

Assessment of masticatory function in patients with non-sagittal occlusal discrepancies

T.-H. CHOI*, B.-I. KIM[†], C. J. CHUNG[‡], H.-J. KIM[§], H.-S. BAIK[¶], Y.-C. PARK[¶] & K.-J. LEE[¶]

*Department of Orthodontics, College of Dentistry, Yonsei University, Seoul, South Korea, [†]Department of Preventive Dentistry and Public Oral Health, College of Dentistry, Yonsei University, Seoul, South Korea, [‡]Department of Orthodontics, Gangnam Severance Hospital, Institute of Craniofacial Deformity, College of Dentistry, Yonsei University, Seoul, South Korea, [§]Department of Oral Biology, Division in Anatomy and Developmental Biology, College of Dentistry, Yonsei University, Seoul, South Korea and [¶]Department of Orthodontics, Yonsei University Oral Science Research Center, Institute of Craniofacial Deformity, College of Dentistry, Yonsei University, Seoul, South Korea

SUMMARY Non-sagittal occlusal discrepancies such as posterior cross-bite and anterior openbite are common types of malocclusion, but studies on masticatory function related to those malocclusions have been scarce. The aim of this study was to quantify the masticatory performance in patients with non-sagittal discrepancies compared to those with normal occlusion, using both objective and subjective measures. Maximum bite force and 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 analysed from 21 people in normal occlusion (Group N) and 64 patients with posterior cross-bite (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 non-sagittal malocclusion groups showed lower values in the maximum bite force, the contact area, the MAI and the FIA compared to those in the normal group ($P < 0.0001$). Compared to Group N, Groups C, O and B showed 61.5%, 42.1% and 40.1% of the maximum bite force, and 84%, 84% and 76% of hard food FIA, respectively. However, there were no significant differences among Groups C, O and B. The MAI showed higher correlation with the FIA ($r = 0.38$, $P < 0.01$), than with the maximum bite force and the contact area (both $r = 0.24$, $P < 0.5$). These results revealed that masticatory function in patients with non-sagittal discrepancies is significantly reduced both objectively and subjectively.

KEYWORDS: bite force, malocclusion, mastication, openbite, orthodontics, questionnaires

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Introduction

Mastication is one of the major functions of the orofacial apparatus and is closely related to the quality of life and the longevity of the dentition (1). From the patient's standpoint, aesthetic issues such as dental irregularities and conditions represented with vague words implicating functional issue, such as 'bad bite', have been shown to be motivational for orthodontic treatment (2). Conventional orthodontic

diagnosis has been made mostly based on the antero-posterior (sagittal) denture and/or skeletal relationship, that is excessive overbite or anterior cross-bite, as they are associated with altered lateral facial aesthetics (3–5). Accordingly, many have focused on the sagittal relationship of the jaws and its effects on the masticatory functions to justify the treatment in those malocclusions, uncovering the positive effects of orthognathic restructuring on the masticatory efficiency (6, 7).

Non-sagittal malocclusions, in contrast, such as posterior cross-bite and/or anterior openbite, have been associated with altered 'bite', with prevalence of up to 30% and 8–19% (8–10), respectively. So far, possible development of abfraction and/or temporomandibular disorders associated with insufficient posterior transverse overjet or posterior cross-bite has been recognised (11, 12). However, it is not yet clear how the masticatory function or efficiency is affected in the subjects exhibiting non-sagittal occlusal discrepancies (13, 14). Therefore, it seems crucial to quantify alterations of masticatory function to assess a need for correction of the non-sagittal malocclusions.

For the quantification of the masticatory function, both objective evaluation of masticatory performance and subjective evaluation of masticatory ability have been considered effective (15). Occlusal force and occlusal contact area have been studied as representatives of functional indices (16). A conventional method of measuring occlusal force and occlusal contact was to measure the static maximum bite pressure using a pressure-sensitive sheet (17). As it does not represent the efficiency of masticatory performance in terms of dynamic occlusion, various methods of evaluating dynamic masticatory performance have been developed.

Among the various ways of evaluating the dynamic masticatory performance, the Mixing Ability Index (MAI) has been suggested as a valid and reliable method (18, 19).

Subjective methods to evaluate the masticatory ability include 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 subjective masticatory ability (20).

The purpose of this study was to quantify the masticatory performance in patients with non-sagittal discrepancies compared to those with normal occlusion, by assessing both objective masticatory performance and subjective masticatory ability.

Materials and Methods

Subjects

The study group consisted of 85 individuals including 21 of normal occlusion group (13 men and eight women) and 64 malocclusion group, exhibiting buccal

cross-bite at at least two molars (Group C; $N = 22$, 11 men and 11 women), anterior openbite (Group O; $N = 22$, six men and 16 women), and both buccal cross-bite and anterior openbite (Group B, $N = 20$, six men and 14 women), respectively (Table 1 and Fig. 1). All subjects in both the normal and the malocclusion groups were assessed with initial cephalometric analysis and met the following criteria.

- 1 Natural dentition with no missing teeth except for the third molars.
- 2 No significant facial deformity, such as mandibular prognathism or asymmetry.
- 3 Normal or marginal cephalometric measurements for anteroposterior and vertical relationships such as ANB, mandibular plane angle and gonial angle (21).
- 4 No previous history of orthodontic treatment.
- 5 No significant temporomandibular disorders or symptoms.
- 6 Minimal crowding of <3 mm in each dental arch.

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 with 0.097 mm thickness.* The subjects were instructed to bite on their maximum intercuspal position, sitting upright in a unit chair. The subjects were then asked to reproduce maximum bite force on the central occlusion for 2 s. The films were digitised by CCD camera (Occluzer FPD 707*) attached to the analysing system, to measure the maximum bite force and the contact area.

Dynamic evaluation of masticatory efficiency by MAI

The mixing ability test was applied to evaluate objective dynamic masticatory efficiency, as previously described (18). Briefly, a two-coloured cuboidal wax cube of $12 \times 12 \times 12$ mm, stacked with red and green wax cuboids of $2 \times 2 \times 12$ mm alternatively, was used. The subjects were instructed to chew a wax cube for 10 strokes at habitual chewing, at preferred side. The procedure was repeated three times. The images of the samples at both sides were taken using

*Dental Prescale® 50H, type R; Fuji Film Corp., Tokyo, Japan.

Table 1. Descriptions of the subjects

	Group N	Group C	Group O	Group B	Total
Age (Mean \pm SD)	24.62 \pm 2.1*	20.36 \pm 4.8*	23.27 \pm 4.6*	23.20 \pm 9.0*	22.82 \pm 5.7
Male (<i>N</i>)	13	11	6	6	36
Female (<i>N</i>)	8	11	16	14	49
Total (<i>N</i>)	21	22	22	20	85

Group N: subjects with normal occlusion; Group C: subjects with buccal cross-bite; Group O: subjects with anterior openbite; Group B: subjects with buccal cross-bite and anterior openbite.

The superscript letter indicates no significant difference at $\alpha < 0.05$ defined by one-way ANOVA.



Fig. 1. Clinical examples of the experimental groups. Group N: subjects with normal occlusion; Group C: subjects with buccal cross-bite; Group O: subjects with anterior openbite; Group B: subjects with buccal cross-bite and anterior openbite.

a digital camera[†] under a standard light and distance condition. All images were then analysed using a digital image analyzer[‡]. From each side of a sample, the total projection area, the projection area above 50 μ m in thickness, the maximum length, the maximum breadth, the red area and the green area were measured. MAI was calculated using the discriminant function (22).

Subjective evaluation by FIA

To evaluate the subjective masticatory performance, FIA test was performed using a self-assessed questionnaires asking the masticatory ability for 30 different foods according to the previous study (23). The sub-

jects 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) and 'can chew well' (5 points). The total FIA score was calculated using the average score of 30 foods, and the FIA scores of five hard foods (dried cuttle fish, dried filefish, French baguette, raw carrots and hard persimmon), five soft foods (tofu, boiled potato, boiled rice, ham and watermelon) and five key foods (dried cuttle fish, raw carrots, peanuts, cubed white radish kimchi and caramel) were also calculated.

Statistical analysis

The normality of the samples was evaluated using Kolmogorov–Smirnov test. For comparisons between the normal group and the malocclusion groups, the

[†]Coolpix 4500; Nikon Corp., Tokyo, Japan.

[‡]Image-Proplus[®] 6.0; Media cybernetics Inc., Bethesda, MD, USA.

independent *t*-test or Mann–Whitney *U*-test was used according to the data distribution. A one-way analysis of variance (ANOVA) and Scheffe test for the *post hoc* comparisons were applied to determine 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 was 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 predetermined at $P < 0.05$.

Results

Compared to Group N, the overall malocclusion group, Groups C, O and B showed reduced maximum bite force, contact area, MAI and FIA ($P < 0.001$, Tables 2 and 3). 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. The MAI value of the normal occlusion group was positive, while those of the malocclusion groups were negative (Table 3). The intra-class correlation coefficient of the MAT was 0.948 ($P = 0.018$). The subjective masticatory ability was also shown to be low in the groups of non-sagittal discrepancies, especially in the hard and the key foods FIA. The hard food FIA of Groups C, O and B was 84%, 84% and 76% of that observed in Group N, respectively. However, there were no differences in the FIA of five soft foods between Groups N and C (Table 3).

The evaluation of the correlation between the maximum bite force and the contact area revealed a strong correlation ($r = 0.99$, $P < 0.001$) (Table 4). On the other hand, the MAI and the maximum bite force showed significant but weak correlation ($r = 0.24$, $P < 0.05$). 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, $P < 0.01$). Among the FIA, the

total FIA was strongly related to hard food FIA and key food FIA ($r = 0.921$, $r = 0.956$, respectively, $P < 0.01$).

Discussion

In spite of the abundant studies claiming the need for the orthodontic treatment for patients with non-sagittal malocclusion, empirical quantification of the masticatory performance in those subjects has been scarce. Due to the underlying difficulty to find a single representative parameter for the masticatory function, this study recruited both objective static and dynamic parameters, and subjective self-evaluation of the masticatory performance. The results were somewhat interesting because very few patients in those categories actually complained of any functional disturbance although their chief complaints were mostly protrusion or to improve their smile. The maximum bite force, the contact area, the MAI and the FIA were prominently lower in the non-sagittal malocclusion groups than those in the normal occlusion group.

Dental Prescale® system is a known measure for the static evaluation of maximum bite force. The thin film enables the measurement near the intercuspal position with minimal interferences in a relatively short time (24). Although this mainly targets the static occlusion, some studies have reported positive correlation between the masticatory efficiency and maximum occlusal force (25). Alternative digital device such as T-scan® was not recruited in this study as it displays relative 'distribution' of the real-time occlusal force along the dental arch during the chewing cycle, but not the absolute value of the bite force (26).

The mean maximum bite force measured in this study was 772 N in the normal occlusion group, which was similar to those of previous studies (27, 28). With the normal group as having the highest maximum bite force and contact area, followed the Groups C, O and B with significant differences ($P < 0.001$). This might be associated with fewer teeth contacts in the maximum intercuspal position in the openbite group. It has also been reported that children with unilateral posterior cross-bite have lower maximum bite force and the number of teeth in contact

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Table 2. Comparisons of masticatory function in the subjects with malocclusion and normal occlusion

	The normal occlusion Group (N) (<i>n</i> = 21)	The malocclusion Groups (C, O and B) (<i>n</i> = 64)	Significance
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 cross-bite; Group O: subjects with anterior openbite; Group B: subjects with buccal cross-bite and anterior openbite. MAI, Mixing Ability Index; FIA, food intake ability.

MAI vales are mean ± s.d.; other values are median (min, max) because of skewed distribution. The significant difference was defined by independent *t*-test or Mann–Whitney *U*-test (**P* < 0.05; ***P* < 0.01; ****P* < 0.001).

Table 3. Comparisons of the objective and subjective evaluations of masticatory function among the experimental groups

	Group N	Group C	Group O	Group B	Significance
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 cross-bite; Group O: subjects with anterior openbite; Group B: subjects with buccal cross-bite and anterior openbite. MAI, Mixing Ability Index; FIA, food intake ability.

MAI vales are mean ± s.d.; other values are median (min, max) because of skewed distribution. The significant difference was defined by one-way ANOVA or Kruskal–Wallis test (**P* < 0.05; ***P* < 0.01; ****P* < 0.001). The superscript letters indicate no significance at α < 0.05 (MAI), α < 0.017 by Bonferroni's correction.

(29). This study also confirmed a strong correlation between the maximum occlusal force and the contact area as in the previous study (27).

Many studies suggested the number of functional unit (30) and posterior teeth contact (31), the severity of malocclusion (32), occlusal contact area and body size (33), other than maximum bite force, as the main factors affecting masticatory performance. It was also reported that only 30–50% of maximum occlusal force is used in chewing foods (34). Therefore, higher maximum bite force does not necessarily mean better masticatory performance. Other study stated that maximum bite force at first molars is known to be the best correlated with masticatory performance and explains 36% of its variation, while the occlusal contact area, the presence of posterior cross-bite and the number of anterior teeth in contact contribute 9% of the variation in masticatory performance (35).

The MAI scores that were previously reported were -0.18 in the patients with temporomandibular joint pain (36) and -1.5 to -1.2 in hemi/segmental mandibulectomy patients (37). Within a patient with a removable partial denture, the MAI was increased from -1.3 to -0.11 with an old RPD to 0.27–1.13 with a new RPD (38). Although the scores in each study are not comparable due to the differences in experimental conditions such as ages, gender and the number of chewing strokes, the MAI scores of the non-sagittal malocclusion patients can be considered remarkably low. This implies the possible increase in the mastication time or insufficient shearing of the food bolus in those malocclusion groups, although they did not express apparent functional disturbance.

Regarding the reduced MAI in the openbite group, Hatch reported that in a dentate population, the number of anterior teeth in contact was positively

Table 4. Pearson's 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.

Significance (* $P < 0.05$; ** $P < 0.01$).

correlated with masticatory performance other than the number of functional post-canine tooth units, and posterior cross-bite was associated with a lower masticatory performance (30). We found significant differences in the values of masticatory performance between the subjects with and without posterior cross-bite and/or anterior openbite. The sequential decrease in MAI in the Groups C/O and in Group B indicated that both anterior occlusion and posterior transverse relation contribute to eventual masticatory efficiency.

The FIA values were significantly lower in the malocclusion groups. In spite of the presence of complete dentition, insufficient occlusal contact appears to impair the trituration of food bolus, like in the edentulous patients (22). Hard foods and key foods seemed to represent one's mastication more discriminately than soft foods especially in the malocclusion groups. This result implies that although the subjects with either posterior cross-bite or anterior openbite may not complain of obvious masticatory difficulty, they may have adapted themselves to softer diet, being conscious of the reduced masticatory function. The mechanism for the self-consciousness of the masticatory function has yet to be studied, using appropriate tools.

The correlation coefficients between the maximum bite force, the MAI and the FIA in this study were in agreement with other studies, which reported moderate correlations between the subjective FIA and the objective MAI (22, 36), and between the FIA and the maximum bite force (23).

Taken together, this study quantified that the masticatory function in patients with non-sagittal malocclusions was significantly reduced in all parameters used, which were objective static and dynamic measure-

ments, and subjective assessment. The empirical quantification of the vague perception of 'bad bite' is clinically important to find the validity of occlusal reconstruction in those patients. This notion also implicates that correct vertical and transverse relationship of occlusion may be critical components of occlusion which contributes to the normal masticatory function. However, radical or aggressive treatment modalities for occlusal reconstruction must be substantiated by additional evidences that those treatments could either restore or elevate masticatory efficiencies. It is yet to be studied whether orthodontic/prosthetic restructuring would eventually restore the masticatory function. In addition, whether reduced masticatory function would eventually lead to structural weakness such as alveolar bone density or volume would have to be investigated in order to add the validity of those approaches (39).

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Correspondence: Kee-Joon Lee, Department of Orthodontics, College of Dentistry, Yonsei University, 134 Shinchon-dong Seodaemun-gu, Seoul 120-752, South Korea.

E-mail: orthojn@yuhs.ac