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Oral Bolus Kneading and Shaping Measured with Chewing Gum

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Abstract. A masticatory test using two-colored chewing gum is presented and analyzed. Two separate parameters of chewing were studied on the same chewing gum bolus after 10 strokes of oral preparation, color mixing, and bolus shaping. The two parameters were evaluated in indices 1–5. A test series should preferably contain three chewing gums, and color mixing can be evaluated on six sides and shape-indexed for each bolus. The medians characterize the subjects' masticatory ability. Color mixing may relate, for example, to ensalivation of the food during chewing, and bolus shape may relate to preparation into a form suitable for swallowing. The tests were used on test subjects with different dental and denture status. Significant differences in both color mixing and shape indices were found between groups with different status. The method is discussed in relation to earlier types of tests, e.g., the comminution test mostly used hitherto.

Key words: Chewing test — Masticatory efficiency — Oral bolus shape—Deglutition—Deglutition disorders.

Masticatory ability has been studied in various ways (for review see [1–3]). Most studies deal with the particulation of food because most researchers probably considered that the major masticatory function of the dental system is to comminute food, and the most plausible reason for mammals to comminute food is that the smaller the particles the more rapid the breakdown and absorption [4]. No studies, however, have defined the extent of the particulation needed to justify such detailed analysis of particle size.

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Some foods break into pieces whereas others flow or form a bolus [5,6]. Lucas and Luke [6] studied the chewing or brazil nuts and carrots and found that brazil nuts after comminution formed a bolus but carrots did not. A difference in the fluid content of the food and the moistening by saliva during chewing may explain this, as well as a difference in the number of chewing strokes needed before swallowing.

It is a well-known fact that saliva needs to be introduced into or onto a dry bolus for lubrication before swallowing can take place, as has been demonstrated experimentally by Liedberg and Öwall [7].

Thexton [8] mentions in an overview of the physiology of mastication and swallowing that a forming/accumulation of a bolus at the back of the tongue takes place in the vallecula, and Lucas and Luke [6] speculate that the bolus of originally particulated food has been transformed at the time of swallowing into a definable entity—a paste, i.e., a solid/liquid mixture that coheres. Some foods, though, for instance whole meat, cannot be or do not need to be particulated. The chewing kneads and shapes the food into a bolus so that it can be swallowed whole. A radiological study [9] has demonstrated that such swallowing can take place in humans.

The need for reduction of the particle size of a friable food to a size that can be accepted by the pharyngeal/esophageal passageway for comfortable swallowing has been indicated in the literature [6,10]. Actual measurements of the transverse width of the pharyngo-esophageal segment have made clear that there are correlations to different parameters of chewing [11]. Liedberg et al. [11] found that subjects with a narrow width pharyngo-esophageal segment when swallowing liquid barium showed more spool-shaped boluses in chewing tests with chewing gum and smaller particles in particulation tests when chewing a friable silicone test food.

Heath [12] noticed that chewing gum boluses have different shapes that relate to the subjects' dentition. We have also used the shaping of boluses during chewing [7,11] according to the method described below and found the same thing.

Kneading of the food mass, as well as the admixture with saliva, moisture from within the foodstuff as with carrots [6], drinking water, or other lubricants, are parameters of chewing that have so far not been elucidated in any tests. Heath [12] approached such a method when he measured the release of sugar from chewing gum. Measuring the mixing of two colored chewing gums during chewing might give a picture of the capacity of the masticatory system in this respect; an evaluation of the capacity of the oral system to shape a bolus so that it becomes ready to enter the pharyngo-esophageal passageway seems possible with the chewing gums.

Thus, it can be concluded from the literature that there are no methods for measuring bolus kneading and bolus shaping, although these parameters seem to be important. It is therefore justifiable to introduce a method for this purpose, and the aim of this study was to analyze in detail a method using two colored chewing gums [7,11] for measuring oral bolus kneading, color mixing, and bolus shaping, and to evaluate whether this method is applicable to chewing tests on different types of dentitions.

Materials and Methods

Chewing Gum

A chewing gum was specially manufactured by A/S Alfred Benzon, Copenhagen, from the same base material used in the commercially available SOR-BITS® chewing gum. The gums were stained blue and red by the manufacturer using dyes insoluble in water. The chewing gums had a hardness of 40–66 kp/cm^2 when tested after storage at 20°C (Zwick penetrometer model 7201; method ASTMD 676).

Test Subjects

The number of strokes to be used in the chewing test was established in a test comprising persons with different dental status and ages.

Test Group A. Twenty-five subjects, representing various ages and dental conditions, were used. There were 7 subjects with complete, natural dentition comprising 28 teeth; 7 subjects having natural dentitions with 21–27 teeth with tooth spaces; 1 subject with a complete maxillary denture and 11 natural teeth in the mandible; 3 subjects with complete maxillary dentures and removable partial mandibular dentures; and 7 subjects with complete dentures in both jaws. There were 20 women and 5 men, ranging in age from 32 to 82 years.

The chewing gum tests were used in two groups of subjects to establish the number of chewing gums needed and whether chewing should be restricted to one side, as preferred.

Test Group B. Students, employees, or patients at the School of Dentistry, Malmö, were used as test subjects. Ten had complete natural dentitions, including two or three molars in each quadrant, and another 10 were missing 1–13 teeth without any prosthetic restorations. The tooth spaces comprised one to five teeth, excluding third molars, if any.

Chewing Test Procedure

Test Group A. Each subject chewed gum test pieces for 10, 20, 40, 60, 80, and 100 chewing strokes, respectively. The order of these chewing tests was individually randomized. Chewing was to take place on either or both sides, as prefered.

Test Group B. As established in test with Group A (see under results), 10 strokes were used for the chewing tests. One red and one blue piece of chewing gum, each measuring 10 × 10 × 5 mm, were placed together, with the colors clearly separated, on the occlusal surface of the right mandibular premolars. Instructions were given to chew on right or left sides, or both, as preferred (habitual chewing), and to terminate in a closed position and thereafter open the mouth to enable to experimenter to remove the gum. The number of strokes was counted by the subject and the experimenter. A test series consisted of 15 chewing gums—5 right, 5 left, and 5 habitual—and was individually randomized.

Evaluation of Chewing Gums

After removal from the oral cavity, the gums were labeled with random numbers and listed. They were later scored blind by visual inspection into a color mixture scale 1–5 according to a reference scale determined in pilot tests (Fig. 1). Both sides of the gum boluses were scored. The color indexes were decided for right, left, and habitual chewing respectively as the median of ten evaluations (five gums × two sides).

The bolus shape was also scored into an index 1–5, determined in pilot tests (Fig. 2). The shape allotted was the median of 5 chewing gums for right, left, and habitual chewing, respectively.

Reproducibility and Interexaminer Reliability of Chewing Gum Scoring

The group B chewing tests were repeated after about 1 week in a new randomized order between right, left, and habitual chewing (test occasion 2). Thus, 15 chewing gums for each of the 20 subjects were doubled.

Interexaminer reliability was established by letting 2 examiners score the chewing gums independently. Reproducibility was measured by the whole test series after at least 1 week.

Statistical Methods

For comparison between groups, Wilcoxon's rank sum test was used.

For calculations of the importance of different parameters of the chewing gum tests, analysis of variance was used.

By using separation of the total variance into variance components, it was calculated how much the different variables influenced the accuracy of the chewing gum parameters.

The experiments comprised 10 subjects with complete natural dentitions and 10 with missing teeth (test Group B), 2 examiners/test occasions, 5 chewing gums for each of the 3 chewing side variables (right, left, habitual), and, when scoring color, 2 sides of the chewing gum. Variance components were calculated from the analysis of variance.

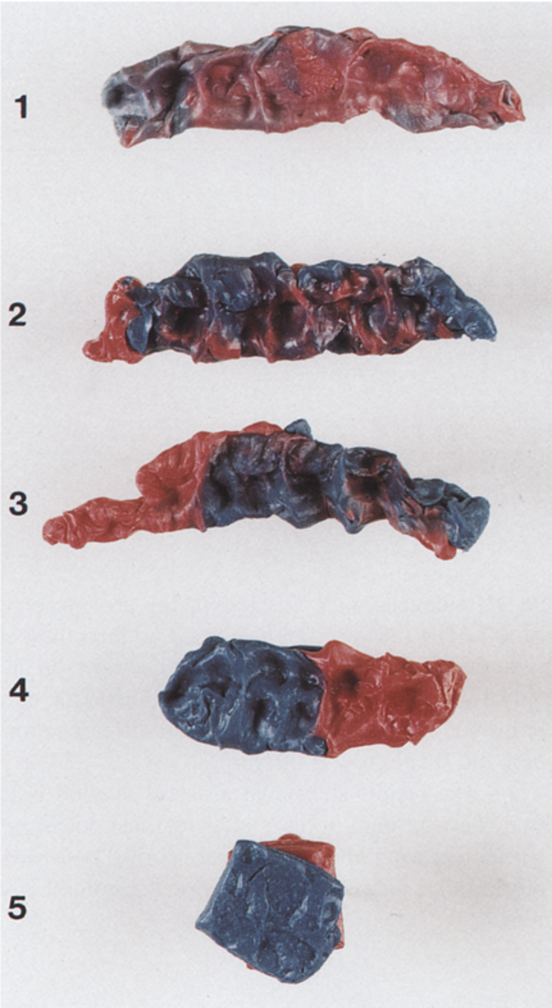

Fig. 1. Chewing gum color mixing. Index 1 (better) to 5 (poorer).

Results

Number of Chewing Strokes

The bolus shape established during the 10-stroke test was the same as for all other tests in 11 subjects. If the 10-stroke test was compared with the 100-stroke test, 15 subjects had the same shape index, and a further 8 differed by 1 score value, 4 upwards and 4 downwards. In the whole material of 150 tests (25 subjects and 6 tests per subject), there were 9 values that differed by more than 1 score value from the 10-stroke value. From this it can be concluded that the shape index was not affected by the number of chewing strokes after the initial 10.

The bolus color changed from the 10-stroke result to the 20-, 40-, 60-, 80-, or 100-stroke result in 19 subjects. The change was always to a lower index score value. In 6 complete (upper and lower) denture wearers the index value was not changed and remained at index 5, unmixed, for all tests. A prolonged chewing up to 100 strokes gave index value 1 in all subjects, except for 6 complete (upper and lower) denture wearers and 1 subject with a complete upper and a removable partial lower denture. Too many chewing strokes could then make it impossible to differentiate between subjects. A 10-stroke chewing sequence was thus found to be the most suitable.

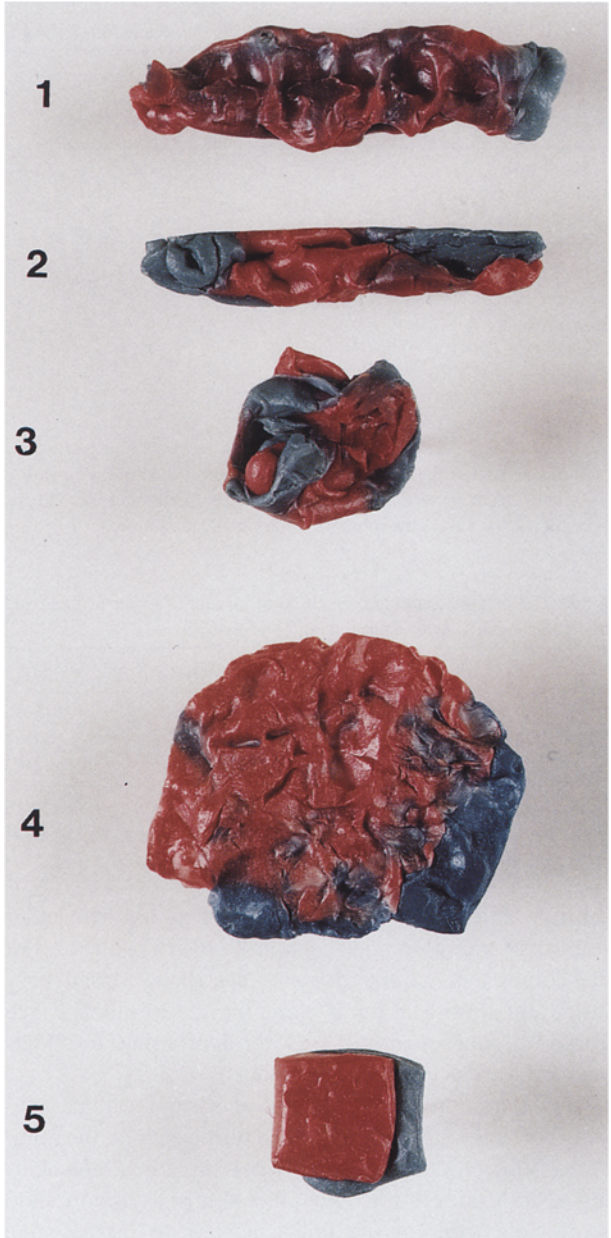

Fig. 2. Chewing gum shape. Index: 1. Long, spool-shaped, flattened 2. Long, spool-shaped, round cross-section 3. Ball 4. Flattened, square or round 5. Cube; almost original shape of test piece

Reproducibility, Chewing Side, Number of Chewing Gums

The variance components showed that the variation of the bolus shape index is most influenced by the number of

Table 1. Variance components demonstrating the relative importance of test and evaluation parameters[a]

Parameters	Number of tests	Color complete dentition	Color missing teeth	Shape missing teeth
Test subjects	10	0.0716	0.1194	0.3386
Test occasions	2	0.0031	0.0348	0.0044
Chewing side (right, left, habitual)	3	0.0123	0.0508	0.0283
Boluses scored	5	0.1088	0.0996	0.3167
Sides of bolus scored	2	0.1188	0.1079	—
Examiners	2	0.0083	——	0.1142
Repetition of scoring	2	0.0691	0.0400	0.0967

— indicates that shape was scored for the bolus as a whole, i.e., only one side.
—— indicates that color mixing was scored by 2 examiners for the group with complete dentitions only.
[a]The higher the value, the more important is the parameter.

Table 2. Chewing gum indexes for color mixing and shape (mean and range) for subjects with natural teeth

	Color mixing	Shape
Complete natural dentitions	2.6 (2–3.5)	1.2 (1–3)
Natural dentitions with missing teeth	3.4 (2–4)	2.6 (1–4)

Ten subjects had complete natural dentitions, and 10 were missing 1–13 teeth. The differences between groups was significant for both types of chewing tests (color: $p = 0.009$; shape: $p = 0.006$).

subjects and the number of chewing gums. The other sources of variation had much less affect (Table 1). For the completely natural dentate, the shape varied very little, and almost all gums were chewed to index 1 (see Table 2), consequently it was not appropriate to undertake any variance component analysis.

Variation in color index of natural dentate subjects with missing teeth was most influenced by the number of subjects, the number of chewing gums, and scoring of both sides of the bolus. It is almost as important to score both sides of the bolus as it is to increase the number of chewing gums. For the completely natural dentate, the number of test occasions, chewing sides (right, left, habitual), and examiner evaluation had less influence (Table 1).

Interexaminer Reliability

There was no significant, systematic difference between the examiners, and the variation is small compared with the results from different chewing gums; it is about the same as that from repeated scorings of the same gum.

Test Results for Different Dentitions

Color-mixing index and shape index for group A, 10 subjects with complete natural dentitions from group B, and 10 subjects with missing teeth, are presented in Table 2. The index scores are based on three first chewing gums after habitual chewing for each person and the evaluation of one examiner (BL). A comparison between the groups shows a highly significant difference for both color and shape ($p < 0.001$).

The results show that a useful method is to use three chewing gum boluses after one test occasion with habitual chewing and 1 examiner scoring both sides for color-mixing index and one side of the bolus for shape index.

Discussion

There has been considerable discussion over the years as to the type of test food and test method that most simulates natural chewing [1]. It has also been found, however, that the correlation between self-assessed chewing ability and the results of various types of masticatory efficienty tests are not very close [2,12–15].

Changes in the dentition by introducing artificial teeth [16], renewing dentures [15], or increasing occlusal contacts by surgical or orthodontic procedures [17,18] increase the efficiency of food pulverization when the mechanical efficacy of the dental system is measured with comminution tests. It is questionable, however, to what extent such an improvement of the pulverization capacity is of importance for the preparation of different foods for swallowing. The term "swallowing threshold" has been used for the number of chewing strokes or the chewing time until a subject feels ready to swallow, but it is not a measure of the dimension of the bolus in relation to the pharynx [10].

Very few publications about chewing efficiency discuss swallowing capacity related to an adherent bolus, and so far it has only been investigated experimentally in a few studies [7,9,11]. Thus, it seems relevant to broaden the efficiency aspect of mastication by incorporating parameters that relate to swallowing, as this is the termination of the masticatory act and the entrance of the bolus into the narrow passageway of the pharynx. If a food mass cannot be swallowed, the preparation by chewing, for example, has been ineffective.

Which characteristics of the bolus are important from a swallowing aspect have not been experimentally established, and so far the pulverization test has not proven any correlation to actual swallowing. Softening and lubrication of an adherent, solid bolus could be reasonably compared to the mixing process of a two-colored chewing gum. It is not the lubrication as such that is measured but the capacity to incorporate lubricant.

The size and shape of a solid bolus is important from a mechanical point of view, and it seems reasonable to evaluate those aspects also in experimental chewing studies.

On several occasions in the past opinions have differed as to whether the most appropriate test should employ natural or artificial test foods [1]. Natural foods have the advantage of giving a correct picture of the intraoral handling of the bolus, even though restricted to one food material, but also the disadvantage of being difficult to standardize, store, and analyze. The release or uptake of moisture, which affects weight and particle size, has also been a problem [1]. Artificial test foods, such as gelatine (e.g., [3]) and silicone (e.g., [19]) have gained over natural test foods in recent years.

Chewing gum is a typical artificial test food which, even if it is chewed to a bolus size that could theoretically pass into the pharyngeal/esophageal passageway, does not initiate swallowing. It is well suited to the task, as it is easy to standardize and easy to label and store when used in surveys of many subjects.

Chewing gums have been used before in masticatory tests [12,19–22] but a disadvantage is that they can stick to the acrylate material of dentures. Heath [12] used a "free dent" type, and Sor-Bits® does not stick to dentures.

During chewing, an increased salivation may affect a test food. Chewing gum does increase salivation [22], but the color mixing and shaping are not affected by saliva. Thus, there is no risk that the chewing test results will be distorted by moistening of the test food, as might occur with test foods that are easily affected, e.g., peanuts.

The color mixing of the two-colored chewing gums can easily be evaluated, and it is simple to establish if one gum is chewed to a better mixing of the colors. The index scoring 1–5, well mixed colors to almost unmixed, needs no explanation.

The shape index has one score, shape no. 5 in which the chewing gum is almost unchanged after chewing. From observations of persons with difficulties in chewing, who form their boluses into shape no. 4, it is a reasonable assumption to characterize shape no. 4 as a bolus that has been flattened out by pressure from the occluding teeth without any real chewing. This shape does not fit the anatomy of the pharynx. A ball, if it is small like a pill, can pass the pharynx anatomically. A larger ball, like the boluses with shape no. 3, cannot pass the pharynx and is therefore scored as less well prepared than nos. 2 and 1. Shape no. 3 is a ball that is similar to what was found by Heath [12] when testing complete denture wearers. In tests on young persons with complete dentitions, van der Bilt et al. [19] found as we did on similar subjects, that their chewing gum boluses became shaped with a long axis (index scores 1 and 2). In view of the width of the pharyngeal/esophageal passageway, it can also be considered reasonable to classify shapes nos. 1 and 2 as more ready for swallowing than nos. 3, 4, and 5. The ranking of shapes nos. 1 and 2 was made on the basis that no. 1 was found in many of the young persons with complete dentitions, and that shape no. 2 could be the result of an actual rotation of the chewing gum bolus around its long axis during chewing, involving less contacts with the teeth than no. 1. During unstrained swallowing of liquid barium, the narrowest part of the pharyngo-esophageal segment has an elliptical cross-section which could accommodate a long, flattened bolus (shape no. 1) better than a long bolus with a round cross-section (shape no. 2).

There is no need for a correlation of the chewing efficiency measured with different methods, as different methods may measure different aspects of chewing. After the findings in this study and considering the swallowing of a solid, adherent bolus, it seems that the chewing gum parameters color mixing and bolus shaping are as relevant as other methods. Comparisons between intact and defective or restored dentitions have the disadvantage that age is mostly correlated to loss of teeth. For the purpose of such comparisons then, one age group covering different dental statuses would be desirable.

The specially made Sor-Bits® chewing gum is not available for further studies. Commercially available brands with two distinct colors can also be used, however.

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