Masticatory performance in children and adolescents with Class I and II malocclusions

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SUMMARY It is not fully understood whether masticatory performance is compromised in individuals with the more common forms of malocclusion (i.e. Class I and Class II). The aim of this prospective investigation was to establish the relationships between masticatory performance, malocclusion (type and severity), age, body size and gender, in children and adolescents. A total of 335 individuals were examined at the average ages of 6, 9, 12 and 15 years. Each subject's occlusal status was described by Angle classification and by the Peer Assessment Ratio (PAR) index. Masticatory performance was quantified by the median particle size (MPS) and the broadness of particle distribution using artificial food.

Masticatory performance improved significantly with age. The 6-year-old children were less able to break down the food particles (MPS 4.20 mm²) than the 15 year olds (MPS 3.24 mm²). Analysis of covariance showed that age differences in performance are related to an increase in body size. There were statistically significant differences in masticatory performance between children with normal occlusion and those with a Class I malocclusion; no differences were found between normal occlusion and Class II malocclusion. Gender differences did not explain the variation in masticatory performance.

It is concluded that occlusal indices are not reliable predictors of masticatory performance. Traditional descriptors of malocclusion type and severity apparently cannot explain most of the variation in masticatory performance in children and adolescents.

Introduction

Mastication is a complex, non-random, process characterized by the comminution and break down of food into smaller particles to facilitate digestion. Because smaller food particles provide a larger surface area for enzymatic function, both food breakdown (Kay and Shiene, 1979) and gastric emptying (Pera *et al*., 2002) are facilitated. The relationship between malocclusion and masticatory function is important because there is no agreement on whether malocclusion is a physiological or a pathological condition (Tang and Wei, 1993; Richmond *et al*., 1995; World Health Organization, 1995). Occlusal factors explain much of the variation in masticatory performance among healthy subjects. Adult masticatory performance is known to diminish with the loss of post-canine teeth (Akeel *et al*., 1992; Van der Bilt *et al*., 1993). Individuals with severe types of malocclusion are less efficient at breaking down food than those with normal occlusion (Shiere and Manly, 1952; Omar *et al*., 1987; Henrikson *et al*., 1998; Van den Braber *et al*., 2001; English *et al*., 2002).

Although a number of studies have examined the relationship between masticatory performance and malocclusion in children, they have been limited in several respects. Some of these investigations used natural foods whose mechanical properties are difficult to standardize over a large number of subjects (Shiere and Manly, 1952). Others have used small numbers of sieves to measure the

distribution of the size of chewed particles (Shiere and Manly, 1952; Helkimo *et al*., 1977; Edlund and Lamm, 1980; Henrikson *et al*., 1998). A small number of sieves limits discrimination of different levels of masticatory performance (Julien *et al*., 1996; Buschang *et al*., 1997). Finally, previous studies have compared different Angle classification of malocclusion, but have not carefully controlled for the severity of the malocclusion within each Class. This has led to conflicting results when comparing masticatory performance among different malocclusion groups (Shiere and Manly, 1952; Henrikson *et al*., 1998; English *et al*., 2002). Although the relationship between the severity of malocclusion and masticatory performance has been investigated in adults (Omar *et al*., 1987), there are no comparable studies in children.

Masticatory performance improves with chronological age, body size, bite force, and an increased area of occlusal contact and near contact areas (Julien *et al*., 1996; Hatch *et al*., 2000). However, not all of these factors are independent. As individuals age, they increase in body size, muscle mass and their ability to generate bite forces. As shown by Julien *et al*. (1996), it is important to control for body size when evaluating group differences in masticatory performance. Masticatory performance also improves with an increased area of occlusal contact and near contact (Yurkstas and Manly, 1949; Bourdiol and Mioche, 2000; Owens *et al*., 2002). Therefore, masticatory performance

should not be expected to improve at a constant rate in growing children, particularly during the change from the primary to the permanent dentition (Shiere and Manly, 1952).

The purpose of this study was to evaluate masticatory performance among children and adolescents with untreated normal occlusion and malocclusion. To overcome the limitations of previous studies, an artificial food (CutterSil®, Heraeus Kulzer, Germany) was used and a seven-sieve quantitation method employed to correlate performance with age, gender, type of malocclusion and the severity of malocclusion, while controlling for the confounding effects of body size.

Subjects and method

A total of 2 344 school children were screened for this study. All the children, who represented middle-class Colombians, attended two private schools in different areas of Medellin, Colombia. The sample was self-selected on the basis of willingness to participate and was subdivided on the following criteria:

1. Boys and girls.
2. Ages between 5.5–6.5 (age group 6), 8.5–9.5 (age group 9), 11.5–12.5 (age group 12), and 14.5–15.5 (age group 15) years.
3. The children in age group 6 did not have the first molars occluding (i.e. they were either in the primary dentition or their first molars had not reached the occlusal plane).
4. Normal occlusion (i.e. Class I molar relationship with less than 3 mm of crowding, less than a 3 mm overjet and an overbite less than one-third coverage of the lower incisors), Class I malocclusion (i.e. Class I molar relationship with more than 3 mm of crowding, more than 3 mm of overjet and an overbite more than one-third coverage of the lower incisors), and Class II malocclusion (i.e. at least one half cusp Class II molar relationship).

The sample had no congenitally missing teeth, was free of signs or symptoms of temporomandibular dysfunction, had no history of previous orthodontic treatment, and had no tooth with more than two-thirds of its occlusal surface restored.

Based on the selection and rejection criteria, a total of 335 children and adolescents (224 males and 111 females) were included in the study (Table 1). Informed consent was obtained from all of the subjects and their parents.

Peer Assessment Rating (PAR) index

Alginate impressions (New Stetic, Medellin, Colombia) were taken from all the subjects, and stone models (Whip Mix, Louisville, Kentucky, USA) were produced. The PAR index was computed for each subject using dental casts. The

Table 1 Sample distribution according to age, gender and type of occlusion.

Age	Gender	Normal occlusion	Class I malocclusion	Class II malocclusion	Total
6	Male	30	18	10	58
	Female	10	6	3	19
9	Male	22	19	20	61
	Female	15	11	12	38
12	Male	13	18	17	48
	Female	10	12	2	24
15	Male	21	21	15	57
	Female	18	7	5	30
Total		139	112	84	335

PAR index was based on the sum of 11 weighted components of malocclusion including posterior right, posterior left and anterior tooth displacement (maxillary and mandibular), right and left buccal occlusion, overjet, overbite, and midline discrepancy (Richmond et al., 1992).

Anthropometric assessments

Standing and sitting height were measured to the nearest 1.0 mm using a stadiometer. Body weight was measured using a calibrated electronic scale to the nearest 0.1 kg. Body Mass Index (BMI) was computed from the height and weight measurements as [weight (kg)/height^2(cm)]. The following anthropometric measurements (Figure 1a,b) were carried out as described by Sánchez and Rodríguez (1987) and Lohman et al. (1988). In addition the following were measured:

1. Cephalic index: (Pa–Pa/Gl–Oc).
2. Arm circumference.
3. Subscapular and tricipital skinfolds.

Median particle size and broadness of the distribution

Due to the inherent variability and errors associated with the evaluation of natural food breakdown, CutterSil® (a condensation silicone impression material) has become the standard test food used to evaluate masticatory performance (Omar et al., 1987; Akeel et al., 1992; Van der Bilt et al., 1993; Julien et al., 1996; Buschang et al., 1997; Henrikson et al., 1998; Van den Braber et al., 2001; English et al., 2002; Owens et al., 2002). CutterSil® does not swell or dissolve in saliva, does not break along predetermined fracture lines, is not sticky, and is of standard consistency. The Cuttersil® was mixed according to the manufacturer's instructions and formed into tablets in a Plexiglas template. After hardening for 15 minutes, the tablets (5 mm thick and 20 mm in diameter) were removed from the template and allowed to set for at least one hour. The hardness of each tablet was between 474
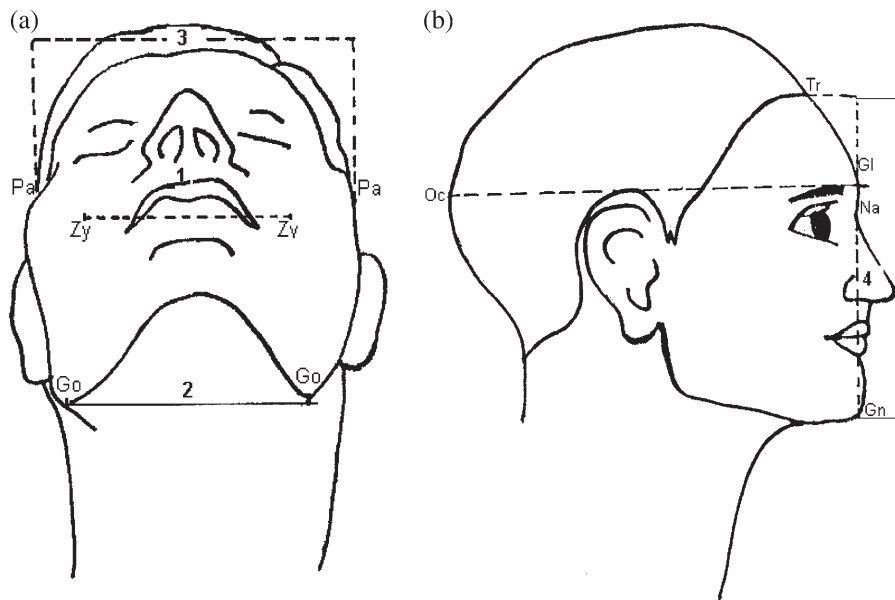
Figure 1 Anthropometric measurements. (a) 1. Bizygomatic width: zygoma– zygoma (Zy–Zy); 2. bigonial width: gonion–gonion (Go–Go); 3. biparietal width: parietal–parietal (Pa–Pa). (b) 4. face height: nasion–gnathion (Na–Gn); 5. total face height: gnathion–triquion (Gn–Tr).

and 512 load grams (62 to 65 in durometer units) and was measured using a model 306L type A durometer (PTC Instruments, Los Angeles, California, USA) and cut into quarters (Albert *et al*., 2003). Each subject placed the three-quarter-sized tablet onto their tongue, posterior to their incisors, and instructed to chew naturally for a total of 20 chews. The investigator counted the number of chews and timed each subject's chewing sequence. The subjects expectorated the sample into a plastic filter and rinsed with water until all the particles were removed from the mouth. Rinsings were also collected in the filter. The procedure was repeated five times until approximately 10 g of CutterSil® had been chewed and expectorated into the filter. The subjects were instructed to rest for 40 seconds between trials to avoid any fatigue. Chewing cycle duration (CCD) was calculated as the total duration of the five trials (excluding rest periods) divided by 100 (5 × 20 cycles).

The chewed sample was transferred to filter paper and dried in an oven for one hour at 80°C (Albert *et al*., 2003). The sample was then separated using seven sieves with mesh sizes of 5.6, 4.0, 2.8, 2.0, 0.85, 0.425, and 0.25 mm, stacked on a mechanical shaker and vibrated for two 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 the 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 (BPD) were estimated using the Rosin–Rammler

equation (Rosin and Rammler, 1933; Olthoff *et al*., 1984: Slagter *et al*., 1992):

$$Q_w = 100 \left[1 - 2^{-(x/x_{50})^b} \right]$$

where Q_w is the weight percentage of particles with a diameter smaller than x (the maximum sieve aperture). The median particle size ($\times 50$) is the aperture of a theoretical sieve through which 50 per cent of the weight can pass, and b a unit-less measure that describes the broadness of the particles distribution. Increasing values of b correspond to cumulative weight percentage curves with steeper slopes and thus to distributions of particle sizes that are less broad (Figure 2).

Statistical analysis

The skewness and kurtosis statistics showed that the distributions of all variables, except BPD and the two skinfolds, were normally distributed. The non-normally distributed measurements were normalized using log transformation. To determine possible covariates needed for subsequent analyses, Pearson's product moment correlations were undertaken to evaluate the associations between masticatory performance and anthropometric measurements. Partial correlations were then carried out to determine whether the relationships between performance and the anthropometric measurements could be explained by an increase in body size. Analyses of variance and covariance were used to evaluate the effects of age, gender, PAR index,

body size and interaction effects. Due to an interaction of age and classification of malocclusion, separate analyses were performed comparing subjects with Class I and Class II malocclusions against those with normal occlusion.

Results

Prior to correction for body height, the anthropometric measurements showed low but statistically significant negative correlations with MPS, BPD and CCD (Table 2a). Height showed the strongest relationship with the performance measurements. Tricipital skinfold thickness and the cephalic index were not significantly correlated with MPS, BPD or CCD. BMI and subscapular skinfold thickness were not related to CCD. After controlling for height, none of the correlations between masticatory performance and anthropometric measurements were statistically significant (Table 2b).

Descriptive statistics for MPS, BPD, CCD and the PAR index are presented in Tables 3 and 4, respectively. Analyses of variance showed significant age, gender, and molar occlusion effects (Table 5a). The most important factor explaining variation in MPS and BPD was age (Figure 3). With increasing age, MPS, BPD and CCD decreased. *Post hoc* tests showed that MPS and BPD in the 6-year-old age group were significantly larger than in the other age groups. The *post hoc* tests also showed that there were no differences between the 9 and 12-year-old age groups, and that MPS and BPD of the 15-year-old age group were significantly smaller than for the other three age groups. They also demonstrated that the 6-year-old age group had a significantly longer chewing cycle duration than the other three age groups. The age effects on MPS were greatest between the 6–9 and the 12–15 age groups, regardless of occlusion (Figure 3). Children with normal occlusion had significantly smaller MPS and significantly wider distributions of particles than children with Class I malocclusions. In contrast, no significant differences in masticatory performance between children with normal and Class II malocclusions were found. A *post hoc* power analysis showed that the differences between normal and Class II malocclusion subjects could not be ruled out. While there
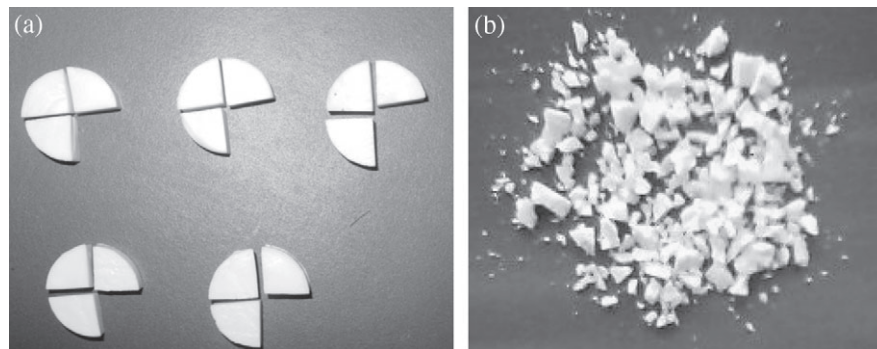

Figure 2 Three-quarter CutterSil® tablets prior to chewing (a) and the chewed particles (b).

Table 2a Pearson's product moment correlations between masticatory performance and anthropometric measurements.

Measures	MPS		BPD		CCD	
	r	*P* value	r	*P* value	r	*P* value
Height (cm)	−0.435	<0.001	−0.397	<0.001	−0.201	<0.001
Weight (kg)	−0.414	<0.001	−0.385	<0.001	−0.165	0.003
Body mass index	−0.255	<0.001	−0.251	<0.001	−0.059	0.280
Bizygomatic width (Zy–Zy)	−0.391	<0.001	−0.362	<0.001	−0.175	<0.001
Bigonial width (Go–Go)	−0.343	<0.001	−0.338	<0.001	−0.153	0.005
Face height (Na–Gn)	−0.378	<0.001	−0.368	<0.001	−0.211	<0.001
Total face heigth (Gn–triquion)	−0.324	<.001	−0.310	<.001	−0.141	0.010
Facial index	−0.167	0.002	−0.182	<0.001	−0.129	0.019
Cephalic index	0.033	0.546	0.032	0.557	0.052	0.345
Arm circumference	−0.336	<0.001	−0.316	<0.001	−0.133	0.015
Subscapular skinfold	−0.134	0.014	−0.155	0.005	0.006	0.910
Tricipital skinfold	−0.093	0.090	−0.093	0.094	0.014	0.793

MPS, median particle size; BPD, broadness particle distribution; CCD, chewing cycle duration.

Table 2b Partial correlations between performance and the anthropometric measurements controlling for height.

Measures	MPS		BPD		CCD	
	r	*P* value	r	*P* value	r	*P* value
Weight (kg)	−0.048	0.383	−0.049	0.376	0.052	0.343
Body mass index	−0.051	0.353	−0.050	0.362	0.054	0.326
Bizygomatic width (Zy–Zy)	−0.097	0.080	−0.105	0.058	−0.042	0.443
Bigonial width (Go–Go)	−0.041	0.459	−0.068	0.217	−0.003	0.944
Face height (Na–Gn)	−0.011	0.841	−0.047	0.389	−0.079	0.152
Total face heigth (Gn–triquion)	−0.031	0.576	−0.028	0.605	0.004	0.936
Facial index	0.055	0.314	0.035	0.523	−0.031	0.566
Cephalic index	0.016	0.770	−0.004	0.937	0.042	0.445
Arm circumference	−0.022	0.692	−0.019	0.729	0.027	0.617
Subscapular skinfold	0.006	0.909	−0.011	0.832	0.084	0.125
Tricipital skinfold	−0.000	0.992	−0.006	0.904	0.059	0.282

MPS, median particle size; BPD, broadness particle distribution; CCD, chewing cycle duration.

Table 3 Central tendencies (means and medians) and measurements of dispersion [standard deviation (SD) and interquartile ranges] for median particle size (MPS; mm²), broadness particle distribution (BPD) and chewing cycle duration (CCD; seconds).

		n	MPS		BPD			CCD		
			Mean	SD	25	50	75	25	50	75
Age	6 years	77	4.20	0.54	4.14	5.30	8.77	0.59	0.67	0.77
	9 years	99	3.73	0.76	3.00	3.59	6.68	0.56	0.62	0.68
	12 years	72	3.58	0.75	2.99	3.62	4.95	0.57	063	0.69
	15 years	87	3.24	0.66	2.84	3.22	3.74	0.55	0.63	0.68
Gender	Male	224	3.74	0.72	3.05	3.89	5.72	0.56	0.61	0.67
	Female	111	3.57	0.83	3.02	3.53	5.10	0.61	0.67	0.75
Occlusion	Normal	139	3.61	0.78	3.00	3.62	5.15	0.57	0.64	0.71
	Class I	112	3.76	0.74	3.11	3.88	6.56	0.57	0.63	0.70
	Class II	84	3.68	0.76	3.08	3.66	5.87	0.56	0.62	0.66

Table 4 Peer Assessment Rating index, means and standard deviations (SD) by malocclusion in the four age groups evaluated.

Age groups	Normal occlusion		Class I malocclusion		Class II malocclusion	
	Mean	SD	Mean	SD	Mean	SD
6	2.7	2.9	4.2	3.9	5.5	5.1
9	7.4	5.1	10.0	5.0	11.7	7.1
12	8.0	4.8	16.3	9.0	14.7	10.3
15	6.9	5.6	13.6	7.7	15.1	6.4

were no gender differences in MPS or BPD, females had a significantly longer (≈ 60 ms) chewing cycle duration than males.

Analyses of covariance evaluating the effects of height, PAR index and gender, showed that height explained significant amounts of variation for MPS and BPD, but not for CCD (Table 5b). After controlling for height, the age group effects identified in the analyses of variance were no longer statistically significant. The PAR index was related to MPS and BPD among children with normal and Class I malocclusions, but not in children with Class II malocclusions. Again, only masticatory cycle duration showed significant gender differences.

Discussion

Age is one of the most important sources of variation in masticatory performance. Using CutterSil® as the test food, Julien *et al*. (1996) also reported significant differences in masticatory performance between 6- to 8-year-old girls and young adult females. The differences they found in MPS between girls and females (1.1 mm) were slightly greater than those observed in the present study between the 6- and 15-year-olds (0.96 mm). This discrepancy could be due to the greater age range and sample composition in the study by Julien *et al*. (1996). Henrikson *et al*. (1998) showed that masticatory performance was significantly better in 15-year-old than in 11-year-old girls.

Table 5a   Analysis of variance evaluating the effects of age, molar occlusion (MO) and gender.

	MPS			BPD			CCD		
	Age	MO	Gender	Age	MO	Gender	Age	MO	Gender
Normal-Class I	<0.001	0.041	0.117	<0.001	0.036	0.115	<0.001	0.511	<0.001
Normal-Class II	<0.001	0.253	0.204	<0.001	0.271	0.126	0.041	0.540	<0.001

MPS, median particle size; BPD, broadness particle distribution; CCD, chewing cycle duration.

Table 5b   Analysis of covariance evaluating the effects of stature (Ht), Peer Assessment Rating (PAR) index and gender.

	MPS			BPD			CCD		
	Ht	PAR	Gender	Ht	PAR	Gender	Ht	PAR	Gender
Normal-Class I	<0.001	0.010	0.067	<0.001	0.011	0.135	0.220	0.130	<0.001
Normal-Class II	<0.001	0.227	0.086	<0.001	0.295	0.087	0.232	0.732	<0.001

MPS, median particle size; BPD, broadness particle distribution; CCD, chewing cycle duration.
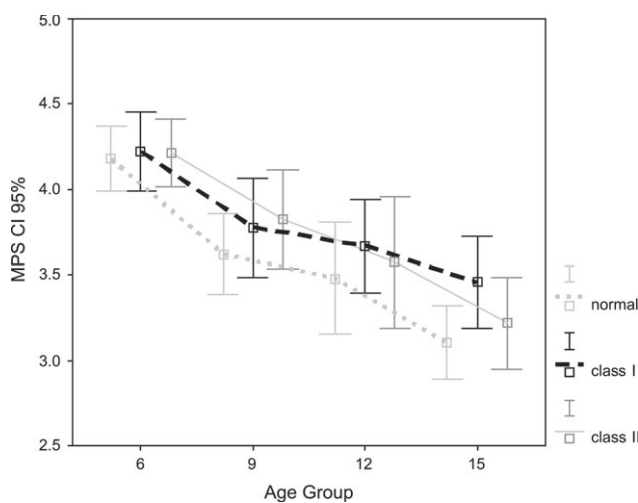

Figure 3   Median particle size (MPS; mm) and standard error by malocclusion and age group.

The observed age differences in masticatory performance were strongly associated with increases in body size. Over the age span covered in this study, body size increased approximately 40 per cent, with presumed concomitant increase in muscle size and strength (Tanner, 1962; Marshall, 1978) and MPS decreased by 23 per cent. Maximum bite force is also known to increase with age (Kiliaridis *et al.*, 1993; Shiau and Wang, 1993; Braun *et al.*, 1996; Maki *et al.*, 2001; Sonnesen *et al.*, 2001). Increases in body size, muscle mass and bite force have been previously related to improved masticatory performance (Julien *et al.*, 1996). In particular, the more dramatic improvements in performance observed between the 12- and 15-year-old age

groups may be associated with the adolescent growth spurt, which is characterized by pronounced increases in body size and muscle mass (Tanner, 1962).

The results also suggest that dental maturation may account for some of the differences observed between age groups, particularly for the younger groups. In a large cross-sectional study, Shiere and Manly (1952) showed that masticatory performance (based on number of chews required to achieve a standard degree of breakdown) for peanuts and carrots increased between 6 and 10 years of age, decreased from 10 to 11 years age, and then increased again through 14 years of age. Based on the selection criteria used for age group 6, eruption of the first molars could explain the greater improvement in performance observed between the 6 and 9 year olds than between the 9- and 12-year-old groups. In adults, the strongest crushing bite occurs at the first molars (Mansour and Reynick, 1975; Pruim *et al.*, 1980). The smaller difference in masticatory performance between the 9- and 12-year-old groups may be related to the transitional nature of the mixed dentition.

While it is established that children with severe malocclusion do not break down foods as well as children with normal occlusion (Shiere and Manly, 1952), the relative differences between individuals with Class I and Class II malocclusions remain controversial. In the present study, 6–15-year-old individuals with normal occlusion had better masticatory performance than children and adolescents with Class I malocclusions, but not necessarily better than those with Class II malocclusions. Shiere and Manly (1952), who reported no differences between children with normal occlusion and malocclusion (either Class I or Class II), used a less sensitive measure of masticatory performance and their sample sizes were smaller. In contrast to the present results,

but using similar methods, English *et al*. (2002) evaluated patients 7 to 35 years of age prior to treatment and showed poorer than normal masticatory performance for Class II, but not for Class I subjects. There are three possible explanations for the different results obtained. First, there may have been differences in the severity of malocclusion among the studies. The patients evaluated by English *et al*. (2002) were seeking treatment and might be expected to have additional components of malocclusion for which treatment was required. The fact that the present Class II sample was not seeking treatment may be important because Henrikson *et al*. (1998) have previously shown that masticatory performance is better among Class II subjects not seeking treatment than Class II subjects seeking treatment, suggesting that untreated patients with more severe forms of malocclusion do not break down CutterSil® as well as those with less severe forms of malocclusion. Secondly, subjects with a Class I malocclusion were defined differently in the two studies. Whereas English *et al*. (2002) defined malocclusion based solely on Angle's classification, the Class I subjects in the present investigation were also required to have at least 3 mm or more of overjet and more than one-third lower incisor overbite. Finally, there were fewer subjects with Class II than Class I malocclusion, which makes it more difficult to establish differences statistically. Additional prospective studies are needed to fully understand differences in masticatory performance between different occlusal classes.

In this study the children and adolescents displayed lower mean PAR scores than previously reported for Class I and Class II subjects. Evaluating individuals 6.9–48 years of age seeking orthodontic treatment, Birkeland *et al*. (1997) reported PAR scores of 26.9 and 30.7 for Class I and Class II subjects, respectively. Pangrazio-Kulbersh *et al*. (1999) reported PAR scores of 15.5 and 16.3 in untreated children 9.8 years of age with Class I and II malocclusions. While the PAR scores in the current study increased with age, they were approximately 30 per cent lower than those reported by Pangrazio-Kulbersh *et al*. (1999). This difference could be explained by the fact that in this sample the subjects were not seeking treatment because they had milder forms of malocclusion.

Finally, the results indicate that traditional descriptions of malocclusion are only weakly related to masticatory performance of individual patients. The differences in performance that have been reported between normal occlusion and malocclusion based on Angle's classification, although statistically significant, are proportionately small. In part this may be because the level of masticatory performance depends upon the intraoral selection and breakage of food particles (Van der Glas, *et al*., 1987), but the morphometric measurements in this study probably contribute only to the breakage process. These two processes were not separated in the analysis and it is possible that factors that contribute to the selection process play an important role in overall performance in children with malocclusions.

Occlusal indices measuring the severity of malocclusion are more objective, but also limited in their ability to assess masticatory performance. The PAR index was more closely related with performance than Angle's classification, but the relationship was too weak to be of clinical relevance. Of the five commonly used occlusal indexes evaluated by Omar *et al*. (1987), the Orthodontic Treatment Priority Index showed the highest correlation, but explained only 37 per cent of the variation in masticatory performance. Most occlusal indices have aesthetic and functional components that are not necessarily predictive of objective functional deficits. Based on the known association between masticatory performance and posterior occlusal contacts and near contact areas (Wilding, 1993; Julien *et al*., 1996; Bourdiol and Mioche, 2000; Hatch *et al*., 2000; Owens *et al*., 2002), bite registrations might provide a more reliable approach for quantifying the functional aspects of posterior occlusion.

Conclusions

1. Age and associated increases in body size are among the most important factors related to individual differences in masticatory performance.
2. Age changes in masticatory performance are partially related to dental maturation.
3. There are no gender differences in masticatory performance of 6- to 15-year-old children and adolescents.
4. Children with Class I malocclusions do not break down foods as well as those with normal occlusion; children with severe Class I malocclusion cannot break down foods as well as those with less severe Class I malocclusion.

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