Masticatory Function Assessment for Patients with Non-sagittal Discrepancies using MAI (Mixing Ability Index) and FIA (Food Intake Ability)

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This certifies that the dissertation thesis of

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최 태 현

Table of Contents

List of Figures

List of Tables

ABSTRACT

Masticatory Function Assessment for Patients with Non-sagittal Discrepancies using MAI (Mixing Ability Index) and FIA (Food Intake Ability)

To assess masticatory efficiency in patients with non−sagittal discrepancies, static and dynamic objective measurements and subjective evaluation were carried out. The maximum bite force and the contact area using Dental Prescale® system as a static objective assessment, Mixing Ability Index (MAI) as a dynamic objective evaluation, and Food Intake Ability (FIA) as a subjective assessment were analyzed from 21 subjects (13 men and 8 women; mean age 24.62 years) in normal occlusion (Group N) and 64 patients with posterior crossbite (Group C), anterior openbite (Group O), or both (Group B). The differences of the maximum bite force, the contact area, the MAI and the FIA were compared and their correlations were figured out. The results of the present study were as follows;

1. The maximum bite force, the contact area, the MAI and the FAI were significantly lower in the non−sagittal malocclusion group compared to those in the normal group ($P < 0.0001$).
2. In both objective and subjective assessments, Group N presented better masticatory function than did those in Group C, O and B ($P < 0.0001$), which did not differ between each other.

3. The maximum bite force and the contact area showed lower correlations with the MAI (both r = 0.24, P < 0.5), representing the limitation of static evaluation of mastication.
4. The FIA showed moderate correlation with the MAI (r = 0.38, P < 0.01), implying that a subjective evaluation of mastication could be used as a simple assessment, especially with the hard foods and the selected key foods.

These results revealed that masticatory function in patients with non-sagittal discrepancies is deteriorated both objectively and subjectively, suggesting a possible rationale of orthodontic treatment in terms of improvement of function.

Key words: masticatory function, bite force, non-sagittal discrepancies

Masticatory Function Assessment for Patients with Non-sagittal Discrepancies using MAI (Mixing Ability Index) and FIA (Food Intake Ability)

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I. Introduction

Transverse discrepancies of dental occlusion and anterior openbite are common types of malocclusion, having prevalence of 13−19% (Carvalho et al., 2011; Dacosta and Utomi, 2011) and 8−19% (Carvalho et al., 2011; Granville−Garcia et al., 2010), respectively. Non−sagittal relations of the maxillo−mandibular complex have been relatively less interested than antero−posterior relation, which is more directly related to esthetic concerns. Non−sagittal dental relation, such as posterior cross/scissors bite and anterior openbite, is difficult to quantify, while sagittal relation can be analyzed with diverse methods in cephalometric analysis and Angle's classification.

Improvement of oral health, functions and esthetics are ultimate goals of dental treatment, but especially of orthodontics (Perry, 1962). Esthetics has been a main need for orthodontic treatment as many indices for orthodontic needs such as Index of Orthodontic Treatment Need (IOTN) and Dental Aesthetic Index (DAI) represent. Various chief complaints of orthodontic treatment reflect patients' demands mostly for improved esthetics, rather than improved oral health or functions. Orthodontists have also pursued for static assessment of the ideal occlusion and the perfect profile (Perry, 1962). Besides esthetics, mastication, one of the functions of maxillofacial complex, is closely related to quality of life (QOL) (Miura et al., 2000; Nguyen et al., 2011; Takata et al., 2006) and thus crucial for getting old well especially in recent eras when long longevity is presumed. However, impaired masticatory function is neither often recognized by patients, nor assessed objectively by orthodontists, eventually not leading to demands or needs for orthodontic treatment.

Masticatory performance is one of the reliable measures of masticatory function and known to be closely related with occlusion (Lepley et al., 2011). Functional aspects of malocclusion are considered to be difficult in quantification and assessment, while assessment of morphological aspects of malocclusion has been carried out using radiographs and models. Occlusal force and occlusal contact area have been studied as representatives of functional indices (Sultana et al., 2002). A conventional method of measuring occlusal force and occlusal contact is to use a pressure sensitive sheet (Harada et al., 2000; Iwase et al., 1998). However, it does not represent masticatory performance in terms of dynamic occlusion because it is assessed in static maximum intercuspation position. It is assumed that subjects with larger contact area and higher occlusal force would masticate better than those with lower values.

Various methods of evaluating masticatory performance have been developed. Most of them being complicated and time consuming, thus a simple and new method, mixing ability index (MAI) was developed by Sato (H. Sato et al., 2003). Its validity and reliability were assured in comparsion with the sieving method

(S. Sato et al., 2003). However, these methods utilize only one kind of test foods.

A subjective method to evaluating masticatory ability includes self-assessment using questionnaires which provide different food intake abilities depending on various kinds of foods. Food intake Ability (FIA) was developed and found to be an effective tool for evaluating masticatory ability in Japan (Sakurai et al., 2005), and further developed and modified in Korea (Kim et al., 2009).

Several studies have been carried out to evaluate masticatory function according to types of skeletal malocclusion. Yoon et al. (Yoon et al., 2010) compared the occlusal force according to skeletal malocclusion type (Class I, II and III), age, gender in Korean population. Other group studied masticatory efficiency with bead system comparing skeletal Class I, II and III (Picinato-Pirola et al., 2012). These studies showed that normal occlusion group had higher occlusal force, larger contact area and better masticatory efficiency than Class II and III malocclusion groups. Other study showed that patients with brachyfacial pattern had higher occlusal force than those with dolicofacial pattern (Kitafusa, 2004). Most of previous studies of the relationship between malocclusions and masticatory performance include sagittal relation either dental or skeletal Class I, II and III (Magalhaes et al., 2010). Objective masticatory function, both static and dynamic, and subjective evaluations of mastication with various types of foods has rarely been reported in the patients with dental transverse and vertical discrepancies.

The purpose of this study was to investigate objective static and dynamic masticatory performance and subjective masticatory ability in patients with non-sagittal discrepancies.

II. Materials and Methods

The study was proven by IRB (Institution of Research review Board) of the Yonsei Dental University Hospital, approval no. 2−2011−0056, and all subjects signed an informed consent form.

A. Subjects

The study sample consisted of 85 individuals including 21 of normal group (13 men and 8 women; mean age 24.62 years) (Table 1). The normal group (Group N) consisted of volunteers assessed as normal occlusion who meet the following criteria by clinical exam, cephalometric analysis and model analysis;

1. Have natural dentition with no missing teeth except for the third molars.
2. Show no alteration of facial morphology or dental occlusion
3. Be in Korean normal range of anteroposterior and vertical measurements such as ANB, Wits, mandibular plane angle, gonial angle. (Kim et al., 2001)
4. Have Class I canine and molar relations and with normal overjet and overbite.

The malocclusion group consisted of 64 patients, visited Yonsei University Dental Hospital, who have dental transverse discrepancy, unilateral/bilateral buccal crossbite at more than two molars (Group C), anterior openbite less than 0mm (Group O) or both (Group B) (Figure 1). All subjects had no missing teeth and no previous orthodontic treatment. Both the normal and the three malocclusion groups were assessed with initial cephalometric analysis (Table 2).

Table 1. Descriptions of the subjects

	Group N	Group C	Group O	Group B	Total
Age (Mean ±SD)	24.62±2.1	20.36±4.8	23.27±4.6	23.2±9.0	22.82±5.7
Male (N)	13	11	6	6	36
Female (N)	8	11	16	14	49
Total (N)	21	22	22	20	85

Group N: subjects with normal occlusion; Group C: subjects with buccal crossbite;
Group O: subjects with anterior openbite; Group B: subjects with buccal crossbite and anterior openbite

Fig. 1 Clinical examples of the experimental groups
(The arrows indicate posterior crossbite or anterior openbite.)

Table 2. Cephalometric measurements of the subjects

	Group N	Group C	Group O	Group B	Sig
SNA	82.3±3.5	80.3±4.6	80.2±3.0	80.3±4.6	NS
SNB	79.3±3.4	79.4±5.0	76.1±5.1	79.1±6.0	*
ANB	3.0±1.7	0.9±2.4	4.1±3.7	1.1±3.8	*
Sn to MP	33.7±5.3	37.2±7.3	42.9±8.4	38.5±6.1	NS
U1 to SN	107.1±6.1	107.4±6.9	107.4±7.3	107.0±8.1	NS
IMPA	96.8±5.2	86.8±6.9	93.9±7.0	90.1±8.6	NS
PFH	93.3±7.6	86.9±9.9	83.8±9.2	89.1±7.5	NS
AFH	139.2±7.5	136.3±10.6	138.7±8.4	140.0±8.7	NS
PFH/AFH	67.0±4.4	63.8±5.7	60.4±6.0	63.7±3.9	NS

Group N: subjects with normal occlusion; Group C: subjects with buccal crossbite;
Group O: subjects with anterior openbite; Group B: subjects with buccal crossbite and anterior openbite
All values are (mean ± SD)
Sig.: The significant difference was defined by one-way ANOVA
* indicates significance; NS indicates no significance.

B. Static evaluation by measurement of maximum bite force and contact area

To evaluate the objective static masticatory performance, the maximum bite force was measured using a pressure−sensitive film of 0.097 mm thickness (Dental Prescale® 50H, type R, Fuji Film Corp.,Tokyo, Japan). The subjects were instructed to bite on their maximum intercuspal position, sitting upright in a unit chair. After practice, the film was inserted into their mouth and the subjects were asked to bite on the central occlusion as hard as possible for 2 seconds. The films were digitized by CCD camera (Occluzer FPD 707, Fuji Film Corp., Tokyo, Japan) attached to the analyzing system (Figure 2). The maximum bite force and the contact area were measured.

Fig. 2 A Prescale® sheet and the Occluzer

C. Dynamic evaluation of masticatory efficiency by MAI (Mixing Ability Index)

The mixing ability test (MAT) using a two-colored wax cube was applied to evaluate objective dynamic masticatory efficiency. The test food used was a cuboidal wax cube of 12x12x12 mm, made up of six sheets of 12x12x2 mm, stacked one by one at right angle, each sheet consisted with three red and three green paraffin wax cuboids of 2x2x12 mm stacked facing each other, manufactured following Sato's study (H. Sato et al., 2003)(Figure 3a). The wax cubes were kept at 37° C to maintain their properties. The subjects were asked to chew a wax cube for 10 strokes at habitual chewing. The procedure was repeated three times. The chewed waxes were carefully removed from the mouth and dried. The images of the samples at both sides were taken using a digital camera (Coolpix 4500, Nikon Corp., Tokyo, Japan) under a standard light and distance condition. All images were saved as JPEG files and were analyzed using a digital image analyzer (Image-Proplus® 6.0 Media cybernetics Inc., Bethesda, MD, USA). From one side of a sample, the total projection area, the projection area above 50 um in thickness, the maximum length, the maximum breadth, the red area and the green area were calculated (Figure 3b). Mixing ability index (MAI) was calculated using the discriminant function optimized for Koreans, shown below (Jeong et al., 2010; Lee, 2008).

$$MAI = 1.00\times10^{-1}MIXR(50) - 1.5\times10^{-2}TR + 2.98\times10^{-1}LB + 0.00FF - 1.00\times10^{-3}AH - 7.336$$

MIXR(50): The ratio of color mixed area above 50μm thickness

TR: the ratio of area above 50μm thickness to total projection area

= (AH−A)/AH x100

LB: the ratio of maximum length to maximum breadth

= ML/MB

FF: the shape factor shows how flat the sample is

= ML2xπ/4xAHx100

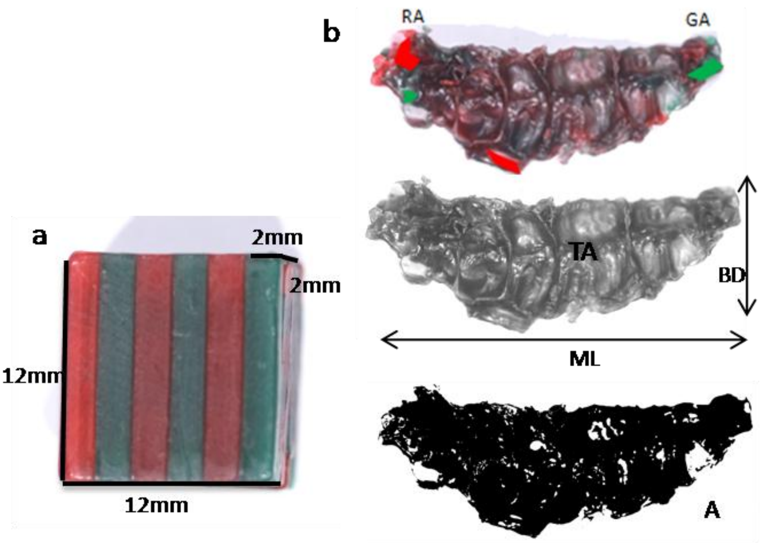

Fig. 3 Mixing Ability Test; a) The paraffin cube, b) A schematic diagram of the measurements of the test wax cubes

(GA: Green Area, RA: Red Area, TA: Total projection area, A: area >50um in thickness, ML: Maximum Length, BD: Maximum Breadth)

D. Subjective evaluation by Food Intake Ability (FIA)

To evaluate the subjective masticatory performance, food intake ability test was performed using a self-assessed questionnaires consisting of 30 foods. The 30 food types were adapted from a previous study (Kim et al., 2009). The subjects were requested to check FIA questionnaires using a five-point Likert scale: 'cannot chew at all' (1 point), 'difficult to chew' (2 points), 'cannot say either way' (3 points), 'can chew some' (4 points), 'can chew well' (5 points) (Figure 4). The total FIA score was calculated using the average score of 30 foods and the FIA scores of 5 hard foods (dried cuttle fish, dried filefish, French baguette, raw carrots and hard persimmon), 5 soft foods (Tofu, boiled potato, boiled rice, ham and watermelon), and 5 Key foods (dried cuttle fish, raw carrots, peanuts, cubed white radish Kimchi and caramel) were also calculated.

Questionnaire for evaluating subjective masticatory efficiency

date: ____________

Thank you for involving in the current study. This study includes not only the objective evaluation of masticatory efficiency but also subjective evaluation using a questionnaire. This questionnaire is for self-assessment of chewing. Please check a box corresponding to your status. All the data are secured and any other personal information is not asked to be written. We appreciate your sincere involvement.

Food items	Cannot chew all(1)	Difficult to chew(2)	Cannot say either way(3)	Can chew some(4)	Can chew well(5)
1.Ham					
2.Boiled rice					
3.Boiled fish					
4.Boiled fish paste					
5.Sweet jelly of red beans					
6. Boiled chicken meat					
7.Apple					
8.Tofu					
9.Hard rice cracker					
10.Peanuts					
11.Raw carrots					
12.Pickled radish					
13.Dried cuttle fish					
14.French baguette					
15.Caramel					
16.Glutinous rice cake					
17.Hard boiled burdock					
18.Watermelon					
19.Noodles					
20.Mandarin					
21.Yellow melon					
22.Stuffed cucumber pickle					
23.Cabbage kimchi					
24.Rib of pork					
25.Hard persimmon					
26.Cubed white radish kimchi					
27.Roast beef					
28.Steamed short ribs					
29.Boiled potato					
30.Dried filefish					

Fig. 4 The questionnaire for FIA

E. Statistical analysis

The normality of the samples was evaluated using Kolmogorov–Smirov test. For comparisons between the normal group and the malocclusion groups, the independent t–test or Mann–Whitney U test was used according to the data distribution. A one–way analysis of variance (ANOVA) and a Scheffe test for the post–hoc comparisons were applied to determine whether significant differences in the MAI among the groups. For the other variables, a Kruskal–Wallis test followed by Mann–Whitney U test with the Bonferroni's correction were applied for multiple comparisons between Group N and each of the other groups, which resulted in a new α–error level of 0.017. For reliability analysis of the MAT, one examiner performed the analysis with a given sample three times to derive intra–class coefficient. Pearson's correlation analysis was carried out to evaluate the relationships among the maximum bite force, the contact area, the MAI, and the FIA. All statistical analyses were carried out using the SPSS 20.0 (SPSS Inc., Chicago, IL, USA) statistical package program. The level of significance was pre–determined at $P < 0.05$.

III. Results

A. Evaluation of masticatory function

The measures of the maximum bite force, the contact area, the MAI in the patients of the malocclusion groups (Group C, O, and B) were significantly lower than those in Group N (P < 0.0001) and had wider ranges. The mean maximum bite force was 772 N in Group N and 373 N in the malocclusion groups (Group C, O, and B), both slightly higher than the corresponding median values. The FIA also showed significant differences between the normal and the malocclusion groups, while the FIA with soft foods being least significant (P < 0.01) (Table 3).

Table 3. Comparisons of masticatory function in the subjects with malocclusion and normal occlusion

	The normal occlusion Group (N) (n=21)	The malocclusion Groups (C, O and B) (n=64)	Sig.
Max. bite force (N)	752.6 (321.1, 1555.0)	367.1 (65.6, 1737.7)	***
Contact area (mm^2)	20.0 (6.7, 45.2)	6.8 (1.4, 48.6)	***
MAI	0.24 ± 1.06	−1.52 ± 1.52	***
Total FIA	5.0 (4.8, 5.0)	4.8 (2.1, 5.0)	***
Hard FIA	5.0 (4.0, 5.0)	4.2 (1.2, 5.0)	***
Soft FIA	5.0 (5.0, 5.0)	5.0 (2.8, 5.0)	**
Key food FIA	5.0 (4.4, 5.0)	4.6 (1.8, 5.0)	***

Group N: subjects with normal occlusion; Group C: subjects with buccal crossbite;
Group O: subjects with anterior openbite; Group B: subjects with buccal crossbite and anterior openbite
MAI: Mixing ability index, FIA: Food intake ability
MAI vales are mean ± SD, other values are median (min., max.) because of skewed distribution.
Sig. * The significant difference was defined by independent t-test or Mann-Whitney U test.
(* P < 0.05; ** P < 0.01; *** P < 0.0001)

Table 4. Comparisons of the objective and subjective evaluations of masticatory function among the experimental groups

	Group N	Group C	Group O	Group B	Sig.
Max. bite force (N)	752.6 (321.1, 1555.0)[b]	387.0 (87.3, 1737.7)[a]	293.3 (100.7, 669.1)[a]	226.3 (65.6, 779.9)[a]	***
Contact area (mm^2)	20.0 (6.7, 45.2)[b]	8.8 (2.2, 48.6)[a]	6.5 (1.7, 17.1)[a]	5.8 (1.4, 23.1)[a]	***
MAI	0.24 ± 1.06[b]	−1.27 ± 1.55[a]	−1.24 ± 1.43[a]	−2.06 ± 1.49[a]	***
Total FIA	5.0 (4.8, 5.0)[b]	4.8 (3.6, 5.0)[a]	4.8 (2.8, 5.0)[a]	4.4 (2.1, 5.0)[a]	***
Hard FIA	5.0 (4.0, 5.0)[b]	4.2 (2.4, 5.0)[a]	4.2 (1.2, 5.0)[a]	3.8 (1.8, 5.0)[a]	***
Soft FIA	5.0 (5.0, 5.0)[b]	5.0 (4.4, 5.0)[b]	5.0 (4.0, 5.0)[a]	5.0 (2.8, 5.0)[a]	**
Key food FIA	5.0 (4.4, 5.0)[b]	4.8 (2.6, 5.0)[a]	4.6 (1.8, 5.0)[a]	4.1 (2.0, 5.0)[a]	***

Group N: subjects with normal occlusion; Group C: subjects with buccal crossbite;
Group O: subjects with anterior openbite; Group B: subjects with buccal crossbite and anterior openbite
MAI: Mixing ability index, FIA: Food intake ability
MAI vales are mean ± SD, other values are median (min., max.) because of skewed distribution.
Sig. The significant difference was defined by one-way ANOVA or Kruskal-Wallis test
(* $P < 0.05$; ** $P < 0.01$; *** $P < 0.0001$)
[a,b] The same letter indicates no significance at $\alpha < 0.05$ (MAI), $\alpha < 0.017$ by Bonferroni's correction.

1. The maximum bite force and the contact area

The maximum bite force and the contact area of Group C, O and B showed significant differences compared to those of Group N ($P < 0.0001$, $P < 0.0001$, $P < 0.0001$, respectively) (Table 4). Within the malocclusion groups, Group C showed the highest values in the maximum bite force and the contact area, followed by Group O and Group B (Table 4, Figure 5 and 6). The mean maximum bite forces were 772 N in Group N, 475 N in Group C, 325 N in Group O and 310 N in Group B, which were only 61.5%, 42.1% and 40.1% of that of Group N, respectively. There were no significant differences among the malocclusion groups.

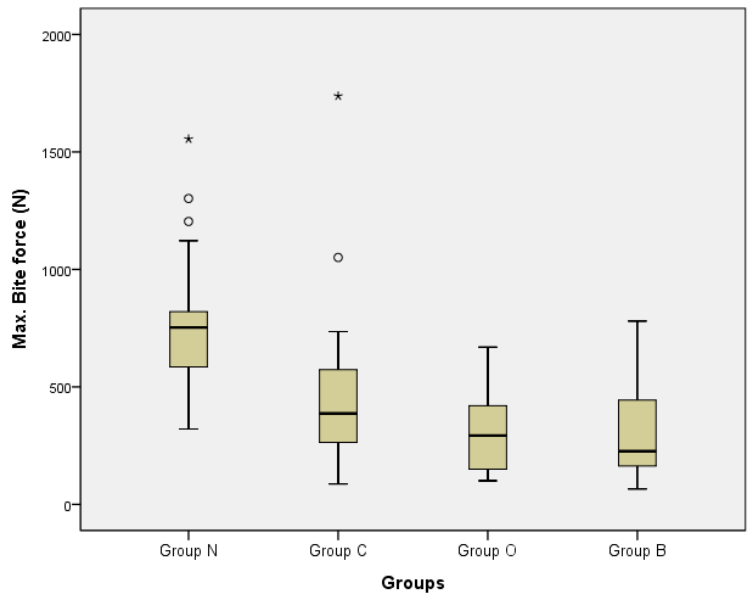

Fig. 5 The distribution of the maximum bite force

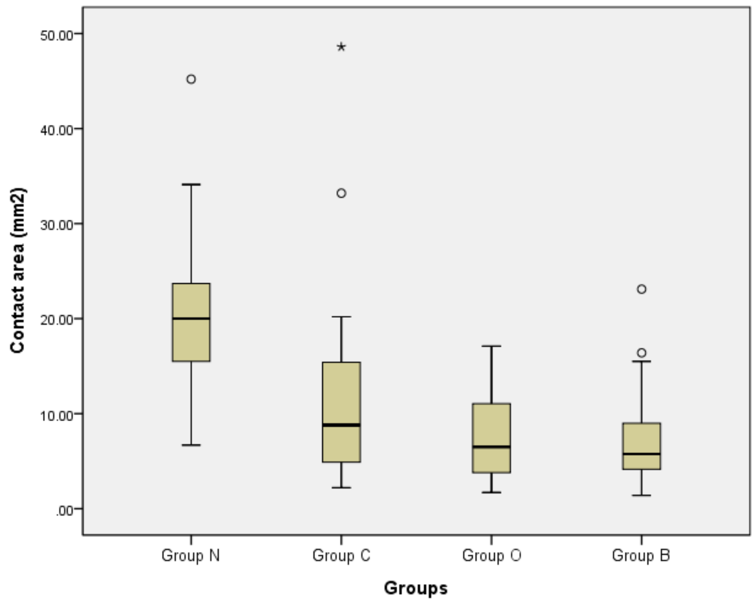

Fig. 6 The distribution of the contact area

2. Mixing Ability Index

The MAI value of the normal occlusion group was positive, while those of the malocclusion groups were negative, each showing significant differences compared to that of Group N (Table 4). The MAI of Group C and Group O were similar each other, and higher than that of Group B, the lowest (Figure 7). There were no significant differences among the malocclusion groups. The intra-class correlation coefficient was 0.948 (P =0.018).

It was easy to distinguish the chewed wax blocks representing various masticatory efficiencies. There are some typical examples of the test wax cubes; a well-mixed wax represented good masticatory efficiency (Figure 8a), while medium and poorly mixed waxes showed low mixing ability (Figure 8b, c and d).

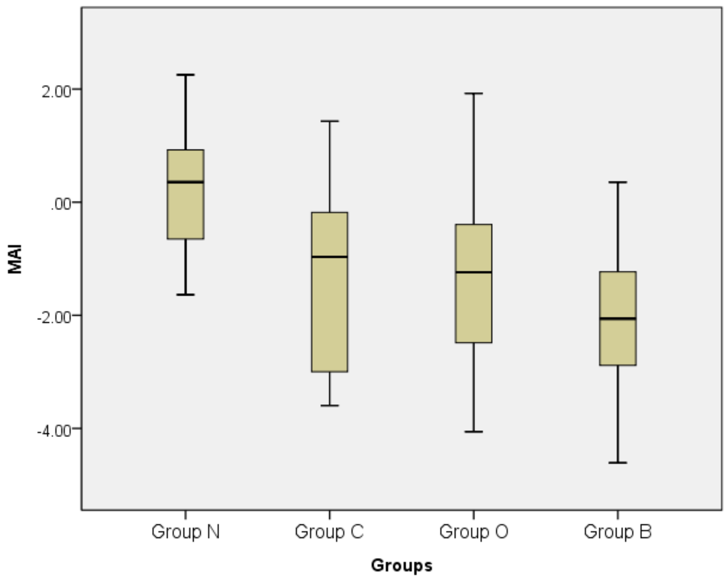

Fig. 7 The distribution of the MAI

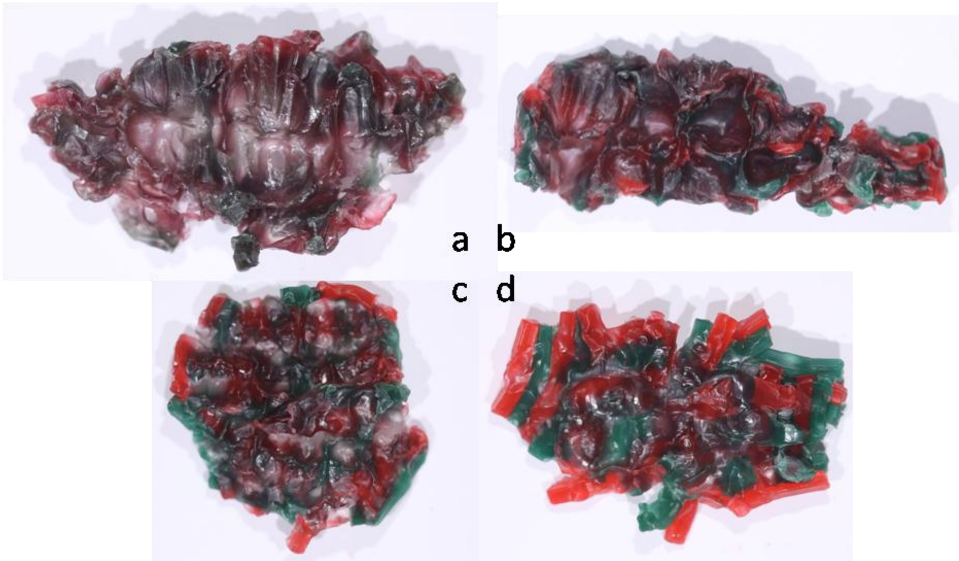

Fig. 8 The examples of the chewed test waxes: a) one in Group N, b) one in Group C, c) one in Group O, d) one in Group B

3. Food Intake Ability

The mean FIA scores of total 30 foods, 5 hard foods, and 5 Key foods of subgroups showed significant differences compared to those of Group N. The subjects in Group N scored their masticatory ability above 4 even with hard foods, while the patients in Group C, O and B showed wider range of FIA, especially with the hard and the key foods. There were no differences in the FIA of 5 soft foods between Group N and C (Table 4 and Figure 9).

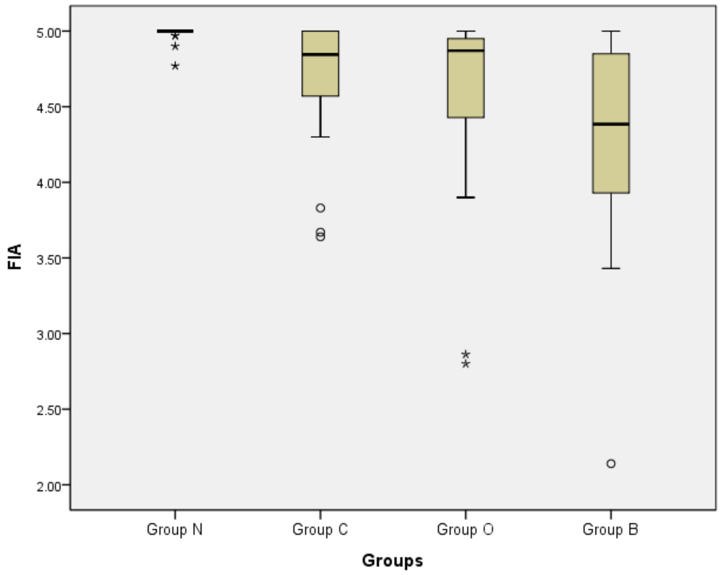

Fig. 9 The distribution of the total FIA

B. Correlations

The evaluation of the correlation between the maximum bite force and the contact area revealed a strong correlation (r = 0.99, P < 0.0001) (Table 5, Figure 10). On the other hand, the MAI and the maximum bite force showed significant but weak correlation (r = 0.24, P < 0.5) (Table 5, Figure 11). The correlations between the maximum bite force and the FIA and between the MAI and the FIA showed moderate correlations (r = 0.358, r = 0.383 respectively, P < 0.01) (Table 5, Figure 12). Among the FIA, the total FIA was strongly related to hard food FIA and key food FIA (r = 0.921, r = 0.956 respectively, P < 0.01).

Table 5. Pearson correlation coefficients between the maximum bite force, the contact area, the MAI and the FIA

	Max. bite force	Contact area	MAI	Total FIA	Hard FIA	Soft FIA	Key food FIA
Max. bite force	1	0.986**	0.236*	0.358**	0.399**	0.280*	0.365**
Contact area		1	0.242*	0.364**	0.405**	0.281*	0.369**
MAI			1	0.383**	0.380**	0.241*	0.358**
Total FIA				1	0.921**	0.779**	0.956**
Hard FIA					1	0.553**	0.964**
Soft FIA						1	0.615**
Key food FIA							1

MAI: Mixing ability index, FIA: Food intake ability
* indicates significance (*$P < 0.05$; ** $P < 0.01$).

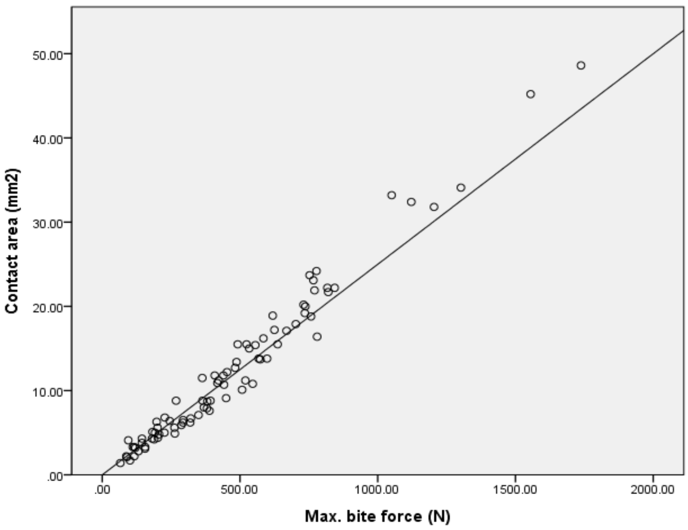

Fig. 10 The correlation between the maximum bite force and the contact area

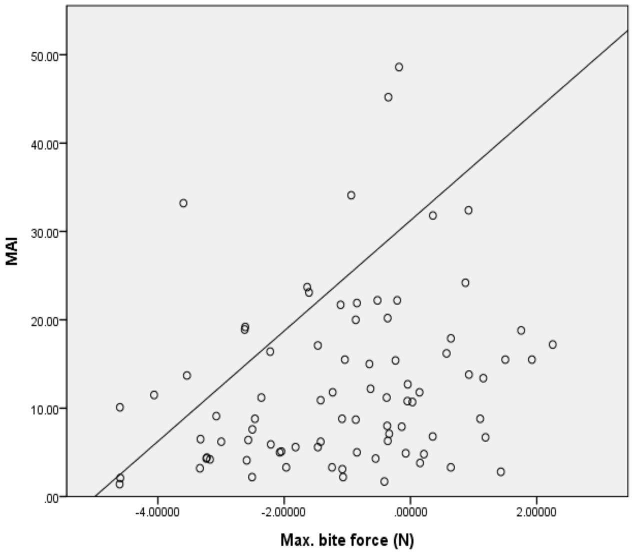

Fig. 11 The correlation between the maximum bite force and the MAI

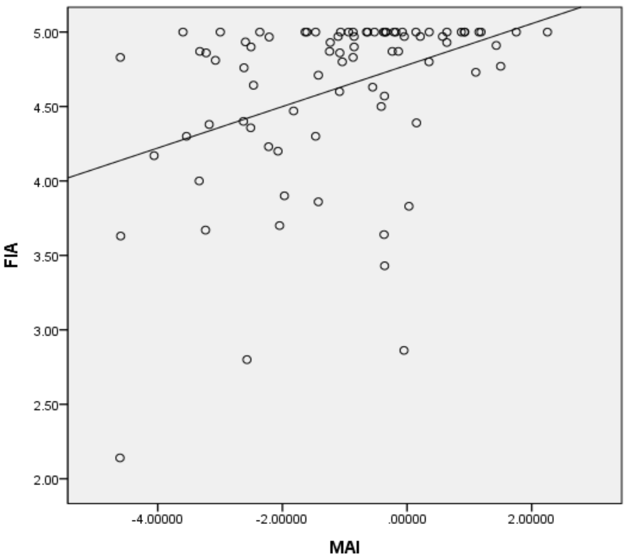

Fig. 12 The correlation between the MAI and the FIA

IV. Discussion

In this study, masticatory function of the patients with non-sagittal discrepancies was evaluated using objective static and dynamic methods and subjective questionnaires. The maximum bite force, the contact area, the MAI and the FIA were prominently lower in the non-sagittal malocclusion group than those in the normal occlusion group, representing significantly lower masticatory function both objectively and subjectively.

As a static evaluation, maximum occlusal force and contact area were measured using pressure sensitive sheets, Dental Prescale® system. It is known that this method has several advantages; the thin film enables a subject to bite at a position near the intercuspal position with minimal interferences, relatively short period of time is needed to study and the equipment is simple (Suzuki et al., 1997). Although this is a measuring method of static occlusion, some previous studies reported that there is positive correlation between the masticatory efficiency and maximum occlusal force (Fontijn-Tekamp et al., 2000; Suzuki et al., 1994). Another method to measure maximum occlusal force is using T-scan (Tekscan Inc., South Boston, MA, USA) which displays dynamically the occlusal forces on each tooth throughout chewing cycles. However, the values measured from T-scan are not absolute values so that only comparable within the same individual, thus making it impossible to compare the values between individuals. Therefore, Prescale® system was used in this study.

The mean maximum bite force measured in this study was 772 N in the normal occlusion group and 373 N in the malocclusion groups. The median value of maximum bite force in this study was similar with that of the previous studies (Sato et al., 1999; Yoon et al., 2010), which were 740.2 N, 744.5 N respectively. Group N showed the highest value of the maximum bite force and the contact area, followed by Group C, O and B with significant differences ($P < 0.0001$). This might be because fewer teeth contacts or fail to contact in the maximum intercuspal position results in less contact area. In previous studies, it is reported that children with unilateral posterior crossbite have lower maximum bite force and the number of teeth in contact (Andrade et al., 2009). This is coincident with the results of the studies that the maximum occlusal force is positively correlated with the contact area (Hidaka et al., 1999; Ingervall and Minder, 1997; Yoon et al., 2010), and this study which showed very strong correlation. This is not surprising because the maximum bite force and the contact area were measured by a same tool.

Evaluation of masticatory performance has been studied mostly in prosthetic field (Suzuki et al., 1997). Various methods have been introduced, using peanuts (Manly, 1951), almonds (Huggare and Skindhoj, 1997), impression materials (Slagter et al., 1993), color-changeable chewing gum (Hayakawa et al., 1998) and chewing gum (Halazonetis et al., 2013). The seiving test, known as a gold standard method for evaluating masticatory efficiency, utilizes almonds as a chewing material.

As a dynamic evaluation of masticatory performance, MAI was used in this study. It assesses dynamic masticatory function beyond static maximum occlusion, as do other methods mentioned above. While higher occlusal force or greater occlusal contact or sieving test represents one's ability to grind foods into smaller particles, MAI utilizes a wax cube and evaluates one's ability to mix, more likely to natural chewing. Although it was reported that tongue and cheek forces were not solely key predictors of masticatory performance (Lujan-Climent et al., 2008), the functions of them on mastication would be reflected indirectly in a dynamic evaluation. Mastication incorporates many factors such as dentition, movements of jaws, a complex coordination of not only masticatory muscles but also a tongue and cheeks, muscle activity, muscle force, rhythmic movement of a tongue, salivary flow, activity of a neuro-muscular complex, central control of a brain and so on (Van der Bilt et al., 2006). This dynamic procedure of mastication is reflected in chewing food-like wax cubes.

The normal MAI derived in this study was 0.24, which is similar with the range of the normal group, 0.21±0.69 from 10 chewing cycles in 20s male, in a previous study which derived MAI scores according to the number of chewing, ages and gender (Lee, 2008). The MAI scores previously studied were −0.18 in the patients with pain in temporomandibular joints (Ahn et al., 2011), −1.5 to −1.2 in hemi/segmental mandibulectomy patients (Kadota et al., 2008). Within a patient with a removable partial denture, the MAI was increased from −1.3 ~ −0.11 with an old RPD to 0.27 ~ 1.13 with a new RPD (Tumrasvin et al., 2005). Although the scores are not equally comparable due to different ages, gender and the number of chewing strokes, the MAI scores of the non−sagittal malocclusion patients are considered comparably low.

Many studies to find factors affecting masticatory performance suggested the number of functional unit (Hatch et al., 2001) and posterior teeth contact (van der Bilt et al., 1993), the severity of malocclusion (Omar et al., 1987), occlusal contact area and body size (Julien et al., 1996), other than maximum bite force. It is also reported that only 30 to 50% of maximum occlusal force is used in chewing foods (Longquan, 2011). Therefore, higher maximum bite force does not necessarily imply better masticatory performance. Other study stated that maximum bite force at first molars is known to be best correlated with masticatory performance, and explains 36% of its variation, while occlusal contact area, the presence of posterior crossbite and the number of anterior teeth in contact contribute 9% of the variation in masticatory performance (Lujan−Climent et al., 2008).

Manly & Braley reported that masticatory efficiency was deteriorated with the loss of teeth and not compensated by longer mastication time (Manly and Braley, 1950). However, Hatch reported that in a dentate population, the number of anterior teeth in contact was positively correlated with masticatory performance other than the number of functional postcanine tooth units, and posterior crossbite was associated with a lower masticatory performance (Hatch et al., 2001). We found significant differences in the values of masticatory performance between the subjects with and without posterior crossbite and/or anterior openbite. The difference of the bite force are in coincident with the findings of a previous studies with pre-orthodontic children (Sonnesen et al., 2001), but in contrast to that of another study (Lujan-Climent et al., 2008). Our findings are also coincident, although the methods and the ages are different, with the findings of a study with primary dentition, which showed the normal occlusion group presented better masticatory performance than did those in the groups with posterior crossbite and anterior crossbite, which did not differ between each other (Gaviao et al., 2001).

For a subjective assessment of mastication, FIA was used in this study. From the results of this study, it is considered that having both posterior crossbite and anterior openbite make the patients recognize their deteriorated masticatory function. Other study reported that FIA was related with the number of post-canine teeth lost and from 3 and more teeth lost caused a significant FIA decrease (Jeong et al., 2010). It seems interesting to find that transverse discrepancy in dentition would cause decrease in FIA without any teeth lost, and anterior openbite also does as well as posterior crossbite. Hard foods and key foods seemed to represent one's mastication more discriminately than soft foods especially in the malocclusion groups.

The correlation coefficients between the maximum bite force, the MAI and the FIA in this study were lower but in agreement with other studies, which reported that there were moderate correlations between the subjective FIA and the objective MAI (Ahn et al., 2011; Jeong et al., 2010), and between the FIA and the maximum bite force (Kim et al., 2009). Considering the limitations of the maximum bite force to represent masticatory performance and the lower correlation with the MAI, whose validity and reliability compared to the sieving method were assured, it is regarded that it is inappropriate to evaluate masticatory performance only with a static assessment of occlusion, the maximum bite force or the contact area in aspects of simplicity in use. The FIA seemed to indicate masticatory function better than the maximum bite force or the contact area. Considering the differences of food bolus results in different masticatory function, the subjective FIA could be a simple but effective tool for evaluating masticatory ability in clinical fields prior to dental treatments, especially with the hard and the key foods.

There were some limitations in this study. There were some underlying skeletal discrepancies among the experimental groups, although the strict inclusion criteria were applied to minimize the differences of skeletal discrepancies among the groups. Because dental malocclusion is accompanied by diverse skeletal discrepancies, the inclusion of skeletal discrepancies was inevitable. Also, the FIA may not discriminate the difficulties in incising and grinding, because the questionnaire is based on self−assessing the difficulties in overall food−intake. There might be inconsistency of one's recognition of food and the term of 'food intake'. Detailed explanation of the food and the term 'food intake' might have helped reduce the individual variations of the assessment.

When full mouth rehabilitation takes place during orthodontic treatment, a subject's occlusal pattern is likely to be changed. Our results imply that an orthodontic treatment could enhance masticatory function of patients with posterior crossbite and/or anterior openbite, and thus propose a necessity of orthodontic treatment besides improvement of esthetics. However, our results do not suggest actual quantitative measurement of improvement because it was cross−sectional.

V. Conclusions

This study revealed that the masticatory function in patients with non-sagittal malocclusion is impeded in both objective and subjective assessments, and that an evaluation of masticatory function needs to include not only static but also dynamic components, and a subjective evaluation with different kinds of foods should also be considered. The methods of evaluating masticatory efficiency and subjective masticatory ability could be used further in a longitudinal study to assess the actual improvement in mastication after orthodontic treatment. Studies in different ages and population could be included in future studies.

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국 문 요 약

MAI (Mixing Ability Index) 및 FIA (Food Intake Ability)를 이용한 비시상 부정교합자군에서의 저작기능 평가

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교정치료의 목표인 심미성과 안정성에 대해서는 정량화된 방법으로 연구가 이루어지고 있으나, 기능적인 요소를 평가하는 데는 기존의 평가 지표인 최대교합력, 교합접촉면 등 저작 기능을 대표한다고 판단되는 정적인 평가가 이루어져 왔다. 저작 기능의 효율을 평가하기 위해 동적인 저작기능 평가 및 다양한 음식에 대한 섭식 능력을 나타내는 주관적인 평가가 필요하다. 또한 그간 국내외에서의 교합 기능에 관한 연구는 전후방적 부조화에 따른 교합력 비교에 국한되었으며, 수직적 혹은 횡적 부조화에 따른 저작 기능 비교 연구는 미비하였다. 이로 인해 개방교합 및 횡적 부조화 등의 부정교합을 치료하는 데 당위성을 부여하기에 어려움이 있었다. 이에 본 연구에서는 비시상적 부정교합을 가진 환자에서 저작기능을 정량화하여 비교하고자 하여, 정상교합자군과 세가지 비시상 부정교합자군 (협측 반대교합자군- Group C, 전방 개방교합자군- Group O, 복합 부정교합자군- Group B)에서 객관적인 평가인 최대교합력과 교합접촉면, MAI (Mixing ability index)와 주관적인 평가인 FIA (Food intake ability)를 비교하고, 다음과 같은 결과를 얻었다.

1. 비시상 부정교합자군은 정상교합자군보다 최대교합력, 교합접촉면, MAI, FIA 계측치가 유의하게 낮았다 ($P < 0.0001$).

2. 정적, 동적의 객관적인 측정과 주관적인 평가에서 최대교합력, 교합접촉면, MAI, FIA 계측치는 정상교합자군에 비하여 Group C와 O, Group B 순으로 유의하게 낮았고 (P <0.0001), 군간의 차이는 보이지 않았다.

3. 저작능력의 객관적인 평가에서 정적인 지표인 최대교합력과 교합접촉면은 동적인 지표인 MAI와 낮은 상관관계를 보였다 (r = 0.24, P < 0.5).

4. 주관적인 저작능력의 평가인 FIA는 객관적인 평가인 MAI와 중등도의 상관관계를 보였으며 (r = 0.38, p < 0.01), 특히 단단한 음식과 key food에서 부정교합자군과 정상교합자군의 차이가 컸다 (P < 0.0001).

본 연구를 통해서, 비시상 부정교합자군의 저작능력이 객관적인 측정과 주관적인 평가에서 모두 정상교합자군보다 저하됨이 나타났으며, 저작 능력은 개인이 인지하지 못해도 객관적인 평가가 필요함을 시사하였다.

핵심되는 말: 저작효율, 비시상 부정교합, 최대교합력, 저작기능평가