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Preliminary analysis of mastication dynamics and fragmentation during chewing of brittle cereal foods

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ABSTRACT

We studied the masticatory behaviour of five commercial brittle cereal foods, with different formulations, shapes and mechanical properties, chewed by an individual. The investigation of oral behaviour consisted in a simultaneous recording of jaw kinematics and muscle activity by electromyography (EMG) and we also determined the food size distribution at the swallowing point by image analysis. Similar behaviour was found for the evolution of all criteria, and especially the predominance of compression, which could be attributed to the brittle behaviour of the foods. The amplitude of the jaw motion decreased with the number of chewing cycles, or sequence duration, whereas the maximum mastication force led to the larger fragments of cereal foods when bolus was close to the swallowing point. Despite similar texture, mechanical properties, assessed by Kramer shear cell, influenced mastication work and bolus homogeneity.

1. Introduction

Chewing is the first step of the digestion process and is meant to prepare the food for swallowing and further processing in the digestive system. During chewing, food particles are reduced in size and assembled with the incorporation of saliva into a cohesive form suitable for swallowing (Prinz & Lucas, 1995). The urge to swallow can be triggered by a threshold level in both food particle size and lubrication of the food bolus (Prinz & Lucas, 1995, 1997). Masticatory performance, defined as the particle size distribution after a given number of chewing cycles, depends on dental state and body size of individual (Engelen, Fontijn-Tekamp, & van der Bilt, 2005; Peyron, Blanc, Lund, & Woda, 2004). Beside individual influence, differences in food texture have a major influence on the masticatory performance and swallowing (Agrawal, Lucas, Bruce, & Prinz, 1998; Jalabert-Malbos, Mishellany-Dutour, Woda, & Peyron, 2007).

However, few studies gave a complete cover of the human mastication. Some of them look at the food breakdown from the sensory perception viewpoint, focusing on a single type of food like wheat flakes (Lenfant, Loret, Pineau, Hartmann, & Martin, 2009). Besides, many other works did not consider food texture aspects and focused on oral phenomena such as chewing kinematics (Buschang, Hayasaki, & Throckmorton, 2000), jaw motion and robotics (Xu et al., 2008), electromyography (EMG) analysis (Throckmorton, Teenier, & Ellis, 1992), food fragment models (Flynn et al., 2011; Prinz & Lucas, 1997) and some combinations of these facets (Lin, Chang, Liu, Lin, & Lin, 2011; Lucas, Ow, Ritchie, Chew, & Keng, 1986; Schindler, Stengel, & Spiess, 1998). These works had a large interest, for surgery applications and for the information they brought on the physiological parameters of mastication, which could, in turn, be used to simulate mastication conditions (Chung, Degner, & McClements, 2012; Mishellany-Dutour et al., 2011); however they did not take into account the complete mechanisms of food breakdown during mastication. Cereal foods provided a good opportunity to study this phenomenon, not only because they are the basis of human diet, but also because some of them, such as breakfast cereals, display an airy microstructure and a brittle behaviour. This last property, defined by rupture occurring in the elastic domain, allowed to focus on the fragmentation under mechanical stresses.

In preceding studies, we have determined the contribution of mechanical properties of corn flakes on the crispy perception (Chaunier, Courcoux, Della Valle, & Lourdin, 2005) and ascertained their structural basis (Chaunier, Della Valle, & Lourdin, 2007); this approach was extended to other particle foams, i.e. breakfast cereals, the mechanical properties of which were related to their density and shape (Sandoval, Chaunier, Courcoux, & Della Valle, 2008). Recently, we have underlined the importance of these mechanical properties for two different corn flakes chewed by one subject and set up an image analysis method to assess the evolution of food size during chewing (Yven, Guessasma, Chaunier, Della Valle, & Salles, 2010). Similar approach recently allowed to set up rheological methods to assess the destructuration of bread by an individual (LeBleis, Chaunier, Della Valle, Panouillé, & Réguerre, 2013).

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In this context, the aim of this study was twofold. First, we wanted to provide the necessary information to apply relevant boundary conditions to the on-going mechanical modelling studies of brittle food foam destructuration during chewing by an individual (Hedjazi, Guessasma, Abbasi, Della Valle, & Khraishi, 2011; Hedjazi, Martin, Guessasma, Della Valle, & Dendievel, 2012). This first modelling step would not take into account the inter-individual variability but rather address the interactions of this type of foods with the oral behaviour of this subject. So we needed to collect data defining his chewing dynamics. Clearly, the extension of the mechanical model of destructuration to other individuals was a longer term goal, which would require the knowledge of their chewing dynamics, by taking into account their statistical variability through the implementation of different boundary conditions. Secondly, the objective was also to ascertain the role of mechanical properties on the subject's chewing behaviour of brittle particulate cereal foods. So, in this study, we have selected breakfast cereal foods with different textures, shapes, structures and formulations and we have assessed the mastication dynamics of our subject by muscle activity, mandible motion and their final particle size distribution before swallowing.

2. Material and methods

2.1. Volunteer

One of the authors, a 28 year old male and, willed to participate to this study, and gave informed consent after a full explanation of the experiment. He will be called afterwards the subject or the volunteer. Note that these experiments were not invasive and based on the consumption of commercial foods. Furthermore, prior this study, none of us was aware of the results of the mechanical models under development, which minimised any possible bias due to this choice. The volunteer had natural dentition and a good dental status with no periodontal or occlusion disorders. His saliva flow rate under stimulated conditions (parafilm chewing) is 3.1 ± 0.2 mL/min and his masticatory performance, determined by sieving (Shi, Ouyang, & Guo, 1990), was 65 ± 4%; both values were rather large, but still in the range of values encountered in the literature (Chen, 2009; Van der Bilt & Fontijn-Tekamp, 2004). Although only one subject was used in this study, his mastication characteristics were in the range of the values currently encountered; so we considered that the results obtained could be used as relevant information for our first step modelling purpose and that they gave a sketch of the relations between the volunteer's mastication dynamics, size reduction and the physical properties of the cereal foods.

2.2. Cereal food products

Five different types of test foods (commercial breakfast cereals) were used: Chocapic, C, Golden Grahams, G (Nestlé S.A., Vevey, Switzerland), Miel Pops, M, Kellogg's corn flake, K (Kellogg's Produits Alimentaires, Rosny-sous-Bois, France) and one organic cornflake B (Cereco, Domagné, France) (Fig. 1). The physical characteristics of these products (e.g. density, water content, fat percentages and mechanical properties) have been previously reported (Chaunier et al., 2005; Sandoval et al., 2008). Table 1 recalls here their basic composition and some physical characteristics.

2.3. Jaw kinematic records

The mandibular movement was recorded for each experiment using an Optotrak Certus® motion capture system (Northern Digital Inc., Waterloo, Ontario, Canada). This system allowed 3D jaw kinematic records with contrast to other solutions that give only vertical movement (Peyron et al., 2004). Three infrared diodes were used as markers (M1, M2, M3). Their 3D coordinates were recorded at 100 Hz with a resolution of 0.01 mm via the triangulation allowed by the three infrared cameras of the Optotrak tracker. These markers were positioned on the volunteer face with adhesive surgical tape as shown in Fig. 2a. One marker (M1) was placed on the forehead to be used as the reference, because the forehead is not involved in the chewing process. The second marker (M2) placed on the chin captured the lower mandible movement whereas the third marker was placed on the throat for the swallowing point detection (M3). Although any head movement would be discarded by this method, this configuration allowed us to determine all characteristics of the mandible motion such as opening and closing. Inclination (α) and shearing (θ) were calculated as the angles formed by the vectors M1–M2 and M1–M3, as only M2 is involved in the shearing movement (Fig. 2b). Post-treatment of the signals included the determination of mandible displacement and velocity in the frontal plane (Fig. 2b). Further processing was performed using ImageJ, a public domain software. Mandible displacement loops were approximated as elliptical shapes and related quantities were computed such as area (a), inclination (α), and minor (dx) and major (dy) axis lengths.

Fig. 1. Breakfast cereals used in this study and related boluses before swallowing.

2.4. Muscular activity records

Muscular activity was recorded by electromyography. The records were synchronized with jaw kinematic records. Electromyographic (EMG) activity was recorded in a similar way to a previously published work (Yven et al., 2010). Activities of masseter and temporalis muscles were recorded. Prior electrode positioning, the skin areas were cleaned with alcohol to reduce the impedance and enhance signal conductivity. Chewing time (t), number of bursts (N), swallowing time (T), mean (fm) and maximum (fx) voltage of bursts, and apparent cycle muscle work (w) were the main variables collected from each EMG sequence. For comparison purpose with texture variables, we also defined a maximum value of apparent mastication work by $Wm = fx \cdot N$. This