Original Article

Does Malocclusion Affect Masticatory Performance?

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Abstract: This purpose of this study was to evaluate the largely untested assumption that malocclusion negatively affects masticatory performance. A sample of 185 untreated subjects (48% male and 52% female) from 7 to 37 years of age, representing subjects with normal occlusion (n = 38), Class I (n = 56), Class II (n = 45), and Class III (n = 46) malocclusion, were evaluated. Masticatory performance was evaluated objectively using artificial (CutterSil®, median particle size and broadness of the distribution) and real foods (number of chews for jerky and almonds), and subjectively using a visual analog scale. The results showed no significant differences in age or the body mass index (Wt/Ht^2) between the occlusion groups. Subjects with normal occlusion had significantly smaller particle sizes ($P = .001$) and broader particle distributions ($P < .001$) than subjects with malocclusion. Compared with the normal occlusion group, the median particle sizes for the Class I, II, and III malocclusion groups were approximately 9%, 15%, and 34% larger, respectively. There were also significant group differences in their subjective ability to chew fresh carrots or celery ($P = .019$) and firm meat ($P = .003$). Class III subjects reported the greatest difficultly, followed by Class II subjects, Class I subjects, and subjects with normal occlusion, respectively. We conclude that malocclusion negatively affects subjects' ability to process and break down foods. (*Angle Orthod* 2002;72:21–27.)

Key Words: Mastication; Oral function; Human; Masticatory ability

INTRODUCTION

Mastication is the first step of the digestive process. Mechanical breaking down of the food into smaller pieces increases its surface area and facilitates enzymatic processing in the digestive system. The amount of total digestion appears to be related to how well the food is masticated.[1] Subjects with poor masticatory function have reported changes in the types of food they choose to eat,[2–4] with malnutrition as a possible consequence.[5,6] The association of poor masticatory performance with gastritis, gastric ulcers, and gastric carcinoma[7–10] suggests that the digestive process is directly affected.

Masticatory performance, whether measured as the number of chews to process and swallow foods or as the ability to break down foods, has been related to deficiencies of the dentition. Adults with missing teeth are not able to perform as well as adults with natural dentitions,[4,11–19] although it appears that the selection of foods will not be altered as long as a minimum number of occluding pairs of teeth are present.[20–22]

The number and size of occlusal contacts are primary determinants of masticatory function for individuals with complete dentitions[23–27] because contacts between occluding teeth determine the area available for shearing and grinding food during each chewing cycle. Omar et al[28] and Luke and Lukas[29] also reported that chewing efficiency decreases as the number of teeth in contact decreases. Van der Bilt et al[15] and Wilding[26] found significant correlations between occlusal contact area and chewing efficiency.

Contact area has also been related to occlusion and malocclusion. Gazit and Lieberman[30] studied the relationship between the alignment and articulation of the dentition in a sample of young adults by assessing the total contact areas obtained in the intercuspal position. Their results showed that occlusions that were closer to the ideal had the greatest contact area. Preliminary findings in a pilot study conducted by Owens et al[31] suggest that individuals with normal occlusion and those with malocclusion differ in how well the teeth fit together.

Few studies have been conducted to evaluate the effects of malocclusion on masticatory performance. Presurgical adult patients with severe skeletal and dental malocclusions have more limited masticatory performance than individu-

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Accepted: July 2001. Submitted: April 2001.

als with normal occlusion.[32–34] Adults classified as having excellent buccal segment relationships showed a 40% better ability to break down carrots than individuals with less than ideal posterior occlusion.[29] Based on global indices of malocclusion, Omar et al[28] reported a moderate correlation ($R = -0.61$) between masticatory efficiency and the orthodontic treatment priority index; Akeel et al[27] showed a low correlation ($R = -0.31$) between masticatory efficiency and the orthodontic treatment need index.

Even fewer studies have evaluated the effect of malocclusion on masticatory performance in children. Manly and Hoffmeistr[35] reported similar masticatory performance for children with Class I and Class II malocclusion; patients with end-on malocclusion performed less well. Shire and Manly[36] demonstrated similar levels of masticatory performance for children with normal occlusion, Class I malocclusion, or Class II malocclusion, all of whom performed better than children with Class III malocclusion. Henrikson et al[37] showed that girls with normal occlusion had better masticatory performance than their Class II counterparts. In contrast, Shire and Manly[36] reported no significant difference in masticatory performance between children with normal, Class I, and Class II malocclusions.

The purpose of this pilot study was to establish relationships between normal occlusion and malocclusions and their effects on masticatory performance—specifically, whether occlusion is more closely related to the number of chews it take to preprocess foods or to the individuals' ability to break down foods. Chewing ability was also assessed subjectively to determine whether patients with malocclusion perceived any limitations of masticatory ability

MATERIALS AND METHODS

Subjects were chosen after an initial screening examination at the Department of Orthodontics, Baylor College of Dentistry. They were evaluated after being admitted for treatment, but before their orthodontic consult. Each patient's occlusion, temporomandibular joint function, craniofacial form, and state of dentition were evaluated. Written and verbal consent were obtained from each participant. The participants were selected based on the following inclusion criteria:

1. Approximately equal number of males and females,
2. Ages 7 years through young adult with malocclusions requiring orthodontic treatment.

Subjects were excluded based on the following criteria:

1. Missing teeth (excluding third molars);
2. Symptoms of TMJ dysfunction to include pain and crepitus;
3. Active orthodontic treatment;
4. Full-coverage dental restorations or tooth replacements.

A malocclusion sample of 147 untreated subjects (51% female and 49% male), ranging from 7 to 37 years of age, participated in the study. The sample included 56 subjects with Class I malocclusion, 45 with Class II malocclusion, and 46 with Class III malocclusion. A control sample of 38 subjects (55% female and 45% male) was selected based on the same selection and exclusion criteria. Additionally, the control subjects had normal Class I occlusion (defined as no more than 2 mm arch length discrepancy, overjet less than 3 mm, and overbite less than 3 mm).

Anthropometric assessments

Stature or standing height was measured as the linear distance from the floor to the vertex of the skull using a wall-mounted steadiometer as described by Cameron.[38] Body weight (wearing light clothing without shoes) was recorded using a standard scale.

Evaluation of median particle size and broadness of the distribution

Standardized tablets of CutterSil® (Heraeus Kulze, Inc, South Bend, Indiana), a condensation silicone impression material, were formed in a Plexiglas template. The tablets were 5 mm thick and 20 mm in diameter. After hardening for at least 1 hour, the tablets were cut into quarters. Five portions, containing 3 quarter-tablets each, were packaged for each subject.[39] Each subject was instructed to chew 3 of the quarter-tablets naturally for a total of 20 chews. The investigator counted the number of chews and timed each subject's chewing sequence. At the end of the 20th cycle, subjects were instructed to stop chewing, expectorate the sample into a plastic filter and rinse with water until all particles were removed from the mouth. Particles loosened during rinsing were also collected in the filter. The procedure was repeated 5 times until approximately 10 grams of CutterSil® had been chewed and expectorated into the filter. The subjects were instructed to rest between trials if they felt any fatigue.

The chewed samples were transferred to filter paper and dried in an oven for 1 hour at 80°C.[28] The sample was then separated using a series of 7 sieves, with mesh sizes 5.6 mm, 4.0 mm, 2.8 mm, 2.0 mm, 0.85 mm, 0.425 mm, and 0.25 mm, stacked on a mechanical shaker and vibrated for 2 minutes. Once the sample was separated, the content of each sieve was weighed to the nearest 0.01 g.

Cumulative weight percentages (defined by the amount of sample that could pass through each successive sieve) were calculated for each individual. From these percentages, the median particle size (MPS) and broadness of particle distribution were estimated using the Rosin-Rammler equation,[40–42]

$$Q_w = 100\ [1–2^{-(x/x_{50})^b}]$$

where Q_w is the weight percentage of particles with a diameter smaller than x (the maximum sieve aperture). The

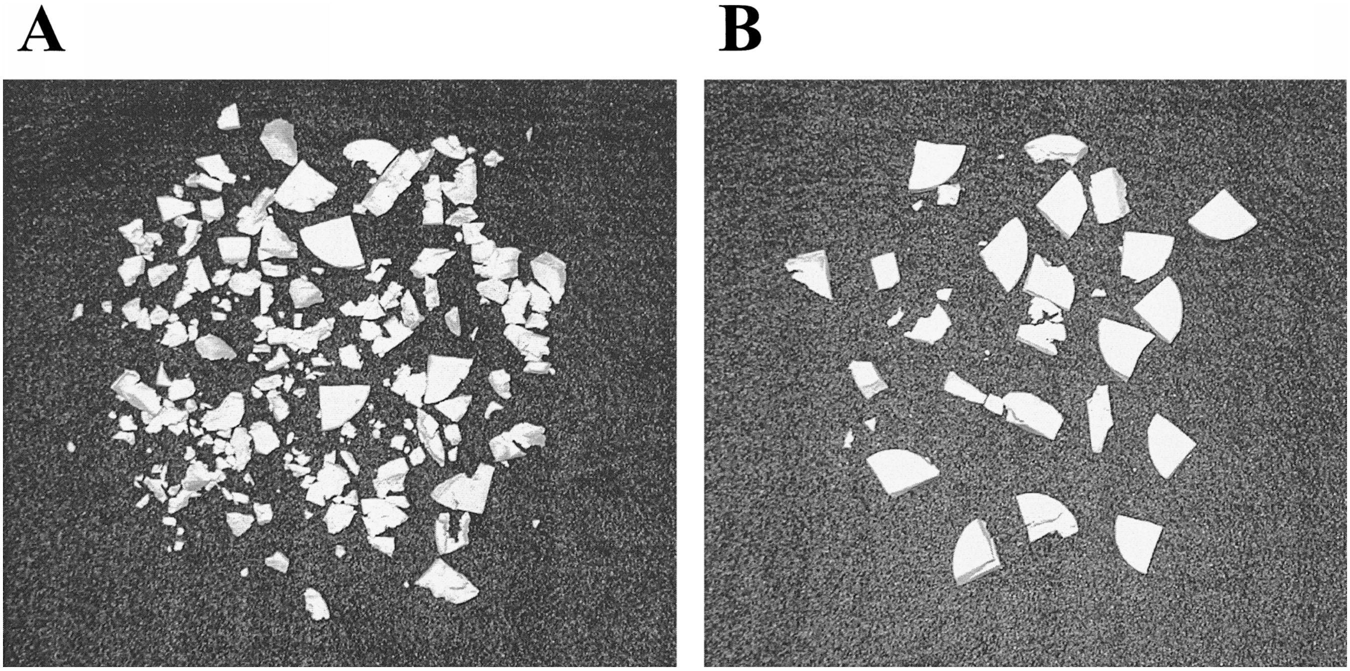

FIGURE 1. Chewed CutterSil® particles. (A) Small median particle size and broad distribution of particles. (B) Large median particle size and narrow distribution of particles.

median particle size (x_{50}) is the aperture of a theoretical sieve through which 50% of the weight can pass, and ''b,'' a unitless measure, describes the broadness of the distribution (similar to the range) of the particles (Figure 1).

Increasing values of ''b'' correspond to cumulative weight percentage curves with steeper slopes and thus to distributions of particle sizes that are less broad.

Objective chewing performance with natural foods

A 2 g bolus of almonds and a 2 g bolus of beef jerky were presented randomly to each subject and they were asked to chew it naturally and swallow at will. The subject indicated the end of their chewing sequence by raising their hand. The investigator counted the number of chews and timed the duration with a stopwatch.

Subjective evaluation of masticatory ability

A questionnaire was used to evaluate the subjects' perceived masticatory performance, including specific questions pertaining to how well the subjects chewed. The following 5 questions were asked to evaluate the patients' ability to chew foods of different hardness:

1. Are you ordinarily, or would you be, able to chew or bite fresh carrot or celery sticks?
2. Are you ordinarily, or would you be, able to chew or bite fresh lettuce or spinach?
3. Are you ordinarily, or would you be, able to chew or bite steaks, chops or firm meat?
4. Are you ordinarily, or would you be, able to chew or bite boiled peas, carrots, or green or yellow beans?
5. Are you ordinarily, or would you be, able to chew or bite a whole fresh apple without cutting?

After having read the questions, or having had the questions read to them, each subject was asked to indicate his or her response on a visual analog scale 150 mm long (delimited by ''not'' and ''very'') located below each question. The scale provided a means of assigning a metric value to each response, based on the distance of the marked response from the ends of the line.

Statistical Analysis

Because the performance measures were not normally distributed, central tendencies and dispersions were described with medians and interquartile ranges. The Kruskal-Wallis test was used to assess group differences between the normal occlusion and 3 malocclusion groups. Mann Whitney tests were performed post-hoc to define the individual group differences.

RESULTS

The descriptive statistics for age, stature, and weight of subjects with normal occlusion and those with Class I, Class II, and Class III malocclusions are listed in Table 1. Age, weight, or statural differences among the normal occlusion group and 3 malocclusion groups were not statistically significant.

TABLE 1. Medians and Interquartile Ranges for Age (y), Stature (cm) and Weight (lb) of Subjects with Normal Occlusions and Malocclusions

	Normal			Class I			Class II			Class III			Significance
	25th	50th	75th	25th	50th	75th	25th	50th	75th	25th	50th	75th	(*P*-value)
Age	11.6	14.0	25.4	12.0	13.6	15.6	11.5	12.9	15.3	11.9	14.0	17.2	.52
Stature	54.7	61.0	66.3	59.5	62.0	65.0	56.5	62.0	64.0	59.0	64.0	66.8	.20
Weight	81.0	109.0	148.0	104.0	118.0	139.0	90.0	106.0	139.0	99.5	120.0	139.0	.30

TABLE 2. Medians and Interquartile Ranges for Median Particle Size (mm^2), Broadness of the Particle Distribution, Number of Jerky Chews, and Number of Almond Chews for Subjects with normal Occlusions and Malocclusions

	Normal			Class I			Class II			Class III			Significance
	25th	50th	75th	25th	50th	75th	25th	50th	75th	25th	50th	75th	(*P*-value)
Particle size	2.7	3.3	3.9	3.0	3.6	4.2	3.2	3.8	4.5	3.7	4.4	4.7	<.001
Broadness	2.2	3.0	4.1	2.5	3.7	5.6	3.1	4.6	8.5	3.7	6.8	13.1	<.001
Jerky chews	13.5	21.0	23.5	18.0	22.0	24.0	17.0	21.0	27.0	16.0	22.0	27.0	.531
Almond chews	14.7	20.0	26.0	19.0	23.0	28.0	16.0	20.0	26.5	15.0	20.0	27.8	.333

TABLE 3. Medians and Interquartile Ranges for Subjective Questions of Masticatory Performance (VAS 0-100) for Subjects with Normal Occlusions and Malocclusions

	Normal			Class I			Class II			Class III			Significance
	25th	50th	75th	25th	50th	75th	25th	50th	75th	25th	50th	75th	(*P*-value)
Boiled vegetables	87.2	94.3	95.4	91.7	94.0	94.7	85.7	94.0	94.7	84.7	92.3	95.3	.734
Fresh lettuce/spinach	91.7	94.0	94.7	87.2	93.7	94.7	84.2	93.3	94.6	66.3	93.0	94.5	.291
Fresh apple w/o cutting	91.3	94.0	95.3	65.7	93.3	94.0	47.2	92.3	94.0	62.7	90.7	94.7	.095
Fresh carrot/celery	93.3	94.0	95.3	70.5	93.3	94.2	66.2	93.0	94.7	55.0	81.7	94.5	.019
Steak/firm meat	78.3	93.3	94.7	52.5	85.0	94.7	42.3	68.0	90.5	40.5	68.7	88.2	.003

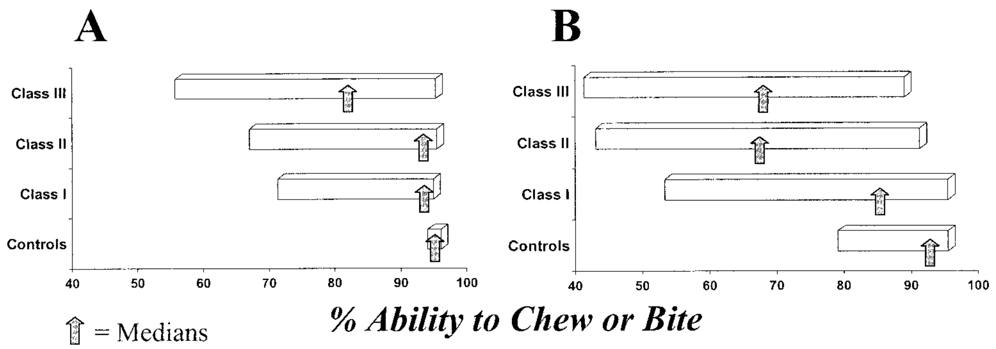

FIGURE 2. The effect of malocclusion on masticatory ability (0% unable; 100% very able). (A) Ability to chew or bite fresh carrots or celery sticks. (B) Ability to chew or bite steak or other firm meats (25% and 75% depicted by left and right edge of each box, respectively).

Median particle size and broadness of the particle distribution (Table 2) showed statistically significant ($P < .001$) group differences. The Class I, Class II, and Class III malocclusion groups had median particle sizes approximately 9%, 15%, and 34% larger than the group with normal occlusion, respectively. Post-hoc tests showed that the group with normal occlusion had significantly ($P < .02$) smaller median particle size and broader distributions than the Class II and Class III groups. The Class I group also had significantly ($P < .01$) smaller particles and a broader distribution of particles than the Class III group. There were no significant group differences in the number of chews to swallow either jerky or almonds.

Patients with malocclusion also perceived chewing disabilities with the harder foods. There were significant group differences (Table 3) in the reported ability to chew fresh carrots or celery and steaks or other firm meats (Figure 2). The group with normal occlusion reported a significantly ($P < .05$) greater ability to chew fresh carrots and celery than all 3 malocclusion groups. They also reported being better able ($P < .01$) to chew steak and other firm meats than the Class II or Class III groups. The Class I group also reported being more able ($P < .05$) to chew steak and other firm meats than the Class III group. Approximately 25% of the Class III group reported difficulties in chewing raw carrots, raw celery, steak, or other firm meats.

DISCUSSION

Both the objective and subjective measures of masticatory performance showed relationships with malocclusion. Correlations between the number of occluding teeth and perceived chewing ability have been reported.[4,43] It has also been shown that Class II girls perceive greater reductions in masticatory abilities compared to girls with normal occlusion.[44] On the other hand, it has been reported that adult masticatory performance is not related to food choices[44] or satisfaction with chewing ability.[15,27] The disagreements between studies may be influenced by the way in which the questionnaires were administered to the subjects, a process that is more difficult to control than the collection of objective measures of masticatory performance. For example, studies showing no correlations often used ''yes'' and ''no'' answers to assess difficulty chewing, while those finding correlations used a visual analog scale to evaluate difficulty chewing. Importantly, the study using techniques similar to ours reported agreement between subjective and objective measures of masticatory performance.[37]

Comparisons of median particle size are confounded by the use different methodologies. Our estimates of central tendency for normal occlusion (3.3 mm^2) fall between those reported by Julien and coworkers[24] for young adults (2.2–3.1 mm^2) and young girls (4.2 mm^2), who used similar methods to collect and analyze masticatory performance. Our intermediary values might be expected given the age distribution of sample and the established relationship between performance and body size.[24] The subjects with malocclusions all had substantially larger median particle sizes, with the median particle size of our Class III subjects being larger than the median particle size of normal 7 year olds (4.4 mm^2 vs 4.2 mm^2).[24]

Shiere and Manly[36] did not publish their data comparing masticatory performance by type of malocclusion, making it difficult to determine why they found no significant differences between Class I normal children and Class I and Class II malocclusion children. However, Shiere and Manly used peanuts and only a single sieve to determine their measure of performance, and the single sieve method of measuring performance cannot determine the breadth of particle size distribution. Peanuts are also a less consistent test food than CutterSil®. Because individuals differ in the breadth of their particle size distribution,[45] Shiere and Manly's method probably had less resolution of intergroup differences than our method with multiple sieves.[45] Henrickson and coworkers[37] found a decreased masticatory performance in Class II children that is similar to our results.

Our results indicate that malocclusion does result in lower masticatory performance, in agreement with several previous studies.[27,28,32,36,37,46] Two of these studies examined only Class III adults[32,46] and our study suggests that Class III individuals have the poorest performance. Shiere and Manly[36] also found the poorest performance in a small sample of Class III children, although they reported no impairment of performance in Class II and Class I children. Henrikson et al[37] compared only Class II and normal occlusion girls, but found a deficiency in masticatory performance in Class II subjects similar to ours.

The possible reasons why subjects with malocclusions, especially Class III malocclusions, have poorer masticatory performance are not completely understood. Three factors that influence masticatory performance are: (1) the number and area of occlusal contacts,[23–27] (2) occlusal forces as reflected by maximum bite force,[13,14,24,44,47] and (3) the amount of lateral excursion during mastication.[48–50] Which of these factors is most important in reducing masticatory performance in subjects with malocclusion?

Yurkstas and Manly[23] first identified the relationship between performance and contact area. Yurkstas[49] later showed that total surface area is not a good predictor of contact area, as confirmed by Julien.[24] There have been few studies of occlusal contact areas and, therefore, it has not been established that subjects with malocclusions, especially Class III malocclusions, have fewer contacts or smaller contact area. Hisano and Soma[51] showed that the adult dentition of both Class II and Class III malocclusions theoretically might be expected to apply less energy for food breakage during mastication than the Class I dentition. However, their analysis did not predict lower masticatory performance in Class III malocclusions compared to Class I or Class II malocclusions.

The strength of the jaw muscles determines the amount of available force to cut or crush the food. Maximum bite force, which is related to body size,[52,53] is primarily a measure of muscle size or mass.[54] Shiere and Manly[36] found that maximum bite forces remained unchanged between the ages of 6 and 15 years of age, while masticatory performance increased, suggesting that bite force is not related directly to masticatory performance. There have also been relatively few studies evaluating the relationship between malocclusion and maximum bite forces in subjects with malocclusions. It has not been established that subjects with malocclusions have lower occlusal forces. Although several studies indicate that adults with vertical deformities have lower than normal bite forces,[33,52] it is not clear whether patients with other forms of malocclusion also have generally lower bite forces. Throckmorton et al[55] found that adult anteroposterior relationships of the dentition were not correlated with maximum bite forces. Further studies of maximum bite forces in subjects with malocclusions are needed to establish that lower bite forces result in lower masticatory performance.

Finally, there are few studies of the amount of lateral excursion subjects use during mastication. Larger occlusal contacts may be associated with fewer interferences, permitting a greater range of lateral excursion.[50] Wilding and Lewin[48] showed that wide chewing cycles with predominately lateral paths of closure are closely related to improved masticatory performance. Yurkstas[49] also reported that individuals performed better when lateral vs vertical mandibular movements predominated. Although it is believed that some malocclusions (eg, deep bite, prognathism) may limit the amount of lateral excursion, we have not found any studies documenting a consistent relationship between malocclusion and reduced lateral excursions during chewing. Hinotume et al[56] showed that muscle activity patterns change with tooth crowding, but how this might be related to lateral excursions or occlusal force is not clear.

Recently, Krall et al[6] showed that progressive loss of functioning teeth in adults was related to decreasing intake of calories, protein, carbohydrates, fiber, and numerous vitamins and minerals. Although their study used a questionnaire to evaluate masticatory function, it is well established that loss of functioning teeth results in poorer scores in objective measures of masticatory performance.[4,11–18] Therefore, it is reasonable to assume that lower masticatory performance might also be related to decreasing intake of nutrients. If this is the case, it might well be a more significant problem in young and growing children than it is in aging adults. If malocclusion does indeed reduce nutritional status in children, then correction of malocclusions might benefit the children's general health as well as their oral health.

CONCLUSIONS

Malocclusion negatively affects subjects' ability to process and break down foods. Compared to normal occlusion, the median particle sizes for Class I, Class II, and Class III malocclusions were approximately 9%, 15%, and 34% larger, respectively. Individuals with normal occlusion also produced a wider distribution of particles, which indicates better masticatory performance.

Malocclusion has no effect on the number of chews required to swallow jerky and almonds. Malocclusion affects an individual's perception of how well they can chew. Groups differed significantly in their subjective ability to chew fresh carrots and celery and firm meat. Compared with normal occlusion, individuals with Class III malocclusions reported the greatest difficulty, followed by Class II malocclusions and Class I malocclusions.

ACKNOWLEDGMENTS

This research was partially funded by the American Association of Orthodontists Foundation and the Center for Craniofacial Growth and Diagnosis.

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