Archives of Oral Biology 91 (2018) 63–77

Contents lists available at ScienceDirect

Archives of Oral Biology

journal homepage: www.elsevier.com/locate/archoralbio

Determining chewing efficiency using a solid test food and considering all phases of mastication

Ting Liu, Xinmiao Wang, Jianshe Chen, Hilbert W. van der Glas*

School of Food Science & Biotechnology, Zhejiang Gongshang University, Xiasha, Hangzhou, China

ARTICLE INFO

Keywords:
Chewing efficiency
Chewing performance
Food comminution
Mastication

ABSTRACT

Objectives: Following chewing a solid food, the median particle size, X_{50}, is determined after N chewing cycles, by curve-fitting of the particle size distribution. Reduction of X_{50} with N is traditionally followed from $N \geq$ 15–20 cycles when using the artificial test food Optosil®, because of initially unreliable values of X_{50}. The aims of the study were (i) to enable testing at small N-values by using initial particles of appropriate size, shape and amount, and (ii) to compare measures of chewing ability, i.e. chewing efficiency (N needed to halve the initial particle size, $N(1/2\text{-}Xo)$) and chewing performance (X_{50} at a particular N-value, $X_{50,N}$).

Design: 8 subjects with a natural dentition chewed 4 types of samples of Optosil particles: (1) 8 cubes of 8 mm, border size relative to bin size (traditional test), (2) 9 half-cubes of 9.6 mm, mid-size; similar sample volume, (3) 4 half-cubes of 9.6 mm, and 2 half-cubes of 9.6 mm; reduced particle number and sample volume. All samples were tested with 4 N-values. Curve-fitting with a 2nd order polynomial function yielded $log(X_{50})\text{-}log(N)$ relationships, after which $N(1/2\text{-}Xo)$ and $X_{50,N}$ were obtained.

Conclusions: Reliable X_{50}-values are obtained for all N-values when using half-cubes with a mid-size relative to bin sizes. By using 2 or 4 half-cubes, determination of $N(1/2\text{-}Xo)$ or $X_{50,N}$ needs less chewing cycles than traditionally. Chewing efficiency is preferable over chewing performance because of a comparison of inter-subject chewing ability at the same stage of food comminution and constant intra-subject and inter-subject ratios between and within samples respectively.

1. Introduction

A major function of mastication is to prepare food for swallowing (van der Bilt, Engelen, Pereira, van der Glas, & Abbink, 2006). Furthermore, mastication influences the release of flavour. Before a coherent bolus is formed which keeps food particles together, comminution of a solid food during a chewing cycle includes collecting and transport of particles by the tongue from the oral cavity to the occlusal area of the posterior teeth and subsequently breakage of part of these particles between antagonistic teeth while closing the jaw (Hiiemae & Palmer, 2003). Every chewing cycle begins thus with selection, in which food particles have a chance to be placed between the teeth in such a way that they are at least damaged, if not broken by the subsequent breakage process (Lucas, 2004). For any particle size, the selection chance can be defined as the weight of fragments with respect to the total weight of damaged and non-damaged particles. Because of the essential initial role of the tongue, the break-down of solid foods is most challenging, in particular for subjects whose chewing ability is impaired. For example, in wearers of full dentures without fixation by implants or adhesives, the tongue assists in stabilizing the denture, which disturbs its role in collecting and transporting particles. For serving feasibility in subjects in which apart from tongue function, the delivery of force by jaw muscles may be impaired, chewing tests have been developed using a soft bolus made of a colour-changeable or two-coloured chewing gum (Komagamine, Kanazawa, Minakuchi, Uchida, & Sasaki, 2011; Schimmel, Christou, Herrmann, & Müller, 2007), or wax (Sato et al., 2003; Speksnijder, Abbink, van der Glas, Janssen, van der Bilt, 2009). However, such tests measure a subject's ability of mixing a semi-solid artificial test food between the teeth, or between tongue and palate, rather than an integrated functioning of all oral structures which are involved in the breakdown of solid foods. A test using a solid food remains relevant, the more as an impairment of chewing such foods will inevitably cause diet restrictions.

When chewing starts on a sample of single-sized particles, the comminution process is reflected in the reduction of the median particle size (X_{50}) with the number of chews (N). Furthermore, food comminution changes the variation in particle size which is reflected in the broadness (b) of the size distribution. For a particular N-value, X_{50} and b

* Corresponding author at: School of Food Science & Biotechnology, Zhejiang Gongshang University, 18 Xuezheng Street, Xiasha, Hangzhou, 310018, China.
E-mail address: h.vanderglas@dundee.ac.uk (H.W. van der Glas).

https://doi.org/10.1016/j.archoralbio.2018.04.002
Received 7 December 2017; Received in revised form 7 March 2018; Accepted 3 April 2018

can be determined by curve-fitting of the particle size distribution by cumulative weight, hence volume, using the Rosin-Rammler equation (Olthoff, van der Bilt, Bosman, & Kleizen, 1984). Chewing performance is quantified by X_{50} at a particular N-value, $X_{50,N}$, and chewing efficiency by the number of chews needed to achieve an X_{50} value that equals half of the initial particle size, *N(1/2-Xo)* (van der Bilt, Olthoff, van der Glas, van der Weelen & Bosman, 1987). A larger chewing performance corresponds with a smaller value of $X_{50,N}$, and a larger chewing efficiency with a smaller value of *N(1/2-Xo)*.

Regardless of the measure of chewing ability, a test on food comminution which includes solely short chewing sequences will be most feasible because it requires the least endurance of a subject. Furthermore, the initial phase of chewing is important to be considered rather than being ignored (see below), because (1) most reduction in particle size occurs here, and (2) this phase includes a transition from a slower rate of reduction to a faster rate which reflects the influence of selection in particular (cf. Discussion). To date chewing sequences in tests have been longer than necessary for some reasons.

First, the present study will show that it is important to choose an initial size of the single-sized particles on which chewing is started which is a mid-size of the upper class of sizes. However, in several studies using sieving to separate size classes of an artificial test food (Optosil®), chewing has been started on cubes, which had an edge size of either 8.0 mm (Olthoff et al., 1984; Slagter, Olthoff, Steen, & Bosman, 1992; van der Bilt et al., 1987) or 5.6 mm (Barbosa, Tureli, Nobre-dos-Santos, Puppin-Rontani & Gavião, 2013; Caputo et al., 2012; Eberhard, Schneider, Eiffler, Kappel, & Giannakopoulos, 2015; Eberhard et al., 2012; Fontijn-Tekamp et al., 2000; Gomes, Custodio, Faot, Del Bel Cury, & Garcia, 2010; Gonçalves, Viu, Gonçalves, & Garcia, 2014; Marquezin, Kobayashi, Montes, Gavião, & Castelo, 2013; Mendonça et al., 2009; Pereira et al., 2012; Slagter, Bosman, & van der Bilt, 1993; Soares et al., 2017). These particle sizes corresponded with the aperture of a wire sieve (included in a stack of sieves) that retains the original particle size. However, cubes of 8.0 or 5.6 mm have a border size rather than a mid-size with respect to the limits of the size classes 8.0–11.3 mm and 5.6–8.0 mm respectively, which are determined by successive sieve apertures. In order to avoid bias in the estimation of X_{50} and b while initial particles are still present, a determination of chewing performance has been carried out when the initial phase of chewing had passed in all subjects, *i.e.* at least after 15–20 chewing cycles.

Second, the first larger sieve aperture through which the total weight of all particles and fragments will pass, should be included as a data point with the value 1.0 in the cumulative underweight distribution. Hence, the relevance will be shown of considering the first empty sieve as the top sieve of the series used, rather than the sieve below (the sub-top sieve) on which most if not all initial particles are retained in an initial phase of chewing.

Third, a fairly large amount of initial particles has been used in the abovementioned studies using Optosil, i.e. 8 cubes of 8 mm or 17 cubes of 5.6 mm. Because of a limited number of posterior teeth and predominantly one-sided chewing, such numbers of large particles (which are easily transported by the tongue) will initially saturate the breakage sites on the teeth (van der Glas, van der Bilt, & Bosman, 1992; van der Glas, Kim, Mustapa & Elmanaseer, 2018). The number of selected cubes per chew is then limited to a maximum. This maximum, the number of breakage sites on the teeth, is about 5 particles for a size of 8.0 mm and 8 particles for a size of 5.6 mm, which is smaller than the number of offered particles. The selection chance of the initial particles will therefore be reduced, yielding initially a lower rate of reduction in X_{50}. Another reason for a lower rate of size reduction is that initially the selection of small fragments will be hampered by the presence of large cubes (van der Glas et al., 2018; cf. Discussion). A particular stage of particle size reduction can be attained after less chews by reducing the number of particles on which chewing is started (Baragar, van der Bilt & van der Glas, 1996, theoretical study; van der Bilt, van der Glas & Bosman, 1992; Voon, Lucas, Chew, Luke, 1986, simulation studies).

Another advantage for limiting the amount of initial particles is reducing the bite force which is required to fracture particles. This bite force is approximately proportional to the number of selected particles, which decreases with smaller numbers of offered particles (van der Glas et al., 1992; van der Glas et al., 2018). Thus in order to enhance feasibility of a chewing test by shortening chewing sequences, it will be advantageous to limit the number of offered particles for avoiding an initial saturation of the breakage sites, a delayed selection of the fragments, and for reducing the amount of force needed for fracturing.

Limiting the required bite force can further be attained by using half-cubes rather than cubes as initial particles. With the same percentage of deformation needed to initiate fracture, the work (force x displacement) needed to initiate fracture will be half for half-cubes than for cubes of the same size. Another advantage of using half-cubes is that the volume of a half-cube corresponds more than that of a cube with the mean volume of irregularly shaped flakes, which are formed during chewing on Optosil (van der Bilt, van der Glas, Mowlana & Heath, 1993; Eberhard et al., 2012).

The first aim of the present study is to enhance feasibility of carrying out a test on chewing ability using a solid test food without ignoring the initial phase of chewing. To that end, the effect of using initial particles of appropriate shape, size and amount will be examined on the quality and validity of curve-fitting with the Rosin-Rammler equation and on relationships between X_{50} and N. Apart from chewing ability, summarizing the size distributions during all phases of chewing using the Rosin-Rammler equation with reliable values of X_{50} and b, is relevant for computer simulation studies. Simulation studies may give insight, for example, into flavour release during chewing. In order to decide whether chewing efficiency or chewing performance may be preferred as measure of chewing ability, the second aim is to examine whether intra-subject and inter-subject ratios in chewing ability are constant between and within types of particle samples respectively.

2. Materials and methods

2.1. Subjects

The study was carried out in compliance with the Helsinki Declaration, and approved by the University Ethics Committee (Ref no. 2017060201). Eight students from the School of Food Science and Biotechnology, Zhejiang Gongshang University (4 males and 4 females), gave informed consent, and participated in the chewing experiments. The mean age was 23.6 years (SD 1.3, Table 2). The subjects had a good general health (no medication), and a sufficiently complete natural dentition (allowing missing third molars) with normal occlusal relationships. Jaw muscle pain and/or pain in the temporomandibular joint, or disturbances of intra-oral or peri-oral sensory function were absent.

2.2. Test food

Using brass moulds, cubes with an edge size of 8.0 mm and half-cubes with a larger edge size of 9.6 mm were made of Optosil® (Bayer, Germany; version 1980), a silicone dental impression material which has a constant consistency, and is not affected by saliva. Versions of Optosil with similar or reduced strength have been used as an artificial test food in many previous studies (cf. Introduction). The procedure of preparing Optosil particles has been described in detail previously (van der Glas, Al-Ibrahim, & Lyons, 2012). The ratio between Optosil base and catalyst (Heraeus Kulzer GmbH, Hanau, Germany) was 0.02477 in the present study (24.77 mg catalyst to 1 g of base).

2.3. Chewing experiments

Table 1 shows the test conditions for the various particle samples. Chewing on samples of 8 cubes with an edge size of 8 mm (sample