Masticatory efficiency

A new method for determination of the breakdown of masticated test material

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One of the purposes of mastication is to break down the food and enlarge the area of food particles. A method is described by which the masticatory efficiency is estimated by calculating the area of a chewed test material, gelatin-hardened by formalin. When test pieces, after being chewed, are placed in a water-soluble dye, the dye will diffuse into the particles, and consequently the dye concentration in the surrounding solution will decrease. The concentration of the dye solution is read from a photometer. A close correlation was found between the gelatin particle area and the reduction of the dye solution concentration. The method will be applied in clinical studies. □ *Chewing efficiency; masticatory physiology*

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One of the functions of masticatory system is to break down the food into pieces, to mix it with the saliva, and to prepare it for swallowing. From a dental and a medical point of view it is important to be able to determine how well this function can be performed.

The terms masticatory efficiency, masticatory ability, masticatory effect, and chewing efficiency are often used synonymously. In most cases it is the ability to break down a test food that is considered. In the following text the expression masticatory efficiency is used.

Several studies have shown that the masticatory efficiency is reduced in people who have lost many teeth and in those who wear removable dentures (5, 10, 14). Reduced chewing ability (that is, the individual's own assessment of his/her masticatory function) was reported more frequently by people who considered their general state of health to be impaired (2). Not much is known about the importance of the part played by masticatory efficiency in, for example, choice of food or nutrition (3). Our knowledge of the relationship between masticatory efficiency and digestion is incomplete, and it is not known whether impaired masticatory efficiency may cause or predispose to gastrointestinal disorders.

The methods most researchers have used to measure the masticatory efficiency is to have test subjects chew a test material under standardized conditions and then to calculate the degree to which the material has been broken down by fractionating in a sieve system (4–7, 10, 11, 13, 14). Different test materials and different numbers and sizes of the sieves have been used.

Obviously, when the degree of breakdown is determined by using a sieve system, the results will depend on the number of sieves and their mesh sizes. It is difficult to determine which particle sizes are relevant and, if more than one sieve is used, to express the breakdown as a single figure. One of the purposes of mastication is to enlarge the area of food particles, thereby facilitating digestion. Attempts have been made to develop methods by which the area of the masticated test material can been calculated, to obtain a measure of the masticatory efficiency (5, 12). However, the presented methods are too complicated and inexact. It therefore seemed important to develop a simple and more reliable method for measuring the area

of the chewed material. For this purpose gelatin hardened by formalin has been used as a test material because its physical properties can be standardized and continuously checked.

Methods

The test material

The main principles governing the production of the test material have been described earlier (7). In this study, however, instead of fuchsin, 60 mg erythrosin was dissolved in 20 ml water and added to a 1180-ml gelatin solution. The cubes at the side of the brass mold were often defective, and therefore only the center pieces were used, which means that from one batch (= 3 molds) 54 pieces were obtained for the tests. The test pieces were hardened for 24 h at +25°C in a 2.3% formalin solution, in contrast to 4.6% described earlier (7). The mean wet weight of the test pieces from seven batches was 9.39 g (SD = 0.33; range, 8.39–10.28). After being weighed the gelatin cubes were individually packed in numbered plastic bags with a saturated humidity and then stored in a cold-storage room at +8°C until required for testing.

The ratio of the wet weight to the dry weight of the test material was determined as described earlier (7). The mean value for the ratio was 8.14 (SD = 0.20; range, 7.91–8.43).

Clinical procedure

The subject sat in an upright position in a dental chair and was informed that several pieces of gelatin were to be chewed. Nothing was said about how much time was allowed for the chewing. The pieces were shown to the patient and it was emphasized that no part of the piece was to be swallowed. The subject was then allowed to chew in whatever manner he chose—that is, he was able to choose the side and the chewing speed. After the subject had finished chewing he spat the masticated test material into a plastic container, rinsed his mouth with water several times, and then spat the water into the same container. The supervisor examined the oral cavity for any remaining test material. Finally, to rinse it clean of all saliva, the masticated material from each test piece was placed on a sieve with a mesh size of 0.45 mm, which permits rinsing without any appreciable loss of test material. The loss of the original weight has been calculated to be 0.5–1.5%. The test material was then poured into a container with water.

Analysis of the masticated test material

The test material consisted of a gel with 90% water. If this material is placed in a water-soluble dye, the dye diffuses into the gelatin. Furthermore, depending on the dye, a chemical binding can take place between the gelatin and the dye. If the dye diffuses into the gelatin only a few tenths of a millimeter, the amount of dye that spreads in will be in proportion to the area of the gelatin particles. When the dye spreads into the gelatin, the concentration of dye is decreased in the surrounding color solution. Thus the change in the concentration of the surrounding dye solution will also be proportionate to the area of the particles. Since the area is a measure of the breakdown of the test material, the change in concentration of dye can be used to calculate masticatory efficiency. The monoazo dye Amaranth, C.I. no. 16185 (Bayer, FRG) was used for this purpose.

Several factors determine the diffusion of the dye into the gelatin and its chemical affinity to it. There have been several experiments to 1) study the effect of these factors on the color absorption of the gelatin and 2) to establish how these variables should be standardized from a practical point of view. The factors and how they have been standardized are given in Table 1. Under these conditions the depth of dye penetration into the gelatin is approximately 0.15 mm.

The dye absorption was determined in the following manner: The gelatin particles, free from water, were placed in a dry glass beaker. The beaker was then placed in a thermostatically regulated waterbath at a temperature of +25°C. Fifty milliliters of dye solution at a temperature of +25°C was

Table 1. Standardization of the factors determining the diffusion and chemical affinity of the dye solution used for determining the area of chewed gelatin

Factors that determine diffusion and chemical affinity of the dye	How the factors were standardized
Isoelectrical point of gelatin	Gelatin from the same batch
pH of dye solution	pH 4
Amount of dye solution	50 ml
Concentration of dye solution	1 g/500 ml
Time	10 min
Temperature	+25°C
Stirring	Propeller stirrer: 420 rpm

added, and a propeller stirrer was placed in the beaker and set in action. After 10 min ± 10 sec, the beaker was taken out of the waterbath, and 5–10 ml of the dye solution was poured into another glass beaker upon which a sieve with a mesh size of 0.45 mm had been placed. The sieve is used to separate gelatin particles from the dye solution. Two milliliters of the dye solution were diluted to 100 ml, using deionized water at room temperature. The absorption, which is proportional to the concentration, was then read off from a photometer (Kifa, Siemens-Elema, Stockholm, Sweden) at the wavelength 515 nm.

The relationship between the dye absorption and the area of the gelatin particles was calculated in the following manner. Each of some gelatin cubes with a 22-mm-long side was divided into 64 cubes with sides of 5.5 mm and an approximate area of 1.8 cm^2. It was thereby possible to establish various known area sizes of gelatin to be tested for dye absorption. In Table 2 these areas range from 57.6 to 288.0 cm^2. The dye absorption for several known areas was measured as mentioned above. The difference in light absorption (ΔA) of the dye solution before and after the gelatin cubes had been placed in the solution was calculated. Two determinations were made for each area (Table 2). The values from Table 2 were then plotted in Fig. 1. As can be seen in Fig. 1, the curve inclines somewhat toward the x-axis for increasing ΔA values. This is due to the fact that when the area of the gelatin cubes is large, the concentration in the dye solution will be so low at the end of the dyeing period that it will influence the speed of diffusion. A special calibration curve must be drawn for each batch of test material and from this an area value can be obtained for each ΔA value. This area is a measure of the breakdown of the test material and the

Table 2. Differences in light absorption of the dye solution, Δ-absorption, before and after the gelatin cubes have been placed in the solution. The measurements have been performed for five different known areas of gelatin

	Δ-Absorption		
			1+2
Area, cm^2	Test 1	Test 2	2
57.6	0.103	0.096	0.100
115.2	0.180	0.180	0.180
172.8	0.256	0.247	0.252
230.4	0.317	0.322	0.320
288.0	0.375	0.372	0.374

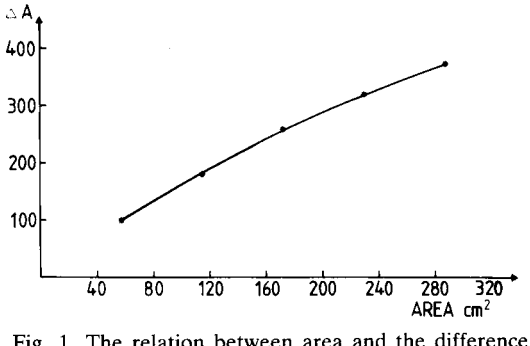

Fig. 1. The relation between area and the difference in light absorption (ΔA) of the dye solution before and after the gelatin cubes have been placed in the solution.

breakdown in turn is an expression of the masticatory efficiency.

After the area for each sample had been determined, the test material was placed in a weighed glass beaker. This was placed in an oven (110°C) for 20 h, and then it was weighed again. Since the original weight of the gelatin pieces is known, any loss of test material can then be calculated. After the area of the masticated test material has been determined it is also possible, if desired, to fractionate the material in a sieve system before the material is dried in an oven.

Discussion

With only a few exceptions (9) masticatory efficiency has been assumed to be the same as the ability to break down the food. Different test materials and different methods of measuring this breakdown have been used.

Test material

In the method presented here, gelatin hardened by formalin has been used. If materials such as almonds, peanuts, and carrots are used, it is difficult to guarantee that the test material will have the same physical properties from one occasion to another. The use of hardened gelatin provides a greater likelihood of obtaining a standardized test material, but, on the other hand, gelatin represents a material with which the test subjects are unfamiliar.

The gelatin used in this study contains the same amount of gelatin as that first used as a test material (5). To obtain a test material that is not so brittle, the concentration of formalin used in the hardening bath was decreased from 4.6% to 2.3%. Erythrosin was used to color the gelatin instead of basic fuchsin because it is more suitable from a biological point of view.

Hardening with formalin took place over 24 h to guarantee that the pieces were homogeneously hardened, and the following control test was carried out to check this. Small pieces of gelatin were taken from the center of some cubes of hardened gelatin and from their surface and were placed in boiling water. They did not dissolve, thus indicating that even the gelatin in the center of the cube was hardened after 24 h.

In an earlier study EMG was used to compare the muscular activity used to chew the impression material Optosil compared with several different foods (6). It was found that chewing Optosil was easier than chewing peanuts and more difficult than chewing white bread. There has been no similar study using gelatin. Test subjects have found that chewing gelatin was different from chewing other foods. Some subjects found that gelatin pieces reminded them of cartilage and some compared the bite force required to that needed to chew apples. A few people found the gelatin unpleasant to chew.

The gelatin pieces increased in volume almost immediately when they were placed in the formalin solution. The increase in volume varied somewhat, 25–30%, among the different pieces, but this should not have had any significant influence on the test results. Gelatin hardened by formalin is not constant at normal humidity. Therefore, up until the time of the clinical test situation, the test pieces were stored in sealed plastic bags with saturated moisture.

Water evaporates if the surrounding medium has a higher salt content than that of the gelatin. When placed in saliva for 2 min, which represents an extreme situation, the volume decreases by approximately 0.5%. This decrease in volume should not be of any significant importance, especially since the contact time between gelatin and saliva did not exceed 60 sec in most cases.

The weights of the test pieces, and the mean weights of pieces from various batches, varied. Even if this does not have any considerable influence on the results, it is still desirable that these differences should be reduced. The mean values for the ratio of the wet weight to dry weight also varied among batches. This ratio influences the ability of the material to absorb dye and means that the ratio of area to dye absorption must be determined for each batch.

Measuring breakdown

The degree of breakdown of the test

material has been calculated by most researchers by fractionating in a sieve system. Ten sieves were judged to be necessary to establish a basis for calculating the area of the gelatin particles (5). If only one sieve is used, we certainly have a simple and quick method. This does not, however, give a complete picture of the breakdown in the sample as a whole. In one study the masticated test material was divided into three portions, and by using a mathematical formula the masticatory efficiency was expressed as a single figure (6). The results were dependent on the mesh size of the sieves, 2.8 and 1.9 mm, respectively, but no explanation was given as to why these particular mesh sizes were chosen. The more the test material is divided into pieces, the further down in a system of several sieves it will pass. The distance the particles are strained can then be used as a measurement of the masticatory efficiency (7). The most important function of chewing must be to break down the food into smaller particles and thus increase the area available for digestion. It must therefore be logically correct and physiologically relevant to aim at an expression of the extent to which the area of the test material is increased by chewing and not to concentrate on the amount of the material that passes through a sieve chosen more or less at random.

The area of masticated carrots has been used as a measure of the masticatory efficiency (12). There was no description of any analysis of method errors, and it is difficult to evaluate the applicability of the method to large clinical samples.

Dye absorption

In the method described here the area is calculated by allowing a water-soluble dye to spread into the particles. A large piece of a given volume shows, in comparison with several smaller pieces with the same total volume, a smaller area. Using the present method for measuring the breakdown, several large particles can be compensated for by a large number of smaller ones. This is because the area is the variable that has been considered the most important. In clinical studies the number of gelatin pieces which are larger than a certain size can be counted by using a sieve. There is then a chance of discerning possible differences between patients with regard to their ability to chew larger pieces. The particle sizes that are to be determined in a test depends, e.g., on the kind of the patient and the hypothesis that is to be tested.

A small difference has been obtained in the double calculations of the dye absorption for the various areas. This difference can be explained, for example, by differences in the individual gelatin cubes, differences in color absorption, and instrument and reading errors. The overall error is 7% for the smallest area of those shown in Table 2. This area (57.6 cm^2) represents a very poor breakdown ability. For the other areas the difference in the double calculations amounted to a maximum of 3.6%. The areas in Table 2 represent the breakdown ability of a wide range of individuals, from those with complete dentures to those with all their own teeth.

Clinical procedure

In preliminary experiments the test subjects were given five gelatin pieces to chew, of which four were analyzed. The first piece was mainly used to familiarize the test subject with the material. The training effect and the intraindividual variation make tests like this difficult. Since the gelatin by its very nature is different from ordinary foods, the training effect can be of greater importance here than in chewing, for example, almonds or peanuts. The training effect will be further studied.

Several researchers have allowed the subjects to chew 20 strokes (1, 6, 15, 16). In other investigations the patients have been given fixed periods of time for chewing (8, 10). Further studies will be carried out to analyze the number of test pieces that should be used and whether the chewing should be done for a certain number of strokes or for a set number of seconds.

Conclusion concerning the method used

I have defined masticatory efficiency as the ability to increase the area of a food or

a test material by chewing. The method presented here measures this ability for a test material and also makes it possible to study the particle sizes of a specific sample. The method requires only such equipment as can be found in any well-equipped laboratory. As many factors as possible have been kept under control, and it should be possible to use the method on large clinical samples both in cross-sectional and longitudinal studies.

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