *J Oral Rehabil* 40(10): 737-743.

Wilding RJ, Lewin A (1994). The determination of optimal human jaw movements based on their association with chewing performance. *Arch Oral Biol* 39(4): 333-343.

Wilding RJ, Shaikh M (1997). Muscle activity and jaw movements as predictors of chewing performance. *J Orofac Pain* 11(1): 24-36.

Yoon W, Hwang S, Chung C, Kim KH (2017). Changes in occlusal function after extraction of premolars: 2-year follow-up. *Angle Orthod* 87(5): 703-708.

Yoshida E, Fueki K, Igarashi Y (2007). Association between food mixing ability and mandibular movements during chewing of a wax cube. *J Oral Rehabil* 34(11): 791-799.

Zarrinkelk HM, Throckmorton GS, Ellis E, 3rd, Sinn DP (1995). A longitudinal study of changes in masticatory performance of patients undergoing orthognathic surgery. *J Oral Maxillofac Surg* 53(7): 777-782; discussion 782-773.

국문 요약

발치 및 비발치 교정치료 후 유지기간동안 저작효율의 변화

연세대학교 대학원 치의학과
(지도교수 이 기 준)
이 송 현

본 연구의 목적은 ViewGum-software를 이용한 두가지 색깔 껌의 혼합능력을 평가하는 방법으로 발치, 비발치 교정치료 후 유지기간 1년동안에 시간에 따르는 저작효율의 변화를 정상교합과 비교 평가하는 것과 동시에 발치가 교정치료 후 저작효율에 영향을 미치는가를 평가하는 것이다.

실험군은 총 32명의 고정성교정장치를 이용하여 교정치료를 끝낸 환자들 중 비발치군 18명(남, 여 각각 9명씩, 평균나이: 25.33±5.26)과 발치군 14명(남, 여 각각 7명씩, 평균나이: 29.14±7.00)으로 나누고 대조군으로는 정상교합군 20명(남, 여 각각 10명씩, 평균나이: 28.3±6.57)으로 구성하였다.

저작효율은 두가지 색상의 껌을 씹은 후 스캔한 이미지를 ViewGum-software를 이용하여 혼합정도를 평가하는 방법으로 측정하였고 최대교합력과 교합면적은 압력감지필름 시스템II를 이용하여 측정하였다.

고정식 교정장치 제거 1주일 후 가철성 유지장치를 장착하는 날과 그 후 1

개월, 6개월, 1년이 되는 시기에 각각 측정하여 다음과 같은 결과를 얻었다.

1. 교정치료 직후 교정치료군의 혼합능력은 정상교합군보다 낮은 값을 보이지만 유지기간 1년동안에 시간에 따르는 증가를 보여주었다 ($P<0.01$).
2. 교정치료군의 혼합능력은 교정치료 1개월 후 정상교합군과 유의한 차이가 없었으나($P>0.05$) 교정치료 1년 후 교정치료군의 최대교합력과 교합면적은 정상교합군보다 여전히 낮은 값을 보여주었다 ($P<0.01$).
3. 교정치료 후 혼합능력은 최대교합력, 교합면적과 유의한 상관관계를 보여주었다 ($P<0.05$).
4. 발치군과 비발치군의 혼합능력을 비교한 결과 어느 시기에도 유의한 차이를 보이지 않았다($P>0.05$).

본 연구를 통하여 교정치료 후 1년간의 유지기간 동안에 교합력과 교합면적은 정상교합수준에 이르지 못하는 것과는 달리 저작효율은 치료 1개월 후 정상교합과 비슷한 수준으로 개선되며 더욱이 발치는 교정치료 후 저작효율에 영향을 주지 않는다는 결론을 내릴 수 있었다.

핵심이 되는 말: 교정치료, 저작효율, 두가지 색깔 껌의 혼합능력, 발치 및 비발치, 유지기간, 교합력과 교합면적