Masticatory efficiency and dental state

A comparison between two methods

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The masticatory efficiency of subjects with all natural teeth, with complete upper and partial lower dentures, and with complete dentures was measured. Two different methods were used. The results showed significant differences among the groups irrespective of the method used. The subjects with dentures compensated for decreasing masticatory efficiency by using more strokes when chewing until swallowing. Great interindividual differences were found within groups with similar dental states. There was no or weak correlation between the two methods. A value from one method corresponded to a large range of values in the other method and vice versa. □ *Chewing efficiency; dentures; masticatory physiology*

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One of the functions of the masticatory system is to grind, salivate, and prepare the food for deglutition. Masticatory function is often estimated by studying the ability to grind or pulverize a test material. Masticatory performance (1), masticatory efficiency (2–4), masticatory effect (5), masticatory function (6), masticatory ability (7), chewing ability (8), and chewing efficiency (9, 10) are all expressions used to describe this ability. In this paper the expression masticatory efficiency is used. The degree of grinding has in most studies been measured by fractionating the masticated test food or material in a sieve system. The ability to extract sugar from chewing gum has also been used as a measure of masticatory efficiency (11). The ability to grind the food can be expressed more physiologically by calculating the area of the masticated particles of hardened gelatin (4) or raw carrots (12).

Individuals with a reduced number of teeth and/or complete or removable partial dentures have a reduced masticatory efficiency compared with those with natural teeth (10). Our knowledge of the relationship between masticatory efficiency and the function of gastrointestinal organs is incomplete. However, an impaired masticatory efficiency could result in the avoidance of hard foods (13, 14), and poor chewing comfort can thus affect the quality of life and be a risk of malnutrition (15).

In studies of masticatory efficiency subjects have chewed with different numbers of strokes (5, 7, 16, 17), for certain numbers of seconds (10, 18), or until they felt ready to swallow (2, 3, 5). When correlations between methods have been tested, contradictory results have been reported (19, 20).

The aims of this study were to measure the masticatory efficiency of individuals with different dental status by means of two different methods, to analyse the correlation between the two methods, and to ascertain whether the number of strokes, when using gelatin as a test material, influenced the precision of repeated recordings.

Materials and methods

The material consisted of four groups of subjects: groups A and D with a full natural dentition; group B with complete upper and partial lower dentures; and group C with complete dentures. The removable partial dentures had a cobalt–chromium alloy framework and bilateral free-end saddles. The number, age, and sex distribution of the subjects are shown in Table 1. Groups A and

Table 1. The number, sex, and age distribution of the four test groups

Test groups*	Sex			Age, years	
	n	F	M	Mean	Range
A	11	11	0	21.8	20–26
B	11	6	5	59.8	51–68
C	13	7	6	63.6	56–77
D	10	10	0	22.2	18–23

* A = dentate; B = complete upper and partial lower denture; C = complete upper and lower dentures; and D = dentate.

D were student dental nurses. All of them had normal jaw relations and had no history or clinical signs of disorder in the stomatognathic system. Groups B and C were patients treated by students at the Department of Prosthetic Dentistry, University of Umeå. The tests were carried out no more than 6 months after the patients had received their dentures. The patients were subjectively free of symptoms from the dentures, the dentures had good retention and stability, and the occlusion/articulation were balanced (bilateral contacts).

Group D was tested later than groups A–C and were subjected to some small changes in the clinical test routines (see below).

Masticatory efficiency was measured in two ways. In the first method the test material was gelatin hardened by formalin (3, 4). The test pieces were 22-mm cubes. After mastication the efficiency was assessed by calculating the area of gelatin particles through diffusion of a water-soluble dye into the gelatin (4). The ratio of dye absorption to area was calculated by placing gelatin particles with known area in the dye solution. For every batch the ratio was calculated, and the formula of linear regression for this function was then used to convert values of absorption to area of particles.

In the other method, developed by Loos (6) and later modified (10), masticated almonds were fractionated in a sieve system. Then the particles were counted and test subjects were classified in accordance with a five-grade chewing efficiency index, Ci. The Ci scores range from I to V, with I representing the highest degree of chewing efficiency.

The test subjects were seated in an upright position in a dental chair, and the tests were performed after an investigation of the oral conditions and the dentures. They chewed 10 test pieces of gelatin (Table 2). For groups A–C the sequence of tests 2–5 was randomized. For group D the order given in Table 2 was used. The chewing time for the 10 gelatin pieces was calculated, and the number of chewing strokes until swallowing was counted. When almonds were chewed, the first one was eaten and swallowed, and then a second, third, and fourth were chewed for 10, 20, and 40 sec, respectively. The subjects in group D were retested after 1 week, using the same methods as on the first testing occasion.

The masticated materials, gelatin and almonds, were analyzed as described above. To calculate areas, chewing time, and number of strokes for gelatin, the mean value of the two test pieces at respective test levels was used as the individual value for a test subject. For group D the first two pieces of gelatin (chewed with 20 strokes) were not analyzed. For groups A–C the first two pieces of gelatin were analyzed to disclose any potential training effect.

Statistical methods

The statistical calculations were made with Student's paired and unpaired *t* test for variables of the gelatin method, with the Mann-Whitney U-test for variables of the almond method, and with the Spearman rank correlation test for variables of both methods (21, 22). A p value < 0.05 has been used as the lowest significance level of tests of

Table 2. The design of the method using gelatin as test material

Test no.	Test piece no.	Mastication
1	1–2	20 strokes
2	3–4	10 strokes
3	5–6	20 strokes
4	7–8	30 strokes
5	9–10	Until swallowing

differences. The following characteristics and abbreviations are used in the text: the mean value ($\bar{x}$), the median value (M), the standard deviation (SD), and the range.

The precision of repeated recordings (Si) was calculated from the formula:

$$Si = \frac{\sqrt{(x_1 - x_2)^2}}{2n}$$, where x_1 and x_2 designate the number of recordings and n the number of subjects. The precision is expressed as a percentage of the mean value of x_1 and x_2.

Results

Chewing gelatin

The calculated areas of the masticated gelatin particles after chewing with 10, 20, and 30 strokes or until the subject felt ready to swallow (Table 3) differed significantly among groups A, B, and C at the four test levels. Since the experimental routines were different for group D, the results from that group have only been used to evaluate the potential differences between testing occasions. Group A achieved the highest values, group C the lowest, and group B was intermediate.

The precision of the method—the reproducibility of recordings on the same testing occasion—is shown in Table 4 and is expressed as a percentage of the mean value of the two test pieces at each test level. Differences were noted, and no test level had constant, small figures of precision for all groups.

The rank order of the test subjects with regard to masticatory efficiency was not the same at the four test levels. The most remarkable differences were found for group C (Fig. 1).

No training effect was observed for groups A–C on the same testing occasion. The calculated area for test piece 1 (20 strokes) and test piece 2 (20 strokes) did not differ significantly for any of the groups. Nor was there any significant difference between test 1 and test 3 (both with 2 × 20 strokes). For group D there were no significant differences between the test pieces in pairs on each of the 2 testing occasions, except for chewing with 20 strokes on the 2nd testing occasion. The subjects had higher values when chewing the second test piece. The subjects of group D had higher values for masticatory efficiency when they were retested after 1 week (Table 3). The differences were significant at all four test levels.

The velocity of chewing varied from 1.4 strokes/sec (for group C, 10 strokes) to 1.8 strokes/sec (group D, until swallowing). The numbers of strokes until swallowing were 29.6 for group A, 45.7 for group B, and 49.5 for group D.

Group A differed statistically significantly from groups B and C. The corresponding

Table 3. Calculated areas in cm^2 (the mean, SD, and range) of masticated gelatin particles after chewing with 10, 20, and 30 strokes and until swallowing for four groups with different dentitions

		10 strokes	20 strokes	30 strokes	Until swallowing
Group A	$\bar{x}$	111.3	152.2	172.2	168.7
	SD	27.1	24.4	26.3	39.7
	Range	70.7–152.0	122.2–189.4	128.4–212.3	99.0–235.4
Group B	$\bar{x}$	91.0	122.6	143.7	167.1
	SD	16.0	16.1	17.5	19.2
	Range	54.6–121.6	100.2–141.3	117.6–169.1	140.6–193.1
Group C	$\bar{x}$	68.3	97.7	118.1	134.1
	SD	22.5	25.6	29.7	35.8
	Range	35.0–111.9	65.3–151.2	58.3–179.0	64.5–176.0
Group D	$\bar{x}$	106.7	140.6	159.2	170.5
Testing	SD	12.9	17.3	18.2	21.3
occasion I	Range	89.0–122.1	117.7–170.1	131.6–194.5	144.6–216.2
Group D	$\bar{x}$	124.6	154.3	174.0	183.6
Testing	SD	12.7	15.7	10.1	16.7
occasion II	Range	108.5–141.7	130.3–172.6	159.5–188.3	150.8–209.5

Table 4. The precision (Si) of the gelatin method expressed as a percentage of the mean value of the two test pieces at each test level and for group D also of the mean value from the two test occasions

	10 strokes	20 strokes	30 strokes	Until swallowing
Group A	10.84	11.65	7.44	10.19
Group B	6.58	9.43	10.13	11.10
Group C	10.88	12.94	12.12	14.63
Group D				
I	8.64	6.10	4.36	3.60
II	5.16	4.32	4.44	2.55

figures for group D on the two test occasions were 41.3 and 35.2, respectively, and that difference was not statistically significant.

Chewing almonds

The distribution of chewing efficiency indices (Ci) and median values are given in Table 5. All test subjects in groups A and D had Ci I; for group B Ci varied from I to III, and for group C from I to V. The two groups with dentate subjects, A and D, differed significantly from groups B and C, and group B differed significantly from group C.

Correlation between the methods

The correlation between Ci and calculated

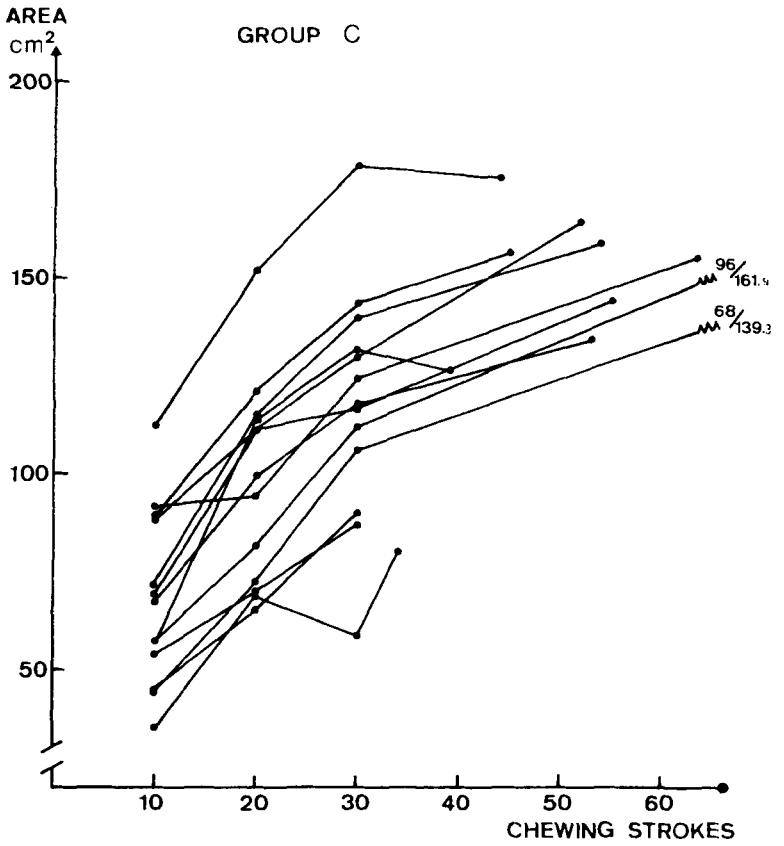

Fig. 1. Calculated areas, in cm^2, of masticated gelatin particles for group C. For each patient the calculated area values after 10, 20, and 30 chewing strokes and chewing until swallowing are measured. The points marking the different values are connected.

Table 5. The distribution of chewing efficiency index (Ci) and the median values (M) for the four groups. Group D was tested on two different occasions (I and II)

	Chewing efficiency index					
	I	II	III	IV	V	M
Group A ($n = 11$)	11	0	0	0	0	I
Group B ($n = 11$)	3	5	3	0	0	II
Group C ($n = 13$)	2	1	9	0	1	III
Group D ($n = 10$)						
I	10	0	0	0	0	I
II	10	0	0	0	0	I

areas of masticated gelatin pieces for groups A–C when chewing with 20 strokes is given in Fig. 2. For the same Ci there was a large range of corresponding areas of gelatin particles, and this range was largest for Ci I. Furthermore, for the same area there was a large range of corresponding Ci's. The analyses for chewing with 10 and 30 strokes or until swallowing showed the same pattern. There was no, or very weak, correlation between Ci and masticatory efficiency expressed with areas of gelatin particles.

Discussion

The test subjects in this study were considered to represent different categories with regard to masticatory function. Young individuals with normal jaw relations and with-

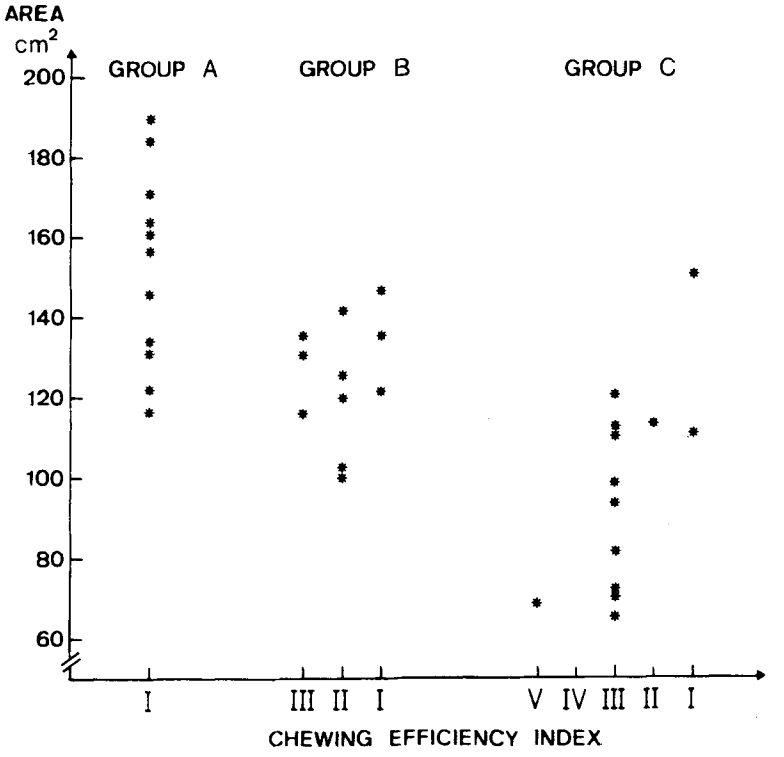

Fig. 2. The relationship between areas of gelatin particles after chewing with 20 strokes and Ci for groups A, B, and C.

out symptoms from the stomatognatic system were considered suitable subjects for the fully dentate group.

One of the purposes of mastication is to enlarge the surface area of chewed material to be exposed to digestive juices. The method using gelatin as a test material (4) measures this factor. It seemed important to compare this method with the one developed by Loos (6). The latter method has been used in several studies (9, 10, 23, 24) and is simple and rapid to perform.

The masticatory efficiency measured with the gelatin method differed significantly between groups A, B, and C irrespective of whether 10, 20, or 30 chewing strokes were used. If the masticatory efficiency is expressed as a percentage of what group A performed, the masticatory efficiency of group B varied between 80 and 83% and of group C between 61 and 69%. These results by and large conform with the results from other studies (17, 25).

In chewing gelatin until the swallowing point the masticatory efficiency of groups A and B did not differ and that of group C was 80% of what group A performed. Thus, group B compensated completely and group C partially by an increased number of strokes when chewing until swallowing. This is not in agreement with other studies (5, 26, 27). The present study indicates that complete dentures and removable partial dentures cannot re-establish masticatory efficiency to the level of fully dentated individuals but that patients try to compensate for the impaired efficiency by chewing for a longer time.

Marked interindividual variation in masticatory efficiency was noted in all groups at all four test levels. The masticatory efficiency of the best subjects in group C was equal or superior to the mean value for group A. This is in agreement with results from other studies of masticatory efficiency (5, 17).

The subjects in group D (dentate) increased their masticatory efficiency between testing occasions I and II. This is evidently a training effect. Gelatin is different from most foodstuffs and is difficult to handle in the mouth, and on the second testing occasion the subjects were more familiar with the experimental situation. Within the same testing occasion there was no training effect for any of the groups with one exception: group D chewed with 20 strokes on the second testing occasion. Pilot studies and clinical studies in progress in our laboratory have not shown any training effect for denture subjects when retested after 1 week.

When masticatory efficiency was evaluated by the almond method, the chewing efficiency index, Ci, differed significantly among groups A, B, and C. Of the complete denture wearers 70% obtained Ci III. When 26 subjects with old complete dentures were tested (10), the Ci median value was the same as in the present study. However, the results for the group as a whole were better in the present study, which can probably be ascribed to the fact that all the present subjects had new dentures with good retention and stability, an important factor when chewing hard and brittle almonds. In another study the median value for patients with new complete dentures was still higher (28).

There was no interindividual variation between the dentate subjects in groups A and D with regard to Ci. For the complete denture wearers the Ci varied along the whole scale, from I to V. The partial denture wearers had a variation intermediate to the above. In a previous study (10), in which subjects with more than 20 teeth were tested, Ci varied from I to III; for complete denture wearers, from II to V; for subjects with osseo-integrated bridges in one jaw, from I to II (9); and for subjects who 12 months earlier had undergone surgical reconstruction of the mandibular residual ridge and then got new dentures, from I to IV (28). These findings and other studies show that denture patients are handicapped in mastication. However, masticatory efficiency is an activity that is dependent on many factors and cannot be predicted from the dental status alone.

The lack of correlation between the two methods used in the present study is in agreement with previously reported results (20). When peanuts, almonds, and soya beans were used as test materials and fractionated in a sieve system, high correlations were found between the different communition tests (19). In our study two test materials

with different rheological properties were analyzed, which could partly explain the discrepancy between the results. All dental subjects obtained Ci I but showed great variation when tested with the gelatin method, indicating that it might be possible to differentiate between subjects with this method. It seems that the two methods measure different aspects of masticatory efficiency.

One of the purposes of this study was to analyze how the number of strokes influenced the precision when gelatin was used as a test material. In studies of masticatory efficiency 20 strokes is the number most commonly used. A small number of strokes could provide information about the subjects' ability to handle the rather large gelatin piece. A previous study showed that complete denture wearers often use more than 30 strokes before they feel ready to swallow (3). Therefore, besides chewing until swallowing, 10, 20, and 30 strokes were used. Considering that the figures of precision are an expression of the reproducibility of the method and the biological intraindividual variation, the difference between repeated recordings were small. When the precision from the four test levels was compared, there were differences. However, none of the test levels was superior to the others in this respect. The precision varied from 4.3 to 14.6% (Table 4), and this could partly explain why the rank order of test subjects at different test levels was not the same. Even if there is a difference in the subject's efficiency during different parts of the test, the result will be the same.

In this study the masticatory efficiency differed significantly among groups with different dental states when measured by two different methods. Subjects with removable dentures compensated for the decreased masticatory efficiency by more chewing strokes. The almond method was simple and rapid to perform, but with the gelatin it was easier to differentiate between the subjects, and the masticatory efficiency was expressed with values on an interval scale. Different qualities are required to grind comparatively large gelatin pieces and hard and brittle almonds. There was no statistically significant correlation between the methods, indicating that different aspects of masticatory efficiency were measured. This also means that when evaluating the effect of prosthetic treatment on masticatory efficiency, more than one method should be used.

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