Chewing efficiency and state of dentition

A methodologic study

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Chewing efficiency, defined as the ability to grind a certain portion of a test food during a given time, was tested in 139 Skolt Lapps, aged 14–65. 94 persons had natural teeth and the remaining 45 wore dentures (partial and/or complete). The test food was almonds. Number of chewing strokes, swallowings and chewing time was denoted. The chewing efficiency was classified after a scale from 1 to 5 where 1 meant very good and 5 very poor ability to reduce the particle size of the test food.
Clear associations were found between chewing efficiency and dental state. Number of occluding pairs of teeth was closely correlated with chewing efficiency and individuals with less than 20 teeth had a higher index score than those with more than 20 teeth. The values noted for number of chewing strokes, swallowings and chewing time were smaller for those with a good chewing efficiency, but the variation was not linear and not always significant. Denture wearers had statistically significantly higher chewing efficiency score than those with natural teeth, without dentures, and needed more chewing time before swallowing.

Key-words: Mastication; denture wearers; dental state

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Despite the presumedly important role played by mastication in the maintenance of health of the body as a whole, this function has received relatively little attention in the dental and medical literature. This could partly be ascribed to the fact that chewing is a very complex process and its role in deglutition and digestion is difficult to judge. Of the pertinent investigations, most have dealt with chewing pattern, chewing rate and the problems encountered in the use of methods available for the study of masticatory efficiency (for review see 2, 3). Successful research in mastication and deglutition, etc., probably requires the joint efforts of members of the medical and dental professions. An opportunity for such co-operative research was offered by the Scandinavian Human Adaptability Project, IBP/HA, in Inare, Finland (6).

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Purpose

The purpose of the investigation was to devise a simple reproducible test method for assessing chewing efficiency and to apply it in a search for correlations between chewing efficiency, the state of dentition, the functional state of the masticatory system, the state of general health, and the state of nutrition. This paper is the first in a series where chewing efficiency as a standard will be correlated to functional state of masticatory system, general health etc.

Definitions

Chewing efficiency is to be understood as the ability to grind a certain portion of a test food during a given time.

Chewing time is used to designate the period necessary to grind and swallow a certain portion of a test product.

MATERIAL AND METHOD

The material consisted of 139 Lapps (63 males and 76 females), aged 14 to 65 years (mean 32), who took part in the general health surveys including the IBP/HA program in Inare, Finland, 1970. Ninety-four of the persons had natural teeth, while the remaining 45 wore dentures. Of the latter group, 26 wore complete upper and lower dentures, and 19 a complete or partial upper denture, and still some natural teeth in the lower jaw (Table 1).

The method used was based on those described by (4) and (7) for estimating the sizes of fragments of a masticated food product. Scalded almonds were used as a test food. The almonds were of roughly uniform size and weighed on an average 1.5 g. Each subject chewed six almonds as described below.

The subjects, who were seated on ordinary chairs, were instructed to eat the first almond naturally, *i.e.* using whatever chewing side they preferred, chew it at a normal rate and swallow the bolus at leisure as they would if they were not being tested. Two observers counted the chewing strokes to the first and to the last swallowing as well as the number of swallowings. The interval between the first chewing stroke and the last swallowing, *i.e.* when the patient said he no longer had any of the test product left in his mouth, was recorded as *chewing time*. The mean of the observations made by the two observers were used for the calculations.

The subjects were instructed to chew the 2nd, 3rd and 4th almonds naturally for 10, 20 and 40 seconds, respectively, but not to swallow the ground almond, and to spit it into a sieve-system consisting of 3 sieves with meshes of 5.6, 4.0 and 2.0 mm (Fig. 1). After having chewed the almond, the mouth was carefully rinsed with water, which was also transferred into the sieve-system. To let all particles smaller than the screen meshes pass through the screen, the sieve was washed with water before the particles were counted. The particles retained in the uppermost sieve (> 5.6 mm) were called A-particles; those in the middle sieve, B-particles ($5.6 < 4.0$ mm); and those in the lowest, C-particles ($4.0 < 2.0$ mm).

The 5th almond was chewed at a normal rate but not swallowed. After 20 strokes the person tested ejected the ground almond into the uppermost sieve and rinsed his mouth. The 5th almond was then treated in the same way as almonds 2, 3 and 4. The 6th almond was eaten in the same way as number 1 and numbers of chewing strokes, chewing time and swallowings were recorded. The average values for chewing strokes, chewing time and swallowings for almonds number 1 and 6 were used for the analyses.

In 18 individuals the entire test was repeated, on an average 6 hours later. The retest was made in subjects who were not occupied by other researchers and had not recieved any dental treatment between the two tests.

To facilitate analysis of the findings, the subjects were classified according to criteria for a 5-grade index for chewing efficiency (Table 2). In the table Ci 1 denotes very good chewing efficiency, Ci 5 very poor.

Table 1. *Age and sex distribution in the different dentition groups*

		Age (years)					
		14–24	25–34	35–44	45–54	55–65	Total
Dentate	Male	27	9	4	7	6	53
	Female	27	9	2	2	1	41
	Total	54	18	6	9	7	94
Dentures in the upper, natural teeth in the lower jaw*	Male			3	2		5
	Female	1	3	6	3	1	14
	Total	1	3	9	5	1	19
Complete dentures	Male			3	1	3	7
	Female		5	6	4	4	19
	Total		5	9	5	7	26
Total		55	26	24	19	15	139

* This group includes two partial dentures

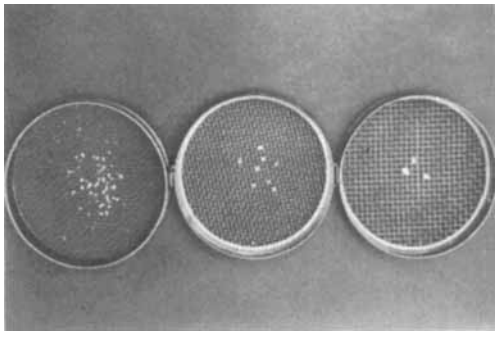

Fig. 1. Sieve-system, consisting of 3 sieves with meshes of 5.6, 4.0 and 2.0 mm

The number of teeth and the occlusal contact relationship of each subject were studied clinically. Notation was made of the number of natural teeth, of occluding tooth contacts in the intercuspal position, and occluding pair of teeth in the intercuspal position. In an occluding pair of teeth only one tooth, the main antagonist, in each jaw was counted. The maximum of pairs of occluding teeth in a 28 tooth dentition was thus 14.

Statistical methods

Conventional methods were used for calculating the mean value ($\bar{x}$), standard deviation (S.D.), and the coefficient of correlation (r). The Mann-*Whitney test for*

Table 2. *Index for chewing efficiency*

Ci 1.	No A-particles, few B-particles (≤ 5) after 10 seconds
Ci 2.	No A-particles, few B-particles (≤ 5) after 20 seconds
Ci 3.	Few A-particles (≤ 5, none larger than 10 mm) after 20 seconds
Ci 4.	Criteria for index 1, 2 or 3 not filled and no A-particles left after 40 seconds
Ci 5.	Criteria for index 1, 2 or 3 not filled and A-particles left after 40 seconds

estimating the significance of differences between groups was used for the analyses of the chewing index, chewing strokes, chewing time, swallowings, number of teeth and contacts between teeth for the different test groups. The precision of repeated recordings (accidental error) was calculated from the formula

$$S_i = \sqrt{\Sigma (x_1 - x_2)^2 / 2n}$$

RESULTS

In those 18 individuals studied with double determinations of chewing efficiency, 9 showed a difference in index. In all 9 the index was lower on the second occasion, *i.e.* improvement of chewing efficiency. The precision (s_i) of determination of chewing time was 17 seconds (standard deviation of a single determination). If one person with a wide variation of chewing time (179 and 48 secs, respectively) was excluded, the precision would be 7 seconds. The corresponding difference for precision of determination of the number of chewing strokes was 17. The person with a large difference of chewing time also had a wide variation of number of chewing strokes (193 and 63, respectively) and if he was excluded, the corresponding figure would be 7. The corresponding figures for the number of swallowings were 0.8 and 0.5, respectively. The calculations are based on the mean averages for the 18 people tested on two occasions. In the 139 persons studied the precision of the determination of chewing time calculated on the values for almonds 1 and 6 was 7 seconds and that of the total number of chewing strokes and of swallowings 11 and 0.7, respectively.

The index values found for chewing efficiency ranged from the lowest to the highest level of the scale (Figs. 2, 3).

No significant differences in chewing efficiency, number of chewing strokes or swallowings were found between sexes. The values were therefore pooled.

Despite a wide interindividual variation clear associations were found between chewing efficiency and dental state. In individuals with natural teeth (without dentures) an inverse relationship was found between the number of teeth, the number of occluding pairs of teeth and occluding tooth contacts, on one hand, and the chewing efficiency index on the other (Table 3). Of all comparisons of two consecutive index values of the three variables (3 x 10 comparisons), only four did not reach significant levels. Of the remaining 26 comparisons, one reached the 5% level ($p < 0.05$), five the 1% level ($p < 0.01$) and 20 were significant on the 0.1% level ($p < 0.001$).

The values noted for the number of chewing strokes and chewing time were also smaller for individuals with the best chewing efficiency index than for those with the higher index, but the variation was far from linear (Table 3). In index group 5 the number of chewing strokes and the chewing time were statistically greater ($p < 0.01$) than in index groups 1, 2 and 3, but as far as the other comparisons are concerned, only single significant differences were found. No correlation was found between the number of swallowings and chewing efficiency.

The analysis of individuals with natural teeth without dentures divided into two groups, more than 20 teeth and less than 20 teeth, showed that those with more than 20 teeth had statistically significantly ($p < 0.01$)

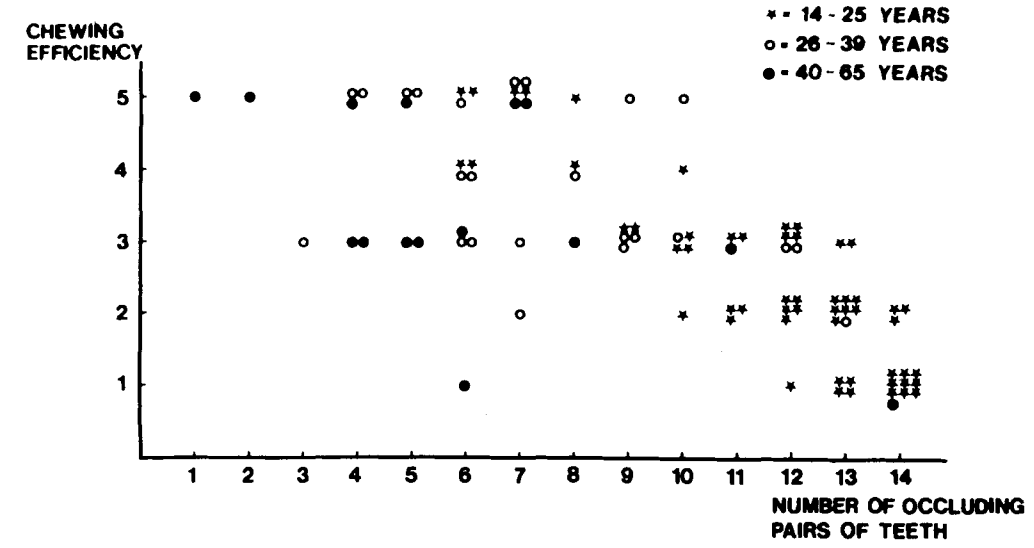

Fig. 2. Distribution of number of occluding pairs of teeth according to chewing efficiency group in 94 dentate persons

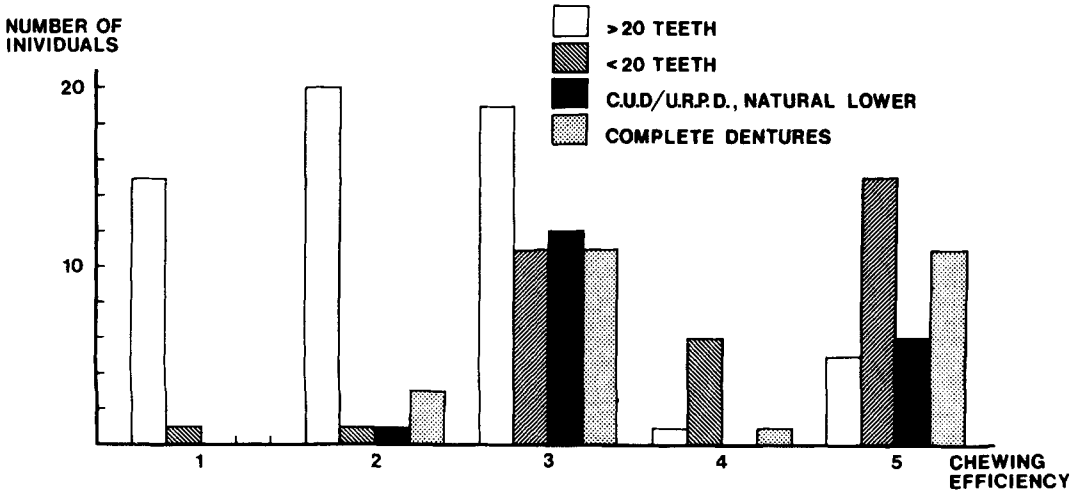

Fig. 3. Distribution of material in respect of different chewing efficiency groups: > 20 teeth; ≦ 20 teeth; complete upper denture or upper removable partial denture (C.U.D./U.R.P.D.) /natural teeth in the lower jaw; complete upper and lower dentures.

lower number of chewing strokes (number of chewing strokes to the first swallowing as well as total number of chewing strokes) and shorter chewing time than the others (those with less than 20 teeth). Even the chewing efficiency index differed statistically ($p < 0.001$) between the two groups. The individuals with more than 20 teeth had lower index score than those with less than 20 teeth.

The number of occluding pairs of teeth was correlated with chewing efficiency ($r = -0.78$; Fig. 2). Chewing efficiency never scored an index value of 1 in any of the denture wearers (Fig. 3). The denture wearers had statistically significantly ($p > 0.001$) higher chewing efficiency score than those with natural teeth

Table 3. *Means ($\bar{x}$), standard deviations (S.D.) and range of some variables for individuals with natural teeth without dentures in the 5 chewing efficiency groups (Ci 1–5)*

	Ci 1 (n = 16)			Ci 2 (n = 21)			Ci 3 (n = 30)			Ci 4 (n = 7)			Ci 5 (n = 20)		
	$\bar{x}$	S.D.	Range	$\bar{x}$	S.D.	Range	$\bar{x}$	S.D.	Range	$\bar{x}$	S.D.	Range	$\bar{x}$	S.D.	Range
Age	20.6	11.3	14–54	18.9	4.7	15–34	30.5	14.7	16–61	31.4	15.3	20–54	36.9	15.5	18–64
Number of occluding pairs of teeth	13.1	2.0	6–14	12.5	1.1	10–14	9.1	3.0	3–13	7.1	1.6	6–10	5.9	2.2	1–10
Number of occluding tooth contacts	22.6	4.9	6–26	19.6	3.6	13–26	13.7	5.2	2–22	11.0	3.4	6–16	9.5	3.1	1–14
Number of teeth	27.4	2.6	18–30	26.2	2.1	20–29	22.2	4.5	12–28	17.3	3.5	14–23	18.4	6.0	8–30
Number of chewing strokes to first swallowing	27.2	10.6	16–56	19.9	4.8	11–28	32.4	21.5	13–95	39.6	21.7	18–83	40.7	16.6	20–293
Total number of strokes	32.5	13.6	17–71	24.0	6.8	11–37	40.0	27.7	13–132	42.4	21.1	18–83	56.0	38.2	28–396
Total chewing time	32.9	11.4	19–55	24.3	9.0	12–44	34.7	16.2	12–89	42.6	18.6	29–83	52.9	32.7	30–262
Swallowings	2.4	0.9	1–4	2.4	0.8	1–4	2.4	1.0	1–5	1.6	0.8	1–3	2.8	1.8	1–7

without dentures. In general the denture wearers needed significantly more chewing strokes and longer chewing time before swallowing a bolus than did the individuals with natural teeth ($p < 0.01$), yet no significant difference in number of swallowings was found between the two groups (Table 4).

The correlation between chewing efficiency and chewing time was relatively weak ($r = 0.56$; Fig. 4). The chewing frequency (number of chewing strokes per minute) showed no variation with chewing efficiency (Fig. 5).

DISCUSSION

The method for determining the chewing efficiency was also tested by making double determinations in 20 students with practically complete sets of teeth (*Helkimo, E.*, in preparation). No difference in index was found between the two determinations, but the index score was 1 in 19 of the students and 2 in one. In the present series, in which the index score ranged from 1 to 5, there was a lower chewing efficiency index score in nine of the individuals; none had a higher score at the

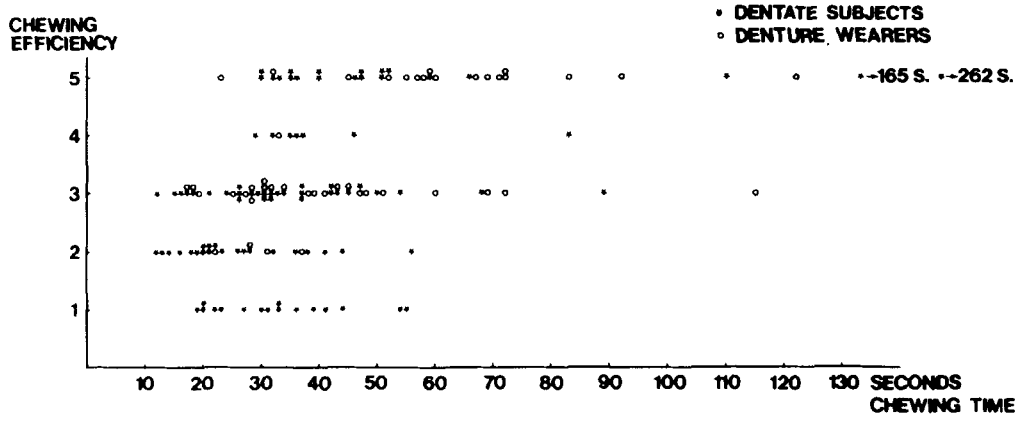

Fig. 4. Distribution of chewing time according to chewing efficiency in 94 persons with natural teeth and 45 with partial and complete dentures. Chewing time is an average of 2 measurements.

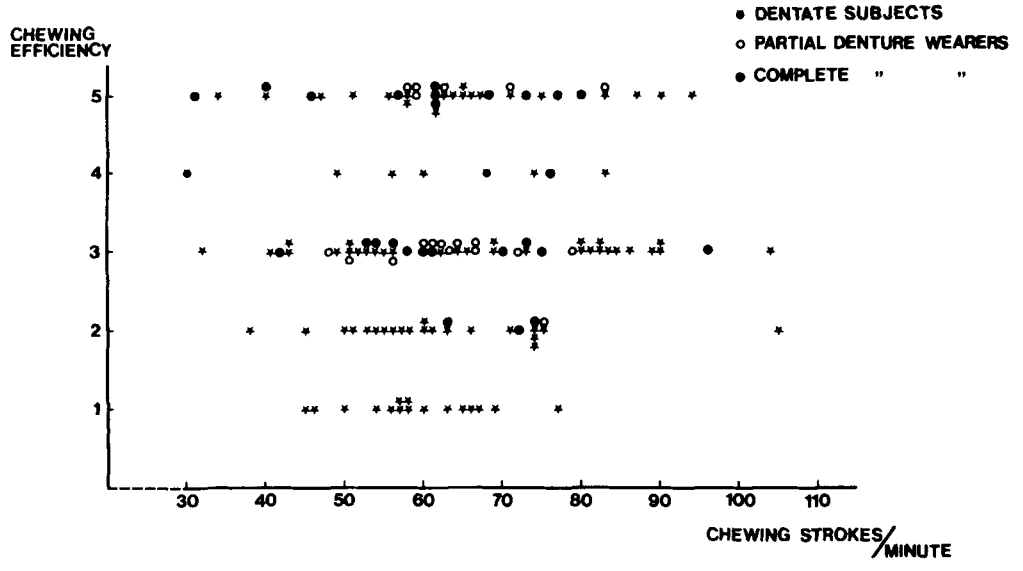

Fig. 5. Distribution of number of chewing strokes per minute according to chewing efficiency in 94 individuals with natural teeth, 19 with complete or partial dentures in upper jaw and natural teeth in lower jaw and 26 persons with complete dentures in both jaws. Number of chewing strokes is an average of 2 registrations.

second determination. This indicates that the test subjects scored better once they had become better acquainted with the test procedure.

The test method has also been used by (1) in an investigation of the chewing efficiency in patients with deformities of the jaw (mostly prognathism). The index values for masticatory efficiency was found to differ one index unit from one occasion to another in 6 out of 20 of these individuals and in 1 out of 10 with normal jaws. Such test-retest differences may be attributed to variation of performance rather than to lack of precision of the technique *per se*. In cross-sectional epidemiological studies the precision of the method is usually not regarded as critical. In longitudinal studies the precision may be more important. However, (1) has shown that the method used in this study can be used also in such longitudinal investigation.

The repeatibility of the chewing time and of

Table 4. *Mean ($\bar{x}$), standard deviation (S.D.) and range in the different test groups for number of chewing strokes, chewing time and number of swallowings. A = individuals with natural teeth, B = those with dentures in the upper and natural teeth in the lower jaw, and C = those with full dentures in the upper and lower jaw*

		Chewing strokes			Chewing time			Swallowings			Age (years)		
	n	$\bar{x}$	S.D.	Range	$\bar{x}$	S.D.	Range	$\bar{x}$	S.D.	Range	$\bar{x}$	S.D.	Range
A	94	38.6	26.6	11–184	36.4	21.1	12–165	2.4	1.1	1–7	27.6	14.2	14–64
B	19	51.9	22.0	20–98	50.2	23.3	19–116	2.7	1.1	1–5	39.7	8.4	22–59
C	26	49.6	32.1	15–163	47.8	24.4	17–122	2.5	1.1	1–6	45.8	11.7	25–65

Differences $A-B^{***}$ $A-C^{**}$ $B-C^{ns}$ $A-B^{**}$ $A-C^{**}$ $B-C^{ns}$ $A-B^{ns}$ $A-C^{ns}$ $B-C^{ns}$

Level of significance $^{***}p \leq 0.001$; $^{**}0.001 < p \leq 0.01$; $^{*}0.01 < p \leq 0.05$; ns = non-significant

the number of masticatory strokes was also fairly weak, but better when one individual with extremely large test-retest differences was excluded. In all the measured variables, intra-individual (biological) variations apparently had a dominating effect on the precision of the procedures.

The results of this study corroborate the view shared by many authors (for review see (2)) that chewing efficiency depends to a large extent on dental state. The number of teeth is less important than the number of contacts. A noteworthy finding was the correlation ($r = -0.78$) between occluding pairs of teeth and chewing efficiency. In fact, it was just as close as that previously found (8) between occlusal contact area and masticatory performance. Thus, instead of the occlusal contact area which is difficult to judge, one might use the number of occluding pairs of teeth as a relatively reliable measure of chewing efficiency.

Only exceptionally (4 out of 45 persons) did denture wearers have the lowest index values (1 and 2) and were then comparable to patients with fewer than 10 occluding pairs of teeth (Figs. 2, 3).

Judging from the present investigation of chewing efficiency, the widely held belief among clinicians that 20 teeth (or second premolar to second premolar in the upper and the lower jaw) are sufficient for «adequate mastication» is unfounded. At any rate people with such a dentition have a significantly reduced capacity to grind the test food used in this study. The importance of good chewing efficiency for digestion and general state of health is not well known, but the results of published investigations have been reviewed and discussed by (3) among others.

The weak, though significant, correlation between chewing efficiency and chewing time suggests that persons with poor chewing efficiency in general tended to chew for a longer time, but this did not prove to be the case in many of the persons tested (Fig. 4). The frequently quoted conclusion by (5) and (8) that poor chewing efficiency is compensated by swallowing less well ground boluses of food and not by chewing for a longer time was partly, but by no means convincingly, corroborated by the present investigation. The inter-individual variation was so wide that generalization should be avoided. As also found in the above mentioned investigations no significant correlation was found between the rate of chewing and chewing efficiency.

The index values noted for chewing efficiency will be used in future analyses of the correlations between chewing efficiency and such factors as biting force, symptoms of dysfunction, general state of health and of nutrition.

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