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Impact of oral physiology of elderly people on their food consumption; what solutions can be found to maintain nutritional status?

Impact de la physiologie orale de la personne âgée sur sa prise alimentaire; quelles solutions pour maintenir le statut nutritionnel ?

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Titre : Impact de la physiologie orale de la personne âgée sur sa prise alimentaire; quelles solutions pour maintenir le statut nutritionnel ?

Mots clés : population âgée, santé orale, alimentation

Résumé : Contexte. Chez l'homme, la mise en bouche d'un aliment est l'étape ultime de la chaîne alimentaire et le début du processus de dégradation et de digestion. Avec l'âge la santé orale évolue et peut parfois rendre l'acte alimentaire difficile.
Objectif. L'objectif de cette étude est de déterminer les facteurs (salivaire, dentaire, musculaire) impactant sur les dimensions physiologiques (faculté à former un bol alimentaire, libération et perception de la flaveur) de l'acte alimentaire et/ou la prise alimentaire et la corpulence des séniors. Ceci permettra de d'identifier des techniques culinaires permettant d'adapter la texture des aliments aux problèmes bucco-dentaires.
Matériel et méthode. 108 séniors (>65 ans) vivant à domicile et ne présentant pas de pathologie chronique ont été recrutés et caractérisés sur la base des dimensions suivantes : santé orale (examen clinique), auto-évaluation de la santé orale, perceptions sensorielles, faculté à former un bol alimentaire, comportement alimentaire, état de santé général. En parallèle, des techniques culinaires permettant d'améliorer la texture de la viande ont été testées. Leur efficacité a été évaluée via des mesures rhéologiques et la perception du confort en bouche par les séniors eux-mêmes.
Résultats et conclusion. L'analyse multidimensionnelle des données montre que les facteurs de santé orale (dentition, salivation, force musculaire) jouent des rôles différents dans les processus de mastication et de prise alimentaire chez les personnes âgées. De plus, l'étude du confort en bouche a permis de sélectionner des techniques culinaires optimisant la tendreté et la jutosité de la viande. Ces résultats permettront de développer une offre alimentaire adaptée aux troubles oraux survenant avec l'âge.

Title : Impact of oral physiology of elderly people on their food consumption; what solutions can be found to maintain nutritional status?

Keywords : elderly people, oral health, food behavior

Abstract : Context. In human, oral food intake is the ultimate stage of food supply chain and the beginning of food disintegration and digestion process. During aging, the oral health changes and sometimes eating food can be a real challenge as food can be hard to masticate, humidify or swallow.
Objective. The aim of the present study is to determine which oral factors (salivary, dental, tongue strength) have an impact on physiological – ability to form a food bolus – and psychological – pleasure to eat – dimensions of food oral processing in order to select culinary techniques and help elderlies maintaining an appropriate protein intake in spite of the occurrence of poor oral health.
Material and method. Resting and stimulated salivary flow, oral status, the ability to form a food bolus, the pleasure induced by food consumption and the nutritional status were measured on 108 elderly people (65-92 years old, living at home, with no acute pathology at the time of the study). In parallel, culinary technics that aimed at improving meat texture were developed and evaluated throughout physical measurements and oral comfort assessment by the elderly volunteers.
Results and conclusion. Multivariate analysis highlighted the fact that oral factors (salivary, dental, muscular) play different roles in food oral processing and eating behavior in elderly people. Moreover, the assessment of oral comfort on the culinary technics showed that some technics improve significantly meat tenderness and juiciness. Those results will help the development of food offer tailored to elderly people with or without oral health impairments.

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COMMUNICATIONS

PUBLICATIONS (RESEARCH PAPER)

Vandenberghe-Descamps, M., Labouré, H., Prot, A., Septier, C., Tournier, C., Feron, G. and Sumont-Rossé, C. (2016). Salivary Flow Decreases in Healthy Elderly People Independently of Dental Status and Drug Intake. *Journal of Texture Studies. 47, 353-360. 10.1111/jtxs.12191*

Vandenberghe-Descamps, M., Sulmont-Rossé, C., Septier, C., Feron, G. and Labouré, H. (2017). Using food comfortability to compare food's sensory characteristics expectations of elderly people with or without oral health problems. *Journal of Texture Studies. 10.1111/jtxs.12250*

Muñoz-González, C., **Vandenberghe-Descamps, M.**, Feron, G., Canon, F., Labouré, H. and Sulmont-Rossé, C. (2017). Association between salivary hypofunction and food consumption in the elderlies. A systematic literature review. *The journal of nutrition, health & aging. 10.1007/s12603-017-0960-x*

Vandenberghe-Descamps, M., Labouré, H., Septier, C., Feron, G. and Sulmont-Rossé, C. (2017). Oral comfort : a new concept to understand elderly people's expectations in terms of food sensory characteristics. *Food Quality and Preference. 10.1016/j.foodqual.2017.08.009*

Schwartz, C., **Vandenberghe-Descamps, M**., Sulmont-Rossé, C., Tournier, C. and Feron, G. 2017. Behavioral and physiological determinants of food choice and consumption at sensitive periods of the life span, a focus on infants and elderly. *Innovative Food Science & Emerging Technologies. 10.1016/j.ifset.2017.09.008*

Vandenberghe-Descamps, M., Labouré, H., Fleury, S., Septier, C., Prot, A., Feron, G., Tournier, C., Hennequin, M., Vigneau, E., Sulmont-Rossé, C. *Submitted*. Relationship between oral status, food oral processing and food intake in healthy elderly people.

Vandenberghe-Descamps, M., Sulmont-Rossé, C., Septier, C., Follot, C., Feron, G., Labouré, H. *Submitted*. Impact of blade tenderization, marinade and cooking temperature on oral comfort when eating meat in an elderly population.

Vandenberghe-Descamps, M., Sulmont-Rossé, C., Feron, G., Labouré, H. *Submitted*. Impact of easy-to do culinary techniques on meat shear force and water content.

ORAL COMMUNICATIONS

Vandenberghe-Descamps, M. Evolution de la perception sensorielle et vieillissement. Training for the French Professional Organization of Dietitians, Mai 21 2015, Colmar, France

Vandenberghe-Descamps, M. Pas de retraite pour la fourchette, impact de l'âge sur le plaisir à manger. Large audience presentation for the week of seniors, october 15, Caen, France

Vandenberghe-Descamps, M., Confort en bouche, un nouveau concept pour évaluer l'acceptabilité de différentes textures alimentaires auprès de personnes âgées ayant des problèmes bucco-dentaires. Forum des jeunes chercheurs, June 16 2016, Besançon, France

Vandenberghe-Descamps, M., Sulmont-Rossé, C., Septier, C., Feron, G. and Labouré, H. Food comfortability: a new concept to assess the acceptance of various food textures by elderly people suffering from oral health problems. 4th International conference on Food Oral Processing, July 3-6 2016, Lausanne, Switzerland

Vandenberghe-Descamps, M., Sulmont-Rossé, C., Septier, C., Feron, G. and Labouré, H. Food comfortability: a new concept to understand elderlies' expectations in terms of sensory characteristics. Eurosense 2016 Conference, September 11-14 2016, Dijon, France

Vandenberghe-Descamps, M. Les seniors et la salive au cœur d'une enquête scientifique. Journée des doctorants UMR CSGA, December 8 2016, Dijon, France

Vandenberghe-Descamps, M. Âge et perceptions sensorielles. Journée de restitution des résultats du projet AlimaSSenS, December 15 2016, Dijon, France

Vandenberghe-Descamps, M., Sulmont-Rossé, C., Septier, C., Prot, A., Tournier, C., Hennequin, M., Vigneau, E., Feron, G., Labouré, H. Safe structural food bolus in elderly : the relevant parameters. 25th annual meeting of the Society for the Study of Ingestive Behavior, July 18-22 2017, Montreal, Canada

Fleury, S., **Vandenberghe-Descamps, M.,** Septier, C., Feron, G., Labouré, H., Sulmont-Rossé, C. Santé orale et alimentation chez les personnes âgées : une adaptation multifactorielle. Journées francophones de nutrition, December 13-15 2017, Nantes, France

Vandenberghe-Descamps, M., Sulmont-Rossé, C., Septier, C., Prot, A., Tournier, C., Vigneau, E., Feron, G. and Labouré, H. Comportement alimentaire des seniors: impact des différents facteurs de santé orale sur les dimensions de l'acte alimentaire. Journées francophones de nutrition, December 13-15 2017, Nantes, France

INTRODUCTION

INTRODUCTION

The proportion of elderly people in the world is growing rapidly. Representing 8.5 percent of the worldwide population in 2016, the elderly population should reach 17 percent by 2050, that is to say 1.6 billion people (He *et al.*, 2016). Although people are living longer in most developed countries they are not necessarily living healthier, which will lead to several public health challenges in the coming years.

One of those public health challenges which is already encountered in developed countries is malnutrition. Malnutrition is the result of a physiological decline in food intake, which leads to an imbalance between nutritional needs and nutritional intake. This imbalance can be due to several causes, mainly related to socioeconomic status or functional ability (Evans, 2005). Widowhood, an income decrease, lack of cooking skills, oral health impairments, acute pathology, depression or even hospitalization could be some of the reasons causing the imbalance. When elderly people eat less than required due to one or several reasons cited above, they lose weight and their muscle mass decreases rapidly. Malnutrition also causes immune deficiency thus increases the risk of infection or an aggravation of existing disease, those consequences are represented in the “spiral of malnutrition” established by Ferry (1993) (Figure 1).

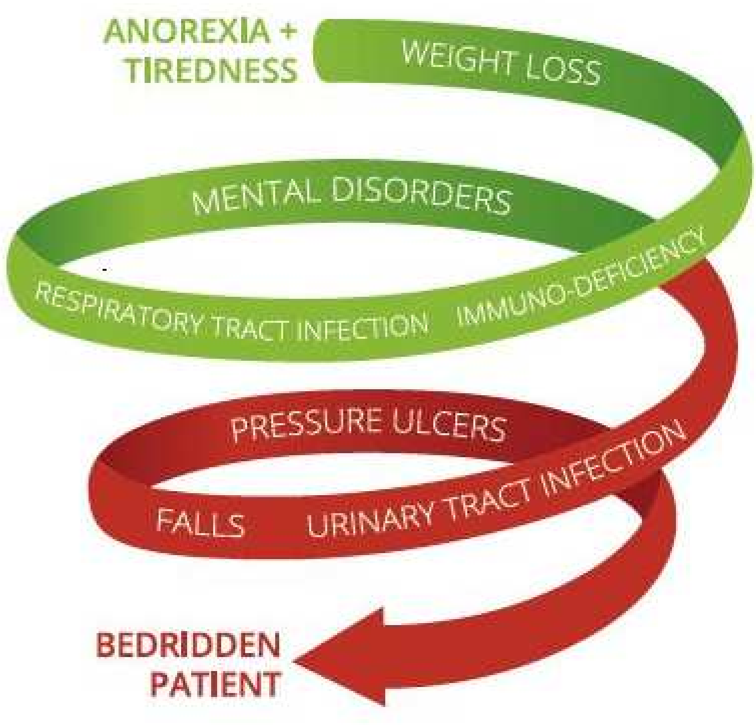

Figure 1. The spiral of malnutrition

Keeping in mind the causes of malnutrition, the development of products specifically tailored for the elderly population seems essential and is one of the World Health Organization's recommendations for facing the specific health challenges of the 21st century, caused by the ageing of the population. The question of what the needs are of elderly people, in terms of food products with optimized nutritional and sensory values in order to permit longer life and better ageing without deficiencies, is therefore of crucial importance.

The AlimaSSenS project was born in this context. AlimaSSenS is a large and highly integrated project whose main objective is to develop and provide a food supply specifically adapted to elderly population (>65 y/o) living at home. The project aims at:

- Understanding the impact of oral health impairments due to ageing on food oral processing and their consequences on eating pleasure and bio-accessibility of nutrients using in vivo and in vitro approaches;
- Developing a food supply adapted to the food oral processing capacities of the elderly and still considering meal and purchase practices of this specific population. Three product universes are investigated in the project: meat-based, cereal-based and dairy products.

To reach its objectives, AlimaSSenS proposes a multidisciplinary approach associating expertise in odontology, physiology, sensory evaluation, consumer behavior, nutrition, epidemiology, data mining, food process, sociology and economy. AlimaSSenS is a public-private collaborative research project involving 10 academic and 4 industrial partners as well as a network of technical centers represented by 1 technical center.

The project is divided into 4 work-packages, each of them having a specific objective. The fourth work package is dependent of the first three as it will take into account the results of the preliminary steps (Figure 2).

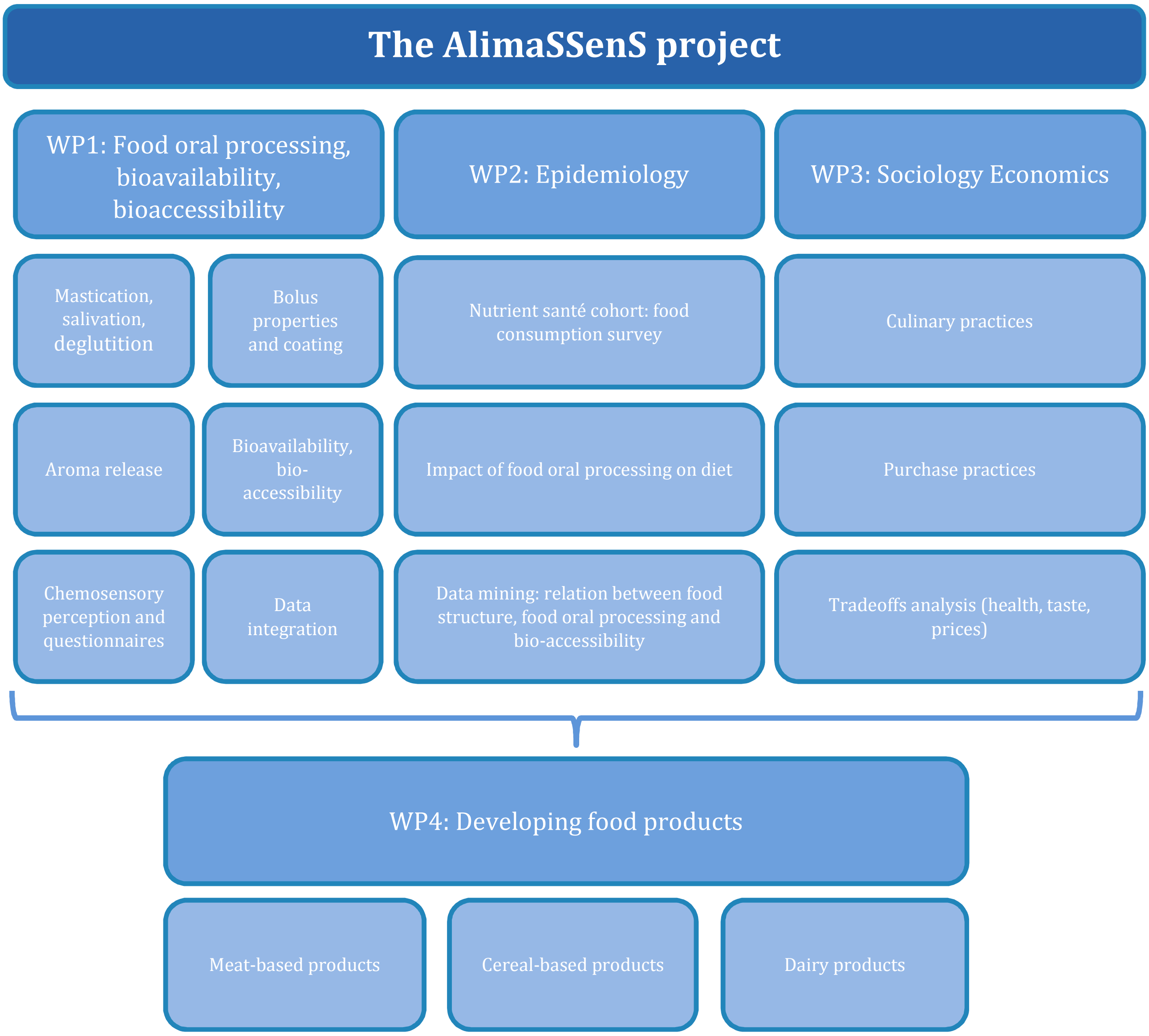

Figure 2. The AlimaSSenS project

The present thesis is part of the AlimaSSenS project and more specifically integrated into the work-package #1 (WP1) *i.e.* understanding the impact of oral health impairments due to ageing on food oral processing and their consequences on eating pleasure as well as food and nutrient intake.

CHAPTER 1: SCIENTIFIC CONTEXT

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In order to understand the non-negligible effect of ageing on food oral processing, it is important to identify the oral components that are implicated during food oral processing that are impacted in ageing. This chapter is divided into three parts. The first topic of interest will be mastication, with a focus on its alteration due to ageing and the impact of an altered masticatory function on food perception; as well as food and nutrient intake. Second, the salivation function will be developed focusing on the impact of ageing on salivation and its consequences on food perception; as well as food and nutrient intake. Finally, the deglutition will be examined with a focus on its alteration due to ageing and the impact on food intake.

1. MASTICATION

The masticatory apparatus has an essential role in food breakdown as it is a key for the formation of a food bolus ready to be swallowed (Mioche, 2004). Firstly, every tooth has a specific role in food breakdown, as the food is cut with the incisors or the canine teeth when presented to the mouth, then it goes into the back of the mouth to be chewed and sheared by the molar teeth. Altogether, the number of teeth in the mouth are 32, 16 in each jaw, and the combination of all is necessary to breakdown the food properly. Secondly, every tooth is connected to periodontal mechanoreceptors that signal information about tooth loads in a temporal, spatial and intensive aspect. These mechanoreceptors are located in the ligaments that attach the tooth root to the alveolar bone, among the collagen fibers, and have a role of regulation of the muscle activity (Trulsson, 2006). Trulsson and Johansson (1996) have studied the involvement of the periodontal mechanoreceptors on the control of jaw muscles during biting and chewing, and have shown that these receptors have a fine motor control of jaw actions associated with biting and the chewing of food. Finally, mastication is also the result of successive and coordinated muscle movements. Four pairs of muscles, which are located in the jaw area, operate during mastication: the masseter, the temporalis and the medial pterygoid – responsible of the closing mouth movement - and the lateral pterygoid muscles responsible of the mandible opening (Wood, 1987). Those muscles conduct jaw movements by generating forces, which are controlled by the central nervous system.

1.1. IMPACT OF AGEING ON MASTICATION

It is well known that ageing has an impact on the different apparatus of masticatory function. Indeed, many elderly people are exposed to loss of teeth, the need for dentures or a decrease in muscle strength, which might induce some changes in masticatory pattern.

1.1.1. TOOTH LOSS

Tooth loss is a common oral impairment that occurs during ageing. According to a German National Surveys on oral health published in 2006 (Micheelis and Schiffner, 2006), the most frequently lost teeth are the molars followed by the maxillary premolar and front teeth. Regarding the prevalence of edentulism, an average of 18 remaining teeth was noticed in a US survey among an elderly population aged between 65 and 69 years (Carlos and Wolfe, 1989). In France, 35 % of 65-79 year olds and 56 % of over 80 year olds claim they have lost all or roughly all their teeth against 11% in 40-64 year olds according to a national survey conducted by the CREDES (Auvray *et al.*, 2003). Studying the younger segment of the elderly population, the DMS IV cross-sectional study conducted in Germany evaluated the edentulism up to 22.6% among the 65-74 year old elderly people (Hoffmann *et al.*, 2006). Many studies have shown that elderlies with few remaining teeth have a different biting and chewing behavior than the dentate elderlies (Steele *et al.*, 1997; Savoca *et al.*, 2010; Akpata *et al.*, 2011). Steele *et al.* (1997) have indeed highlighted the fact that having 21 or more natural teeth was related to the absence of eating problems. However, more than the number of teeth, recent studies have focused on the number of occlusal contacts which represent the pairs of posterior antagonist teeth that have at least one contact area during chewing (Leake *et al.*, 1994; Kikutani *et al.*, 2009; Ikebe *et al.*, 2012). Several authors showed that masticatory performance was significantly associated with posterior occlusal contact. In the study performed by Leake *et al.* (1994), 338 older volunteers were recruited in order to evaluate the social and functional impact of tooth loss. The volunteers were divided into 5 groups according to their number of functional unit and their dentition status. Their chewing ability was assessed throughout a questionnaire. The results showed that 23% of the elderly subjects having 0 to 2 pairs of occluding teeth declared taking longer to chew food while none of the elderly subjects with 8 pairs of occluding teeth did. Ikebe *et al.* (2012) adopted a similar strategy by recruiting 1274 older volunteers (mean age of

66.2 year old) and stratifying them into 3 groups according to their number of occluding pairs of posterior teeth (Group 1: 4 zones with occlusal contact; group 2: 1-3 zones with occlusal contact; group 3: no occlusal contact at all). In order to measure the masticatory performance, the concentration of dissolved glucose from a masticated gummy jelly was calculated. The results highlighted a decrease in masticatory performance in the groups with less occluding pairs of teeth. Considering that the first group had a masticatory performance of 100%, group 2 showed decreased masticatory performance of 19% and group 3 of 50% compared to group 1. Kikutani *et al.* (2009) recruited 268 older volunteers classified into 2 groups (presence or absence of posterior occlusal support by natural teeth) to evaluate masticatory performance using a color-changeable chewing gum. The volunteers were asked to chew the gum very hard for 3 minutes during which the chewing rate and tongue movement were evaluated; then the gum was collected and analyzed using a colorimeter. The results showed that the average chewing rate was higher in group 1 (with posterior occlusal supports) than in group 2 (no occlusal support left). Furthermore, the indicator of masticatory performance was greater in group 1 than in group 2. Looking at the results of these three studies, it is clear that no matter which method is used to measure masticatory performance, the results are positively correlated to the number of remaining occluding pairs of teeth.

1.1.2. WEAR OF DENTURE

While some elderly people decide to overcome tooth loss via dental care (i.e. denture fabrication or implants set-up), others decide to live without replacing the missing teeth, thus leaving empty space in their mouth. Even though wearing dentures improves masticatory ability compared to edentate elderly people, some elderly people do not wear well-adapted dentures; which could lead to chewing impairments. Some studies have indeed shown that the masticatory performance was poorer in elderly wearing old dentures – i.e. dentures judged to be changed by dentists – compared to elderly people wearing new devices. Asakawa *et al.* (2005) recruited 32 elderly volunteers to evaluate the impact of new removable partial dentures on masticatory functions. Each of the volunteers received new removable partial dentures at the beginning of the study. The masticatory function was assessed using a colored wax cube and asking the volunteers to chew the wax cube for 10 strokes then spit it out for image analysis. The results highlighted a significant increase of masticatory ability with new removable partial dentures compared to the old ones. In line with those results, Ishikawa *et al.* (2007) evaluated masticatory performance in elderlies with new or old dentures using the color changeable chewing-gum. The results showed that masticatory performance tends to be better for new denture wearers compared to old denture wearers. Furthermore, throughout a patient satisfaction questionnaire, the authors highlighted the fact that new denture wearers are significantly more satisfied by their denture compared to the old denture wearers. However, it should be pointed out that wearing a prosthesis may partially restore the masticatory function. Sato *et al.* (2003) evaluated masticatory ability of fully dentate, denture-natural dentition and fully denture wearer elderly volunteers using the colored layers paraffin wax cube. The results showed that masticatory ability is significantly different between the three groups, the best performance being the group with natural dentition. In line with those results, Mishellany-Dutour *et al.* (2008) evaluated the masticatory performance of dentate and full denture wearer elderly volunteers, asking the volunteers to chew two different foods: raw carrots and groundnuts. The particle size of the food boluses were measured by a sieving method; the number of cycles and the sequence duration were measured during chewing. The results showed that the denture wearers had longer masticatory sequences and a greater number of cycles compared to the dentate elderlies. In addition, the results highlighted the fact that denture wearer elderlies made a bolus with many more large particles than the ones of the dentate elderlies.

1.1.3. DECREASE IN MUSCLE STRENGTH

Many studies have shown that muscle mass and strength tend to decrease with ageing. As an example, Goodpaster *et al.* (2006) recruited 3075 elderly volunteers to measure the body composition and muscle strength using an isokinetic knee extensor. The results showed that the loss of muscle strength was more rapid than the concomitant loss of muscle mass, which means that muscles decline in terms of quality with ageing. This phenomenon occurs in all body muscles including the masticatory muscles. Galo *et al.* (2007) recruited 10 elderly people (mean age 67.9 ± 4.8 years) and 10 young adults (mean age 25.9 ± 3 years) to study the activation of masticatory muscles when chewing three artificial products with different texture properties; an electromyography evaluation was performed during mastication. The results showed that the group of older adults presented lower electromyographical activity of both masseter and temporalis muscles during chewing. Even though the results were not significant for soft foods, the results were significant for harder foods. Looking at their results, both Peyron *et al.* (2004) and Galo *et al.* (2007) conclude on a decrease in muscular tonus due to either loss of muscle mass or the deterioration of the neuromuscular and sensory control mechanism.

Some studies have also shown a relationship between loss of tooth and muscle strength. Tsuga *et al.* (1998) recruited 160 elderly volunteers to measure the maximal bite force and the endurance time of dentate, edentulous and denture wearer elderly people. The results highlighted that the maximal bite force of the elderly subjects was significantly correlated to the number of remaining teeth. Furthermore, a correlation between the number of remaining teeth and endurance time was observed for women. In the study of Ikebe *et al.* (2012) previously mentioned, the authors measured the masticatory performance as well as bite force for their three groups differing in number of occlusal contacts. The results showed that the bite force was significantly greater for elderly with occlusal contact in four support zones compared to the other groups. There is indeed a positive correlation between the number of occlusal contacts and the measured bite force. To go further, some other studies have highlighted a relationship between wearing dentures and muscle strength. Veyrune and Mioche (2000) recruited 18 elderly volunteers (9 dentate and 9 complete denture wearing elderly) and asked them to masticate cooked pieces of meat while recording the electromyography of the four masticatory muscles activity. The results showed a greater muscle activity for dentate elderly compared to elderly denture wearers. More precisely, dentate volunteers showed a greater intensity of muscle contraction for the masseter muscles. Furthermore, denture wearers had greater difficulty in chewing the samples compared to the dentate elderly volunteers. As a similar study, Kohyama *et al.* (2003) recruited 19 elderly volunteers to evaluate their masticatory ability when eating 6 different foods using electromyography recording. The volunteers were classified into three groups: high dental status (7 to 10 posterior dental occlusions), middle dental status (3 to 6 posterior dental occlusions) and low dental status (0 to 2 posterior dental occlusions). The authors highlighted a significant difference between high, middle and low dental status elderly in terms of muscle activity per chew, mean and maximum electromyography voltage and burst duration. The group with high dental status showed better performance in masticatory ability than middle and low dental status groups.

1.1.4. MASTICATORY PATTERN

When eating food, the mouth operates several movements such as jaw movements, masticatory cycles and even mouth opening amplitude, all of these movements can be defined as masticatory pattern. It is well known that the loss of a tooth can influence masticatory pattern, however, very few studies have investigated the impact of ageing *per se* on masticatory patterns, whether on dentate or denture wearing elderly people. First, the number of masticatory cycles has been shown to increase with ageing. Peyron *et al.* (2004) recruited 67 volunteers aged between 25 and 71 year old with a complete dentition to study jaw movements while chewing four model foods that differ in terms of visco-elastic properties. The results showed an increase of 0.3 cycles per year of life. Second, some studies highlighted the fact that the mouth movements do not have the same amplitude between young and older adults during chewing. Karlsson and Carlsson (1990) measured the distances and angular movements during the mastication on 30 young (24-33 year old) and 14 elderly (78-84 year old) dentate subjects while chewing crispbread. The authors highlighted a significant difference between young and elderly adults in the mean vertical displacement, the amplitude was smaller in the elderly population than in the group of young adults. No significant difference was observed on the lateral component of the movement. However, the variance for the opening angle was greater ($p<0.05$) for the young adults. The authors also reported a smaller mean speed of the lower jaw during opening and closing movements in the elderly people. In line with those results, Kohyama and Mioche (2004) studied the chewing behavior of young and elderly adults using electromyography recording on both sides of the temporal and masseter muscles. The subjects were asked to chew 5 different foods (cooked rice, cooked beef, Edam cheese, raw apple, crispy bead and natural peanuts). The authors did not report any interaction between type of food and age or between age and stage of mastication. However, some age differences were observed on the chewing pattern such as the jaw opening duration or the mean electrical muscle activity measured during chewing, the elderly people showing a less efficient masticatory pattern.

1.2. IMPACT OF MASTICATION ON FOOD ORAL PROCESSING IN THE ELDERLY

1.2.1. IMPACT OF AN IMPAIRED MASTICATION ON FOOD PERCEPTION

As masticatory function might be altered by the physiological consequences of ageing, and knowing that mastication is one of the keys for an optimal food appreciation and consumption, it is worth investigating the impact of an impaired masticatory function on food perception, which is to say texture and flavor perception.

Texture perception

Very few studies have investigated the impact of dental status on food texture perception in the elderly population. Furthermore, and among the scarce literature, very few texture descriptors have already been studied. For example, Veyrune and Mioche (2000) evaluated the sensitivity of denture wearers to different food textures. The recruited volunteers – 9 denture wearers versus 9 dentate control volunteers – were asked to evaluate the subjective texture of meat on a 10 cm analogue scale, the meat samples varied in ripening time and cooking temperature which allowed a large range of textures. Even though the results showed no significant difference of texture perception between dentate and denture wearer elderly, the edentulous seem more sensitive to changes in juiciness of meat. In another study, Manly *et al.* (1952) recruited 20 volunteers (10 with normal dentition and 10 denture wearers) to evaluate texture sensory perception asking the volunteers to bite disks made of high-resin copolymer varying in thickness or hardness. The results showed no significant difference of thickness or hardness discrimination between normal dentition and denture wearers. However, denture wearers and dentate volunteers showed different thresholds when evaluating hard rubber disks; hardness was not perceived at the same level depending on dental status. According to the authors, soft and hard detections involve different relative amount of motion of the mandible which would explain the observed results. Indeed, when biting hard food, one needs a larger dentition movement compared to the biting of soft foods. The denture wearers would therefore be less able to perform large mandible movements when eating. These two studies present some very interesting results that call for more research studies in order to explore a larger amount of texture descriptors on the elderly population with varying dental status.

Flavor perception

Several authors showed an impact of ageing on chemosensory perceptions (Doty, 1991; Schiffman, 1991; Murphy *et al.*, 2002; Doty and Bromley, 2004; Imoscopi *et al.*, 2012). Various factors are likely to affect chemosensory perception: ageing *per se* but also several factors related to elderly's general health such as drug intake (Schiffman, 1991; Doty and Bromley, 2004) or pathological conditions (Doty, 1991; Murphy *et al.*, 2002; Imoscopi *et al.*, 2012). Some authors have also shown an impact of oral health status on olfactory and taste perception capability (Henkin and Christiansen, 1967; Burdach and Doty, 1987; Griep *et al.*, 1996; Duffy *et al.*, 1999; Nalcaci and Baran, 2008; Solemdal *et al.*, 2012; Batisse *et al.*, 2017). In the study conducted by Nalcaci and Baran (2008), 254 elderly volunteers evaluated their perceived taste disturbance throughout a questionnaire measuring the presence or absence of bad breath and distorted taste or loss of taste. The results showed a strong correlation between the perceived taste disturbance and the type of denture (fixed-partial, removable-partial or complete dentures, $p<0.001$). However, the methodology used in this study presents two limits: first, the evaluation of taste perception is a self-evaluation, thus the use of self-report questionnaires could lead to misreports (Levkoff *et al.*, 1987; Angelini *et al.*, 2012). Second, only the correlations were analyzed between taste perception and dental status, it is therefore not possible to conclude on a potential cause and effect relationship. In a study conducted by Duffy *et al.* (1999), 27 dentate or denture wearers with uncovered palate and 46 denture wearers with covered palate were recruited to evaluate the olfactory sensitivity using the Connecticut Chemosensory Clinical Research Center test which pairs an odor threshold component with an odor identification component. The results highlighted a significant difference between the two groups in terms of olfactory flavor threshold. The group wearing dentures with a covered palate showed a higher threshold than the other group. However, it is difficult to say whereas this difference is due to the wear of denture or to the covering of palate, as it is known that the interaction between the palate and the tongue during swallowing is essential for an optimal sending of volatile compounds to the olfactory receptors (Burdach and Doty, 1987). This theory was already stated by Henkin and Christiansen (1967) on taste perception; the authors highlighted the fact that the wear of palate-covering dentures affects the taste of sour and bitter. In another study, Griep *et al.* (1996) recruited 182 free living elderly volunteers (mean age = 68.4 years) classified into 3 groups (dentate, partial denture wearers, complete denture wearers) to investigate how much odor perception is impacted by dental status and oral hygiene. The volunteers were asked to sniff bottles containing solutions of isoamyl acetate in pair and to identify the bottle with the strongest smell. The results showed that there was no significant difference between dentate, partial denture wearers and complete denture wearers in terms of odor perception when evaluating separately the men and women. However, a tendency of the interaction of gender and dental status was observed as among the partial denture wearers, men had a poorer odor perception. Furthermore, and among the complete denture wearers, odor perception threshold increased with age. The authors hypothesized that bacteria, food debris or desquamated oral epithelial cells that can be on denture saddle may lead to oral malodors which may enter the nasal cavity by a fermenting process and therefore may cause masking effects on odor perception. Solemdal *et al.* (2012) concluded on the hypothesis. The authors recruited 174 volunteers characterized in terms of dental status and investigated its impact on taste sensitivity threshold using strips impregnated with sweet, sour, salty and bitter taste solutions in four different concentration each to place in the middle of the anterior region of the tongue. The results showed no significant difference of the total taste score between denture wearers and dentate elderlies but a reduction of the total taste score was observed in patients with high number of decayed teeth. This could be explained by the fact that elderly with a lower number of teeth may have a poorer oral hygiene, and taste loss could be due to toxins and inflammatory products produced by the oral bacteria.

1.2.2. Impact of an impaired mastication on food intake

As ageing can have an impact on food perception and masticatory pattern, it is worth investigating its impact on food intake. The intake of food can be evaluated via several methods, the main ones being the subjective evaluation of food acceptability, food avoidance or food consumption in quantity per day, or the amount of nutrient intake. All of these three approaches bring precious information on food behavior in the elderly population.

Food acceptability

Food acceptability is commonly measured throughout a questionnaire assessing the subjective estimate of food acceptance among a list of varied foods. In the study conducted by Wayler and Chauncey (1983), 335 volunteers aged 50+ performed the food acceptability test by rating the ease of chewing of a list of commonly eaten foods (i.e. French bread, steak, salami, celery, etc.). In parallel, the volunteers were characterized in terms of dental status (intact, partially-compromised or compromised natural dentition or denture wearers). The results highlighted a significant decrease in ease of chewing scores for complete denture wearers compared to the groups having a natural dentition. Those results go in line with the results of similar studies (Garcia *et al.*, 1989; Marcenes *et al.*, 2003; Ikebe *et al.*, 2007). For example, Marcenes *et al.* (2003) evaluated the relationship between dental status and food selection in 753 free-living elderly people, dentate and edentulous. The results showed that among the edentulous group, half of them presented difficulty or impossibility in eating apples. A high percentage also presented difficulty in eating nuts (42%), raw carrot (41%) or well-done steaks (33%). The edentulous had a significantly greater difficulty in eating tomatoes, raw carrots, apples, nuts, lettuce and well-done steaks ($p<0.01$) compared to the dentate elderly. If these studies allow a better understanding of food behavior among the elderly population, their results bring different information to the ones obtained throughout the objective measure of food consumption.

Food consumption

Several studies showed an impact of dental status on modifications in food behavior (Geissler and Bates, 1984; Brodeur *et al.*, 1993; Joshipura *et al.*, 1996; Kagawa *et al.*, 2013). Geissler and Bates (1984) demonstrated in their review that tooth loss was related to a reduced consumption of meat, fresh fruit and vegetables based on the results of a nutrition survey in the British elderly population. These results go in line with the ones of Joshipura *et al.* (1996) who demonstrated that participants with less teeth consumed less vegetables in terms of frequency. However, they did not recruit elderly people specifically (mean age of 55 years, ranging from 40 to 80 years). In terms of food texture, Hildebrandt *et al.* (1997) have demonstrated that elderly people with a reduced number of functional units (pairs of occluding teeth) avoided stringy, crunchy and dry solid foods. Regarding the impact of masticatory performance on food intake, few studies highlighted that elderly people with poor masticatory performance had lowed intake of fruits and vegetables (Brodeur *et al.*, 1993; Kagawa *et al.*, 2013). However, other studies did not find any impact of dental status on food intake. As an example, Tsai and Chang (2011) recruited 1766 elderly volunteers characterized in terms of dental status (wear of fixed or removable denture or dentate elderly) to investigate the impact of dental condition on food consumption using a food frequency questionnaire. The results showed that denture wearers (fixed or removable) consumed dairy and fruits more frequently than dentate elderly ($p<0.001$ and $p<0.005$ respectively). Furthermore, fixed-denture wearers consumed vegetables more frequently than non-denture and removable denture wearers ($p<0.001$). Furthermore, Bradbury *et al.* (2008) did not find any difference of fruit and vegetable intake between dentate and edentate elderly people. Those discrepancies between the studies could be explained by the diversity in the methods used to evaluate food consumption. When some studies used the 24h-recall, others used the food frequency questionnaire, a simple food list, an estimated dietary records, a diet history questionnaires or even some weighing protocols. Furthermore, very few studies have investigated the impact of dental status on food intake or food avoidance, and the used methodology to assess food intake differs between studies.

Nutrient intake

Several studies highlighted an impact of dental status on nutrient intake (Ernest, 1993; Sahyoun *et al.*, 2003; Hung *et al.*, 2005; Yoshihara *et al.*, 2005; Cousson *et al.*, 2012). However, the nutrients that are affected by dental status varied from one study to another, which leads to inconsistencies between the studies and difficulties to conclude on the results. Regarding masticatory ability, Ernest (1993) recruited 30 volunteers to evaluate their dietary intake, food preferences and masticatory ability by asking to answer a 24-hour dietary recall and to eat a piece of raw carrot in order to evaluate their masticatory ability. The results showed that there was a significant negative relationship between masticatory ability and carbohydrates, thiamin, riboflavin, folacin, vitamin B-6 and sodium intake. Regarding dental status, most of the studies showed a decrease of nutrient intake for poor dental status elderly; even though the evaluation criteria of dental status differs between studies (number of teeth, number of functional units, denture status)(Sahyoun *et al.*, 2003; Hung *et al.*, 2005; Yoshihara *et al.*, 2005; Cousson *et al.*, 2012). Cousson *et al.* (2012) have for example compared fully dentate and complete denture wearer elderly on nutrient intake throughout a 3-day dietary record. The results showed that even though both groups (dentate and denture wearers) had lower nutrient intake than the recommended daily allowance, the group of denture wearers had lower energy intake than the control group ($p<0.05$). Furthermore, the control group had greater lipid ($p<0.05$) and carbohydrate ($p<0.01$) intake than the denture wearer group. Yoshihara *et al.* (2005) recruited 57 elderly volunteers to evaluate the relationship between the number of remaining teeth and dietary intake. The results showed that the number of teeth was significantly associated with total energy and animal protein intake ($p<0.0001$) as well as many nutrients such as sodium, potassium or even many vitamins ($p<0.05$). When dividing the population into two groups (>20 teeth *versus* <20 teeth), the results showed that the mean intake of nutrients was lower for the group with less than 20 teeth compared to the group having more than 20 teeth.

Take home message

Mastication is essential to food breakdown as teeth and masticatory muscles altogether reduce food into a bolus ready to be swallowed. With aging, the loss of teeth, the wear of denture or the decrease in muscle strength alter the efficacy of mastication and can induce food breakdown impairments. Many studies have shown that masticatory impairments can impact food perception and food intake.

2. SALIVATION

Saliva is a physiological fluid that plays a crucial role in preserving and maintaining oral health and eating comfort (Carpenter, 2012). Saliva is secreted by three major salivary glands (submandibular, sublingual and parotid glands) and several minor salivary glands located all over the oral cavity (Christensen, 1986). During oral food consumption, saliva has three major functions.

First, saliva plays a key role in the acceptance of food and beverage by modulating the perception of oral sensations (taste, viscosity, smoothness, juiciness, astringency, etc.) and aroma release. In fact, taste compounds should be in an aqueous solution to reach and activate taste buds (Fischer *et al.*, 1994), and it has been demonstrated that taste sensitivity is related to saliva composition (Dsamou *et al.*, 2012). Furthermore, texture perception is influenced by saliva composition. (Engelen *et al.*, 2007) have demonstrated that subjects with a high α-amylase activity had a decreased thickness perception of starch-based custard. Finally, saliva can impact aroma release by assisting in the food breakdown process, by retaining or releasing aroma compounds depending on their affinity with saliva, and by inducing chemical reactions likely to produce new volatile compounds (Gierczynski *et al.*, 2011).

Second, saliva, as well as mastication, transforms a food sample into a bolus that can be safely swallowed (Prinz and Lucas, 1997). The water in saliva moistens the food particles, whereas the salivary mucins bind masticated food into a coherent and slippery bolus that can easily slide through the esophagus without damaging the mucosa. Saliva enzymes also initiate the digestion of carbohydrates in the food bolus (Salt and Schenker, 1976; Hamosh and Burns, 1977).

Third, saliva dilutes and removes substances from the oral cavity after swallowing, i.e. “oral clearance”; (Lagerlof and Oliveby, 1994; Lenander-Lumikari and Loimaranta, 2000). In fact, salivation and swallowing are acknowledged to be important processes for eliminating injurious and noxious agents and bacteria from the oral cavity (Pedersen *et al.*, 2002). Saliva clears sugar and acids from the oral cavity and thereby protects teeth from erosion. Finally, teeth and mucous membranes are covered by a protective film of saliva, which prevents the occurrence of caries (Ericsson, 1953).

2.1. IMPACT OF AGEING ON SALIVATION

In elderly people, it has been demonstrated that the cumulative effect of ageing and associated changes, such as tooth loss (Dormenval *et al.*, 1998; Srinivasulu *et al.*, 2014), drug intake (Handelman *et al.*, 1989; Bardow *et al.*, 2001; Johanson *et al.*, 2015; Thomson, 2015) and disease (Ship *et al.*, 1990; Ship, 1992; Ship and Puckett, 1994; Chu *et al.*, 2015), may affect salivary flow. But a recent study also highlighted the fact that elderly people, independently of the confounding factors cited above, show a decrease of salivary flow rate (Vandenberghe-Descamps *et al.*, 2016). Even though this decrease in salivary secretion was not fully explored in the literature, two hypotheses can be emitted as for its physiological explanation. First, the decrease in salivary secretion could be explained by the ageing of salivary glands themselves. Salivary glands are composed of three major types of cell; acinar cells, ductal cells and myoepithelial cells, and saliva is produced in the end-pieces of the glands – the acini -, where serous cells produce the watery seromucous secretion and mucous cells produce the viscous mucin-rich secretion. Yet the acinar cells are known to degenerate with age, which directly affects salivary flow rates (Edgar and O'Mullane, 1996). Second, as salivary secretion is regulated by the autonomic nervous system, it could be argued that the autonomic nervous system function declines with ageing, which leads to a decrease in salivary secretion. To the best of our knowledge, no studies have investigated the impact of ageing on the salivary secretion function of the autonomic nervous system. However, some studies have investigated the impact of ageing on other autonomic nervous system functions such as cardiovascular ad pupillary autonomic nervous system reflexes (Pfeifer *et al.*, 1983), heart rate during postural change, vasomotor thermoregulatory function and lower-body negative pressure (Collins *et al.*, 1980), or even the expression of autonomic nerves (Burnstock, 1990). All of these previously cited studies showed a decline in the autonomic nervous system function. Those results go in line with the study of Bénard and Doitsidou (2017) who highlighted the fact that age-related neuronal changed occur at a structural, cellular and functional level using the *C. elegans* model.

2.2. IMPACT OF SALIVATION ON EATING IN THE ELDERLY

As described previously, salivary secretion is an essential key for taste and texture perception throughout its quantity and quality. Therefore, a lack of saliva or an alteration in saliva composition can have an impact on taste and texture perception, which could lead to changes in food behavior. In the present thesis, a systematic literature review was conducted to investigate the topic, its aim was to summarize the existing literature on the link between impaired salivation *i.e.* hyposalivation and food consumption in the elderlies (see below).

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ASSOCIATION BETWEEN SALIVARY HYPOFUNCTION AND FOOD CONSUMPTION IN THE ELDERLIES. A SYSTEMATIC LITERATURE REVIEW

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Abstract: *Objectives:* This systematic literature review aims to summarize the existing scientific evidence about the association between a reduced salivary function and food consumption in elderly people. *Methods:* A validated search strategy in two databases (PubMed and ISI Web of Knowledge) was carried out and retrieved papers together with their reference lists were screened by two independent reviewers. The quality of the included studies was critically appraised via the Quality Assessment Criteria for Evaluating Primary Research Papers. *Results:* From the originally identified studies (n=391), only 15 articles (all cross-sectional studies) met the pre-fixed inclusion/exclusion criteria. The methodological quality of the included studies was in general good, although only 3 from 15 obtained the maximum score. The control of confounding factors was the quality variable more poorly rated in the selected studies. Salivary hypofunction was associated with a decrease of the objective chewing and swallowing abilities and taste perception. Moreover, most of the selected studies showed a relationship between salivary hypofunction and food consumption (in terms of appetite loss, unbalanced dietary intake and malnutrition), although no causality could be established. *Conclusions:* This study highlights the fact that salivary hypofunction definition and measurements are different across the studies. Therefore, future research efforts should focus on establishing a gold standard to define and identify salivary hypofunction throughout life and on performing longitudinal studies controlling for confounding factors to establish causality. .

Key words: Hyposalivation, dietary intake, appetite, nutritional status, elderly.

Introduction

Saliva is a complex biological fluid composed by water, inorganic and organic molecules (1). Secreted by several salivary glands, saliva plays an important role in the preservation and maintenance of oral health and functions (2). First, saliva is known to be essential in fulfilling daily activities such as speaking. Second, it exerts a key role maintaining oral health under normal conditions: tooth and oral mucosa integrity, protection against dental caries, periodontal diseases, etc. (3; 4; 5). Third, as the first digestive fluid in contact with food, saliva is a key factor assisting the oral processing of food, whereby food is transformed into a bolus to be swallowed. During the mastication process, the lubrication function of saliva allows moistening of food and supports the creation of a bolus which in turn facilitates the ability to chew (6). Furthermore, some food components are released from the food matrix and dissolved in saliva, where they can be influenced by the presence of salivary components such as salivary enzymes that begin the process of food digestion (i.e. alpha-amylase) or metabolize flavor compounds (i.e. esterases, glycosidases) (7; 8).

In consequence, an alteration in the composition or amount of saliva released to the human mouth, produced as a consequence of a diminished salivary gland function, could have serious consequences. A reduced salivary output could induce a defect in lubrication, compromising the comfort while chewing and swallowing (3). These dysfunctions could be accompanied by an unbalanced flavor perception that could provoke an unpleasant sensory experience. Besides these effects, if the situation of dry mouth is maintained in the long term, the decline (or absence) of salivation per se may change the oral environment, which could cause infections, destruction of taste receptors (9) and formation of dental caries, which can derive in tooth losses (4), thus compromising even more the food oral processing. The sum of these events could therefore provoke a decline in food interest and a loss of appetite, resulting in a modification of people's dietary habits. The quantity, quality and variety of food consumed could be altered, thus contributing to a diminished nutritional status.

This cascade of reactions possibly induced by a reduced salivary output is of especial relevance for elderly people, the population group most affected by salivary disorders. Older people are more likely to take medications compared to other generations, which is a well-known factor of hyposalivation as a side effect (10). A recent meta-analysis has shown that the aging process is associated with reduced salivary flow per se in a salivary-gland-manner (11), and this reduction can not be fully explained on the basis of medications (11) or dental status (12). In the same time, this age group is frequently associated with poor appetite, weight loss and malnutrition (13; 14). However, the relationship between food consumption and salivary hypofunction in elderly population remains unclear. This could be due to the fact that very often the studies on this topic have measured the subjective sensation of dry mouth (xerostomia) instead of performing real measurements of saliva deficiencies (3, 15-19). Indeed, xerostomia and hyposalivation are two separate entities, which are not always correlated (20;

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21). Whereas xerostomia relates to a subjective evaluation of dry mouth, hyposalivation represents a decrease in the amount of saliva secreted to the oral cavity. Therefore the aim of this work was to systematically review the original articles studying the associations between salivary hypofunction measured objectively and alterations in food consumption in elderly population. In this review, food consumption has been addressed by the study of i) food oral processing, ii) food behavior (appetite and dietary intake) and iii) nutritional status. Out of scope of this article are external factors affecting food consumption such as food availability, cultural factors, etc.

Method

Search strategy

A review of the literature was conducted in September 2016 for all published articles containing information about the association between salivary hypofunction and i) food oral processing, ii) food behavior (appetite and dietary intake), and iii) nutritional status in the elderlies. The electronic databases PubMed and ISI Web of Knowledge were used to search for relevant articles (without date restriction). The search strategy consisted of a set of Medical Subject Headings (MeSH) terms and free text words subsequently combined. Following groups of key words were introduced:

1) food oral processing, mastication, chewing, swallowing, flavo(u)r, taste, aroma, texture, flavo(u)r perception, taste perception, aroma perception, texture perception, chemosensory perception, orosensory perception, food sensory perception, texture modification, aroma release, taste release, trigeminal sensation(s), food texture;

2) food consumption, food behavio(u)r, nutrition, appetite, food intake, malnutrition, undernutrition, malnourishment, eating, nutrient intake, eating capability, food liking, dietary pattern, meal frequency, eating frequency;

3) elderly, senior, ag(e)ing, old age, older adult(s), old(er) people, old(er) person(s);

4) saliva, hyposalivation, salivary flow, salivary composition, salivary protein(s), salivary secretion(s), salivary hypofunction, xerostomia, dry mouth, oral mucosa, mucosal wetness, mucosa dryness, oral dryness.

Selection criteria and study selection

Articles were included if they explored the association between an objective measure of salivary deficiencies and i) food oral processing (mastication, swallowing, orosensory perception), ii) food behavior (appetite and food intake) or iii) nutritional status. Only articles that defined salivary hypofunction were included in this systematic literature review (SLR). Therefore articles that did not explore populations with salivary disorders or that did not specify cut-off values of saliva deficiencies were not included in this SLR. Study design and settings were not defined as exclusion criteria because of the exploratory character of the review. Only articles written in English were included, no date limitation was performed.

Two reviewers (CMG and MVD) independently screened the titles and abstracts based on the selection criteria. If the abstract did not provide enough information to decide upon inclusion/exclusion, the full paper was retrieved for further screening. Disagreements about inclusion or exclusion were discussed between the reviewers until consensus was reached.

Data abstraction and synthesis

Two reviewers (CMG and MVD) independently extracted data from the included articles. The extracted data included study characteristics (author and year of publication, study design, sample size, settings (living condition), determinant, outcome, methods, main results and conclusions), and participant characteristics (age, gender, country/ethnicity, functional status). A synthesis of the data is reported in Table 1.

Quality assessment

The quality assessment of the review is based on "The quality assessment criteria for evaluating primary research papers from a variety of fields" (22). The used checklist contains the following items:

1. Is the objective of the study sufficiently described?
2. Is the study design evident and appropriate?
3. Is the method of subject selection described and appropriate?
4. Are subject characteristics sufficiently described (functional status, health, etc.)?
5. Are outcome measures well defined and robust to measurement?
6. Is the sample size appropriate?
7. Are analytic methods described, justified and appropriate?
8. Is some estimate of variance reported for main results?
9. Are they controlled for confounding?
10. Are the results reported in sufficient detail?
11. Are the conclusions supported by results?

Each question can be answered with 'yes', 'partial', 'no' and 'not applicable'. The summary score is the total sum ((number of 'yes' x 2) + (number of 'partial' x 1)) / total possible sum (28 – (number of 'not applicable' x 2). The associated scoring manual (22) was used to guide the scoring process. When the quality of a paper was debatable, a discussion between two independent reviewers was held until consensus was reached.

Results

Selected articles

Figure 1 shows the overview of the search strategy. A total of 391 articles were identified: PubMed (n=219), and ISI Web of Knowledge (n=172). Duplicate articles (n=102) were excluded. Additionally, 248 articles were excluded because the inclusion criteria (based on title and/or abstract) were not met. The full texts of 41 articles were reviewed in detail.

Table 1

Description of the 15 selected studies concerning salivary hypofunction and associated parameters related to food consumption

Reference	Study design*	Study population	Country	Functional status**	Parameter studied and method(s)	Results of the association between the parameter studied and salivary hypofunction
Dormenval et al., 1998	CS	sample size: 99 mean age ± SD (years) 82.5 ± 4.0 gender (% female): 70	Switzerland	H	Nutritional status: Anthropometric (BMI, triceps skinfold thickness and mid-arm circumference), and biological measurements (serum albumin concentration)	- BMI<21 ($p<0.05$) - triceps skinfold thickness: ($p=0.01$) - mid-arm circumference: ($p<0.05$) - serum albumin concentration: ($p=0.01$)
Dormenval et al., 1999	CS	sample size: 99 mean age ± SD (y/o): 82.5 ± 4.0 gender (% female): 70	Switzerland	H	Appetite: questionnaire	- Lack of appetite ($p=0.05$)
Samnieng et al., 2012	CS	sample size: 612 mean age ± SD (y/o): 68.8 ± 5.9 gender (% female): 74	Thailand	C	i) Oral function (tasting, speaking, swallowing, chewing): questionnaire ii) Nutritional status: MNA	- Oral function problems ($p<0.05$) - Low MNA score ($p<0.05$).
Syrjälä et al., 2013	CS	sample size: 157 mean age ± SD (y/o): 79.2± 3.6 gender (% female): 70	Finland	C	Nutritional status (risk of malnutrition): MNA-SF	- Risk of malnutrition (n.s)
Samnieng, 2014	CS	sample size: 612 mean age ± SD (y/o) : 68.8 ± 5.9 gender (% female): 74	Thailand	C	Appetite: questionnaire	- Appetite loss ($p<0.05$)
Iwasaki et al., 2016	CS	sample size: 352 mean age ± SD (y/o): 80.0 ± 0.0 gender (% female): 51	Japan	C	i)Dietary intake: validated food frequency questionnaire ii) Subjective capacities to eat and swallow: questionnaire	- Self-reported chewing difficulties ($p<0.001$) - Self-reported swallowing difficulties ($p<0.036$) -Total energy intake (n.s) - Low intake of n-3 polyunsaturated fatty acid, potassium, vitamin D, vitamin E, vitamin B6 and folate ($p<0.05$) - Low consumption of vegetable, fish and shellfish consumption ($p<0.05$)
Ikebe et al., 2006	CS	sample size: 328 mean age ± SD (y/o): 66.2 ± 4.1 gender (% female): 47	Japan	C	Masticatory performance: Gummy jellies test	- Masticatory ability: bivariate level ($p=0.006$) and multivariate level ($p=0.046$) - Masticatory performance: no support zone ($p<0.003$), 1 to 3 support zones ($p=0.047$), 4 support zones (n.s)

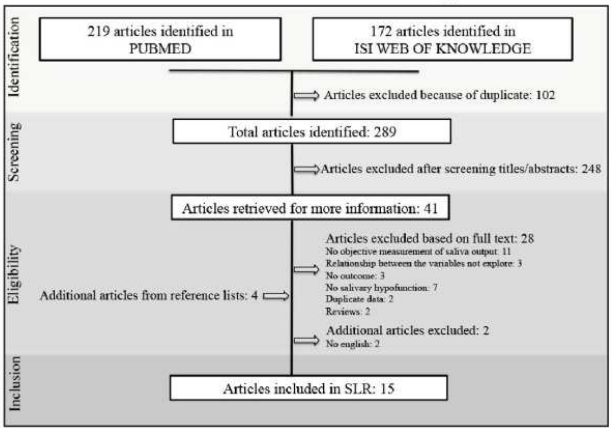
Table 1 (contined)

Reference	Study design*	Study population	Country	Functional status**	Parameter studied and method(s)	Results of the association between the parameter studied and salivary hypofunction
Mesas et al., 2010	CS	sample size: 267 mean age ± SD (y/o): 66.5 ± 4.1 gender (% female): 60	Brazil	C	Nutritional status: MNA	- Nutritional deficit (OR: 2.18, 95% CI: 1.06 – 4.50) (considering stimulated salivary flow <0.7 ml/min)
Poisson et al., 2014	CS	sample size: 159 mean age ± SD (y/o): 85.3 ± 5.7 gender (% female): 68	France	H	i) Dysphagia: swallowing abilities ii) Nutritional status: BMI, serum albumin concentration, MNA-SF iii) Dietary intake: 3-day records	-Dysphagia: univariate level (p<0.001) and multivariate level (n.s) - Malnutrition (n.s) - Protein and energy intake (n.s)
Soini et al., 2003	CS	sample size: 51 mean age ± SD (y/o): 83.7 ± 4.4 gender (% female): 78	Finland	C	Nutritional status (risk of malnutrition): MNA	- Risk of malnutrition (p = 0.049)
Solemdal et al., 2012	CS	sample size: 174 mean age ± SD (y/o): 83.5 ± 6.1 gender (% female): 68	Norway	H	Taste ability: taste strips method	- Total taste score (p=0.001), sweet sum score (p=0.007) and salty sum score (p=0.009) related to friction with mirror test - Total taste score (p=0.007), sweet sum score (p=0.001) and salty sum score (p=0.030) related to dry tongue - Salty sum score (p=0.023) related to salivary flow
Srinivasulu et al., 2014	CS	sample size: 81 mean age ± SD (y/o): 70.0 ± 7.1 gender (% female): 58	India	I	Nutritional status: MNA	- Nutritional status (p<0.001)
Ikebe et al., 2002	CS	sample size: 351 mean age ± SD (y/o): 66.7 ± 4.3 gender (% female): 46	Japan	C	Dissatisfaction with tasting; self-assessed chewing ability: questionnaire	- Dissatisfaction with tasting food (p<0.05) - Self-assessed chewing ability (p<0.01)
Shinkawa et al., 2009	CS	sample size: 502 mean age ± SD (y/o): 72.3 ± 6.7 gender (% female): 51	Japan	C	Satisfaction with chewing and swallowing abilities: questionnaire	- Subjective chewing ability (p=0.002) - Swallowing ability (n.s)

* CS: cross-sectional studies; ** C: community dwelling volunteers (independently living); I: Institutionalized volunteers; H: hospitalized patients

Twenty eight articles were excluded due to different reasons: not an objective measurement of the saliva flow but a subjective sensation of dry mouth (n=11), the relationship between the variables was not explored (n=3), cut-off value to determine salivary hypofunction not specified (n=7), the outcome measurements were not focused specifically on our research topic (n=3), redundant information due to a publication on the same data (n=2), or not original papers but reviews (n=2). The reference lists of all included articles were checked for additional articles. In consequence, four new papers were found to be of interest for this review but two of them (23, 24) were not written in English, so not included in the final list. The final group consisted of 15 articles. All of them were subjected to a methodological quality assessment.

Figure 1
Overview of the research strategy



Methodological quality

The methodological quality of the included studies was in general good: of the 15 selected articles the quality scores varied between 0.77 and 1 in a 0-to-1 rating scale (Table 2). Three articles (25-27) obtained the maximum score according to the above-mentioned manual scoring (22). On the contrary, the lowest score was attributed to the one (28) with the smallest sample size (n=51) (item n° 6). Moreover, in this work the study design (item n° 2), the analytical methods employed (item n° 7) and the results (item n° 10) were not sufficiently described. Furthermore, confounding factors (item n° 9) were partially taken into account.

In fact, the control of confounding factors (item n° 9) was the quality variable more poorly rated in the selected studies. This was due to the fact that most of the studies did not take into account all the factors established as confounding in this study: age, gender, drug intake, diseases, mental status, socio-economic status, dental status and place to live. Therefore this item was often rated as "partial".

Study characteristics

Table 1 gives an overview of the 15 selected articles. Publication year of the studies ranged from 1998 to 2016, showing that the interest on this topic is held and even increased over time (from 1998 to 2004: 4 studies; from 2005 to 2011: 4 studies; from 2012 to 2016: 7 studies). All the studies had a cross-sectional design. The studies were based on populations from all over the world (Brazil: 1, Finland: 2, Japan: 5, Norway: 1, Switzerland: 2, Thailand: 2; France:1; India:1), with exception of the African and Oceanic continent and north America. The sample size varied from 51 (28) to 640 (29) subjects. The gender distribution of subjects varied between 46% (30) and 78% (28) of females. Eighty per cent of the studies presented however, a higher percentage of women compared to men. The mean age was highly dispersed in the selected studies, ranging from 66 to 84 years old. The recruited populations were located either in institutions (5 studies) or in their own homes (10 studies). The subjects recruited in the selected studies were in good general health except for three studies: one study with hospitalized very sick volunteers (31), one study which included subjects receiving home care nurses visits (28) and one study (27) where the elderlies were living in their own homes prior to hospitalization for acute medical problems.

Analytical methods

Salivary hypofunction was determined differently across the selected studies (Table 3). Fourteen of the 15 studies measured the salivary flow rate either at rest, under stimulation by chewing a piece of paraffin-wax during saliva collection or both at rest and under stimulation. Most of these studies used the spitting method for the salivary collection but some preferred to measure the salivary flow using the draining method or the sterile compress method. The draining method consists in allowing saliva to drain out between parted lips into a test tube held near the mouth. The sterile compress method consists in placing a sterile compress under the tongue, then weighting the compress after a certain time to evaluate the amount of saliva incorporated. These studies have defined salivary hypofunction when the salivary flow was below a certain cut-off value. This reference value was 0.1 ml/min of saliva determined at rest in all the selected studies. However, the cut-off values employed to define salivary hypofunction under stimulation were not consensual and varied from 0.5 ml/min to 1.0 ml/min in the different studies. Very few studies have determined salivary hypofunction using alternative methods. Four over fifteen articles employed (besides the determination of salivary flow) additional measures to determine salivary hypofunction, such as the mirror test (that consists of measuring the stickiness of buccal mucosa when passing through it the back of a dental mirror) or the registration of dry tongue (presence of moisture or not). Only one study (32) did not use salivary flow to define hyposalivation. Authors measured the moisture of the buccal mucosa by using a device that evaluates the weight

Table 2
Quality assessment of the 15 selected studies

Reference	Question/ objective sufficiently described?	Study design evident and appropriate?	Method of subject selection is described and appropriate?	Subject characteristics are sufficiently described?	Outcome measures(s) well defined and robust to measurement/ misclassification bias? Means of assessment reported?	Sample size appropriate?	Analytic methods described/ justified and appropriate?	Some estimate of variance is reported for main results?	Controlled for confounding? (age, gender, drug intake, diseases, mental status, socio-economic status, dental status and place to live)	Results reported in sufficient detail?	Conclusions supported by results?	Sum Score
Dormenval et al., 1998	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Partial	Partial	Yes	0.91
Dormenval et al., 1999	Yes	Partial	Yes	Yes	Yes	Yes	Partial	Yes	Partial	Yes	Partial	0.82
Samnieng et al., 2012	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Partial	Yes	Yes	0.95
Syrjälä et al., 2013	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Partial	Partial	Partial	0.86
Samnieng, 2014	Yes	Yes	Yes	Yes	Yes	Yes	Partial	Yes	Yes	Yes	Yes	0.95
Iwasaki et al., 2016	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	1.00
Ikebe et al., 2006	Yes	Yes	Yes	Partial	Yes	Yes	Yes	Yes	Partial	Yes	Yes	0.91
Yoshinaka et al., 2007	Yes	Yes	Yes	Partial	Yes	Yes	Partial	Yes	Partial	Partial	Yes	0.82
Mesas et al., 2010	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	1.00
Poisson et al., 2014	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Partial	Partial	Yes	0.91
Soini et al., 2003	Yes	Partial	Yes	Yes	Yes	Partial	Partial	Yes	Partial	Partial	Yes	0.77
Solemdal et al., 2012	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	1.00
Srinivasulu et al 2014	Yes	Partial	Yes	Yes	Yes	Partial	Yes	Yes	No	Yes	Yes	0.82
Ikebe et al., 2002	Yes	Yes	Yes	Yes	Yes	Yes	Partial	Yes	Partial	Yes	Yes	0.91
Shinkawa et al, 2009	Yes	Yes	Yes	Yes	Yes	Yes	Partial	Yes	Partial	Yes	Yes	0.91

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Table 3
Objectives measurements to determine salivary hypofunction and corresponding cut-off values in the 15 selected studies

Article	Parameters measured	Methodology	Number of measures	Cut-off value to determine hyposalivation	References of the methodology
Articles that performed the measure of salivary flow to determine hyposalivation					
Dormenval et al., 1998	Unstimulated salivary flow rate, stimulated salivary flow rate	Measured during 6 min, spitting out each 2 min; collected between 9h and 11h	2	Unstimulated salivary flow rate < 0.1ml/min, Stimulated salivary flow rate < 0.5ml/min	(61)
Dormenval et al., 1999	Unstimulated salivary flow rate, stimulated salivary flow rate	Measured during 6 min, spitting out each 2 min; Collected between 9h and 11h	2	Unstimulated salivary flow rate < 0.1ml/min, Stimulated salivary flow rate < 0.5ml/min	(61)
Samnieng et al., 2012	Unstimulated salivary flow rate, stimulated salivary flow rate	Measured during 5 minutes	1	Unstimulated salivary flow rate < 0.1 ml/min Stimulated salivary flow rate < 0.5 ml/min	-
Syrjälä et al., 2013	Unstimulated salivary flow rate, stimulated salivary flow rate	Measured during 5 minutes (draining method)	1	Unstimulated salivary flow rate < 0.1ml/min, stimulated salivary flow rate < 1ml/min	(40, 62)
Samnieng, 2014	Unstimulated salivary flow rate	Measured during 5 minutes	1	Unstimulated salivary flow rate < 0.1 ml/min	
Iwasaki et al., 2016	Stimulated salivary flow rate	Measured during 3 minutes; Collected between 9h to 15h	1	Stimulated salivary flow rate < 0.5 ml/min	(58)
Ikebe et al., 2006	Stimulated salivary flow rate	Measured during 2 minutes at their own pace; collected between 10:00 am and 3:00 pm	1	Stimulated salivary flow rate < 0.5 ml/min	(30, 63)
Yoshinaka et al., 2007	Stimulated salivary flow rate	Measured during 2 minutes at their own pace	1	Stimulated salivary flow rate < 0.5 ml/min	(64)
Mesas et al., 2010	Stimulated salivary flow rate	No information provided	1	Stimulated salivary flow rate < 0.5 ml/min; Stimulated salivary flow rate < 0.7ml/min	(30, 36, 62, 66)
Poisson et al., 2014	flow under the tongue	Measured by placing a sterile compress under the tongue for 5 min	1	Salivary flow < 0.1 g/min	-
Articles that combined the measure of salivary flow rate with other measures of oral dryness					
Soini et al., 2003	Unstimulated salivary flow rate, stimulated salivary flow rate, Objective dry mouth	Measured during 5 min (Unstimulated salivary flow rate: let the saliva flow into the tube ; Stimulated salivary flow rate: spitting out each 1 min) ; collected between 9h and 11h	1	Unstimulated salivary flow rate < 0.1 ml/min, stimulated salivary flow rate < 0.8 ml/min Clinical dentist criteria	(67)
Solemdal et al., 2012	Stimulated salivary flow rate, mirror test, dry tongue	Measured during 3 minutes at their own pace	1	Stimulated salivary flow rate < 0.6 g/min Dental mirror sticked to the mucosa Tongue completely devoid of moisture	(68, 69)
Srinivasulu et al 2014	Stimulated salivary flow rate, Total protein content, calcium, pH, buffering capacity	Measured during 5 minutes at their own pace; collected early in the morning	1	Stimulated salivary flow rate < 0.5ml/min	(70)
Ikebe et al., 2002	Stimulated salivary flow rate, pH of saliva	Measured during 2 minutes at their own pace: Collected between 10:00 am and 3:00 pm	1	Stimulated salivary flow rate < 0.5 ml/min	(3, 20, 64, 71)
Articles that used other method to determine hyposalivation					
Shinkawa et al., 2009	Moisture of oral mucosa	Measured at the right buccal mucosa, during 2 sec	3	28.3% of the MCM value	(33)

percentage of water found in the mucosa, and determined salivary hypofunction when the moisture of oral mucosa was below 28.3% according to a previous study that validated the method (33).

Association between salivary hypofunction and food oral processing (8 studies)

The relationship between a diminished salivary function and food oral processing (mastication/chewing, swallowing, orosensory perception) has been examined in 8 articles (25, 27, 29-32, 34, 35). Only 3 studies measured objectively chewing, swallowing and taste abilities (27, 31, 34), while the others (n=5) employed questionnaires. The objective measurements consisted of the determination of masticatory performance, signs of dysphagia and taste ability. The evaluation of masticatory performance was achieved by measuring the amount of dissolved glucose after the mastication of test gummy jellies. The signs of dysphagia were reported using the water test during which the volunteers were asked to swallow four times an increasing volume of water to report any abnormal signs (coughing or voice modification). Finally, the taste ability test consisted in impregnating some strips with sweet, salty and bitter taste, then asking the volunteers to identify the tastes by putting the strips in the anterior region of the tongue.

Six of the eight studies investigated the association between salivary hypofunction and the chewing and/or swallowing abilities (25, 30-32, 34, 35). Ikebe and coworkers (2006) (34) found a significant association between lower values of masticatory performance and hyposalivation in independently living older adults. In another study with hospitalized very sick older patients, Poisson and collaborators (2014) (31) found a strong relationship at univariate level between individuals presenting a low salivary flow (<0.1 g/min) and dysphagia. However this effect was not observed at multivariate level, when considering other independent variables in the model. The rest of the studies evaluated chewing and/or swallowing abilities through questionnaires. Two works (25, 35) found a significant association between reduced saliva flow rate and perceived chewing and swallowing difficulties. Ikebe and collaborators (2002) (30) also found a relationship between hyposalivation and poor self-assessed chewing ability though it was not of statistical level. Finally, Shinkawa et al., (2009) (32) found a significant association between oral dryness (measured via the level of moisture of oral mucosa) and poor self-assessed chewing ability but no with swallowing.

The association between salivary gland hypofunction and orosensory perception was evaluated in four studies (27, 29, 30, 35). However, it is important to notice that all of them were only focused on one modality of flavor perception: taste. In these studies, taste ability was evaluated either objectively (taste detection through the filter-paper disc method) or by questionnaires considering taste as a marker for oral function (dissatisfaction with tasting). Only Solemdal et al., (2012) (27) studied the association of salivary hypofunction on the objective taste ability. These authors reported a significant and markedly reduced total taste score, particularly for sweet and salty taste, in patients with objective dry mouth (measured by the friction with mirror and dry tongue tests). Low sum score for salty taste was also related to low stimulated salivary flow rate. The rest of the studies evaluated taste ability through global questionnaires including self-assessed items on oral function, with contradictory results. Two studies (30, 35) found that hyposalivation was negatively and significantly correlated to self-assessed taste satisfaction, whilst Yoshinaka and coworkers (2007) (29) failed to find this correlation. In addition to the measure of salivary flow rate, Ikebe et al., (2002) (30) measured the pH of the stimulated saliva but no correlation between the pH and taste satisfaction could be established.

In summary, most of the studies on this topic have shown a relationship between a reduced salivary function and alterations in food oral processing (mastication, swallowing, orosensory perception). It should be noted that this relationship seems clearer when the outcomes were measured objectively rather than by questionnaires.

Association between salivary hypofunction and food behavior (4 studies)

Two studies (36, 37) examined the possible relationship between hyposalivation and appetite, and two others between hyposalivation and dietary intake (25, 31). For both categories, the outcomes were evaluated throughout the use of four different questionnaires: a questionnaire related to dietary intakes/nutrition and masticatory function (36), a single question-item on appetite (37); a 3-day record on food intake (31); a brief-type self-administered diet history questionnaire (25). The use of questionnaires could be justified by the fact that appetite is the subjective desire of eating foods. In 1999, Dormenval and coworkers (36) found that lack of appetite was associated with hyposalivation (stimulated salivary flow rate < 0.5 ml/min) in hospitalized Swiss patients. More recently, Samnieng (2014) (37) also found a positive correlation between lack of appetite and low resting salivary flow in independently living older Norwegians.

Regarding dietary intake, the two selected studies found no association between total energy intake and hyposalivation. However, when studying specific nutrient and food intake, Iwasaki and collaborators (2016) (25) found that the hyposalivation group had significantly lower intake of n-3 poly-unsaturated fatty acids, potassium, vit E, D, B6 and folate, which was in line with the observed reduction in the consumption of vegetables, fish and shellfish. Moreover, mean dietary intake of protein and vitamin B12 in the hyposalivation group tended to be lower than in the control group ($0.05 < P < 0.10$).

In summary, the scarce literature available on this topic showed an association between hyposalivation and appetite loss and unbalanced dietary intake in elderly people.

Association between salivary hypofunction and nutritional status (7 studies)

The association between salivary gland hypofunction and nutritional status has been evaluated in 7 studies. Five of them (26, 28, 35, 38, 39) evaluated the nutritional status using the Mini Nutritional Assessment (MNA). Meanwhile, Dormenval and coworkers, (1998) (40) assessed the nutritional status by quantifying biological malnutrition markers (BMI, level of serum albumin) and anthropometric measurements. Finally, Poisson et al., (2014) (31) employed both the MNA and the values of serum albumin concentration.

The results showed that hyposalivation was significantly associated with malnutrition in 4 studies (26, 35, 39, 40). Additionally, Syrjälä and co-workers (2013) (38) showed that subjects with low salivary flow (at rest or under stimulation) were slightly more at risk of malnutrition than subjects with normal salivary flow though their results were not statistically significant. Besides, Soini et al., (2003) (28) stated that no relation was found between hyposalivation and malnutrition. However, they found a significant association between the clinical dentist evaluation of dry mouth and the risk of malnutrition ($p=0.049$). On the contrary, Poisson and coauthors (2014) (31) did not find any relationship between hyposalivation (determined as salivary flow under the tongue <0.1 g/min) and MNA and/or biological malnutrition either at univariate or multivariate level. In addition to the measure of salivary flow rate, Srinivasulu et al., (2014) (39) measured the pH, the buffer capacity, the total protein and the total calcium of saliva samples. However, the authors did not highlight any significant correlation between the saliva composition and nutritional status.

In summary, five studies found a correlation between hyposalivation and malnutrition. Another study observed a relationship between the objective evaluation of dry mouth and the risk of malnutrition. Only one article did not find any association between the two variables. Therefore, and although most of the studies have shown some associations between salivary hypofunction and nutritional status, up to date this relationship is still controversial.

Discussion

Salivary hypofunction refers to alterations in the quality (composition) or quantity (salivary flow, residual saliva in the mouth) of saliva secreted into the human mouth (41). This situation could alter the orosensory perception while eating, which is one of the most recognized determinants for consumer's preferences and food consumption (7). As a result, the appetite, dietary intake and nutritional status of an individual could be compromised. This is of special relevance for elderly people, a population group frequently affected by both salivary and nutritional deficiencies. The aim of this work was to systematically review all the existing papers on this topic, in order to explore the relationships between a reduced salivary output and food consumption in the elderlies. In this paper only objective measurements of salivary hypofunction were considered, since the subjective complaint of dry mouth (xerostomia) is not always associated with an objective evidence of reduced salivary secretions (20; 42).

In total, 15 articles met the criteria for inclusion in this work (see Table 1). Eight of them studied the relationship of salivary hypofunction with food oral processing, 2 with appetite, 2 with dietary intake and 7 with nutritional status. In general, the selected studies clearly showed some associations between salivary hypofunction and the studied parameters. However, some controversial results have also been observed. It should also be noticed that the study characteristics are very different from one study to another, and the presence of not controlled confounding factors or methodological issues should be taken into account to interpret the results.

Discussion on the methods used to measure salivary hypofunction.

This review focuses on studies that objectively measured symptoms of salivary hypofunction. The prevalence of the population suffering these symptoms ranged from 14% (35) to around 50% (26; 28) in the selected articles. These differences were most likely dependent to the different characteristics of the studied populations (such as age, race, living place (community, institutions, and hospitals), functional status (healthy vs ill), drugs consumption, etc.) but also on the methods and cut-off values employed to determine salivary hypofunction.

For most of the selected studies (14 out of 15), the determination of the salivary flow below a cut-off value was the tool used to determine salivary hypofunction (see Table 3). However, a lack of consensus was observed regarding the type of saliva collected (at rest or under stimulation), the protocol employed to measure the salivary flow rate (spitting, draining method, cotton roll), and the cut-off value to determine hyposalivation. Of the 14 studies that measured saliva flow, five of them performed both resting and stimulated measurements (28; 35; 36; 38; 40), seven studies based their results on the measure of stimulated salivary flow (25; 26; 27; 29; 30; 34; 39), one study only measured the resting salivary flow rate (37) whilst one study performed the measure of salivary flow under the tongue (31). The use of resting or stimulated salivary flow rates provides different information since saliva is not delivered to the human mouth by the same salivary glands and in the same proportions under the two conditions. Therefore, whole saliva at rest, where the submandibular gland predominates, differs from that secreted during stimulation (more related to parotid gland function). Consequently, and in spite of the scarce literature on this topic, it is not surprising that the two measures are not always correlated (43).

Moreover, two studies used additional methods (dentist evaluation, mirror test and tongue moisture) to measure salivary hypofunction besides the determination of the salivary flow (27; 28). These methods could show a more advance phase of salivary hypofunction where the oral integrity (mucosa, tongue) has already been affected due to a prolonged hyposalivation situation held over time. In addition, only two studies (30; 39) reported, additionally to the measure of stimulated salivary flow, changes in saliva composition. This could be due to the fact that these analyses are time consuming and expensive, and therefore difficult to be performed to study big populations, as those employed in the selected articles.

Otherwise, one study (32) did not use the measure of salivary flow to determine salivary hypofunction but evaluated it by measuring the moisture of the buccal mucosa. The device used for this evaluation determined the weight percentage of water found in the mucosa. Originally developed to measure the moisture of the skin, the device was modified specifically for this study. As it is not a common method used to measure hyposalivation, it is not possible to compare the results of this study to the results of the other selected studies.

In addition to the different parameters employed to determine hyposalivation (salivary flow at rest or under stimulation, moisture of mucosa, etc), within the same parameter, the protocol was not always performed in the same way. Table 3 highlights the differences observed in collection times (from 1 to 6 minutes), hours of collection (respecting or not the circadian rhythms), collection protocols (free spitting vs controlled), etc., employed to measure salivary hypofunction. Moreover, only three articles (32, 36, 40) measured the selected parameters two or three times, whilst the other studies only performed the measures once. Therefore, no information about the accuracy of the methods could be obtained, that in the worst scenario could be traduced in a misclassification of people across the groups.

The cut-off value to determine salivary hypofunction was consensual across the studies for the saliva at rest. A value lower than 0.1 ml/min was considered hyposalivation. However for the salivary flow under stimulation a high dispersion on the cut-off values was encountered among studies. Indeed, there is no universally accepted reference value to determine hyposalivation using stimulated salivary flow rate. Most of the authors employed a cut-off value of 0.5 ml/min to define hyposalivation (25, 26, 29, 34, 35, 36, 40), whilst others employed values ranged from 0.5 to 1 ml/min (27, 38). The differences in the cut-off points could derive in an erroneous assignation of the participants to the groups and in a misinterpretation of the results, making difficult the comparison of the studies. This was displayed in the study of Mesas et al., (2010) (26). Authors employed two cut-off levels (stimulated salivary flow rate < 0.5 and stimulated salivary flow rate < 0.7 ml/min) to define hyposalivation, and they only found a significant association with nutritional status when using the value of 0.7 ml/min. For the other methods employed to define salivary hypofunction, like the "mirror test'' and dry tongue methods, the comparison across studies is difficult because they are less frequently employed and dependent on the dentist's criteria. The moisture of oral mucosa cannot be either compared since the method was only employed in one article.

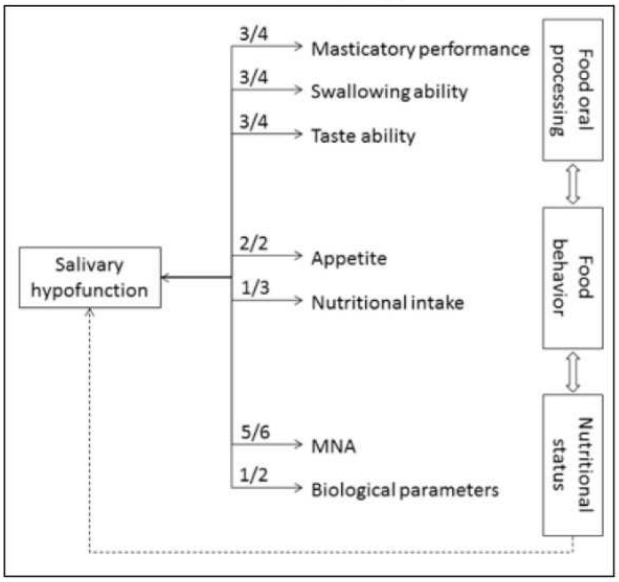
All these remarks highlight the idea that the diagnosis of salivary hypofunction is not consensual across the studies. Therefore, guidelines to measure salivary flow hypofunction with one or several complementary methods to evaluate the degree of dysfunction would be appropriate to allow an international standardization and a better comparison across the studies. Moreover longitudinal studies observing secretory function over time are required to establish causality. This would acknowledge setting up normal ranges or cut-off points to distinguish normal from abnormal salivary function. That amount is probably different across cultures (depending on gland sizes) (44).

Discussion on the relationship between salivary hypofunction with food oral processing, food behavior and nutritional status

Figure 2 represents schematically the associations between salivary hypofunction and food consumption found in the 15 selected articles. As a consequence of the cross-sectional design employed in the studies, no causal-effect relation can be established. Therefore, it cannot be concluded if salivary hypofunction is a cause or a consequence of the studied consumption parameters.

Figure 2

Schema resuming the main correlations found in this SLR between salivary hypofunction and the selected outcomes. The ratio (x/n) indicates the number of articles that highlighted a positive association between salivary hypofunction and the specific outcome (x) from the total number of articles that treated the topic (n)



As can be seen in Figure 2, salivary hypofunction was related to food oral processing, and in particular to mastication. It has been shown that elderly with hyposalivation had a reduced ability to break down foods into discrete portions by chewing to permit swallowing (34). This effect was more important in denture wearers with a lack of posterior occlusal contacts. Moreover, a relationship between hyposalivation and poor self-assessed chewing ability has been shown in four articles. Authors suggested that although presenting an altered masticatory performance is a multifactorial problem, salivary flow is a critical factor for masticatory function. However, the associations with dysphagia or swallowing have been less studied and results were controversial (31, 32).

In spite of chemosensory perception is a key factor for food enjoyment and one of the factors that motivate food consumption, its association with salivary gland hypofunction in the elderlies have received little attention. This could be due to the fact that food science has historically focused on the food and only in the later years some research groups have started to consider the interaction between food and human physiology to explain food perception. Moreover, to date most of the studies regarding the relation between the role of saliva on flavor release and perception have been conducted on healthy and young individuals (<65 y/o), while elderly population remains underexplored. Therefore only 4 articles met the inclusion criteria and they were all based on taste. While it has been found that salivary hypofunction is related to the objectively measured taste perception (27, 45), for the self-assessed taste ability results are controversial. However, most epidemiological studies do not include objective measurements of taste perception, probably because the evaluation through tests is more time-consuming than performing questionnaires.

To the author's knowledge the association between hyposalivation and texture or other modalities of orosensory perception (e.g aroma) in the elderlies has not been addressed by the scientific community yet. Some studies reported age-related loss of texture sensation (46, 47) and ultimately texture preference changes (48), but these studies have not investigated the role of a diminished saliva secretion in the observed results.

Assuming that a reduced salivary output produces an impaired food experience, the desire for food or drink known as appetite could be altered. This is in agreement with the findings of the two selected articles on this topic which shown a relationship between hyposalivation and loss of appetite (37, 40), even when the settings employed were very different in both of them. Consequently, this appetite loss could provoke a diminished food intake. However, the two studies on this topic found that the total energy intake was not impaired in elderly with hyposalivation. Nevertheless, when specific nutrients and/or group of foods were studied, the hyposalivator group presented a reduced consumption of vegetables, fish and seafood which was related to the lower intake of n-3 polyunsaturated fatty acids, potassium, vit C, E, B6 and folate after adjusting for confounders (number of teeth, denture use, sex, income, education, body mass index, smoking status, alcohol use, diabetes, medication, activities of daily living, depression and total calorie intake) (25). A reduced consumption of such specific nutriments/or groups of food, which are recognized for their health benefits (49-51), could have a negative impact on the health of this population.

Finally, an alteration of the dietary intake (quantitative or qualitative) could provoke an impairment of the nutritional status of the elderly population. Numerous studies have been conducted during the last decade to study the relationship between nutritional status and oral conditions in elderly, but to the authors' knowledge, only 7 studies have assessed the relationship between salivary hypofunction and nutritional status. However, some contradictory results have been found. While four articles found a significant correlation between MNA and hyposalivation, one did not. Although the method used to measure salivary flow was similar in the five studies, the cut-off values differed among them, which could explain the differences found in their results. On the other hand, the other two selected articles (28, 38) encountered only weak associations between nutritional status and hyposalivation or the dentist's estimation of dry mouth. Although other reasons (different cut-off levels, circadian rhythms not controlled, differences across populations) could explain these differences, it is interesting to observe that in these last two studies none of the subjects were malnourished but at risk of malnutrition. This is of importance since probably nutritional disturbances held over time can cause atrophy of salivary glands (39), producing a reduction of their function. If this is truth, alterations on saliva would be a consequence of an altered nutritional status. Unfortunately, as all the selected studies presented a cross sectional design no causality could be established and more studies are needed to validate this hypothesis.

Finally, the measure of the food consumption parameters was mostly performed by using subjective than objective methods. This could be due to the fact that the use of self-report questionnaires is less time consuming than performing objective determinations. However, as many studies have shown no correlation between the subjective feeling of dry mouth (xerostomia) and hyposalivation, there are no evidences of links between objective and subjective evaluations of the outcomes (29).

Limitations and strengths of the present SLR

The main strength of this work is that it is a solid literature search, with a complete overview of the relationship between an objective measurement of salivary hypofunction and the determinants of food consumption among the elderly population. Moreover, the selected studies represent the wide heterogeneity found in this population group (from healthy elderly individuals to chronically ill hospitalized old-people). The analysis of the quality of the selected articles let us to identify the most frequent risks across the studies and suggest new ideas for future works. For example, future studies on this topic should control better for confounding factors like gender, age, drug intake, diseases, mental status, socioeconomic status, dental status and place to live, because they are well-known factors that can alter salivary function (52-55) but also food consumption (56-59).

However, this study presents some limitations. Unfortunately, we were not able to perform a meta-analysis due to the obvious heterogeneity among the studies in relation to definitions and measurements as explained above. Also, we could not establish causality due to the cross-sectional nature of the selected studies. Therefore it cannot be concluded if hyposalivation is a cause or a consequence of the selected food consumption parameters.

Implication of this study

This study has revealed the urgent need to introduce and implement universal guidelines to assess salivary hypofunction. Moreover, cohort studies (with comparable groups following the same population for a longer period of time) and statistical control of the confounding factors are required to establish causality. Even if this review has pointed out some evidences about the relationship between salivary hypofunction and food consumption in the elderlies, the literature available on this topic is scarce. This is particularly obvious in some cases such as in the study of the relationship between hyposalivation and flavor perception. Therefore, there is a big opportunity for researchers, clinicians and food industry to better understand this association and if so, give nutritional recommendations and/or conceive products with sensory and nutritional properties adapted for people with salivary dysfunction.

Conclusions

The main findings of this review can be summarized in the following points: 1) to date, salivary hypofunction is mainly based on measures of salivary flow 2) definition and measures of hyposalivation are different across the studies; 3) salivary hypofunction has been related to a decrease of objective chewing and swallowing abilities and taste perception; very little is known about other modalities of chemosensory perception (e.g. aroma) 4) hyposalivation has been associated with appetite loss; 5) hyposalivation has been related to an unbalanced dietary intake but not with total intake; 6) it has been seen a relationship between saliva deficiencies and malnutrition, though some controversial results have also been shown. Although it is not possible to completely eliminate the potential effects of underlying methodological issues and in spite of the scarce number of publications on this topic it is suggested a relationship between salivary hypofunction and food consumption in the elderlies. Unfortunately, due to the cross-sectional nature of the articles, no causality could be established. Therefore longitudinal studies on this topic controlling for confounding factors are needed.

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References

1. Mese H, Matsuo R. Salivary secretion, taste and hyposalivation. J Oral Rehabil, 2007;34, 711-723.
2. Mandel I D. The role of saliva in maintaining oral homeostasis. J Am Dental Assoc, 1989;119, 298-304.
3. Loesche W J, Schork A, Terpenning M S, Chen Y M, Stoll J. Factors which influence levels of selected organisms in saliva of older individuals. J Clin Microb, 1995;33, 2550-2557.
4. Caplan D J, Hunt R J. Salivary flow and risk of tooth loss in an elderly population. Commun Dent Oral Epidemiol, 1996;24, 68-71.
5. Narhi T O, Kurki N, Ainamo A. Saliva, salivary micro-organisms, and oral health in the home-dwelling old elderly - A five-year longitudinal study. J Dent Res, 1999;78, 1640-1646.
6. Prinz J F, Lucas P W. An optimization model for mastication and swallowing in mammals. Proceed Royal Society B-Biol Sci, 1997;264, 1715-1721.
7. Buettner A. Influence of human saliva on odorant concentrations. 2. aldehydes, alcohols, 3-alkyl-2-methoxypyrazines, methoxyphenols, and 3-hydroxy-4,5-dimethyl-2(5H)-furanone. J Agric Food Chem, 2002;50, 7105-7110.
8. Buettner A. Influence of human salivary enzymes on odorant concentration changes occurring in vivo. 1. Esters and thiols. J Agric Food Chem, 2002;50, 3283-3289.
9. Spielman A I. Interaction of saliva and taste. J Dent Res, 1990;69, 838-843.
10. Sreebny L M, Schwartz S S. A reference guide to drugs and dry mouth. Gerodontology, 1986;5, 75-99.
11. Affoo R H, Foley N, Garrick R, Siqueira W L, Martin R E. Meta-Analysis of Salivary Flow Rates in Young and Older Adults. J Am Geriatr Soc, 2015;63, 2142-2151.
12. Vandenberghe-Descamps M, Laboure H, Prot A, Septier C, Tournier C, Feron G, Sulmont-Rosse C. Salivary flow decreases in healthy elderly people independently of dental status and drug intake. J Texture St, 2016;47, 353-360.
13. Mowe M, Bohmer T, Kindt E. Reduced nutritional-status in an elderly population (greater-than-70y) is probable before disease and possibly contributes to the development of disease. Am J Clin Nut, 1994;59, 317-324.
14. McWhirter J P, Pennington C R, Jebb S A. Incidence and recognition of malnutrition in-hospital. Clin Nut, 1994;13, 267-268.
15. Quandt S A, Chen H Y, Bell R A, Savoca M R, Anderson A M, Leng X Y, Kohrman T, Gilbert G H, Arcury T A. Food Avoidance and Food Modification Practices of Older Rural Adults: Association With Oral Health Status and Implications for Service Provision. Gerontologist, 2010;50, 100-111.
16. Quandt S A, Savoca M R, Leng X Y, Chen H Y, Bell R A, Gilbert G H, Anderson A M, Kohrman T, Arcury T A. Dry Mouth and Dietary Quality in Older Adults in North Carolina. J Am Geriatr Soc, 2011;59, 439-445.
17. Stenman U, Ahlqwist M, Bjorkelund C, Hakeberg M. Oral health-related quality of life - associations with oral health and conditions in Swedish 70-year-old individuals. Gerodontology, 2012;29, E440-E446.
18. Nykanen I, Lonnroos E, Kautiainen H, Sulkava R, Hartikainen S. Nutritional screening in a population-based cohort of community-dwelling older people. Eur J Public Health, 2013;23, 405-409.
19. Porter J, Ntouva A, Read A, Murdoch M, Ola D, Tsakos G. The impact of oral health on the quality of life of nursing home residents. HQLF, 2015;13.
20. Narhi T O, Meurman J H, Ainamo A. Xerostomia and hyposalivation - Causes, consequences and treatment in the elderly. Drugs Aging, 1999;15, 103-116.
21. Ohara Y, Hirano H, Yoshida H, Obuchi S, Ihara K, Fujiwara Y, Mataki S. Prevalence and factors associated with xerostomia and hyposalivation among community-dwelling older people in Japan. Gerodontology, 2016;33, 20-27.
22. Kmet L M, Robert C. Lee, and Linda S. Cook. Standard quality assessment criteria for evaluating primary research papers from a variety of fields, 2004.
23. Satoh-Kuriwada S, Sasano, T., Saito, M., Hasimoto, K., Simeno, Y., Oba, M., Sakamoto, M., Aizawa, K. and Watanabe, M. Epidemiological study on taste disorders in the elderly. Part 1: Influence of systemic disease and medication on gustatory disorder. Jpn. J. Oral Diag. Oral Med., 2003;16, 1-8.
24. Satoh-Kuriwada S, Sasano, T., Saito, M., Simeno, Y., Oba, M., Sakamoto, M., Aizawa, K. and Watanabe, M. Epidemiological study on gus- tatory disorders in the elderly. Part 2: Influence of hyposalivation on gustatory disorder. Jpn. J. Oral Diag. Oral Med., 2005;18, 14-18.
25. Iwasaki M, Yoshihara A, Ito K, Sato M, Minagawa K, Muramatsu K, Watanabe R, Manz M C, Ansai T, Miyazaki H. Hyposalivation and dietary nutrient intake among community-based older Japanese. Geriatr Gerontol Int, 2016;16, 500-507.
26. Mesas A E, Andrade S M, Cabrera M A, Bueno V L. Oral health status and nutritional deficit in noninstitutionalized older adults in Londrina, Brazil. Rev Bras Epidemiol, 2010;13, 434-445.
27. Solemdal K, Sandvik L, Willumsen T, Mowe M, Hummel T. The impact of oral health on taste ability in acutely hospitalized elderly. PLoS One, 2012;7, e36557.
28. Soini H, Routasalo P, Lauri S, Ainamo A. Oral and nutritional status in frail elderly. Spec Care Dentist, 2003;23, 209-215.

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29. Yoshinaka M, Yoshinaka M F, Ikebe K, Shimanuki Y, Nokubi T. Factors associated with taste dissatisfaction in the elderly. J Oral Rehabil, 2007;34, 497-502.
30. Ikebe K, Sajima H, Kobayashi S, Hata K, Morii K, Nokubi T, Ettinger R L. Association of salivary flow rate with oral function in a sample of community-dwelling older adults in Japan. Oral Surg Oral Med Oral Pathol Oral Radiol Endod, 2002;94, 184-190.
31. Poisson P, Laffond T, Campos S, Dupuis V, Bourdel-Marchasson I. Relationships between oral health, dysphagia and undernutrition in hospitalised elderly patients. Gerodontology, 2014;33, 161-168.
32. Shinkawa T, Hayashida N, Mori K, Washio K, Hashiguchi K, Taira Y, Morishita M, Takamura N. Poor chewing ability is associated with lower mucosal moisture in elderly individuals. Tohoku J Exp Med, 2009;219, 263-267.
33. Yamada H, Nakagawa Y, Nomura Y, Yamamoto K, Suzuki M, Watanabe N Y, Saito I, Seto K. Preliminary results of moisture checker for Mucus in diagnosing dry mouth. Oral Dis, 2005;11, 405-407.
34. Ikebe K, Matsuda K, Morii K, Furuya-Yoshinaka M, Nokubi T, Renner R P. Association of masticatory performance with age, posterior occlusal contacts, occlusal force, and salivary flow in older adults. Int J Prosthodont, 2006;19, 475-481.
35. Samnieng P, Ueno M, Shinada K, Zaitsu T, Wright F A, Kawaguchi Y. Association of hyposalivation with oral function, nutrition and oral health in community-dwelling elderly Thai. Community Dent Health, 2012;29, 117-123.
36. Dormenval V, Mojon P, Budtz-Jorgensen E. Associations between self-assessed masticatory ability, nutritional status, prosthetic status and salivary flow rate in hospitalized elders. Oral Dis, 1999;5, 32-38.
37. Samnieng P. Appetite loss and related factors in community-dwelling elderly thai. Int. J Clin. Prev. Dent., 2014;10, 23-30.
38. Syrjala A M, Pussinen P I, Komulainen K, Nykanen I, Knuuttila M, Ruoppi P, Hartikainen S, Sulkava R, Ylostalo P. Salivary flow rate and risk of malnutrition - a study among dentate, community-dwelling older people. Gerodontology, 2013;30, 270-275.
39. Srinivasulu G, Fareed, N., Sudhir, K.M., Kumar, K. Relationship between Stimulated Salivary Factors, Dental Caries Status and Nutritional Condition among Institutionalized Elderly People. OHDM, 2014;13, 49-53.
40. Dormenval V, Budtz-Jorgensen E, Mojon P, Bruyere A, Rapin C H. Associations between malnutrition, poor general health and oral dryness in hospitalized elderly patients. Age Ageing, 1998;27, 123-128.
41. Glore R J, Spiteri-Staines K, Paleri V. A patient with dry mouth. Clinical Otolaryngology, 2009;34, 358-363.
42. Villa A, Abati S. Risk factors and symptoms associated with xerostomia: a cross-sectional study. Aust Dent J, 2011;56, 290-295.
43. Neyraud E, Palicki O, Schwartz C, Nicklaus S, Feron G. Variability of human saliva composition: Possible relationships with fat perception and liking. Arch Oral Biol, 2012;57, 556-566.
44. Ship J A, Fox P C, Baum B J. How much saliva is enough - normal function defined. J Am Dental Assoc, 1991;122, 63-69.
45. Satoh-Kuriwada S, Shoji N, Kawai M, Uneyama H, Kaneta N, Sasano T. Hyposalivation Strongly Influences Hypogeusia in the Elderly. J Health Sci, 2009;55, 689-698.
46. Kremer S, Bult J H F, Mojet J, Kroeze J H A. Compensation for age-associated chemosensory losses and its effect on the pleasantness of a custard dessert and a tomato drink. Appetite, 2007;48, 96-103.
47. Kremer S, Mojet J, Kroeze J H A. Perception of texture and flavor in soups by elderly and young subjects. J Texture St, 2005;36, 255-272.
48. Forde C G, Delahunty C M. Examination of chemical irritation and textural influence on food preferences in two age cohorts using complex food systems. Food Qual Pref, 2002;13, 571-581.
49. Carr A C, Frei B. Toward a new recommended dietary allowance for vitamin C based on antioxidant and health effects in humans. Am J Clin Nut, 1999;69, 1086-1107.
50. Lemaitre R N, King I B, Mozaffarian D, Kuller L H, Tracy R P, Siscovick D S. n-3 polyunsaturated fatty acids, fatal ischemic heart disease, and nonfatal myocardial infarction in older adults: the Cardiovascular Health Study. Am J Clin Nut, 2003;77, 319-325.
51. Rimm E B, Willett W C, Hu F B, Sampson L, Colditz G A, Manson J E, Hennekens C, Stampfer M J. Folate and vitamin B-6 from diet and supplements in relation to risk of coronary heart disease among women. JAMA, 1998;279, 359-364.
52. Bardow A, Nyvad B, Nauntofte B. Relationships between medication intake, complaints of dry mouth, salivary flow rate and composition, and the rate of tooth demineralization in situ. Arch Oral Biol, 2001;46, 413-423.
53. Kreher J M, Graser G N, Handelman S L. The relationship of drug-use to denture function and saliva flow-rate in a geriatric population. J Prosthetic Dent, 1987;57, 631-638.
54. Ship J A, Baum B J. Is reduced salivary flow normal in old-people?. Lancet, 1990;336, 1507-1507.
55. Ship J A, Decarli C, Friedland R P, Baum B J. Diminished submandibular salivary flow in dementia of the alzheimer type. J Gerontology, 1990;45, M61-M66.
56. Dean M, Raats M M, Grunert K G, Lumbers M, Food Later Life T. Factors influencing eating a varied diet in old age. Public Health Nut, 2009;12, 2421-2427.
57. Johnson A E, Donkin A J M, Morgan K, Neale R J, Page R M, Silburn R L. Fruit and vegetable consumption in later life. Age Ageing, 1998;27, 723-728.
58. Mioche L, Bourdiol P, Peyron M A. Influence of age on mastication: effects on eating behaviour. Nut Res Rev, 2004;17, 43-54.
59. Moreira N C F, Krausch-Hofmann S, Matthys C, Vereecken C, Vanhauwaert E, Declercq A, Bekkering G E, Duyck J. Risk Factors for Malnutrition in Older Adults: A Systematic Review of the Literature Based on Longitudinal Data. Adv Nut, 2016;7, 507-522.
60. Savoca M R, Arcury T A, Leng X Y, Chen H Y, Bell R A, Anderson A M, Kohrman T, Frazier R J, Gilbert G H, Quandt S A. Severe tooth loss in older adults as a key indicator of compromised dietary quality. Public Health Nut, 2010;13, 466-474.
61. Sreebny L M, Yu A, Green A, Valdini A. Xerostomia in diabetes-mellitus. Diabetes Care, 1992;15, 900-904.
62. Flink H, Bergdahl M, Tegelberg A, Rosenblad A, Lagerlof F. Prevalence of hyposalivation in relation to general health, body mass index and remaining teeth in different age groups of adults. Community Dent Oral Epidemiol, 2008;36, 523-531.
63. Hirotomi T, Yoshihara A, Ogawa H, Ito K, Igarashi A, Miyazaki H. A preliminary study on the relationship between stimulated saliva and periodontal conditions in community-dwelling elderly people. J Dent, 2006;34, 692-698.
64. Sreebny L M, Zhu W T. Anti-SS-A and anti-SS-B Ab's in the saliva and blood of patients with dry mouth and dry eyes. J Dent Res, 1996;75, 2031-2031.
65. Michael E C D, Denis O. Saliva and oral health. London.
66. Cabrera M A S, Mesas A E, Rossato L A, De Andrade S M. Salivary flow and psychoactive drug consumption in elderly people. Revista Da Associacao Medica Brasileira, 2007;53, 178-181.
67. Narhi T O, Tenovuo J, Ainamo A, Vilja P. Antimicrobial factors, sialic-acid, and protein-concentration in whole saliva of the elderly. Scand J Dent Res, 1994;102, 120-125.
68. Henricsson V, Svensson A, Axell T. Evaluation of some electrical methods for objective assessment of oral mucosal dryness. Scand J Dent Res, 1990;98, 520-528.
69. Navazesh M. Methods for collecting saliva. Annals of the New York Academy of Sciences, 1993;694, 72-77.
70. Navazesh M, Kumar S K S. Measuring salivary flow - Challenges and opportunities. Journal of the American Dental Association, 2008;139, 35S-40S.
71. Osterberg T, Landahl S, Hedegard B. Salivary flow, saliva, ph and buffering capacity in 70-year-old men and women - correlation to dental-health, dryness in the mouth, disease and drug-treatment. J Oral Rehabil, 1984;11, 157-170.

Take home message

Saliva has a major role in maintaining oral health, food perception and food bolus formation. With aging, salivary composition and saliva secretion can be altered do to the cumulative effect of ageing and associated changes, but also to aging itself throughout the aging of salivary glands. Many studies have demonstrated that an impaired salivation can affect food perception (flavor, texture) as well as food and nutrient intake.

3. DEGLUTITION

Deglutition is the act of swallowing, whether it be foods, beverages or saliva, and it is composed of four phases: the oral, oral transit, pharyngeal and esophageal phases (Figure 3).

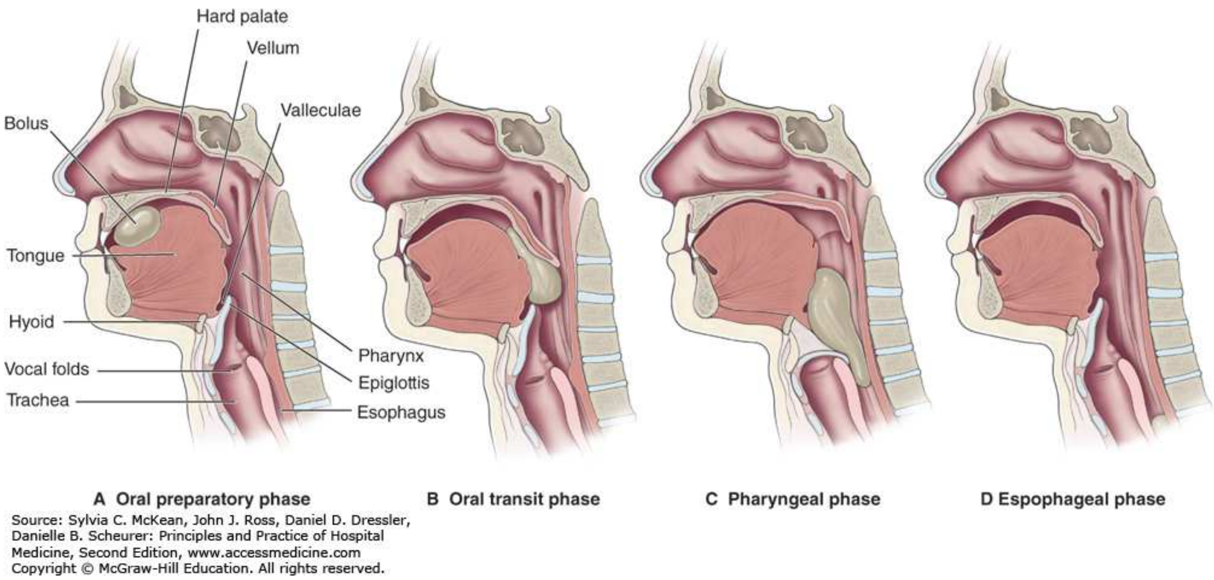

Figure 3. The swallowing steps

The oral phase aims at transporting the food bolus – once ready to be swallowed – towards the pharynx in behalf of the tongue propulsion. It starts with the entry of food into the oral cavity and can be divided into two steps: the voluntary oral preparatory and the oral transport steps. The voluntary oral preparatory phase consists in food destructure and humidification in order to form a swallowable food bolus, where facial muscles are involved to maintain food bolus under the teeth for an optimal mastication. During this step, some sensory information such as bolus size or its position in the mouth are sent through trigeminal nerve afferent fibers. Once food is reduced into a swallowable bolus, the oral transport begins (oral transit phase). During this phase, the tongue bends itself to receive the food bolus and the anterior part of the tongue presses the hard palate, which stimulates the hard palate mechanoreceptors. Peristaltic movements of the tongue are then initiated to move the food bolus into the oropharynx. The oral transit phase ends when the bolus crosses the velum. The third phase is called the pharyngeal phase and is triggered by the contact between the food bolus and the velum. This phase works by reflex and aims at propelling the food bolus towards the esophagus. During this phase, there is a stimulation of tactile receptors in the oral pharynx by the food bolus. The velopharyngeal muscles seal the nasopharynx to the muscular pharynx in order to prepare the passage of the food bolus. While the tongue blocks the oral cavity in order to prevent any food going back to the mouth, the soft palate bulges to block the entry to the nasal cavity. Furthermore, the vocal chords close to protect the airway to the lungs and the entry of the trachea is covered by the larynx and the epiglottis. At that time, no respiratory movements are possible. Food bolus is then directed from the pharynx to the esophagus. Finally, the fourth and last phase – called the esophageal phase – consists in the passage of the food bolus through the esophagus to end in the stomach. Under involuntary control, the striated muscles of the upper esophagus then the smooth muscle of the distal esophagus lead the food bolus into the stomach. Once again, bolus stimulation allows an inhibition of the lower esophageal sphincter and a gastric distention to ensure the passage of the food bolus into the stomach (Schindler and Kelly, 2002; Lambert and Ménage, 2013).

3.1. Impact of ageing on deglutition

With ageing, physiological modifications can occur on every component of the oral cavity that is involved in the deglutition and therefore disrupts the transport of the food bolus towards the stomach. Whether these impairments are due to ageing (presbyphagia) or other age-related events (dysphagia) such as acute pathologies (dementia or stroke) or multiple drug intakes for instance, it can have serious consequences on the deglutition of food (Humbert and Robbins, 2008).

During the oral phase, the decrease in muscle strength that can occur with ageing (description in section 1.1.3 of the present thesis) may lead to impairments in food bolus preparation, which could induce swallowing disorders. However, very little effects of ageing on lingual motility and labial occlusion force were observed in the literature (Baum and Bodner, 1983; Crow and Ship, 1996). In the study conducted by Crow and Ship (1996), 99 volunteers aged between 19 and 96 years old were recruited to evaluate the impact of aging on tongue strength and endurance using the Iowa Oral Performance Instrument. The results showed a significant decrease in tongue strength related to age in males but not in females. However, no difference was observed between age groups for tongue endurance.

Some disturbances can also be encountered in the pharyngeal phase due to ageing. The reflex of swallowing can be slowed down and the amplitude and the speed of the peristalsis diminished (Tracy *et al.*, 1989; Robbins *et al.*, 1992; Lesourd, 2006). In the study conducted by Tracy *et al.* (1989), 24 volunteers from 20 to 79 years old were recruited to evaluate the effect of age on the oropharyngeal phase using videofluorography and pharyngeal manometry. The results showed that the duration of the pharyngeal phase was longer for the elderly people. Furthermore, the duration of the opening of cricopharyngeal, the peristatic amplitude and the peristaltic velocity decreased significantly with ageing. In addition, during the oral phase, the elderly volunteers held the food bolus more posteriorly in the oral cavity compared to the younger volunteers, which supposedly increases the risk of swallowing the wrong way. In line with those results, Robbins *et al.* (1992) recruited 80 volunteers characterized in terms of swallowing ability to study the impact of aging on the oropharyngeal swallowing. The results showed that stage transition, pharyngeal transit and upper esophageal sphincter opening durations were longer for elderly people compared to younger adults. However, no significant difference was observed in terms of pharyngeal pressure between the groups.

Finally, the esophageal phase is the one that is less impacted by ageing. Some little dysfunction on the superior sphincter and the esophagus peristalsis can be observed, as well as a slowdown of the relaxation after swallowing. However, those dysfunctions are more difficult to identify due to modifications in esophageal sensations with aging (Shaker and Lang, 1994; Ren *et al.*, 1995; Achem and Devault, 2005).

3.2. IMPACT OF DEGLUTITION ON EATING IN THE ELDERLY

3.2.1. IMPACT OF AN IMPAIRED DEGLUTITION ON FOOD PERCEPTION

Many studies have investigated the role of food sensory characteristics on swallowing. It has now been proven that bolus volume, viscosity, taste and texture have an impact on oropharyngeal swallow physiology in normal adults as swallowing patterns differ according to food characteristics (see Loret (2015) for a review). However, very few studies focused on elderly people with impaired deglutition. Bisch *et al.* (1994) asked 28 volunteers with or without swallowing impairment to eat bolus type food. The boluses were calibrated in terms of temperature, volume and viscosity. The swallowing patterns were evaluated throughout videofluorography. The results showed that for normal volunteers, there were significant differences of swallowing patterns depending on bolus temperature compared to the impaired volunteers. Indeed, normal volunteers performed longer pharyngeal response times and longer laryngeal elevation with cold boluses. However, for both groups the bolus volume and viscosity had an impact on pharyngeal delay time; a larger bolus volume and a more viscous bolus decreased pharyngeal delay time. Regarding the impact of impaired deglutition on food perception, to the best of our knowledge no studies have been conducted. It would be interesting to investigate whereas elderly volunteers with swallowing disorders have a reduced capacity in sensory perception compared to healthy elderly volunteers, independently of other oral factors.

3.2.2. Impact of an impaired deglutition on food intake

Impairment in swallowing efficacy may result in swallowing food the wrong way, which could lead to lung infections or choking. In order to avoid those difficulties, it is probable that elderly people reduce or alter their food and beverage intake (Sura *et al.*, 2012). However, minimal information is available in the literature to support this hypothesis. When elderly people encounter swallowing impairment, a specific feeding strategy is set-up such as providing elderly people with "texture-modified foods", in the form of chopped, blended or pureed foods. Obviously, this food transition deeply modifies elderly's food pattern for two reasons: first, the nutritional characteristics of a mixed food is different from normal texture food. Second, eating only texture-modified foods may result in a decrease in appetite and in food intake. The texture modified foods are indeed often perceived as unattractive and not very palatable (Rofes *et al.*, 2011). This reduction of food intake can lead to malnutrition. In the study conducted by Cabre *et al.* (2010), 134 elderly subjects were recruited among which 74 subjects presented oropharyngeal dysphagia. The authors showed that within the latter segment, 36.8% were malnourished and 54.4% were at risk of malnutrition. Furthermore, Serra-Prat *et al.* (2012) highlighted in their cohort study that 18.6% of the elderly volunteers with dysphagia were malnourished or at risk of malnutrition while 12.3% of the population without dysphagia was malnourished or at risk. Also, after a one year follow-up, the authors have noticed a significant difference between the two groups in terms of nutritional status as the prevalence of malnutrition and risk of malnutrition increased for elderly with oropharyngeal dysphagia. However, most of the studies that investigated dysphagia and its risk factors on an elderly population included elderlies with acute pathologies such as dementia or pneumonia, which are known as confounding factors. To the best of our knowledge, there is no study that aimed at investigating presbyphagia – the impact of ageing per se on deglutition - and the ability to eat foods on a healthy elderly population.

Take home message

Deglutition is the act of swallowing food bolus safely in order to send food to the stomach. Three major steps are identified during swallowing, each of them can be impacted with aging. Very few studies have investigated the impact of aging itself on swallowing disorders, however it has been shown that swallowing disorders can have an impact on food intake and that elderly presenting swallowing disorders are less sensitive to food sensory characteristics.

4. PERSONAL WORK

4.1. RESEARCH QUESTION

The previous sections highlight that ageing can affect three dimensions of food oral processing: mastication, salivation and deglutition. It has been shown that the impairments of those three dimensions can have an impact on diet, in a qualitative way (food avoidance) or in a quantitative way (decrease in appetite and food intake). Furthermore, those oral impairments can have an impact on pleasure to eat (Figure 4).

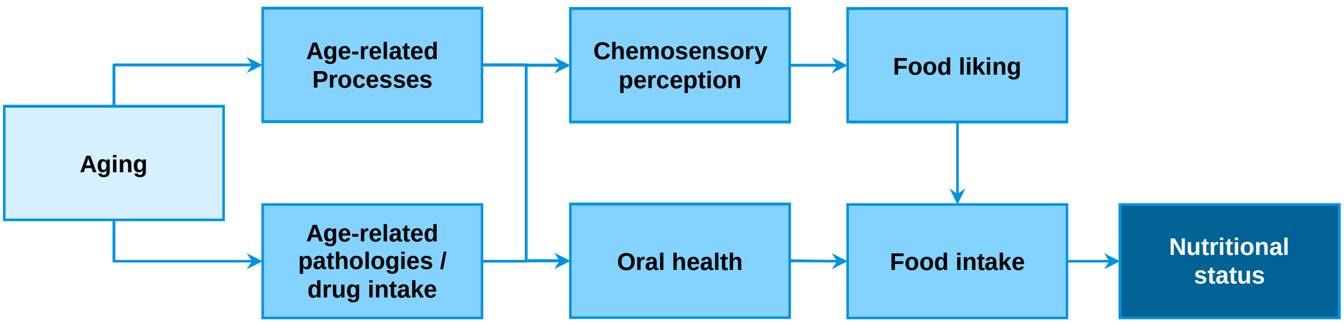

Figure 4. Representation of the physiological determinants likely to explain food choice, food behavior and nutritional status in elderly people.

Nowadays, the main solution provided to elderly people in order to fight against oral health problems consists in providing elderly people with "texture modified foods" in the form of chopped, blended or pureed foods. While industries have made efforts in recent years to improve their acceptability, texture modified food is often unattractive. Furthermore, many catering services in institutions or hospitals chop or blend the foods themselves: a portion of the normal-texture meals is blended for older individuals suffering from chewing and/or swallowing difficulties. This kind of food seems essential for elderly people suffering from dysphagia as the risk to swallow food the wrong way may lead to a risk of stroke or even death. However, one could wonder whether this approach is pertinent for elderly people suffering from masticatory or salivatory impairments. Indeed, the result is often visually unpleasant and not very palatable. As a consequence, texture modified diet goes along with a lack of appetite and a decrease in food intake. Wright *et al.* (2005) have highlighted in their study that elderly people consuming a texture modified diet had lower intake of energy and protein compared to elderly people eating a normal diet. Furthermore, the authors specified that modified-texture diet eaters rated the dishes as poorly palatable or poorly presented. Texture modified diet is indeed recognized as a risk factor for undernutrition (Keller *et al.*, 2012). Furthermore, this solution is particularly deleterious as it may put elderly people into a vicious spiral: the less a person chews, the more difficult it is to chew (Mioche *et al.*, 2004). Finally, while masticatory impairments are often taken into account in the research studies investigating food for elderly people, salivary impairments are usually left behind. It is thus of crucial importance to consider new solutions to improve food intake in terms of quantity and quality and maintain eating pleasure for elderly people, taking into account masticatory and salivary impairments that can occur with ageing.

Therefore, the general objective of this thesis was to understand what oral health factors (dental, salivary, muscular) have an impact on the physiological and psychological dimensions of eating a food, in order to identify culinary techniques that could preserve food intake in elderly people having a poor oral health. To meet this goal, the work I handled during this thesis was divided into three priority axes.

First the priority was to investigate the association between oral health and diet in elderly people. As highlighted in the literature, many authors investigated the impact of ageing on mastication or salivation, the impact of an impaired mastication or salivation on food oral processing, the impact of a decrease in masticatory ability or salivation on food and/or nutrient intake, or the impact of a decrease in masticatory ability or salivation on nutritional status (for reviews, see Tada and Miura (2014); Kiesswetter *et al.* (in press) and Muñoz-González *et al.* (2017). However, to date, none of the studies investigated all those dimensions together, inside one elderly panel, in order to model the impact of oral status on food behavior as a whole. The originality of the present thesis was to perform an in-depth investigation of the association between oral health and diet in elderly people by recruiting a panel of elderly people aged over 65; half of the participants having a good dental status and half having a poor dental status; and to consider i. masticatory, salivary and chemosensory functions, and ii. parameters that account for the status of the oral components involved in food consumption (*i.e.* dental status, salivary flow, bite force, tongue strength, gustatory abilities, olfactory abilities) as well as parameters that account for the efficiency of the oral processes involved in food consumption (*i.e.* food bolus formation, food aroma release). The objective of this data collection was to answer the following research questions: What is the importance of salivation during food consumption in the elderly population? What are the impacts of mastication and salivation on food oral processing and the impacts of food oral processing on food behavior in an elderly population? Is there a direct or indirect relationship between the oral health status and food oral processing as well as food and nutrient intake and corpulence?

To date, only a part of the statistical analysis has been performed; therefore only the two following research questions will be reached in the present thesis: what is the relationship between the functional status of oral components and the oral processes in an elderly population? What is the impact of these different oral parameters on nutritional parameters?

Second, I investigated the concept of oral comfort when eating a food. In the literature, while many studies have focused on the impact of oral health on food consumption, the impact of oral health on the difficulties encountered by the elderly when eating was less explored. Furthermore, most of the few studies that have explored eating difficulties in the elderly have targeted only one dimension, usually chewing difficulties (Fontijn-Tekamp *et al.*, 2000; Takata *et al.*, 2008; Hsu *et al.*, 2014). Some have targeted two dimensions (e.g., chewing difficulties and pain sensations in Brennan *et al.* (2008), but to the best of our knowledge, none have targeted all the difficulties liable to be encountered by the elderly when eating a food. Moreover, former studies used either a general question (e.g., "Have you found it uncomfortable to eat any foods because of problems with your teeth or mouth?" in Silva *et al.* (2015)) or a question related to a specific food category (e.g., "boiled vegetables" or "firm foods such as steak or dried apricots" in Brennan *et al.* (2008)), but as far as we know, none asked questions during the actual consumption of a food. Thus, it is worth exploring in more detail which difficulties are encountered by the elderly in an eating situation, both to better understand the impact of oral health on food intake (namely, to better understand which difficulties lead an older individual to avoid one food or another), and consequently to develop a food supply tailored to the oral capacities of the elderly people. The originality of this work was to explore the concept of oral comfort asking a panel of elderly people, taking into account the diversity that is available in the food offer in France; and to develop a tool that aims at assessing oral comfort when eating a food by the elderly people. The objective of this investigation was to answer the following research questions: Is it meaningful to explore the concept of oral comfort when eating food among an elderly population? Would they understand this concept and what would be their definition of oral comfort? What are the sub-dimensions that result from the definition of oral comfort? What is the impact of mastication and salivation on oral comfort when eating a food?

Finally, in the AlimaSSenS project, industrials partners have worked on food supply tailored for elderly people with or without oral health impairments. In parallel, I have looked up and tested some culinary techniques that are easy-to-do at home in order to help elderly people keep eating meat, which is a great source of protein. The originality of this work was to investigate culinary techniques that everyone could do at home without specific equipment, and to ask elderly people to assess oral comfort on those developed culinary techniques in order to validate them in terms of texture improvement. The objective of this part was to answer the following research questions: what culinary techniques are feasible at home by elderly people? In an "at-home" condition, does the application of these culinary techniques have an impact on rheological characteristics of the meat samples or on the perceived oral comfort by an

elderly panel? Would the elderly people appropriate themselves the culinary techniques at home?
To date, the last question was not investigated and therefore will not be developed in the present thesis.

Each of the three topics will be developed in the following sections as well as in the next three chapters; a summary of the results will be presented as the beginning of the discussion.

4.2. Oral health characterization of the AlimaSSenS panel

The objective of this task was to recruit a panel of about 100 elderly people – half with good oral health and half with poor oral health – in order to characterize them in terms of oral status. Elderly people (<65 years old) were recruited several ways: by using the Panelsens database (database of every volunteer being involved in one or several studies in the laboratory during the last years), by contacting associations for elderly people such as the "senior house", or by presenting the project during the "senior exhibition" in Dijon.
The inclusion criteria were the following:

- Older than 65 years old
- Living at home
- No acute pathological episodes neither at the time of the experiment nor in the recent past
- Scoring at least 24 on the Mini Mental State Evaluation
- Having a number of functional units ≤ 4 or ≥ 7; a functional unit was defined as a pair of posterior antagonist teeth that had at least one contact area during chewing.

107 elderly volunteers were recruited, 60 having at least 7 functional units (good dental status group) and 47 having 4 or less functional units (poor dental status group). The volunteers participated in three sessions during which 6 categories of measurements were performed (Figure 5).

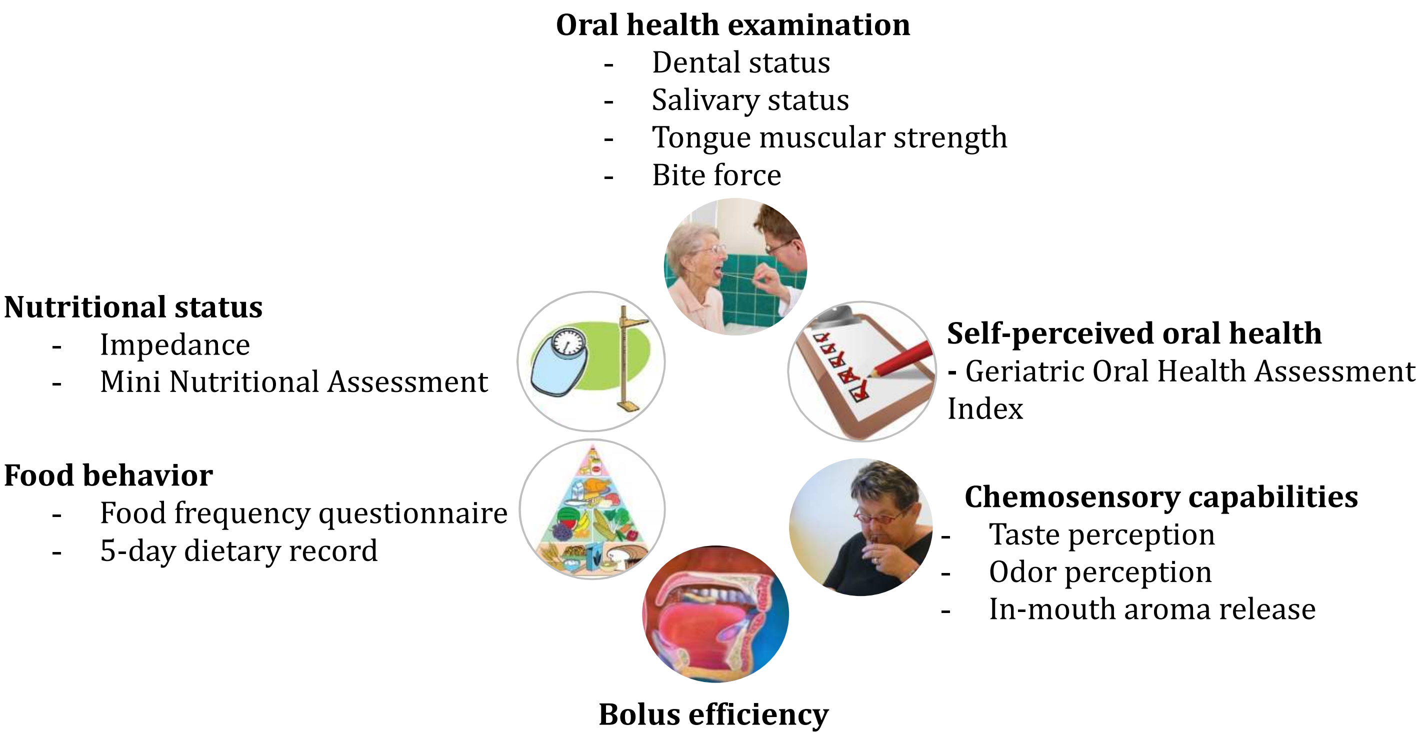

Figure 5. Characterization of the elderly panel. The physiological dimensions correspond to the oral health examination, the chemosensory capabilities, bolus efficiency, food behavior and nutritional status evaluation. The physiological dimension corresponds to the self-perceived oral health.

The oral examination was constituted of the following evaluation: *Teeth counting:* the number of remaining teeth was noticed. *Functional units counting:* the number of occluding pairs of teeth was evaluated asking elderly people to masticate an articulating paper that colors the contact areas in blue. *Resting salivary flow:* Elderly people were asked to spit out the saliva into a pre-weighted cup during 10 minutes. *Stimulated salivary flow:* Elderly people were asked to spit out the saliva into a pre-weighted cup during 5 minutes while masticating a piece of parafilm. *Tongue muscular strength:* Elderly people were asked to press a pressure probe between the tongue and the soft palate. *Bite force:* Elderly people were asked to masticate a two-colored chewing-gum during 20 masticatory cycles, the masticated chewing-gum was analyzed using image analysis.

The self-perceived oral health consisted in asking elderly people to answer the Geriatric Oral Health Self-Assessment Index (Slade and Spencer, 1994; Tubert-Jeannin *et al.*, 2003).

The chemosensory capability dimension consisted in the following tests: *Taste perception:* Elderly people were asked to taste some water solutions containing plain water, diluted salt or diluted sugar, and to indicate whether they perceived water or a taste. A score was established based on their answers. *Odor perception:* Elderly people were asked to sniff bottles containing odors or not, and to indicate whether they perceived an odor or nothing. A score was established based on their answers. In-mouth aroma release: the mint aroma release was evaluated using atmospheric pressure chemical ionization–mass spectrometry, the elderly people were asked to place a mint pastille in mouth and to consume it freely.

The bolus efficiency was evaluated throughout the analysis of a carrot bolus, the elderly people were asked to masticate a piece of raw carrot until they felt ready to swallow, then to spit the carrot bolus. The bolus characteristics constitute the information for bolus efficiency.

The food behavior dimensions was evaluated throughout a food frequency questionnaire containing 17 food categories, and a 5-days dietary record where elderly people were asked to weight every food they eat and to report all the information in a specific notebook.

Finally, the nutritional status was assessed throughout anthropometric measurements (weight, height), the Mini Nutritional Assessment questionnaire as well as a measure of the percentage of fat mass using an impedance device.

To analyze this data, an in-depth analysis of salivary flow rates was performed to understand the impact of ageing on salivation, as very few studies have already investigated this topic on an independently-living healthy elderly population (article presented in Chapter 2 section 1). Then the whole database was analyzed using multiple regression analysis in order to understand the relationship between the different dimensions (article presented in Chapter 2 section 2). Finally, Partial least square Path Modeling analyses were carried on in order to perform a multiple data frame analysis. However, the latter analysis were not robust enough to be published, they will not be presented in the present thesis.

4.3. DEVELOPMENT OF A NEW CONCEPT: ORAL COMFORT WHEN EATING A FOOD

The aim of this task was to explore the concept of oral comfort when eating a food in the elderly population; then develop a tool to assess oral comfort when eating a food among an elderly panel.

4.3.1. UNDERSTANDING THE CONCEPT OF ORAL COMFORT FROM THE ELDERLY POINT OF VIEW

In order to understand the meaning of oral comfort when eating a food in the elderly point of view, 18 elderly people were invited to take part in focus groups, 6 persons per focus group, each focus group consisted of three parts:

1) Brainstorming about oral comfort. The participants were asked the question "what comes to your mind when I say "oral comfort"?" and were invited to tell out loud the first words that popped-up to their minds.
2) Personal experience on most comfortable and most uncomfortable food. The volunteers were asked to express what were the most uncomfortable food and the most comfortable food for them, and describe what makes the food uncomfortable or comfortable during its consumption.
3) Tasting phase. Participants were served with 8 delicatessen and salads (starter course), 8 meat and veggie dishes (main course), 8 cheeses and breads (cheese course) and 8 sweet products (dessert course). For each course, they were asked to choose one uncomfortable and one comfortable food among the eight proposals, to taste it, to confirm or not their choice and to describe what makes the food uncomfortable or comfortable during its consumption.

4.3.2. DEVELOPING A QUESTIONNAIRE TO ASSESS ORAL COMFORT WHEN EATING A FOOD

Following the focus groups and based on its transcription, a questionnaire was developed as a tool to assess oral comfort when eating a food. The questionnaire is divided into 5 parts and must be presented to volunteers at the same time as a food tasting in order to rate oral comfort when masticating and swallowing foods:

- A first general question on food comfort that the participants answered using a 5-point scale from "Very uncomfortable" to "Very comfortable."
- A second section on bolus formation included five items: the ability to cut the food with incisors, the ability to cut the food with premolars, the ability to masticate the food, the ability to humidify the food with saliva, and the ability to swallow the food. For each item, participants answered on 6-point scale from "Impossible" to "Very easy." This section also included an item on the time needed to form the food bolus; participants answered using a 6-point scale from "Impossible" to "Very brief."

- A third section on pain perception included five items: burning or spicy sensation, muscular pain, articular pain, dental pain and gum pain. For each item, participants answered on a 4-point scale from "Extremely" to "Not at all."
- A fourth section on texture perception included eight items that were evaluated on their intensity: sticky, stringy, greasy, dry, doughy, melting, firm and hard. The items were rated on a 4-point scale from "Extremely" to "Not at all."
- A fifth section on taste perception included five items: taste intensity and the saltiness, sweetness, sour and bitter perceptions. For each item, participants answered on a 4-point scale from "Extremely" to "Not at all."

4.3.3. VALIDATION OF THE QUESTIONNAIRE ASSESSING ORAL COMFORT OF PRODUCTS DELIVERED BY THE INDUSTRIALS' ALIMASSENS PARTNERS

Thirty-nine and 40 elderly volunteers that were included in the AlimaSSenS project were selected to rate oral comfort when eating cereal-based and meat-based products respectively. The recruitment criteria were the following: older than 65 years old, no acute pathological episodes at the time of the experiment, scoring at least 24 on the mini mental state evaluation (MMSE) (Folstein *et al.*, 1975). In each group, we managed to have volunteers ranging from a poor to a good oral health, based on the number of functional units (i.e. a pair of posterior antagonist teeth that had at least one contact area during chewing) and salivary flows (Leake *et al.*, 1994; Gupta *et al.*, 2006). Six cereal-based and six meat-based products were chosen in order to have contrasted textures, each volunteer was asked to rate oral comfort on either the six cereal-based or the six meat-based products during a one-hour session at the laboratory.

4.4. CULINARY TECHNICS' IDENTIFICATION AND DEVELOPMENT

The aims of the present task were:

1) To identify culinary techniques that aim at improving food texture adapted to elderly people with oral health impairments while preserving food intake
2) To validate those culinary techniques using physical measurements as well as asking elderly people to rate oral comfort.

The choice was made to work on meat texture as it is a commonly eaten food by the elderly population and it is a great source of proteins, necessary for muscle enforcement. Indeed, meat is a highly digestible source of proteins that can prevent muscle loss or sarcopenia. Reduction in meat consumption due to eating difficulties contributes significantly to the lower daily intake of proteins observed in the elderly population. One of the reasons for lower consumption of meat among the elderly is linked to the sensory and texture properties of such food products, with difficulties in elderly people suffering from masticatory dysfunction to consume actual food products. Giving advices on how to improve meat texture at home constitute an important challenge.

In order to identify culinary techniques that could improve meat texture, the first step was to prospect among food service professionals and butchers. Following the interview of several professionals met at exhibitions or directly at workplaces, the identified lever to improve meat texture were the following:

- The choice of the pieces of meat *i.e.* age of animals, kind of muscle etc.
- Meat preparation *i.e.* marinade, tenderizer
- Cooking conditions *i.e.* oven temperature, cooking bag etc.
- Before eating *i.e.* let rest the meat before serving

It was decided to work on three different kinds of meat: chicken breast, roast beef and beefsteak. Those three meats are commonly eaten in France and their cooking modes require two common techniques: the oven and the frying pan.

The culinary techniques that were selected for the experiment were the following:

- Blade tenderization: the meat was perforated with sharpened edged blades being closely spaced in order to cut muscle fibers (Figure 6);
- Marinade: the meat was left on a marinade mad or soy sauce and water for 2 to 4 hours depending on the kind of meat;
- Cooking bag: the meat was put into a cooking bag to preserve tenderness of the muscles (for chicken breast and roast beef only, see Figure 7);
- Cooking temperature: the samples were cooked either at high or low temperature in the oven (220°C and 110°C respectively, for chicken breast and roast beef only).

Figure 6. Blade tenderizer Hendi Profi Line 51 blades used for the present study

Figure 7. Cooking bag Albal® used for the present study on chicken breast and roast beef samples

As a first step, the culinary techniques were evaluated using physical measurements (*i.e.* shear force and water content) in order to select the most efficient techniques. The latter were presented to an elderly panel who was asked to assess oral comfort when eating the samples, using the oral comfort questionnaire.

CHAPTER 2: ORAL CHARACTERISATION OF ELDERLY PEOPLE

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1. SALIVATORY CHARACTERISTICS OF THE POPULATION

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SALIVARY FLOW DECREASES IN HEALTHY ELDERLY PEOPLE INDEPENDENTLY OF DENTAL STATUS AND DRUG INTAKE

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ABSTRACT

In humans, oral food consumption is by far the most important point where food's organoleptic properties can be perceived and can elicit sensory pleasure. It is also the ultimate stage of the food supply chain and the beginning of the food disintegration and digestion process. However, in regard to the influence of ageing on food oral processing, this topic has been mainly investigating through mastication, whereas salivation remains largely unexplored. The present experiment aimed at studying the impact of normal ageing on salivary flow taking into account the dental status and the number of drugs taken by the elderly people. This was achieved by comparing resting and stimulated salivary flows of young versus healthy elderly adults (i.e., autonomous elderly people without acute pathology). Ninety-three young adults (22–55 years old) and 84 elderly people (70–92 years old) underwent a measurement of resting and stimulated salivary flows and an oral examination (teeth counting; functional unit counting i.e., counting occluding tooth pairs). The present study showed an average 38.5% reduction of resting salivary flow and 38.0% reduction of stimulated salivary flow in healthy elderly people compared to young adults. This reduction was observed independently of the dental status and drug intake: elderly people presented reduced salivary flow even if they did not take any drugs or if their dental status was similar to the one of the young adults. The results also highlight a large inter-individual variability both in young and elderly adults.

PRACTICAL APPLICATIONS

During oral food consumption, saliva plays a key role in the acceptance of food and beverage by modulating the perception of texture, taste and aroma, as well as providing eating comfort by assisting the food breakdown process into a bolus that can be safely swallowed. However, in regard to the influence of ageing on food oral processing, the present results demonstrate a reduced salivary flow in healthy elderly people. Consequently, there is a need for developing foods tailored to the salivary capacities of elderly people aside from the efforts put into the development of foods tailored to the mastication and swallowing abilities of this population. In fact, in the context of an ageing population, the development of products meeting an elderly person's functional capacities becomes a major challenge for the food industry as well as for society.

INTRODUCTION

In humans, oral food consumption is by far the most important point where food's organoleptic properties (texture, taste and aroma) can be perceived and elicit sensory pleasure. It is also the ultimate stage of the food supply chain and the beginning of the food disintegration and digestion process (Chen 2009). The different mechanisms involved in oral food consumption, which is referred to as "food oral processing," depend both on the food's structure and the individual's oral physiology (Salles *et al.* 2011). However, in regard to the influence of ageing on food oral processing, this topic has been mainly investigating through mastication whereas salivation remains largely unexplored.

Saliva is a physiological fluid that plays a crucial role in preserving and maintaining oral health and eating comfort (Carpenter 2012). Saliva is secreted by three major salivary glands (submandibular, sublingual and parotid glands) and several minor salivary glands located all over the oral cavity (Christensen 1986). During oral food consumption, saliva has three major functions. First, saliva plays a key role in the acceptance of food and beverage by modulating the perception of oral sensations (taste, viscosity, smoothness, juiciness, astringency, etc.) and aroma release. In fact, taste compounds should be in an aqueous solution to reach and activate taste buds (Fischer *et al.* 1994), and it has been demonstrated that taste sensitivity is related to saliva composition (Dsamou *et al.* 2012). Furthermore, texture perception is influenced by saliva composition. Engelen *et al.* (2007) have demonstrated that subjects with a high α-amylase activity had a decreased thickness perception of a starch-based custard. Finally, saliva can impact aroma release by assisting in the food breakdown process, by retaining or releasing aroma compounds depending on their affinity with saliva, and by inducing chemical reactions likely to produce new volatile compounds (Gierczynski *et al.* 2011). Second, saliva, as well as mastication, transforms a food sample into a bolus that can be safely swallowed (Prinz and Lucas 1997). The water in saliva moistens the food particles, whereas the salivary mucins bind masticated food into a coherent and slippery bolus that can easily slide through the oesophagus without damaging the mucosa. Saliva enzymes also initiate the digestion of carbohydrates and triglycerides in the food bolus (Salt and Schenker 1976; Hamosh and Burns 1977). Third, saliva dilutes and removes substances from the oral cavity after swallowing ("oral clearance"; Lagerlof and Oliveby 1994; Lenander-Lumikari and Loimaranta 2000). In fact, salivation and swallowing are acknowledged to be important processes for eliminating injurious and noxious agents and bacteria from the oral cavity (Pedersen *et al.* 2002). Saliva clears sugar and acids from the oral cavity and thereby protects teeth from erosion. Finally, teeth and mucous membranes are covered by a protective film of saliva, which prevents the occurrence of caries (Ericsson 1953).

In elderly people, it has been demonstrated that the cumulative effect of ageing and associated changes, such as tooth loss (Dormenval *et al.* 1998; Srinivasulu *et al.* 2014), drug intake (Handelman *et al.* 1989; Bardow *et al.* 2001; Johanson *et al.* 2015; Thomson 2015) and disease (Ship *et al.* 1990; Ship 1992; Ship and Puckett 1994; Chu *et al.* 2015), may affect salivary flow. However, to the best of our knowledge, very few studies have investigated the impact of normal ageing on salivary flow taking into account the dental status and the number of drugs taken by the elderly people. In these studies, many methods were used to measure the salivary flow. Therefore, a comparison of the results is difficult to make. Moreover, none of the studies have explored the relationship between dental status and salivary flow in elderly people.

Consequently, the present experiment aimed at studying the impact of normal ageing on salivary flow taking into account dental status and the number of drugs taken by the elderly people. This was achieved by comparing resting and stimulated salivary flows of young versus healthy elderly adults (i.e., autonomous elderly people without acute pathology).

MATERIALS AND METHODS

Participants

Young Adult Panel. A panel of young adult volunteers ($n = 93$) was recruited in Dijon during a period of 2 months. The recruitment criteria were the following: aged between 20 and 55 years and good dental status (no missing teeth except the third molar, no occlusion disorders and no daily drug intake). An interview was carried out with each volunteer to ensure that they met the inclusion criteria.

Elderly Adult Panel. The data were collected as part of a programme aimed at studying the relationship between oral health and eating behavior (AlimaSSenS project: toward an adapted and healthy food supply for elderly people). A panel of elderly volunteers ($n = 84$) was recruited from a population of elderly people living at home in Dijon during a period of 6 months. The recruitment criteria were the following: older than 70 years old, no acute pathological episodes at the time of the experiment, and scoring at least 24 on the mini mental state evaluation (MMSE) (Folstein *et al.* 1975). An interview was carried out with each volunteer to ensure that they met the inclusion criteria.

Procedure

Young adult volunteers underwent a salivary flow test (resting and stimulated). The session was organized as a face-to-face interview that was conducted by three experimenters who had previously participated in a 1-day training session.

Elderly adult volunteers took part in one session with a duration of approximately 1 h and 30 min. During this session, participants completed the Geriatric Oral Health

Assessment Index, which is a questionnaire that evaluates self-perception of oral health (Slade and Spencer 1994; Tubert-Jeannin *et al.* 2003). The participants were also interviewed on their food habits and drug intake. Then, the participants sat in an articulated resting chair, and a trained experimenter carried out the oral examination (teeth counting and functional unit counting). Finally, the participants completed the xerostomia questionnaire (Thomson *et al.* 1999) and performed a measure of salivary flow (resting and stimulated). The sessions were organized as face-to-face interviews that were conducted by three experimenters who had previously participated in a 4-h long training session.

Measurements

Salivary Flow. Resting and stimulated salivary flows were measured as previously described (Neyraud *et al.* 2012; Feron *et al.* 2014). The participants were asked not to smoke, eat or drink at least 1 h before collecting the saliva. Resting salivary flow was measured by instructing the participant to spit out the saliva into a pre-weighed screw-cap cup every time they felt like swallowing over a period of 5 min for the young adults and 10 min for the elderly participants. Stimulated salivary flow was measured by instructing the participants to masticate a piece of pre-weighed parafilm while spitting out the saliva into a pre-weighed screw-cap cup every time they felt like swallowing over a period of 5 min. Cups were weighed, and salivary flow rates were expressed in mL/min assuming that 1 g of saliva corresponds to 1 mL.

Teeth Counting. A trained experimenter counted the number of natural, restored and fixed prosthetic teeth (participants who wore dentures were asked to remove them for this measure).

Functional Unit Counting. A functional unit was defined as a pair of posterior antagonist teeth that had at least one contact area during chewing. The number of functional units was evaluated by asking the participants to chew 1–2 cycles on 200-μm thick articulating paper; the number of teeth on the mandibular arch that had at least one color mark provided the number of functional units. The participants with dentures were asked if they had used their dentures while eating during their three last meals. Those who had not done so were asked to remove their dentures before completing this measure.

Data Analysis. Student's *t*-tests were performed using the TTEST procedure provided in the SAS software (SAS Institute INC., Cary, NC). Equality of variance was first assessed by using a folded form of the *F* statistic (Steel and Robert 1980). Depending on the results, groups were compared using the *t* statistic when the variances were equal or the Cochran and Cox (1950) approximation when the variances were unequal. Analyses of variance (ANOVA) were done using the general linear model procedure provided in the SAS software (ss3 option). Post hoc analyses were performed using the Student Newman Keuls test. Means (*M*) are associated with the Standard Error of the Mean. The threshold for significance was set to 5%.

RESULTS

Ninety-three young adults (48 women and 45 men) and 84 elderly participants were included (47 men and 37 women). No significant differences were observed regarding sex distribution ($\chi^2 = 1.01$; ns). Characteristics of the participants are summarized in the Table 1. As expected, the dental status of the young participants was better than that of the elderly participants (number of missing teeth for young adults: 0).

Impact of Ageing on Salivary Flow

Figure 1 presents the box-plot distributions of the resting and stimulated salivary flow for the young and elderly panels. The box-plot distributions reveal a median difference but also a larger variability for the young adult participants for both the resting and stimulated salivary flow. Actually, variances in age groups were significantly unequal for the stimulated flow [F (92,83) = 2.11; $P < 0.001$] but not for the resting flow [F (92,83) = 1.35; $P = 0.17$]. Both the resting and stimulated salivary flow were lower in the elderly participants than in the young participants [resting: $t(175) = 6.00$; $P < 0.001$; stimulated: $t(164) = 6.91$; $P < 0.001$].

With regard to resting salivary flow, no impact of sex was observed for the elderly participants [$t(78) = -0.30$; $P = 0.76$; $M = 0.30$ mL/min ± 0.03; $M = 0.31$ mL/min ± 0.03, for elderly women and elderly men, respectively], while a tendency was observed for the young participants

TABLE 1. CHARACTERISTICS OF THE YOUNG AND ELDERLY PANELS

	Young panel (*n* = 93)			Elderly panel (*n* = 84)		
	M	SEM	Range	*M*	SEM	Range
Age	38.94	8.37	22–55	76.19	4.63	70–92
Number of teeth				21.40	9.00	0–32
Number of functional units				6.02	2.06	0–10
Resting salivary flow	0.50	0.23	0.05–1.19	0.31	0.19	0.03–0.86
Stimulated salivary flow	2.47	1.06	0.70–5.45	1.52	0.73	0.11–4.01

M, mean; SEM, standard error of the mean.

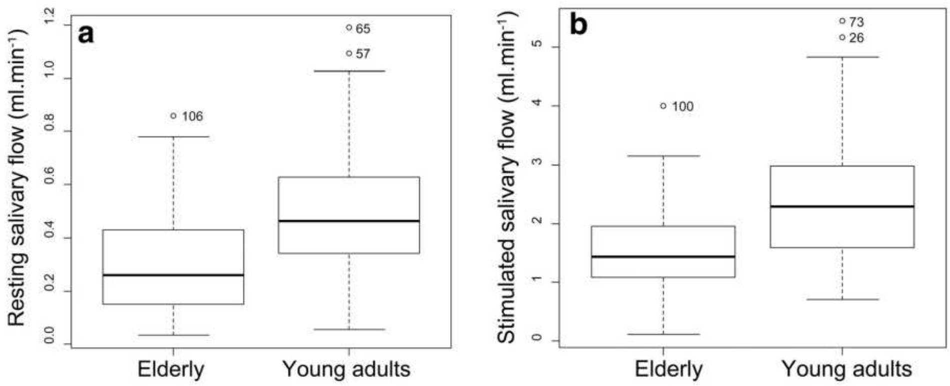

FIG. 1. BOX-PLOT DISTRIBUTIONS OF THE RESTING (a) AND STIMULATED (b) SALIVARY FLOW FOR THE YOUNG AND ELDERLY PANELS
The bottom and the top of the box correspond to the 25th and 75th percentile, respectively. The thick band corresponds to the median. The ends of the whiskers represent the lowest/highest data still within the 1.5 interquartile range. Any data points not included between the whiskers are plotted as outliers with a dot.

[$t(90) = -1.76$; $P = 0.08$], with young women tending to have a lower resting flow [$M = 0.46$ mL/min $\pm$ 0.03] than young men [$M = 0.54$ mL/min $\pm$ 0.03]. With regard to stimulated salivary flow, a significant impact of sex was observed for both the young [$t(86) = -2.15$; $P < 0.05$] and elderly participants [$t(82) = -2.20$; $P < 0.05$], with women having a reduced stimulated flow [young: $M = 2.24$ mL/min $\pm$ 0.14; elderly: $M = 1.34$ mL/min $\pm$ 0.10] compared with men [young: $M = 2.70$ mL/min $\pm$ 0.17; elderly: $M = 1.67$ mL/min $\pm$ 0.12].

Impact of Ageing Versus Dental Status and Drug Intake on Salivary Flow

To further study the impact of dental status, two subgroups were considered among the elderly participants: elderly participants with a good dental status, which had 7 or more posterior functional units and no dentures ($n = 27$), and elderly participants with a poor dental status, which had 4 or fewer posterior functional units ($n = 19$). The thresholds of 7 and 4 functional units to define good and bad dental status, respectively, were defined according to Leake *et al.* (1994). It should be noted that all 93 young adults presented 7 or more posterior functional units. Figure 2 presents the resting and stimulated salivary flow for the young adults and each elderly dental group. The ANOVA revealed a significant group effect (resting: F (2,136) = 16.40; $P < 0.001$; stimulated: F (2,136) = 16.11; $P < 0.001$). According to the post hoc analyses, the salivary flows of young adults were significantly greater than the salivary flows of elderly people regardless of their dental status. No significant effect of dental status was observed in the elderly participants.

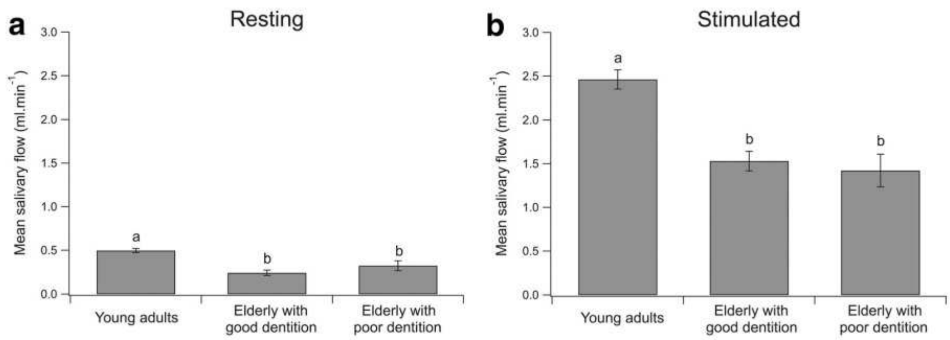

FIG. 2. REPRESENTATION OF THE RESTING (a) AND STIMULATED (b) SALIVARY FLOWS FOR YOUNG ADULTS, ELDERLY WITH GOOD DENTITION AND ELDERLY WITH POOR DENTITION
The error bars correspond to the standard error of the mean. For each variable, the means with the same letter are not significantly different ($P < 0.05$). Resting (2.a): $M_{young} = 0.50$ mL/min $\pm$ 0.02; $M_{elderly\ good\ dentition} = 0.24$ mL/min $\pm$ 0.03; $M_{elderly\ poor\ dentition} = 0.33$ mL/min $\pm$ 0.06. Stimulated (2.b): $M_{young} = 02.46$ mL/min $\pm$ 0.11; $M_{elderly\ good\ dentition} = 1.53$ mL/min $\pm$ 0.11; $M_{elderly\ poor\ dentition} = 1.42$ mL/min $\pm$ 0.19.

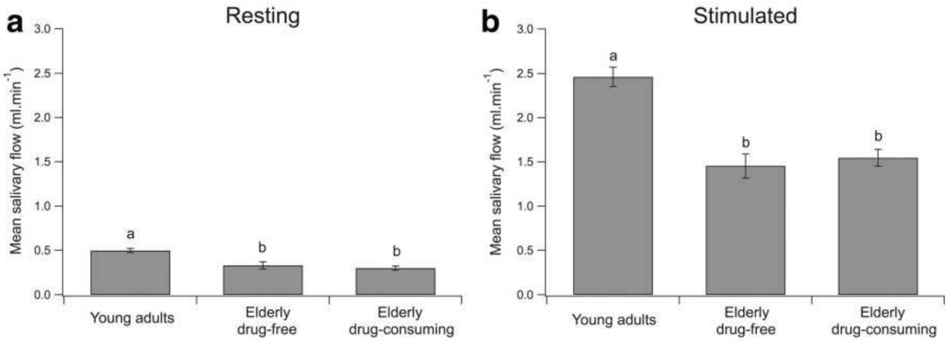

FIG. 3. REPRESENTATION OF THE RESTING (3.a) AND STIMULATED (3.b) SALIVARY FLOWS FOR YOUNG ADULTS, ELDERLY DRUG FREE AND ELDERLY CONSUMING DRUGS
The error bars correspond to the standard error of the mean. For each variable, the means with the same letter are not significantly different ($P < 0.05$). Resting (3.a): $M_{young} = 0.50$ mL/min ± 0.02; $M_{elderly\ drug\ free} = 0.33$ mL/min ± 0.04; $M_{elderly\ drug\ intake} = 0.30$ mL/min ± 0.02. Stimulated (3.b): $M_{young} = 02.46$ mL/min ± 0.11; $M_{elderly\ drug\ free} = 1.45$ mL/min ± 0.13; $M_{elderly\ drug\ intake} = 1.55$ mL/min ± 0.10.

To investigate the impact of drug intake, two subgroups were considered among the elderly participants: elderly participants not taking any drugs ($n = 19$) and elderly participants taking at least four or more drugs per day ($n = 28$). The thresholds of intake of four or more drugs per day was defined according to Handelman *et al.* (1989) who showed a significant decrease in stimulated salivary in elderly people taking four drugs per day. It should be noted that none of the 93 young adults took drugs during the time of the experiment. Figure 3 presents resting and stimulated salivary flow for young adults and each elderly drug intake group. The ANOVA revealed a significant group effect (resting: F (2,137) = 13.02; $P < 0.001$; stimulated: F (2,137) = 16.07; $P < 0.001$). According to the post hoc analyses, the salivary flows of young adults were significantly greater than salivary flows of elderly people whether they took drugs or not. No significant effect of drug intake was observed within the elderly population recruited for this study.

DISCUSSION

The present study showed, on average, a 38.5% reduction in the resting salivary flow and 38.0% for the stimulated salivary flow in healthy elderly people compared with young adults. This reduction was observed independently of drug intake and the dental status: elderly people presented a reduced salivary flow even if they did not take any drugs or if their dental status was similar to the one of the young adults. These results support the results of Affoo *et al.* (2015) who recently conducted a meta-analysis on the impact of ageing on salivary flow. According to Affoo *et al.*, ageing is associated with reduced salivary flow that cannot be fully explained by drug intake or disease (dental status was not explored). In fact, from a biological standpoint, ageing is accompanied by structural changes in the salivary glands, such as a reduction in acinar volume, a loss of secretory tissue and an increase of adiposity (Scott 1986; Scott *et al.* 1987). Furthermore, it has been suggested that age-related neurophysiological changes may account for the changes in salivary secretion (Baum 1987). However, further studies are needed to clarify the link between these changes and saliva secretion in elderly people and to uncover the mechanisms beyond the impact of ageing *per se* on salivary flow.

Beyond these age-related processes, it has been demonstrated that drug intake may have a strong impact on saliva flow (Handelman *et al.* 1989; Bardow *et al.* 2001; Johanson *et al.* 2015; Thomson 2015). According to Sreebny and Schwartz (1997), 42 drug categories and 56 subcategories are known to be xerogenic, i.e., inhibit saliva secretion through various pathways. In fact, Handelman *et al.* (1989) observed that participants who took more than three drugs per day had a stimulated salivary flow significantly lower than participants who did not take any drugs. However, in the present experiment, no difference was observed between elderly people who did not take any drugs and elderly people who took more than three drugs per day. A similar result was previously observed by Nagler and Hershkovich (2005) who observed no significant difference in the resting salivary flow between drug-free elderly participants and elderly people who were taking drugs. This study included 28 subjects aged between 60 and 90 years old with an average age of 75.8 years with 14 participants that were drug free and 14 participants that consumed drugs (patients treated routinely).

In the same way, previous studies have demonstrated a correlation between the number of remaining teeth and a reduction in the salivary flow in an elderly population (Ikebe *et al.* 2011; Samnieng *et al.* 2012). Interestingly, whereas some authors have hypothesized that the age-related decline in bite strength may result in less stimulation of salivary glands and,

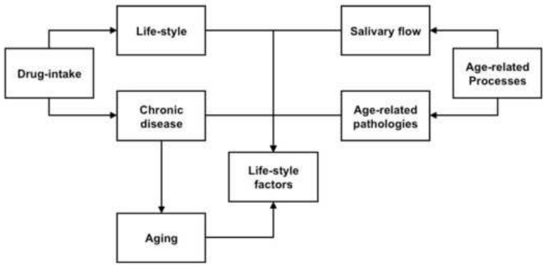

FIG. 4. REPRESENTATION OF THE FACTORS LIKELY TO EXPLAIN THE VARIABILITY OBSERVED IN THE ELDERLY PANEL WITH RESPECT TO THE SALIVARY FLOW

thus, in a reduced salivary flow (Affoo *et al.* 2015), other authors have demonstrated that elderly people with a low salivary flow rate were more likely to lose teeth (Caplan and Hunt 1996). However, in the present experiment, no correlation was observed between the dental status and the saliva flow. Furthermore, Flink *et al.* (2008) showed a relation only in the case of severely reduced salivary flow among women over 50 years old. The author proposed that this link was mainly explained by the development of caries due to a lack of saliva secretion and, thus, protection.

The present study included "healthy" elderly people: older adults who lived independently at home, who did not suffer from an acute pathology (e.g., no cancer) or dementia (e.g., Alzheimer' disease) and who had a good nutritional status. Indeed, the mean MMSE score for the present sample was 28.7 out of 30; no participant scored below 25 (the MMSE screens for cognitive impairment; scores that are greater than or equal to 25 points indicate normal cognition). The mean mini nutritional assessment score of the present sample was 27.3 out of 30; only two participants were at risk for malnutrition (the mini nutritional assessment screens for malnutrition; scores that are greater than or equal to 24 points indicate normal nutritional status; scores that range from 17 to 23.5 indicate a risk of malnutrition and scores below 17 points indicate malnutrition). This means that these participants were free from any pathology. In fact, 65 of the participants took an average of 3.6 drugs per day mainly for chronic diseases, such as hypertension. However, the present sample may be quite free of confounding factors that are often associated with drug intake and/or poor dental status, such as poor nutritional status, decline in general health, onset of neurological disorders. This question of confounding factors was evidenced in the study conducted by Flink *et al.* (2008) on 1,247 volunteers and considered similar variables as the ones in the present study. The authors showed that, for instance, in young adults (less than 50 years old) drug intake did not explain the decrease in salivary flow. The authors suggest the involvement of other variables, such as body mass index greater than 25 kg/m^2, malnutrition and disease. For instance, the authors showed that the only variable that explained a very low stimulated salivary flow in a subset of this population was a diagnosed disease. Conversely, in the same study, the effect of drugs on salivary flow was demonstrated in the older population (65–69 years old), but in this population, an average of 52% of women and 58% of men with a disease had poor general health.

Finally, the present experiment highlighted the large inter-individual variability both in the young and elderly panel. Among the elderly panel, 13% of the participants were suffering from hyposalivation (resting salivary flow less than 0.1 mL/min), whereas 18% of the participants had a salivary flow greater than the mean salivary flow of the young panel. A similar conclusion was performed by Flink *et al.* (2008). In their best model predicting a very low unstimulated salivary flow rate, the independent variables explained only 10% of the difference between individuals. Two types of factors can be proposed to account for the variability observed in the elderly panel for the salivary flow (Fig. 4):

- Life-style factors, such as diet or smoking habits. In fact, Ernest (1993) showed a positive relationship between flow rate and the intake of 18 out of 22 nutrients, with a highly significant correlation for calories, protein, carbohydrates and vitamin C and B-6, among others. Moreover, it has been demonstrated that a modification in diet (liquid, less acidogenic or firmer texture) can either increase or decrease the salivary flow (Dodds *et al.* 2005). Regarding smoking habits, the salivary flow rate was significantly reduced in long-term smokers (mean salivary flow: 0.38 mL/min) compared to non-smokers (0.56 mL/min) (Rad *et al.* 2010).
- Ageing factors including ageing-related processes, such as the hydration status (Buffa *et al.* 2011), structural changes in the salivary glands, neurophysiological changes or ageing-related events, such as the onset of a pathology or dementia, may impact the salivary flow directly or indirectly through drug intake.

However, longitudinal studies are expected to decipher the correlation between the salivary flow of young and older adults, and, namely, whether individuals who have the greatest salivary flows when they are young will have reduced but still the greatest salivary flows when older compared with their age group. Furthermore, studies are expected to disentangle the relative impact of each factor on the reduction of the salivary flow in an elderly population.

ETHICAL STATEMENTS

Conflict of Interests: The authors declare that they do not have any conflicts of interest.

Ethical Review: For the young panel, the experimental protocol was approved by the French Ethics Committee for Research (Comité de Protection des Personnes Est-1 N°2008/15) and by the Direction Générale de la Santé, France (N° DGS2008-0196). For the elderly panel, the experimental protocol was approved by the French Ethics Committee for Research (CPP Est III, Nancy, #15.04.04, ANSM #2015-A00279-40).

Informed Consent: In accordance with ethical standards, all participants received written and oral information on the study before signing a consent form.

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REFERENCES

AFFOO, R.H., FOLEY, N., GARRICK, R., SIQUEIRA, W.L. and MARTIN, R.E. 2015. Meta-analysis of salivary flow rates in young and older adults. J. Am. Geriatr. Soc. *63*, 2142–2151.

BARDOW, A., NYVAD, B. and NAUNTOFTE, B. 2001. Relationships between medication intake, complaints of dry mouth, salivary flow rate and composition, and the rate of tooth demineralization in situ. Arch. Oral Biol. *46*, 413–423.

BAUM, B.J. 1987. Neurotransmitter control of secretion. J. Dent. Res. *66*, 628–632.

BUFFA, R., FLORIS, G.U., PUTZU, P.F. and MARINI, E. 2011. Body composition variations in ageing. Coll antropol. *35*(1), 259–265.

CAPLAN, D.J. and HUNT, R.J. 1996. Salivary flow and risk of tooth loss in an elderly population. Community Dent. Oral Epidemiol. *24*, 68–71.

CARPENTER 2012. *Role of Saliva in the Oral Processing of Food. Food Oral Processing*, pp. 45–60, Oxford: Wiley-Blackwell.

CHEN, J. 2009. Food oral processing – a review. Food Hydrocolloids *23*, 1–25.

CHRISTENSEN, C.M. 1986. Role of saliva in human taste perception. In *Clinical Measurement of Taste and Smell* (M.L. Meiselman and R.S. Rivlin, eds.) pp. 414–428, Macmillan, New York.

CHU, C.H., NG, A., CHAU, A.M. and LO, E.C. 2015. Oral health status of elderly Chinese with dementia in Hong Kong. Oral Health Prev. Dent. *13*, 51–57.

COCHRAN, W.G. and COX, C.G. 1950. *Experimental Designs*, John Wiley and Sons, New York.

DODDS, M.W., JOHNSON, D.A. and YEH, C.K. 2005. Health benefits of saliva: A review. J. Dent. *33*, 223–233.

DORMENVAL, V., BUDTZ-JORGENSEN, E., MOJON, P., BRUYERE, A. and RAPIN, C.H. 1998. Associations between malnutrition, poor general health and oral dryness in hospitalized elderly patients. Age Ageing *27*, 123–128.

DSAMOU, M., PALICKI, O., SEPTIER, C., CHABANET, C., LUCCHI, G., DUCOROY, P., CHAGNON, M.C. and MORZEL, M. 2012. Salivary protein profiles and sensitivity to the bitter taste of caffeine. Chem. Senses. *37*, 87–95.

ENGELEN, L., VAN DEN KEYBUS, P.A., DE WIJK, R.A., VEERMAN, E.C., AMERONGEN, A.V., BOSMAN, F., PRINZ, J.F. and VAN DER BILT, A. 2007. The effect of saliva composition on texture perception of semi-solids. Arch Oral. Biol. *52*, 518–525.

ERICSSON, Y. 1953. [Clinical determination of salivary buffering]. Sven Tandlak Tidskr. *46*, 379–386.

ERNEST, S.L. 1993. Dietary intake, food preferences, stimulated salivary flow rate, and masticatory ability in older adults with complete dentitions. Spec. Care Dentist. *13*, 102–106.

FERON, G., AYED, C., QANNARI, E.M., COURCOUX, P., LABOURE, H. and GUICHARD, E. 2014. Understanding aroma release from model cheeses by a statistical multiblock approach on oral processing. PLoS ONE *9*, e93113.

FISCHER, U., BOULTON, R.B. and NOBLE, A.C. 1994. Physiological factors contributing to the variability of sensory assessments: Relationship between salivary flow rate and temporal perception of gustatory stimuli. Food Qual. Prefer. *5*, 55–64.

FLINK, H., BERGDAHL, M., TEGELBERG, A., ROSENBLAD, A. and LAGERLOF, F. 2008. Prevalence of hyposalivation in relation to general health, body mass index and remaining teeth in different age groups of adults. Community Dent. Oral Epidemiol. *36*, 523–531.

FOLSTEIN, M.F., FOLSTEIN, S.E. and MCHUGH, P.R. 1975. "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. J. Psychiatr. Res. *12*, 189–198.

GIERCZYNSKI, I., GUICHARD, E. and LABOURE, H. 2011. Aroma perception in dairy products: The roles of texture, aroma release and consumer physiology. A review. Flavour Fragr. J. *26*, 141–152.

HAMOSH, M. and BURNS, W.A. 1977. Lipolytic activity of human lingual glands (Ebner). Lab Invest. *37*, 603–608.

HANDELMAN, S.L., BARIC, J.M., SAUNDERS, R.H. and ESPELAND, M.A. 1989. Hyposalivatory drug use, whole stimulated salivary flow, and mouth dryness in older, long-term care residents. Spec. Care Dentist. *9*, 12–18.

IKEBE, K., MATSUDA, K., KAGAWA, R., ENOKI, K., YOSHIDA, M., MAEDA, Y. and NOKUBI, T. 2011. Association of masticatory performance with age, gender, number of teeth, occlusal force and salivary flow in Japanese older adults: Is aging a risk factor for masticatory dysfunction? Arch. Oral. Biol. *56*, 991–996.

JOHANSON, C.N., OSTERBERG, T., LERNFELT, B., EKSTROM, J. and BIRKHED, D. 2015. Salivary secretion and drug treatment in four 70-year-old Swedish cohorts during a period of 30 years. Gerodontology *32*, 202–210.

LAGERLOF, F. and OLIVEBY, A. 1994. Caries-protective factors in saliva. Adv. Dent. Res. *8*, 229–238.

LEAKE, J.L., HAWKINS, R. and LOCKER, D. 1994. Social and functional impact of reduced posterior dental units in older adults. J. Oral Rehabil. *21*, 1–10.

LENANDER-LUMIKARI, M. and LOIMARANTA, V. 2000. Saliva and dental caries. Adv. Dent. Res. *14*, 40–47.

NAGLER, R.M. and HERSHKOVICH, O. 2005. Relationships between age, drugs, oral sensorial complaints and salivary profile. Arch. Oral Biol. *50*, 7–16.

NEYRAUD, E., PALICKI, O., SCHWARTZ, C., NICKLAUS, S. and FERON, G. 2012. Variability of human saliva composition: Possible relationships with fat perception and liking. Arch. Oral Biol. *57*, 556–566.

PEDERSEN, A.M., BARDOW, A., JENSEN, S.B. and NAUNTOFTE, B. 2002. Saliva and gastrointestinal functions of taste, mastication, swallowing and digestion. Oral Dis. *8*, 117–129.

PRINZ, J.F. and LUCAS, P.W. 1997. An optimization model for mastication and swallowing in mammals. Proc. Biol. Sci. *264*, 1715–1721.

RAD, M., KAKOIE, S., NILIYE BROJENI, F. and POURDAMGHAN, N. 2010. Effect of long-term smoking on whole-mouth salivary flow rate and oral health. J. Dent. Res. Dent. Clin. Dent. Prospects. *4*, 110–114.

SALLES, C., CHAGNON, M.C., FERON, G., GUICHARD, E., LABOURE, H., MORZEL, M., SEMON, E., TARREGA, A. and YVEN, C. 2011. In-mouth mechanisms leading to flavor release and perception. Crit. Rev. Food Sci. Nutr. *51*, 67–90.

SALT, W.B., 2ND and SCHENKER, S. 1976. Amylase – its clinical significance: A review of the literature. Medicine *55*, 269–289.

SAMNIENG, P., UENO, M., SHINADA, K., ZAITSU, T., WRIGHT, F.A. and KAWAGUCHI, Y. 2012. Association of hyposalivation with oral function, nutrition and oral health in community-dwelling elderly Thai. Community Dent. Health *29*, 117–123.

SCOTT, J. 1986. Structure and function in aging human salivary glands. Gerodontology *5*, 149–158.

SCOTT, J., FLOWER, E.A. and BURNS, J. 1987. A quantitative study of histological changes in the human parotid gland occurring with adult age. J. Oral Pathol. *16*, 505–510.

SHIP, J.A. 1992. Oral health of patients with Alzheimer's disease. J. Am. Dent. Assoc. *123*, 53–58.

SHIP, J.A. and PUCKETT, S.A. 1994. Longitudinal study on oral health in subjects with Alzheimer's disease. J. Am. Geriatr. Soc. *42*, 57–63.

SHIP, J.A., DECARLI, C., FRIEDLAND, R.P. and BAUM, B.J. 1990. Diminished submandibular salivary flow in dementia of the Alzheimer type. J. Gerontol. *45*, M61–66.

SLADE, G.D. and SPENCER, A.J. 1994. Development and evaluation of the oral health impact profile. Community Dent. Health *11*, 3–11.

SREEBNY, L.M. and SCHWARTZ, S.S. 1997. A reference guide to drugs and dry mouth – 2nd edition. Gerodontology *14*, 33–47.

SRINIVASULU, G., FAREED, N., SUDHIR, K.M. and KRISHNA KUMAR, R.V. 2014. Relationship between stimulated salivary factors, dental caries status and nutritional condition among institutionalized elderly people. Oral Health Dent. Manag. *13*, 49–53.

STEEL, G.D. and ROBERT, R.T. 1980. *Principles and Procedures of Statistics: A Biometrical Approach*. McGraw-Hill, New York.

THOMSON, W.M. 2015. Dry mouth and older people. Aust. Dent. J. *1*, 54–63.

THOMSON, W.M., CHALMERS, J.M., SPENCER, A.J. and WILLIAMS, S.M. 1999. The Xerostomia Inventory: A multi-item approach to measuring dry mouth. Community Dent. Health *16*, 12–17.

TUBERT-JEANNIN, S., RIORDAN, P.J., MOREL-PAPERNOT, A., PORCHERAY, S. and SABY-COLLET, S. 2003. Validation of an oral health quality of life index (GOHAI) in France. Community Dent. Oral Epidemiol. *31*, 275–284.

2. CHARACTERIZATION OF THE STUDIED POPULATION

RELATIONSHIP BETWEEN ORAL STATUS, FOOD ORAL PROCESSING AND FOOD INTAKE IN HEALTHY ELDERLY PEOPLE

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Key words: Elderly, oral health, chemosensory perception, food oral processing, food intake

Abstract

In humans, oral food intake is the ultimate stage of the food supply chain and the beginning of food disintegration and the digestion process. During aging, oral health changes and sometimes food consumption can pose a challenge, as food can be hard to masticate, moisten or swallow. The aim of the present study was to investigate the association between oral health and diet in elderly people by considering i. masticatory, salivary and chemosensory functions, and ii. parameters that account for the status of the oral components involved in food consumption (*i.e.* dental status, salivary flow, tongue strength, gustatory abilities, olfactory abilities) as well as parameters that account for the efficiency of the oral processes involved in food consumption (*i.e.* masticatory ability, chewing efficiency, food aroma release). The study was executed by recruiting a panel of 61 elderly people living

independently with good or poor oral health. The results showed that food bolus formation was related not only to dental status, but also to salivary flow and tongue strength. When considering the impact of oral health on nutritional variables, the study found that raw vegetables intake was related to dental status in healthy elderly people, but protein intake was related to salivary status as well as food bolus formation. The present study highlights the importance of exploring the oral sphere as a whole when investigating the impact of oral health on food behavior in an elderly population.

INTRODUCTION

In humans, oral food intake is the ultimate stage of the food supply chain and the beginning of food disintegration and the digestion process. A first objective of this oral phase is to breakdown food into a swallowable bolus, which is propelled to the digestive tract. A second objective is to stimulate perception of food sensory properties (taste, aroma, texture) which play a key role in the control of food behavior and food intake. During food consumption, the joint action of the teeth and masticatory muscles crushes the food into small particles. Food is cut with the incisor or canine teeth when presented to the mouth and is sent to the back of the mouth to be chewed and sheared by molar teeth (Kaplan & Baum, 1993; Mioche, 2004). Masticatory muscles are responsible for opening and closing mandible movements (Wood, 1987). Water in saliva moistens the food particles and the salivary mucins bind the particles into a coherent and slippery bolus that can easily slide through the esophagus without damaging the mucosa (Prinz & Lucas, 1997). At the same time, food breakdown causes the release of taste and aroma components, which are detected by the gustatory and olfactory receptors. Both senses are important in terms of appetite and eating pleasure, and inform the consumer of food nutritional value (Goff & Klee, 2006; Jacobs & Sharma, 1969). Moreover, the sensory characteristics of a food play an important role in the quantity and variety of food we ingest through the mechanism of sensory specific satiation (de Graaf, 2012; Havermans, Siep, & Jansen, 2010; Larson, Redden, & Elder, 2014; O'Doherty, 2000; Rolls, 1986).

As demonstrated in numerous studies, ageing is often accompanied by changes in the oral sphere, which can cause impaired food bolus formation and/or impaired food sensory perception (Schwartz, Vandenberghe-Descamps, Sulmont-Rossé, Tournier, & Feron, 2017). These impairments can affect food and nutrient intake as well as the nutritional status of elderly people. Among age-related oral changes, tooth loss is the most obvious. According to a German National Survey published in 2006 (Micheelis & Schiffner, 2006), the most frequently lost teeth are the molars, followed by the maxillary premolar and front teeth. The survey also found that up to 22.6% of 65-74 year old was edentulous (DMS IV study; Hoffmann et al. (2006)). In an American survey, among people between 65 and 69 years, an average of 18 remaining teeth was reported (Carlos & Wolfe, 1989). In France, 35% of 65-79 year olds and 56% of people over the age of 80 claim they have lost all or roughly all their teeth compared to 11% of 40-64 year olds (CREDES survey; Auvray, Doussin, and Le Fur (2003)). It should be pointed out that wearing prosthesis may restore the masticatory function, but this option remains less effective than natural dentition (Fucile et al., 1998; Veyrune & Mioche, 2000). Besides tooth loss, muscle mass and strength are also known to decrease with ageing (Galo, Vitti, Mattos Mda, & Regalo, 2007; Goodpaster et al., 2006). Muscle mass decreases around 3-8% per decade after the age of 30, and the rate can increase by 15% after the age of 60 (Melton et al., 2000). With respect to masticatory muscles, some studies have highlighted age-related changes in muscle anatomy (Newton, Abel, Robertson, & Yemm, 1987), muscle activity (Kohyama, Mioche, & Bourdiol, 2003) and decline in bite force (Bakke, Holm, Jensen, Michler, & Moller, 1990). Similarly, a decline in salivary flow was observed in elderly people when compared to a younger population (Vandenberghe-Descamps et al., 2016) and can induce changes in saliva composition (Vissink, Spijkervet, & Amerongen, 1996). Salivary impairment caused by ageing has been related to changes in salivary gland anatomy and physiology (Edgar & O'Mullane, 1996), as well as tooth loss (Srinivasulu, Fareed, Sudhir, & Krishna Kumar, 2014), drug intake (Bardow, Nyvad, & Nauntofte, 2001) or disease (Chu, Ng, Chau, & Lo, 2015). Finally, ageing is accompanied by a deterioration in the acuity of taste and smell perception. For olfaction, the literature shows an increase of odor detection thresholds in older people (J. C. Stevens & Dadarwala, 1993), a decrease in perceived odor intensity of supra-threshold concentration (Koskinen & Tuorila, 2005; J.C. Stevens, Bartoshuk, & Cain, 1984; J. C. Stevens, Plantinga, & Cain, 1982) and a decrease in the ability to distinguish between odors (Kaneda, Maeshima, Kobayakawa, Ayabe-Kanamura, & Saito, 1998; Sulmont-Rossé et al., 2015). In terms of gustation, a literature review of Methven, Allen, Withers, and Gosney (2012) showed that older adults display higher detection thresholds in more than 70% of the studies (80% for saltiness). Perceived taste intensity at supra-threshold levels was found to be significantly lower for older adults in 64% of studies.

Three recent studies have conducted a systematic literature review on the relationship between oral parameters and eating behavior in elderly populations. Tada and Miura (2014) focused on the association between mastication and diet (*i.e.* food and nutrient intake). Kiesswetter et al. (in press) investigated chemosensory function and “oral” function (*i.e.* mastication and salivation) as independent determinants of diet. Finally, Muñoz-González et al. (2017) studied the relationship between hyposalivation and food behavior (*i.e.* food perception, food preference and diet). All these reviews restrained their scope to community-dwelling older adults (over 50 years old in Tada and Miura (2014); over 65 years old in Kiesswetter et al. (in press) and in Muñoz-González et al. (2017). Both Tada and Miura (2014) and Kiesswetter et al. (in press) observed that a majority of the studies display lower intake of certain foods and nutrients in elderly people suffering from dental or chewing impairments compared to those with a good oral status (22 out of 28 studies in Tada et al.; 14 out of 18 studies in Kiesswetter et al. (in press)). However, Kiesswetter et al. (in press) underlined the fact that the role of chemosensory function on the elderly’s diet remains unclear and poorly documented compared to masticatory function. Similarly, in Muñoz-González et al. (2017), only four studies providing mixed results were included on the association between the elderly’s diet and hyposalivation. The three literature reviews also highlighted that research on oral health and diet in the elderly is fragmented. None of the above-mentioned studies simultaneously evaluated masticatory, salivary and chemosensory functions in the same sample despite an impact of dental status was demonstrated on odor perception (Sulmont-Rossé et al., 2015). In Muñoz-González et al. (2017), only 8 studies out of 14 have considered masticatory and salivary function in the same experiment. Finally, while some studies have investigated the impact of oral components (*e.g.* dental status, salivary flow) on the efficiency of oral processes (*e.g.* chewing performance, bolus formation) and others investigated the impact of oral components on nutritional variables (*e.g.* food or nutrient intake), none considered both oral components, oral processes and nutritional variables in one experiment.

Consequently, the aim of the present study was to investigate the association between oral health and diet in elderly people by considering i. masticatory, salivary and chemosensory functions, and ii. parameters that account for the status of the oral components involved in food consumption (*i.e.* dental status, salivary flow, tongue strength, gustatory abilities, olfactory abilities) as well as parameters that account for the efficiency of the oral processes involved in food consumption (*i.e.* masticatory ability, chewing efficiency, food aroma release). The first objective was to investigate the relationship between the functional status of oral components and the oral processes in an elderly population. The second objective was to investigate the relationship between these different oral parameters and nutritional parameters (*i.e.* nutrient intake, food intake, corpulence). As dental status was often set as a major oral health criterion in elderly population (Kiesswetter et al., in press; Tada & Miura, 2014), we maximized the variation range of this oral parameter by recruiting half of the participants with a good dental status and half with a poor dental status.

MATERIAL AND METHODS

Participants

The data was collected as part of a program that aimed at studying the relationship between oral health and eating behavior (AlimaSSenS project: toward an adapted and healthy food supply for elderly people). A panel of elderly volunteers was recruited from a population of elderly people living at home in Dijon. The recruitment criteria were the following: older than 65 years of age, no acute pathological episodes at the time of the experiment, scoring at least 24 on the mini mental state evaluation (MMSE) (Folstein, Folstein, & McHugh, 1975) and having a number of functional units either equal to seven or more (good dental status) or equal to four or less (poor dental status). The thresholds of seven and four functional units to identify good and poor dental status, respectively, were defined according to Leake, Hawkins, and Locker (1994). A functional unit was defined as a pair of posterior antagonist teeth that had at least one contact area during chewing. An interview and a dental examination were carried out with each volunteer to ensure that they met the inclusion criteria. In addition, socio-demographic (*e.g.* income) and health information (*e.g.* self-perceived health, drug intake) were collected during this interview. Sixty-one elderly participants were included, 29 with a good dental status and 32 with a poor dental status. Table 1 shows basic characteristics of the participants.

Table 1: General characteristics of the participants of the whole sample and for each dental status groups

	All participants (n=61)		Good dental status (n=29)		Poor dental Status (n=32)	
	n	%	n	%	n	%
Age						
65-69	24	39%	10	35%	14	44%
70-74	18	30%	11	38%	7	22%
75-79	14	23%	5	17%	9	28%
> 80	5	8%	3	10%	2	6%
Gender						
Male	30	49%	15	52%	15	47%
Female	31	51%	14	48%	17	53%
Income						
< 1000€	0	0%	0	0%	0	0%
1000€ to 1500€	19	31%	5	17%	14	44%
1500€ to 2000€	14	23%	11	38%	3	9%
2000€ to 2500€	15	25%	6	21%	9	28%
> 2500€	13	21%	7	24%	6	19%
Number of drug intake						
1 to 4 pills / day	49	80%	22	76%	27	84%
> 4 pills / day	12	20%	7	24%	5	16%
Self-perceived general health compared to elderly people of the same age						
Lower	3	5%	0	0%	3	9%
Equal	30	49%	16	55%	14	44%
Greater	27	44%	13	45%	14	44%
Don't know	1	2%	0	0%	1	3%

Experimental Design

The volunteers took part in 4 sessions with duration of approximately 4 hours in total. During the first session, participants performed a clinical oral examination to measure dental status, salivary flow rates and an oral health self-assessment, then answered a food frequency questionnaire. The volunteers were also weighted, measured and they completed the Mini

Nutritional Assessment Index in order to be characterized in terms of nutritional status. The second session consisted in a measure of salivary flow rates, tongue muscular strength and a masticatory ability test. During the third session, the salivary flow rates were measured once again along with the aroma release of a mint pastille. The fourth session consisted in the fourth measurement of salivary flow rates and the evaluation of odor and gustatory perception. In parallel, the participants were asked to complete a five-day dietary record.

Measurements

Evaluation of Oral Components

Teeth counting

A trained experimenter counted the number of natural, restored and fixed prosthetic teeth (participants who wore dentures were asked to remove them for this measure).

Functional units counting

The number of functional units was evaluated by asking the participants to chew 1–2 cycles on 200-mm thick articulating paper; the number of teeth on the mandibular arch that had at least one color mark provided the number of functional units. The participants with dentures were asked if they had used their dentures while eating during their three last meals. Those who had not done so were asked to remove their dentures before completing this measure.

Tongue muscular strength

Maximal strength and strength at swallow were measured using the IOPO® device. Maximal strength was measured by instructing the participants to place the pressure probes on the surface of their tongues and press the pressure probes against their soft palate as hard as they could. Strength at swallow was measured by instructing the participants to place the pressure probes on the surfaces of the tongues, closing their mouths and swallowing saliva as naturally as possible. These measures were repeated three times and a mean value was calculated for data analysis.

Salivary flow rates

Unstimulated and stimulated salivary flows were measured as previously described (Feron et al., 2014; Neyraud, Palicki, Schwartz, Nicklaus, & Feron, 2012). The participants were asked not to smoke, eat or drink at least 1 hour before collecting the saliva. Unstimulated salivary flow was measured by instructing the participant to allow their saliva to flow into a pre-weighed screw-cap cup every time they felt like swallowing over a period of 10 minutes. Stimulated salivary flow was measured by instructing the participants to masticate a piece of pre-weighed parafilm while spitting out the saliva into a pre-weighed screw-cap cup every time they felt like swallowing over a period of 5 minutes. Cups were weighed, and salivary flow rates were expressed in mL/min assuming that 1 gram of saliva corresponds to 1 mL. The measure of salivary flow was assessed at every session and a mean value was calculated for data analysis.

Taste perception

Salt and sugar perceptions were evaluated using the water solution test previously described in Sulmont-Rossé et al. (2015). For each taste, eight solutions were presented one by one to the participants. The solutions included 2 blanks (Evian water) and 4 concentrations of NaCL or saccharose (for Nacl: S1: 0.21g/L, S2: 0.59g/L, S3: 1.90g/L, S4: 5.90g/L; for saccharose: S1: 0.59g/L, S2: 1.49g/L, S3: 3.70g/L, S4: 9.40g/L). The two middle concentrations (S2 and S3) were replicated. The solutions were presented in the following sequence: S1, S2, blank, S2, S3, S3, blank, S4. The participants were asked to taste a glass of water (Evian) and, then, to taste 20mL of each sample and to indicate whether they perceived water or a taste. They were asked to rinse with water between each sample. A combined score corresponding to the number of right answers was calculated for salt and sugar perception (/16).

Odor perception

The odor perception score was evaluated using the European Test of Olfactory Capabilities (ETOC). Sixteen trials of 4 vials were presented one by one to the participants, only one of the vials contained an odorant (Thomas-Danguin et al., 2003). For each trial, the participants were asked to note which vial contained the odorant. A score corresponding to the number of right answers was calculated (/16). The odorants of the ETOC test were provided by the creators of this test (EZUS LYON, France).

Evaluation of Oral Processes

Masticatory ability

The masticatory ability was assessed from granulometry of carrot bolus collected after oral processing (Lucas & Luke, 1986). The participants were asked to masticate a calibrated piece of raw carrot (3,1g ± 0.08) until deglutition. Once the participants considered the bolus ready to be swallowed, they were asked to spit the carrot bolus into a pre-weighted cup. After each sequence, they rinsed their mouths freely with water (10 ml), until clearing the mouth of remaining particles. The expectorated particles were then added to the initially bolus formed. The carrot bolus was then spread out on a black tissue and dried in an oven for 2 hours at 25°C before image analysis. The time needed for every participant to masticate the carrot was recorded. The number of particles as well as two parameters from the particles size distribution were considered: the median (d50) and the 99-percentile of the mini Féret diameters (d99, with only 1% of the observed particle diameters above this value).

Chewing efficiency

Chewing efficiency was measured using the two-colored chewing-gum method (Halazonetis, Schimmel, Antonarakis, & Christou, 2013; Schimmel et al., 2015). Two pieces of chewing-gum of different color were manually stuck together to form a two-colored chewing gum. The volunteers were asked to masticate the two-colored chewing gum for 20 masticatory cycles. The masticated chewing-gums were put into 2 transparent plastic sheets and were manually squeezed until obtaining a 1mm think chewing-gum before image analysis. Images of both Recto and verso faces of the gum were automatically processed and transformed from RGB values (red, green, blue) to the HSI color space (hue, saturation, intensity). The variance of the Hue component (SDH) was considered the measure of mixing.

In-mouth aroma release

Retro-nasal olfaction is a key factor of food perception, food acceptability and food intake (Mishellany-Dutour et al., 2012). Its mechanism involves the tongue-velum movements, which allow the air transfer from the oral cavity to the nasal cavity (Buettner, Beer, Hannig, & Settles, 2001). With ageing, a decrease of muscle strength can be observed (Galo et al., 2007; Goodpaster et al., 2006) and could lead to a different tongue-velum behavior compared to younger adults. In order to validate this hypothesis, an evaluation of aroma release was performed in the elderly panel based on a methodology described previously on middle-age adults (Repoux, Sémon, Feron, Guichard, & Labouré, 2012). The subjects were asked not to eat, drink or smoke for at least 1 hour before the session. Each participant was asked to position a plastic tube in both nostrils and to breathe normally. After an initial swallow, the participants were instructed to place a mint pastille in their mouth (Mentos® Now Mints Sweet Mint) and to consume it freely while keeping the lips closed. The participants had to notify the experimenter every time they swallowed. In vivo aroma release was measured using atmospheric pressure chemical ionization–mass spectrometry (API-MS). Air from the nose was sampled from the two nostrils at an average flow rate of 37ml/min and introduced into the API source of anion trap Esquire-LC mass spectrometer (Bruker Daltonique, Wissembourg, France) via fused silica capillary tubing (i.d., 0.53mm) heated at 150°C to which a 5kV positive ion corona pin discharge was applied (Repoux et al., 2012). Menthone (m/z=155), the principal aroma compound in the mint tablet was followed continuously as a tracer of aroma release during mint consumption .The amount of menthone released in the nostrils was evaluated by averaging the area under the curve of the obtained API signal. Three replicates were performed, with each session lasting 6 minutes.

Self-Assessment of Oral Health

Geriatric Oral Health Assessment Index

This questionnaire evaluates self-perception of general oral health (Slade & Spencer, 1994; Tubert-Jeannin, Riordan, Morel-Papernot, Porcheray, & Saby-Collet, 2003). The questionnaire comprises 12 items such as difficulties while eating a food due to dental impairments, difficulties in speaking due to oral impairments, or even the intake of drugs to reduce oral pain. The final score varies from 0 (very poor perceived oral health) to 60 (very good perceived oral health).

Nutritional Variables

5-day dietary record

The participants were asked to keep a 5-day dietary record (4 week days/1 weekend) of all intake of food and beverages. Data was collected by asking the volunteers to weigh their food on a scale or estimate the eaten quantity using the SU.VI.MAX iconographic method (SU.VI.Max, Candia, Polytechnica). The data was converted into nutrient content based on the CIQUAL French food composition table (2016). The choice was made to analyze data on macronutrients and on three relevant micronutrients: Calcium, vitamin D and vitamin B9. Calcium is an essential micronutrient for the elderly population as it helps prevent bone density loss and parathyroid malfunctions (McKane et al., 1996). Vitamin D, deficiencies can also lead to fractures and falls (Boucher, 2012; Dawson-Hughes, Harris, Krall, & Dallal, 1997). Finally, vitamin B9 deficiency is known to cause anemia in the elderly, which may have adverse effects on cognitive function or quality of life (Yildirim et al., 2015). Therefore, the consumption of these three essential micronutrients seemed important to follow as they play determinative roles in the general health of elderly populations.

Food frequency questionnaire

The dietary intake of 17 food categories was evaluated asking the participants their eaten frequency *i.e.* 2-3 times a day, 1 time a day, 2-3 times a week, 1 time a week, less often or never. Only three variables are analyzed in the present study as they are known to be hard to chew: meat, crude vegetables and crude fruits (Lee et al., 2004). Furthermore, several authors showed that elderly people with a poor dental status eat less meat, fruits and vegetables compared to elderly people with a good dental status (Geissler & Bates, 1984; Lee et al., 2004). Therefore, the consumption of those three food categories seemed important to observe in the AlimaSSenS panel.

Corpulence

BMI calculation. The participants were weighted using a standardized scale and measured with a measuring rod at the beginning of the first session. Each participant was asked to take off their shoes and clothes in the exception of a tee-shirt and pants.

Impedance measurement. The fat and fat-free masses were measured using the Bioelectrical Impedance Analysis (Nutriguard-M, Data-Input, Germany). Each participant was asked to lie down at least 10 minutes before the measurement in order to make sure that masses were well distributed over the body. Two electrodes were put on the dominant hand and two others on the corresponding foot. The Bioelectrical Impedance analyzed the body electrical conductivity, the percentage of fat mass among whole body mass was calculated following the equation validated by Roubenoff et al. (1997).

Statistical analyses

As a first step, correlation coefficients were calculated for all the oral parameters amongst themselves. As a second step, multiple regression analyses were conducted using the oral process variables as dependent variables. Age, gender, drug intake and self-perceived general health were added as co-variables. As a third step, multiple regression analyses were conducted using the nutritional variables as dependent variables. Age, gender, drug intake, self-perceived general health and income were added as co-variables. All statistical analyses were conducted using R-studio software version 3.3.1.

Results

Characterization of the oral components involved in food consumption

Volunteers were recruited based on their dental status i.e. according to their number of functional units; the oral status characteristics of the whole sample and for each dental status groups are presented in table 2. As expected, the number of teeth of the elderly in the poor dental status group was significantly lower than that of the elderly participants in the good dental status group ($t(59) = 6.76$; $p < 0.001$). Furthermore, the two groups significantly differed in terms of self-perceived oral health; the poor dental status group perceived their oral health as poorer compared to the good dental status group ($t(59) = 4.46$; $p < 0.001$). However, no significant differences were observed on the other oral parameters i.e. salivary flow rates, tongue muscular strength and sensory capacities. Regarding the correlations between the oral health parameters (Table 3), significant correlations were observed between number of teeth and unstimulated salivary flow, odor perception and self-perceived oral health. Elderly people with a lower number of teeth had greater salivary flow rate and a poorer odor perception score as well as a poorer self-perception of their oral health. Furthermore, the two salivary flow rates were significantly correlated as for both tongue strength measurements.

Table 2: oral status characteristics of the whole sample and for each dental status groups

	All participants		Good dental status		Poor dental status		Good *versus* poor dental status
	Mean	**SEM**	**Mean**	**SEM**	**Mean**	**SEM**	**p-value**
Number of teeth	22.62	1.17	28.90	0.37	16.94	1.65	< 0.001
Salivary flow rates (ml/min.)							
Unstimulated salivary flow	0.35	0.02	0.32	0.03	0.38	0.03	0.144
Stimulated salivary flow	1.65	0.09	1.75	0.13	1.56	0.12	0.290
Tongue muscular strength (kPa)							
Maximum tongue strength	43.17	1.64	44.72	2.12	41.77	2.47	0.372
Tongue strength at swallow	33.25	1.71	32.32	1.89	34.09	2.79	0.609
Sensory capacities							
Taste perception	9.61	0.25	9.93	0.41	9.31	0.30	0.225
Odor perception	14.79	0.26	14.72	0.36	14.84	0.38	0.820
Self-assessed oral health							
GOHAI	53.85	0.73	56.83	0.53	51.16	1.11	< 0.001

(SEM): Standard Error of the Mean

GOHAI Geriatric Oral Health Assessment Index

Table 3: Correlation table between the oral parameters

Variables	Number of teeth	Unstimulated salivary flow	Stimulated salivary flow	Maximum tongue strength	Tongue strength at swallow	Taste perception	Odor perception	Self-perceived oral health
Number of teeth		**-0,283***	0,187	-0,032	-0,119	0,206	**0,284***	**0,565*****
Unstimulated salivary flow			**0,377****	0,206	0,210	-0,031	-0,252	-0,193
Stimulated salivary flow				0,027	-0,032	0,017	-0,109	0,187
Maximum tongue strength					**0,756*****	-0,051	-0,023	0,033
Tongue strength at swallow						0,010	-0,083	-0,011
Taste perception							0,112	0,241
Odor perception								0,077
Self-perceived oral health								

* p<0.05; **p<0.01; ***p<0.001

Characterization of oral process involved in food consumption

Table 4 presents the multiple regression analyses for each food process variable: the in-mouth aroma release and the food bolus variables i.e. number of particles, d50, d99 and time needed to form the carrot bolus. None of those variables was associated with co-variables such as age, gender, drug intake and self-perceived general health. Regarding in-mouth aroma release, no significant association was observed for any of the oral status characteristics. However, some significant associations were observed for some of the food bolus formation variables. The number of particles was significantly associated with the number of teeth ($p<0.001$), stimulated salivary flow rate ($p<0.01$), maximum tongue strength ($p<0.05$) and self-perceived oral health ($p<0.05$). Elderly people who made a food bolus with fewer particles had less remaining teeth, a greater stimulated salivary flow rate, poorer maximum tongue strength and a poorer self-perception of oral health. Furthermore, the D99 was negatively significantly associated with self-perception of oral health ($p<0.05$).

Table 4: multiple regression analyses for each food process variables, after adjustment on age, gender and drug intake co-variables

	Food process variables					
	In-mouth aroma release	Number of particles	D50	D99	Time needed to form the carrot bolus	Chewing efficiency
Age	0.004	6.83	-0.02	0.07	0.44	-0.0001
Gender[+]	0.68	16.11	0.02	0.20	1.11	0.15
Number of drug intake	-0.14	-0.42	0.03	-0.02	2.52	-0.05
Self-perceived general health	-0.51	-17.36	-0.09	0.12	-8.39	-0.09
Number of teeth	-0.005	**10.90*** **	0.01	-0.08	-0.83	-0.004
Dental status[+]	0.63	13.77	0.28	1.92	1.23	0.09
Resting salivary flow	3.17	217.22	-1.10	-2.79	-15.91	-0.38
Stimulated salivary flow	-0.23	**-90.57** **	0.16	-0.008	-0.36	0.05
Maximum tongue strength	-0.01	**5.11***	-0.01	-0.03	0.07	-0.008
Tongue strength at swallow	0.02	-3.50	0.01	0.02	0.10	0.005
Taste perception	-0.10	0.49	-0.001	-0.22	0.06	0.02
Odor perception	-0.03	10.19	0.019	0.03	0.19	-0.04
Self-perceived oral health	0.09	**13.13** **	-0.02	**-0.28** **	-0.15	-0.03
R^2 (%)	24	62	28	36	37	28
p-value	0.35	<0.001	0.19	0.04	0.03	0.20

Presentation of the correlation coefficients and significance level (* $p<0.05$; ** $p<0.01$; *** $p<0.001$)

[+] Correlation ratios

Impact of masticatory, salivary and chemosensory functions on nutritional variables

The number of particles, the median diameter (d50) and the 99-percentile diameter (d99) were submitted to a clustering method. Results revealed two clusters: participants having a poor bolus efficiency (n= 23) and participants having a good bolus efficiency (n= 38). The former produced a carrot bolus with fewer and bigger particles (number of particles = 203.65 ± 22.43; d50 = 2.01 mm ± 0.10; d99 = 9.51 mm ± 0.82) than the latter (number of particles = 464.06 ±25.05; d50 = 1.49 mm ± 0.08; d99 = 2.61 mm ± 0.42). Furthermore, the former took longer to masticate the raw carrot (43.90 seconds ± 4.88) than the latter (36.41 seconds ± 3.12).

Table 5 presents the multiple regression analyses for each nutritional variable (nutrient intake, food frequency consumption and corpulence variable). The included independent variables were the co-variables (age, gender, drug intake, self-perceived oral health and income); the oral health parameters (dental status, salivary flow rates, tongue muscular strength, sensory capacities and self-assessed oral health) as well as the oral process variables (bolus efficiency, time needed to form the carrot bolus and in-mouth aroma-release).

Table 5: multiple regression analyses for each nutrient or food intakes variables as a function of oral characteristics of elderly people, after adjustment on age, gender, drug intake and income co-variables

	Nutrient intake								Food frequency consumption					Corpulence
	Energy (Kcal)	Protein	Carbohydrate	Lipid	Fiber	Calcium	Vitamin D	Vitamin B9	Meat	Raw fruits	Raw vegetables	Dairy products	Fat mass (%)	Body Mass Index
Age	18.67	0.51	3.07	0.04	0.19	3.14	0.02	1.51	0.02	0.25	0.05	0.02	0.08	-0.01
Gender	295.50	8.78	29.15	7.56	5.11	66.40	0.40	3.20	0.71	0.51	0.53	0.34	**8.21*****	**3.82***
Number of drug intake	-45.61	-0.31	**-9.50***	-1.60	-1.00	-26.05	-0.01	-10.31	0.05	-0.14	0.03	0.07	-0.12	0.22
Self-perceived general health	-16.01	-0.02	-14.76	0.91	-2.23	-1.08	0.01	-23.28	-0.36	-1.75	-0.39	0.92	-1.34	**-2.45***
income	0.11	0.003	0.02	0.002	0.002	-0.02	-0.00004	0.03	0.001	0.001	0.001	0.002	-0.0002	-0.0003
Number of teeth	3.06	0.41	0.85	-0.01	0.22	8.20	0.03	3.57	-0.02	-0.06	**0.27****	-0.01	-0.02	-0.18
Dental status[+]	16.12	2.12	13.63	2.96	0.28	-3.19	-0.16	-52.19	-0.02	-2.93	**5.38****	1.74	4.15	2.53
Unstimulated salivary flow	729.81	**42.41***	68.63	27.88	-0.42	504.56	1.10	41.96	-1.18	-3.51	-3.03	-1.73	-8.69	-3.52
Stimulated salivary flow	-125.28	-5.76	**-27.79***	-3.29	**-4.85***	**-135.92**	-0.43	-23.17	1.00	-1.19	-1.13	-0.25	0.0004	0.11
Maximum tongue strength	-10.23	-0.41	-0.99	-0.82	-0.07	-3.77	0.02	-3.32	0.005	-0.04	0.04	-0.09	0.13	0.06
Tongue strength at swallow	5.18	0.21	0.25	0.29	-0.12	3.38	-0.03	1.08	0.001	0.07	-0.02	0.02	-0.07	-0.03
Taste perception	-22.75	-1.09	-0.30	-0.68	0.23	-7.64	-0.22	6.68	-0.01	0.40	-0.39	0.21	-0.40	-0.21
Odor perception	-49.43	**-3.70***	-6.16	-2.25	-1.09	**-51.69***	-0.25	-11.30	-0.11	0.28	-0.11	-0.29	-0.77	-0.16
Self-perceived oral health	4.95	1.02	-1.15	0.28	-0.42	13.39	-0.04	-3.05	-0.16	0.10	0.044	-0.05	0.17	0.08
Masticatory ability[+]	150.25	**16.96***	18.95	4.99	-1.53	206.41	0.97	65.55	-1.97	1.57	-2.09	-1.46	0.40	-0.52
Chewing efficiency	60.52	3.11	13.96	-4.99	5.04	187.06	0.10	32.96	-2.26	0.58	1.41	-2.12	0.49	-0.23
Time needed to form a carrot bolus	2.30	-0.04	0.26	0.20	-0.01	**4.99***	**0.04***	-0.26	-0.03	-0.03	0.03	-0.03	0.04	-0.02
In mouth aroma release	-36.79	0.38	-5.22	-1.30	-0.67	-25.67	0.03	0.05	-0.13	-0.10	0.27	0.01	-0.20	-010
R^2 (%)	41	47	45	25	43	39	30	35	27	26	42	34	57	45
p-value	0.10	0.02	0.04	0.71	0.06	0.15	0.46	0.26	0.64	0.67	0.08	0.29	<0.001	0.04

Presentation of the correlation coefficients and significance level (* p<0.05; **p<0.01; ***p<0.001)

[+] Correlation ratios

As shown in table 5, after adjusting for age, gender, drug intake, self-perceived oral health and income, protein intake was significantly associated with unstimulated salivary flow, odor perception and masticatory ability ($p<0.05$). Elderly people with a lower unstimulated salivary flow, a poorer masticatory ability and better odor perception as well as had a lower protein intake. Carbohydrate and fiber intake were negatively significantly associated with stimulated salivary flow ($p<0.05$), carbohydrate was also negatively significantly associated with drug intake. Elderly people with greater drug intake and greater stimulated salivary flow had lower carbohydrate intake; elderly people with a greater stimulated salivary flow had lower fiber intake. Calcium intake was negatively associated with odor perception and positively associated with time needed to form a food bolus. Finally, Vitamin D intake was positively associated with the time needed to form a carrot bolus.

Regarding food frequency consumption, the vegetable consumption was the only one being significantly associated with oral parameters. Elderly people with a lower number of teeth and occlusal contact consumed vegetables less frequently.

Regarding corpulence, both fat mass and body mass index were significantly associated with gender, with women having a greater percentage of fat mass and a greater body mass index. Furthermore, body mass index was significantly associated with self-perceived general health, elderly people with a poorer general health self-perception had a greater body mass index.

Discussion

Oral health and food oral processing

Three results should be highlighted from the characterization of oral components. To begin with, a decrease in number of teeth was associated with a decline in olfactory capacities. A similar result was observed by Griep, Mets, and Massart (1997), Lamy, Mojon, Kalykakis, Legrand, and Butz-Jorgensen (1999) and Sulmont-Rossé et al. (2015). The latter argued that such association might not reflect a causal effect from one factor to another, but rather the fact that similar factors are responsible for the decline of both dental status and olfactory capacities. However, further research is needed to understand the exact nature of the correlation between olfactory perception and dental status. Conversely, a decline in dental status was not associated with a decline in salivary flow. A similar result was observed in Vandenberghe-Descamps et al. (2016): a decline in salivary flow was observed in healthy elderly people compared to young adults independently of their dental status. However, some studies demonstrate a correlation between the number of remaining teeth and reduction in salivary flow in elderly populations (Ikebe et al., 2011; Samnieng et al., 2012). It has been argued that people with a low salivary flow are more likely to lose teeth because of the cleaning and protecting function of saliva in the oral cavity (Caplan & Hunt, 1996; Pedersen, Bardow, Jensen, & Nauntofte, 2002). Once again, further research is necessary to decipher the link between dental status and salivary function, and to identify surrounding factors such as oral care or food habits that might modulate this relationship. Finally, results show that self-perceived oral health (GOHAI questionnaire) correlates with the number of remaining teeth. This may be due to the fact that tooth loss is often experienced as a "traumatic" event and a visible symbol of ageing (Saintrain & de Souza, 2012). On the contrary, the decline of the other oral parameters (salivary flow, muscle strength, olfactory and gustatory perception) is progressive over time, without the individual necessarily becoming aware of it. In fact, elderly people often underestimated the decline in their chemosensory abilities (Hoffman, Cruickshanks, & Davis, 2009; Murphy et al., 2002; Schubert et al., 2012). In Sulmont-Rossé et al. (2015), more than one-half of elderly people who obtained olfactory scores lower than those of younger people reported that they perceived odors as well as when they were young.

This distortion in self-reporting appeared to be even higher for gustation: only 10% of elderly people who suffered from gustatory impairment reported that their ability to perceive the saltiness was lower than when they were young.

Regarding the relationship between the functional status of oral components and the oral mechanisms, the number of particles in the carrot bolus was associated with three oral components that are known to play a key role in bolus formation: number of teeth, tongue strength and salivary flow. In fact, several authors have observed a correlation between dental status and masticatory performance (Ikebe et al., 2012; Ikebe et al., 2011; Kikutani et al., 2009; Leake et al., 1994). In Ikebe et al. (2011), participants were asked to chew a gummy jelly and the authors assessed masticatory performance by measuring the remaining glucose from the masticated gummy jelly. In parallel, the number of residual teeth was measured. The results highlighted a significant correlation between masticatory performance and number of residual teeth. However, none of those studies included data on food bolus formation. The present results demonstrate that in addition to dental status, tongue strength can also modulate food bolus formation in elderly people. To the best of our knowledge, the present study is the first to look at the relationship between muscle strength and food bolus formation. In fact, several studies have explored the impact of ageing on masticatory muscle strength (*e.g.* Goodpaster et al. (2006); Peyron, Blanc, Lund, and Woda (2004)) and the relationship between dental status and masticatory strength (*e.g.* Veyrune and Mioche (2000); Kohyama et al. (2003)). Finally, this study found that the higher the salivary flow of the participant, the lower the number of particles produces in the boli. In fact, a great amount of saliva will allow particles to agglomerate more easily and thus require less mastication to obtain a swallowable bolus (Humphrey & Williamson, 2001). In addition, an association between the number of particles and the self-perceived oral health was observed as well as an association between the d99 and the self-perceived oral health. The latter means that the diameter of the larger particles was higher for participants who self-reported poor oral health compared to participants who self-reported good oral health. Interestingly, one could argue that making food bolus with big particles lead the elderly to perceive their oral health as quite poor, but one could also argue that the elderly who self-perceived their oral health are cautious when masticating hard-to-chew food such as carrot and restraint their efforts to masticate such food.

Oral health, food oral processing and food behavior

The present results show a significant association between the consumption of raw vegetables and dental status: a decline in the number of teeth and in the number of occlusal contacts is associated with a lower intake of raw vegetable. This result is consistent with the literature. In fact, a review of Kiesswetter et al. (in press) revealed that 6 out 6 studies observed that participants suffering from dental impairment reported lower consumption of vegetables, and therefore had significantly lower intake of vitamin C and fiber (Inomata et al., 2014; Masanori Iwasaki et al., 2014; Österberg, Tsuga, Rothenberg, Carlsson, & Steen, 2002; Tsai & Chang, 2011; Yoshida et al., 2011; Yoshihara, Watanabe, Nishimuta, Hanada, & Miyazaki, 2005). For instance, Inomata et al. (2014) showed that a decline in occlusal force was associated with lower intake of vegetables as well as lower intake of vitamin C and fiber (food and nutrient intake were assessed by using the BDHQ – Brief-type Self-administrated Diet History Questionnaire). In the present experiment, fiber intake was associated with a decrease in stimulated salivary flow but not with impairment in dental status. Conversely, in M. Iwasaki et al. (2016), participants with lower stimulated salivary flow had lower vegetable intake but no effects were observed on fiber intake.

While the impact of dental status on vegetable intake was observed in a very large majority of the studies having investigating this association, results proved to be somewhat mixed when looking at the impact of oral health on meat and protein consumption. In Kiesswetter et al. (in press) 1 and 8 studies observed an impact of oral health on meat and protein intake respectively out of the 9 and 15 studies which investigated these relationships (Inomata et al., 2014; Masanori Iwasaki et al., 2014; Lee et al., 2004; Marcenes, Steele, Sheiham, & Walls, 2003; Marshall, Warren, Hand, Xie, & Stumbo, 2002; Österberg & Steen, 1982; Österberg et al., 2002; Sheiham et al., 2001; Yoshihara et al., 2005). In the present experiment, we observed no association between oral parameters and meat consumption. However, we observed an association between protein intake and three oral parameters: unstimulated salivary flow, bolus efficiency and odor perception. The present result on salivary flow (lower unstimulated salivary flow was associated with lower protein intake) supports the conclusion of the previous research of Vandenberghe-Descamps, Labouré, Septier, Feron, and Sulmont-Rossé (2017) on oral comfort. Indeed, when exploring the dimensions underlining the oral comfort when eating a piece of meat, the ability to moisten the sample with saliva was reported to be an important factor by elderly people for the ability to masticate the sample. In the present study, multiple regressions revealed that protein intake was associated with bolus efficiency (*i.e.* good bolus efficiency *versus* poor bolus efficiency) but not with dental status (*i.e.* number of teeth, number of occlusal). It might be suggested that dental status is not sufficient to account for the impact of oral health on protein consumption in an elderly population, while bolus efficiency better accounts for the complex interactions between dental status, muscle strength and masticatory pattern when eating meat.

The results of the present study showed that odor perception was negatively associated with protein and calcium intake: participants with good odor perception had a lower intake of protein and calcium. According to the review of Kiesswetter et al. (in press), only two studies investigated the impact of chemosensory perception and diet, and both provided mixed results. In Duffy, Backstrand, and Ferris (1995), most correlations between chemosensory perception and food intake were not significant; only a significant but low correlation was observed between odor perception and fat intake. Dean, Raats, Grunert, Lumbers, and Food Later Life (2009) did not identify self-reported ability to taste and smell as predictor of diet variety. In addition, in Griep et al. (1996), no significant correlation was observed between odor perception and nutrient intake, except for energy. However, de Jong, Mulder, de Graaf, and van Staveren (1999) did not observe a decrease of energy intake in participants with poor odor perception.

Finally, the present results did not show any relationship between oral parameters and corpulence variables. Österberg et al. (2010) actually showed that elderly people with fewer remaining teeth had higher body mass index. However, de Marchi, Hugo, Hilgert, and Padilha (2012) highlighted the fact that edentulism could be either associated with underfat or overfat status.

When looking at the results of the present study, but also at the results published in the scientific literature, the associations between oral parameters and nutritional variables are scarce and even contradictory. Obviously, part of the discrepancy between the different studies could be explained by the fact that different methods were used to assess oral parameters as well as nutritional variables. It could also be explained by the sample characteristics. For instance, Poisson, Laffond, Campos, Dupuis, and Bourdel-Marchasson (2016) did not observe any relationship between hyposalivation and protein intake. However, the elderly sample of this study showed a very low level of protein intake (corresponding to less than half of the dietary allowances). On the contrary, the elderly people recruited for the present study were quite healthy and consumed a diet quite close to the recommendations. Nevertheless, it can be argued that oral health is only one factor among many others liable to have an impact on food behavior in the elderly people. Furthermore, it is also very possible that elderly people with a poor dental status change their food choice according to physical criterion rather than to nutritional criterion – for instance by favoring soft meat and cooked vegetables rather than hard-to-chew food.

Limits and perspectives of the present study

The innovative potential of the present experiment lies in the in-depth characterization of food oral processing in an elderly population, by considering both food bolus formation and food sensory perception, as well as by characterizing both oral status and oral processes. However, some methodological limitations should be considered and be taken into account for future studies.

First, the sample size of the present study was relatively small compared to some studies that have investigated the impact of oral health on food behavior. For instance, Appollonio, Carabellese, Frattola, and Trabucchi (1997), Lee et al. (2004), and Tsai and Chang (2011) recruited 1137, 3075 and 2761 volunteers respectively. However, Shinkai et al. (2002) and Gunji et al. (2009) only recruited 54 and 30 volunteers in their study respectively (the first ones studied the impact of dental status on food and nutrient intake and the second ones the impact of denture quality on dietary intake). In the present experiment, we sought a compromise between having a sufficient number of participants to highlight possible effects and having enough resources (technical and human) to achieve the numerous measures planned for each participant. Furthermore, as dental status is often set as a major oral health criterion in elderly populations (Kiesswetter et al., in press; Tada & Miura, 2014), we maximized the variation range of this oral parameter by recruiting half of the participants with a good dental status and half with a poor dental status. If the recruitment of elderly people with a good dental status was quite easy, the recruitment of elderly people with a poor dental health was quite challenging and effortful. In fact, such people are usually frail and dependent, and obviously not the very first ones to be enthusiastic about participating in a project on oral health.

Second, despite the fact that characterization of oral health in the present elderly sample was broader than in similar studies, there are still some oral parameters that were not taken into account, such as masticatory pattern (*e.g.* number and amplitude of masticatory cycles) or texture perception. In fact, given the number of measurements planned for each participant, we had to prioritize the possible measurements. For this reason, measurements of masticatory pattern were not performed in the present experiment. Furthermore, measurements of texture perception were not performed because at the time of the study there were still too few validated tests and these few tests did not shown any strong age effect on texture perception (Optifel, 2017).

Third, the measurement of oral mechanisms was done using a raw carrot for bolus formation and a mint pastille for in-mouth aroma release. Both tests were validated through previous experiments (Woda et al. (2010) for the carrot bolus test; Repoux et al. (2012) for the in-mouth mint release test). Obviously, these two food models do not allow accounting for the large variability of texture and flavor that can be found in food. When looking at the impact of meat oral processing on protein or meat intake, it would be worth investigating meat bolus formation or in-mouth aroma release from a meat sample. However, such measurements still need to overcome some technological challenges. Regarding food bolus formation, a carrot slice is easy to calibrate. Furthermore, the analysis of a carrot bolus is quite easy to perform as the shape of carrot particles is relatively homogeneous, while meat breakdown leads to stringy and round particles. Regarding in-mouth aroma release, the use of a mint pastille allows the monitoring of one specific aroma (menthone) easy to follow regardless of masticatory efficiency, which is a non-negligible factor that explains the inter-individual variability of aroma release, while in-mouth aroma release from a meat sample request to follow several aroma compounds in small quantity. Nevertheless, one can expect that tests to investigate food oral processing in conditions closer to real-life food consumption will be developed in the near future.

Finally, only the nutrient intake data were extracted so far from the 5-day dietary record. It could be interesting to further explore these data not only from a nutritional point of view, but also by taking into account food's physical characteristics. In fact, some elderly people may avoid a roast beefsteak because of chewing difficulties but still be able to eat stewed or even ground meat. Consequently, a short perspective to this work will be to sort the foods collected in the dietary records according to rheological and physical parameters (*e.g.* hardness, water content) and to investigate possible relationships between oral health and the textural properties of food chosen by the elderly population.

Conclusion

In conclusion, the present study revealed only a few effects of oral health parameters on the elderly's diet. In fact, oral health should be considered as one factors among many others liable to have an impact on food behavior in elderly populations. Nevertheless, the results demonstrated that focusing only on dental status is insufficient when investigating oral health in elderly people. Indeed, in the present study, food bolus formation was related not only to dental status but also to salivary flow and tongue strength. Regarding the impact of oral health on nutritional variables, raw vegetable intake was related to the dental status in healthy elderly people, but protein intake was related to salivary status as well as food bolus formation.

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References

Appollonio, I., Carabellese, C., Frattola, A., & Trabucchi, M. (1997). Influence of dental status on dietary intake and survival in community-dwelling elderly subjects. *Age Ageing,* 26(6), 445-456.

Auvray, L., Doussin, A., & Le Fur, P. (2003). Santé, soins et protection sociale en 2002, CREDES.

Bakke, M., Holm, B., Jensen, B. L., Michler, L., & Moller, E. (1990). Unilateral, isometric bite force in 8-68-year-old women and men related to occlusal factors. *Scand J Dent Res,* 98(2), 149-158.

Bardow, A., Nyvad, B., & Nauntofte, B. (2001). Relationships between medication intake, complaints of dry mouth, salivary flow rate and composition, and the rate of tooth demineralization in situ. *Archives of Oral Biology,* 46(5), 413-423.

Boucher, B. J. (2012). The Problems of Vitamin D Insufficiency in Older People. *Aging and Disease,* 3(4), 313-329.

Buettner, A., Beer, A., Hannig, C., & Settles, M. (2001). Observation of the swallowing process by application of videofluoroscopy and real-time magnetic resonance imaging-consequences for retronasal aroma stimulation. *Chem Senses,* 26(9), 1211-1219.

Caplan, D. J., & Hunt, R. J. (1996). Salivary flow and risk of tooth loss in an elderly population. *Community Dent Oral Epidemiol,* 24(1), 68-71.

Carlos, J. P., & Wolfe, M. D. (1989). Methodological and nutritional issues in assessing the oral health of aged subjects. *American Journal of Clinical Nutrition,* 50(5), 1210-1218.

Chu, C. H., Ng, A., Chau, A. M., & Lo, E. C. (2015). Oral health status of elderly chinese with dementia in Hong Kong. *Oral Health Prev Dent,* 13(1), 51-57.

Dawson-Hughes, B., Harris, S. S., Krall, E. A., & Dallal, G. E. (1997). Effect of calcium and vitamin D supplementation on bone density in men and women 65 years of age or older. *N Engl J Med,* 337(10), 670-676.

de Graaf, C. (2012). Texture and satiation: The role of oro-sensory exposure time. *Physiology & Behavior,* 107(4), 496-501.

de Jong, N., Mulder, I., de Graaf, C., & van Staveren, W. A. (1999). Impaired sensory functioning in elders: the relation with its potential determinants and nutritional intake. *Journal of gerontology,* 54A(8), B324-B331.

de Marchi, R. J., Hugo, F. N., Hilgert, J. B., & Padilha, D. M. P. (2012). Association between number of teeth, edentulism and use of dentures with percentage body fat in south Brazilian community-dwelling older people. *Gerodontology,* 29(2), e69-e76.

Dean, M., Raats, M. M., Grunert, K. G., Lumbers, M., & Food Later Life, T. (2009). Factors influencing eating a varied diet in old age. *Public Health Nutr,* 12(12), 2421-2427.

Duffy, V. B., Backstrand, J. R., & Ferris, A. M. (1995). Olfactory Dysfunction and Related Nutritional Risk in Free-Living, Elderly Women. *Journal of the American Dietetic Association,* 95(8), 879-884.

Edgar, W. M., & O'Mullane, D. M. (1996). *Saliva and Oral Health*: British Dental Association.

Feron, G., Ayed, C., Qannari, E. M., Courcoux, P., Laboure, H., & Guichard, E. (2014). Understanding Aroma Release from Model Cheeses by a Statistical Multiblock Approach on Oral Processing. *PLoS ONE,* 9(4), e93113.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. *J Psychiatr Res,* 12(3), 189-198.

Fucile, S., Wright, P. M., Chan, I., Yee, S., Langlais, M. E., & Gisel, E. G. (1998). Functional oral-motor skills: Do they change with age? *Dysphagia,* 13(4), 195-201.

Galo, R., Vitti, M., Mattos Mda, G., & Regalo, S. C. (2007). Masticatory muscular activation in elderly individuals during chewing. *Gerodontology,* 24(4), 244-248.

Geissler, C. A., & Bates, J. F. (1984). The nutritional effects of tooth loss. *American Journal of Clinical Nutrition,* 39, 478-489.

Goff, S. A., & Klee, H. J. (2006). Plant volatile compounds: sensory cues for health and nutritional value? *Science,* 311(5762), 815-819.

Goodpaster, B. H., Park, S. W., Harris, T. B., Kritchevsky, S. B., Nevitt, M., Schwartz, A. V., . . . Newman, A. B. (2006). The loss of skeletal muscle strength, mass, and quality in older adults: the health, aging and body composition study. *J Gerontol A Biol Sci Med Sci,* 61(10), 1059-1064.

Griep, M. I., Mets, T. F., & Massart, D. L. (1997). Different effects of flavour amplification of nutrient dense foods on preference and consumption in young and elderly subjects. *Food Quality and Preference,* 8, 151-156.

Griep, M. I., Verleye, G., Franck, A. H., Collys, K., Mets, T. F., & Massart, D. L. (1996). Variation in nutrient intake with dental status, age and odour perception. *European Journal of Clinical Nutrition,* 50, 816-825.

Gunji, A., Kimoto, S., Koide, H., Murakami, H., Matsumaru, Y., Kimoto, K., . . . Kobayashi, K. (2009). Investigation on how renewal of complete dentures impact on dietary and nutrient adequacy in edentulous patients. *J Prosthodont Res,* 53(4), 180-184.

Halazonetis, D. J., Schimmel, M., Antonarakis, G. S., & Christou, P. (2013). Novel software for quantitative evaluation and graphical representation of masticatory efficiency. *J Oral Rehabil,* 40(5), 329-335.

Havermans, R. C., Siep, N., & Jansen, A. (2010). Sensory-specific satiety is impervious to the tasting of other foods with its assessment. *Appetite,* 55(2), 196-200.

Hoffman, H. J., Cruickshanks, K. J., & Davis, B. (2009). Perspectives on population-based epidemiological studies of olfactory and taste impairment. *Ann N Y Acad Sci*.

Hoffmann, T., John, M., Kerschbaum, T., Micheelis, W., Potthoff, P., Reich, E., . . . Schroeder, E. (2006). Vierte Deutsche Mundgesundheitsstudie (DMS IV). *Köln. Mikrozensus: Fragen zur Gesundheit (2009a): Verteilung der Bevölkerung auf Body-Mass-Index-Gruppen in*.

Humphrey, S. P., & Williamson, R. T. (2001). A review of saliva: Normal composition, flow, and function. *The Journal of Prosthetic Dentistry,* 85(2), 162-169.

Ikebe, K., Matsuda, K., Kagawa, R., Enoki, K., Okada, T., Yoshida, M., & Maeda, Y. (2012). Masticatory performance in older subjects with varying degrees of tooth loss. *J Dent,* 40(1), 71-76.

Ikebe, K., Matsuda, K., Kagawa, R., Enoki, K., Yoshida, M., Maeda, Y., & Nokubi, T. (2011). Association of masticatory performance with age, gender, number of teeth, occlusal force and salivary flow in Japanese older adults: is ageing a risk factor for masticatory dysfunction? *Arch Oral Biol,* 56(10), 991-996.

Inomata, C., Ikebe, K., Kagawa, R., Okubo, H., Sasaki, S., Okada, T., . . . Maeda, Y. (2014). Significance of occlusal force for dietary fibre and vitamin intakes in independently living 70-year-old Japanese: from SONIC Study. *J Dent,* 42(5), 556-564.

Iwasaki, M., Taylor, G. W., Manz, M. C., Yoshihara, A., Sato, M., Muramatsu, K., . . . Miyazaki, H. (2014). Oral health status: relationship to nutrient and food intake among 80-year-old Japanese adults. *Community Dentistry and Oral Epidemiology,* 42(5), 441-450.

Iwasaki, M., Yoshihara, A., Ito, K., Sato, M., Minagawa, K., Muramatsu, K., . . . Miyazaki, H. (2016). Hyposalivation and dietary nutrient intake among community-based older Japanese. *Geriatr Gerontol Int,* 16(4), 500-507.

Jacobs, H. L., & Sharma, K. N. (1969). Taste versus calories - Sensory and metabolic signals in control of food intake. *Annals of the New York Academy of Sciences,* 157(A2), 1084-&.

Kaneda, H., Maeshima, K., Kobayakawa, T., Ayabe-Kanamura, S., & Saito, S. (1998). Comparison between young and elderly people in quality discrimination and identification of mixed odors and tastes. *Chemical Senses,* 23(2), 228.

Kaplan, M. D., & Baum, B. J. (1993). The functions of saliva. *Dysphagia,* 8(3), 225-229.

Kiesswetter, E., Donini, L., Migliaccio, S., Poggiogalle, E., Sulmont-Rossé, C., Feart, C., . . . Volkert, D. (in press). Functional determinants of dietary intake in community-dwelling older adults - a DEDIPAC systematic literature review. *Public Health Nutr*.

Kikutani, T., Tamura, F., Nishiwaki, K., Kodama, M., Suda, M., Fukui, T., . . . Kimura, M. (2009). Oral motor function and masticatory performance in the community-dwelling elderly. *Odontology,* 97(1), 38-42.

Kohyama, K., Mioche, L., & Bourdiol, P. (2003). Influence of age and dental status on chewing behaviour studied by EMG recordings during consumption of various food samples. *Gerodontology,* 20(1), 15-23.

Koskinen, S., & Tuorila, H. (2005). Performance on an odor detection and identification test as a predictor of ortho- and retronasal odor intensity ratings in the young and elderly. *Food Quality and Preference,* 16(5), 383-392.

Lamy, M., Mojon, P., Kalykakis, G., Legrand, R., & Butz-Jorgensen, E. (1999). Oral status and nutrition in the institutionalized elderly. *Journal of Dentistry,* 27(6), 443-448.

Larson, J. S., Redden, J. P., & Elder, R. S. (2014). Satiation from sensory simulation: Evaluating foods decreases enjoyment of similar foods. *Journal of Consumer Psychology,* 24(2), 188-194.

Leake, J. L., Hawkins, R., & Locker, D. (1994). Social and functional impact of reduced posterior dental units in older adults. *J Oral Rehabil,* 21(1), 1-10.

Lee, J. S., Weyant, R. J., Corby, P., Kritchevsky, S. B., Harris, T. B., Rooks, R., . . . Newman, A. B. (2004). Edentulism and nutritional status in a biracial sample of well-functioning, community-dwelling elderly: the health, aging, and body composition study. *Am J Clin Nutr,* 79(2), 295-302.

Lucas, P. W., & Luke, D. A. (1986). Is food particle size a criterion for the initiation of swallowing? *J Oral Rehabil,* 13(2), 127-136.

Marcenes, W., Steele, J. G., Sheiham, A., & Walls, A. W. (2003). The relationship between dental status, food selection, nutrient intake, nutritional status, and body mass index in older people. *Cadernos de Saude Publica,* 19(3), 809-816.

Marshall, T. A., Warren, J. J., Hand, J. S., Xie, X.-J., & Stumbo, P. J. (2002). Oral health, nutrient intake and dietary quality in the very old. *The Journal of the American Dental Association,* 133(10), 1369-1379.

McKane, W. R., Khosla, S., Egan, K. S., Robins, S. P., Burritt, M. F., & Riggs, B. L. (1996). Role of calcium intake in modulating age-related increases in parathyroid function and bone resorption. *The Journal of Clinical Endocrinology & Metabolism,* 81(5), 1699-1703.

Melton, L. J., 3rd, Khosla, S., Crowson, C. S., O'Connor, M. K., O'Fallon, W. M., & Riggs, B. L. (2000). Epidemiology of sarcopenia. *J Am Geriatr Soc,* 48(6), 625-630.

Methven, L., Allen, V. J., Withers, C. A., & Gosney, M. A. (2012). Ageing and taste. *Proceedings of the Nutrition Society,* 71(4), 556-565.

Micheelis, W., & Schiffner, U. (2006). Fourth German oral health study (DMS IV). *Institut der Deutschen Zahnärzte (IDZ, Materialienreihe Band 31).*

Mioche, L. (2004). Mastication and food texture perception: Variation with age. *Journal of Texture Studies,* 35(2), 145-158.

Mishellany-Dutour, A., Woda, A., Laboure, H., Bourdiol, P., Lachaze, P., Guichard, E., & Feron, G. (2012). Retro-nasal aroma release is correlated with variations in the in-mouth air cavity volume after empty deglutition. *PLoS ONE,* 7(7), 17.

Muñoz-González, C., Vandenberghe-Descamps, M., Feron, G., Canon, F., Labouré, H., & Sulmont-Rossé, C. (2017). Association between salivary hypofunction and food consumption in the elderlies. A systematic literature review. *The journal of nutrition, health & aging*.

Murphy, C., Schubert, C. R., Cruickshanks, K. J., Klein, B. E., Klein, R., & Nondahl, D. M. (2002). Prevalence of olfactory impairment in older adults. *JAMA,* 288(18), 2307-2312.

Newton, J. P., Abel, R. W., Robertson, G. M., & Yemm, R. (1987). A computed tomography (CT) study of changes in human masseter and medial pterygoid muscles with age. *Journal of Dental Research,* 66(4), 887-887.

Neyraud, E., Palicki, O., Schwartz, C., Nicklaus, S., & Feron, G. (2012). Variability of human saliva composition: Possible relationships with fat perception and liking. *Archives of Oral Biology,* 57(5), 556-566.

O'Doherty, J. (2000). Sensory-specific satiety-related olfactory activation of the human orbitofrontal cortex (vol 11, pg 399, 2000). *Neuroreport,* 11(4), COVER3-COVER3.

Optifel. (2017). Conférence finale du projet Optifel.

Österberg, T., Dey, D. K., Sundh, V., Carlsson, G. E., Jansson, J. O., & Mellstrom, D. (2010). Edentulism associated with obesity: a study of four national surveys of 16 416 Swedes aged 55–84 years. *Acta Odontol Scand,* 68(6), 360-367.

Österberg, T., & Steen, B. (1982). Relationship between dental state and dietary intake in 70-year-old males and females in Göteborg, Sweden: a population study*. *Journal of Oral Rehabilitation,* 9(6), 509-521.

Österberg, T., Tsuga, K., Rothenberg, E., Carlsson, G. E., & Steen, B. (2002). Masticatory ability in 80-year-old subjects and its relation to intake of energy, nutrients and food items. *Gerodontology,* 19(2), 95-101.

Pedersen, A. M., Bardow, A., Jensen, S. B., & Nauntofte, B. (2002). Saliva and gastrointestinal functions of taste, mastication, swallowing and digestion. *Oral Dis,* 8(3), 117-129.

Peyron, M. A., Blanc, O., Lund, J. P., & Woda, A. (2004). Influence of age on adaptability of human mastication. *Journal of Neurophysiology,* 92(2), 773-779.

Poisson, P., Laffond, T., Campos, S., Dupuis, V., & Bourdel-Marchasson, I. (2016). Relationships between oral health, dysphagia and undernutrition in hospitalised elderly patients. *Gerodontology,* 33(2), 161-168.

Prinz, J. F., & Lucas, P. W. (1997). An optimization model for mastication and swallowing in mammals. *Proc Biol Sci,* 264(1389), 1715-1721.

Repoux, M., Sémon, E., Feron, G., Guichard, E., & Labouré, H. (2012). Inter-individual variability in aroma release during sweet mint consumption. *Flavour and Fragrance Journal,* 27(1), 40-46.

Rolls, B. J. (1986). Sensory-specific satiety. *Nutrition Reviews,* 44(3), 93-101.

Roubenoff, R., Baumgartner, R. N., Harris, T. B., Dallal, G. E., Hannan, M. T., Economos, C. D., . . . Kiel, D. P. (1997). Application of bioelectrical impedance analysis to elderly populations. *J Gerontol A Biol Sci Med Sci,* 52(3), M129-136.

Saintrain, M. V. d. L., & de Souza, E. H. A. (2012). Impact of tooth loss on the quality of life. *Gerodontology,* 29(2), e632-e636.

Samnieng, P., Ueno, M., Shinada, K., Zaitsu, T., Wright, F. A., & Kawaguchi, Y. (2012). Association of hyposalivation with oral function, nutrition and oral health in community-dwelling elderly Thai. *Community Dent Health,* 29(1), 117-123.

Schimmel, M., Christou, P., Miyazaki, H., Halazonetis, D., Herrmann, F. R., & Muller, F. (2015). A novel colourimetric technique to assess chewing function using two-coloured specimens: Validation and application. *J Dent,* 43(8), 955-964.

Schubert, C. R., Cruickshanks, K. J., Fischer, M. E., Huang, G. H., Klein, B. E., Klein, R., . . . Nondahl, D. M. (2012). Olfactory impairment in an adult population: the Beaver Dam Offspring Study. *Chem Senses,* 37(4), 325-334.

Schwartz, C., Vandenberghe-Descamps, M., Sulmont-Rossé, C., Tournier, C., & Feron, G. (2017). Behavioral and physiological determinants of food choice and consumption at sensitive periods of the life span, a focus on infants and elderly. *Innovative Food Science & Emerging Technologies*.

Sheiham, A., Steele, J. G., Marcenes, W., Lowe, C., Finch, S., Bates, C. J., . . . Walls, A. W. (2001). The relationship among dental status, nutrient intake, and nutritional status in older people. *Journal of Dental Research,* 80(2), 408-413.

Shinkai, R. S., Hatch, J. P., Rugh, J. D., Sakai, S., Mobley, C. C., & Saunders, M. J. (2002). Dietary intake in edentulous subjects with good and poor quality complete dentures. *J Prosthet Dent,* 87(5), 490-498.

Slade, G. D., & Spencer, A. J. (1994). Development and evaluation of the Oral Health Impact Profile. *Community Dent Health,* 11.

Srinivasulu, G., Fareed, N., Sudhir, K. M., & Krishna Kumar, R. V. (2014). Relationship between stimulated salivary factors, dental caries status and nutritional condition among institutionalized elderly people. *Oral Health Dent Manag,* 13(1), 49-53.

Stevens, J. C., Bartoshuk, L. M., & Cain, W. S. (1984). Chemical senses and aging: taste versus smell. *Chemical Senses,* 9, 167-179.

Stevens, J. C., & Dadarwala, A. D. (1993). Variability of olfactory threshold and its role in assessment of aging. *Perception & Psychophysics,* 54(3), 296-302.

Stevens, J. C., Plantinga, A., & Cain, W. S. (1982). Reduction of odor and nasal pungency associated with aging. *Neurobiology of Aging,* 3(2), 125-132.

Sulmont-Rossé, C., Maitre, I., Amand, M., Symoneaux, R., Van Wymelbeke, V., Caumon, E., . . . Issanchou, S. (2015). Evidence for different patterns of chemosensory alterations in the elderly population: impact of age versus dependency. *Chem Senses,* 40(3), 153-164.

Tada, A., & Miura, H. (2014). Systematic review of the association of mastication with food and nutrient intake in the independent elderly. *Arch Gerontol Geriatr,* 59(3), 497-505.

Thomas-Danguin, T., Rouby, C., Sicard, G., Vigouroux, M., Farget, V., Johansson, A., . . . Dumont, J. P. (2003). Development of the ETOC: a European test of olfactory capabilities. *Rhinology,* 41, 142-151.

Tsai, A. C., & Chang, T. L. (2011). Association of dental prosthetic condition with food consumption and the risk of malnutrition and follow-up 4-year mortality risk in elderly Taiwanese. *J Nutr Health Aging,* 15(4), 265-270.

Tubert-Jeannin, S., Riordan, P. J., Morel-Papernot, A., Porcheray, S., & Saby-Collet, S. (2003). Validation of an oral health quality of life index (GOHAI) in France. *Community Dent Oral Epidemiol,* 31(4), 275-284.

Vandenberghe-Descamps, M., Labouré, H., Prot, A., Septier, C., Tournier, C., Feron, G., & Sulmont-Rossé, C. (2016). Salivary Flow Decreases in Healthy Elderly People Independently of Dental Status and Drug Intake. *Journal of Texture Studies,* 47(4), 353-360.

Vandenberghe-Descamps, M., Labouré, H., Septier, C., Feron, G., & Sulmont-Rossé, C. (2017). Oral comfort: A new concept to understand elderly people's expectations in terms of food sensory characteristics. *Food Quality and Preference*.

Veyrune, J. L., & Mioche, L. (2000). Complete denture wearers: electromyography of mastication and texture perception whilst eating meat. *Eur J Oral Sci,* 108(2), 83-92.

Vissink, A., Spijkervet, F. K. L., & Amerongen, A. V. N. (1996). Aging and saliva: A review of the literature. *Special care in Dentistry,* 16(3).

Woda, A., Nicolas, E., Mishellany-Dutour, A., Hennequin, M., Mazille, M. N., Veyrune, J. L., & Peyron, M. A. (2010). The masticatory normative indicator. *J Dent Res,* 89(3), 281-285.

Wood, W. W. (1987). A review of masticatory muscle function. *The Journal of Prosthetic Dentistry,* 57(2), 222-232.

Yildirim, T., Yalcin, A., Atmis, V., Cengiz, O. K., Aras, S., Varlı, M., & Atli, T. (2015). The prevalence of anemia, iron, vitamin B12, and folic acid deficiencies in community dwelling elderly in Ankara, Turkey. *Archives of Gerontology and Geriatrics,* 60(2), 344-348.

Yoshida, M., Kikutani, T., Yoshikawa, M., Tsuga, K., Kimura, M., & Akagawa, Y. (2011). Correlation between dental and nutritional status in community-dwelling elderly Japanese. *Geriatr Gerontol Int,* 11(3), 315-319.

Yoshihara, A., Watanabe, R., Nishimuta, M., Hanada, N., & Miyazaki, H. (2005). The relationship between dietary intake and the number of teeth in elderly Japanese subjects. *Gerodontology,* 22(4), 211-218.

CHAPTER 3: ORAL COMFORT WHEN EATING A FOOD

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1. DEFINITION OF ORAL COMFORT AND DEVELOPMENT OF A QUESTIONNAIRE TO ASSESS ORAL COMFORT WHEN EATING A FOOD

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Oral comfort: A new concept to understand elderly people's expectations in terms of food sensory characteristics

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ABSTRACT

In the elderly population, ageing frequently impacts on the different aspects of oral physiology that play a key role in eating behavior. In the context of an aging population, it is crucial to develop a food supply tailored for the elderly people in order to prevent the onset of malnutrition. To meet this challenge, we looked for the concept of "oral comfort" when eating a food. The present study aimed at i) exploring the concept of oral comfort when eating according to elderly people in order to develop a questionnaire to evaluate the oral comfort when eating a food and ii) asking elderly people to evaluate various meat and cereal products using this questionnaire. Results of focus groups highlighted that oral comfort when eating a food is a multi-dimensional concept which includes dimensions related to food oral processing (ability to form and swallow food bolus), food sensory properties (texture and taste) and to a lesser extent pain sensations. Furthermore, the oral comfort questionnaire developed in the present study enabled a discrimination of products and highlighted the fact that some products supposed to fit with elderly people capacities and needs were not rated as the most comfortable foods by the elderly people. The concept of oral comfort when eating a food should be taken into account by those who are willing to design food products tailored to the elderly population. The questionnaire could be an interesting tool to assess oral comfort when eating a food in the elderly population.

1. Introduction

In the elderly population, the cumulative effects of physiological ageing, diseases and drugs frequently impact on the different aspects of oral physiology that play a key role in eating behavior (for a review, see Mioche, Bourdiol, & Peyron, 2004). First, ageing often goes along with a reduced strength in jaw muscles (Fontijn-Tekamp, van der Bilt, Abbink, & Bosman, 2004) or with tooth loss (Ikebe et al., 2012), which in turn alters masticatory ability (Mioche, Bourdiol, Monier, & Martin, 2002). According to Steele, Ayatollahi, Walls, and Murray (1997), the conservation of at least 21 well distributed teeth is necessary to maintain a good masticatory function (see also Kohyama, Mioche, & Bourdiol, 2003). Wearing prosthesis may restore the masticatory function, which remains, however, less efficient compared to natural dentition (Bessadet, Nicolas, Sochat, Hennequin, & Veyrune, 2013; Fucile et al., 1998; Veyrune & Mioche, 2000). Second, ageing may often be accompanied by a decrease in salivary flow (Vandenberghe-Descamps et al., 2016) or changes in salivary composition (Vissink, Spijkervet, & Van Nieuw Amerongen, 1996). As the first digestive fluid in contact with food, saliva is a key factor assisting the oral processing of food, whereby food is transformed into a bolus to be swallowed. During the mastication process, the lubrication function of saliva allows moistening of food and supports the creation of a bolus (Prinz, & Lucas, 1997). Furthermore, some food components are released from the food matrix and dissolved in saliva, where they can be influenced by the presence of salivary components such as salivary enzymes that begin the process of food digestion (i.e. alpha-amylase) or metabolize flavor compounds (i.e., esterases, glycosidases) (Buettner, 2002a, 2002b). Consequently, a decrease in salivary flow or change in saliva composition may have an impact on texture and taste perception (Engelen et al., 2007; Neyraud, 2014). Third, swallowing disorders such as inaccurate initial insertion and foodstuff control, drooling and rapid movements of the tongue as well as delayed swallowing response may also appear with age (Ekberg & Feinberg, 1991; Britton, 2016). According to Ney, Weiss, Kind, and Robbins (2009), presbyphagia corresponds to a moderate impairment of swallowing function induced by a decrease in mastication and salivation efficiency which in turn compromise the formation of a food bolus easy to swallow. Severe swallowing disorder is referred to dysphagia, which may result from an aggravation of presbyphagia (Ney et al., 2009) or from a stroke or a

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neurological disease (Britton, 2016). Dysphagia increases the risk for foods or liquids entering the airway, and thus the risk for pulmonary complications (Marik & Kaplan, 2003) or even choking and mortality (Sharma, Fletcher, Vassallo, & Ross, 2001). Finally, elderly people may suffer from dry mouth or xerostomia, gum disease, mycosis which may induce uneasiness or even pain during food consumption. These oral sensorial complaints often result from drug intake and polypharmacy (Nagler & Hershkovich, 2005). For instance, Sreebny and Schwartz (1997) reported 42 xerogenic drugs categories among which some are frequently prescribed to the elderly (e.g., antihypertensives, anti-arrhythmic medications, psychotropics agents).

Several studies have demonstrated a negative impact of oral disorders on food intake. In particular, a negative relationship between masticatory ability and/or dental status (e.g. number of teeth, number of occlusal contact, denture fitting) on the intake of fruits and vegetable (see Tada & Miura, 2014, for a review), meat (Marcenes, Steele, Sheiham, & Walls, 2003; Savoca et al., 2010), fish (Kim et al., 2007) and nuts (Kimura et al., 2013; Marcenes et al., 2003) was observed. For instance, in Kimura et al. (2013), low chewing abilities evaluated by color-changeable gum was associated with lower intake of vegetables, beans and nuts. Savoca et al. (2010) observed lower fruit, meat and beans intake in older adults with severe tooth loss (0–10 teeth remaining) compared to those with 11+ teeth after adjusting for age, gender, ethnicity, economic status and dental insurance. Only a few studies considered the impact of salivation on food intake (see Muñoz-González et al. (in press) for a review). Actually, Iwasaki et al. (2016) observed lower vegetable and fish intake in older adults with low salivary flow (< 0.5 mL/min) compared to those with high salivary flow. Obviously, these changes in food intake go along with changes in nutrient intake (Van Lancker et al., 2012; Tada & Miura, 2014), which in turn can induce weight loss, sarcopenia, and even malnutrition (Chen, Schilling, & Lyder, 2001; Keller, 1993).

While the impact of oral health on food intake in the elderly has been largely reported in the literature, the impact of oral health on the difficulties encountered by the elderly when eating is less explored. Furthermore, most of the few studies that have explored eating difficulties in the elderly have targeted only one dimension, usually chewing difficulties (e.g., Fontijn-Tekamp et al., 2000; Hsu et al., 2014; Takata et al., 2008). Some have targeted two dimensions (e.g., chewing difficulties and pain sensations in Brennan, Spencer, & Roberts-Thomson, 2008), but to the best of our knowledge, none have targeted all the difficulties liable to be encountered by the elderly when eating a food. Moreover, former studies used either a general question (e.g., "Have you found it uncomfortable to eat any foods because of problems with your teeth or mouth?" Silva, Demarco, & Feldens, 2015) or a question related to a specific food category (e.g., "boiled vegetables" or "firm foods such as steak or dried apricots" in Brennan et al., 2008), but as far as we know, none asked questions during the actual consumption of a food. However, it is worth exploring more in detail which difficulties are encountered by the elderly in an eating situation, both to better understand the impact of oral health on food intake (namely, to better understand which difficulties lead an older individual to avoid one food or another), and consequently to develop a food supply tailored to the oral capacities of the elderly people. To meet this challenge, we looked for the concept of "oral comfort" when eating a food. By "oral comfort", we mean the "oral sensations" experienced by the elderly people when eating a food, which may range from a negative side (e.g. discomfort, pain) to a positive side (e.g. easiness, pleasure). In the elderly population, it could be hypothesized that these oral sensations influence food choices as well as eating pleasure, appetite and willingness to eat, which in turn may impact dietary variety and food intake. Consequently, oral comfort might be an essential concept to evaluate the acceptability of food products by an elderly population, and thus a key concept to develop foods for the elderly people that meet their oral capacities, namely foods that are associated with positive oral sensations such as easiness to eat and eating pleasure.

In the literature, Witter, De Haan, Kayser, and Van Rossum (1994) associated "oral comfort" with the absence of pain in the mouth, satisfaction toward masticatory ability and aesthetic, and for denture wearers, the absence of complaints regarding their denture. However, this definition of "oral comfort" is more related to "dental comfort" than to the "oral sensations" perceived when eating a food. In food area, some authors outlined the concept of "comfort food", which refers to palatable foods that are consumed to meet physiological needs (i.e., some foods can have addictive qualities) or psychological needs related to factors such as social context or social identification (de Castro & de Castro, 1989; Wansink, Cheney, & Chan, 2003). Also, this concept of "comfort food" does not relate to the perceived oral comfort during food consumption.

Consequently, the aim of the present study was to explore the concept of "oral comfort" when eating a food in the elderly population. A first step consisted in running focus groups with elderly people in order to develop a questionnaire to evaluate the oral comfort when eating a food (qualitative phase). A second step consisted in asking elderly people to evaluate various meat and cereal products using this questionnaire (quantitative phase). Expected results of these studies were i) to set up a definition of "oral comfort" when eating a food in the elderly population, ii) to propose a validated tool, suitable for elderly people, to evaluate the oral comfort when eating a food, and iii) to assess whether the "oral comfort" concept can differentiate food products.

2. Developing a questionnaire through focus group to assess oral comfort when eating a food (qualitative phase)

2.1. Focus groups

2.1.1. Materials and methods

Three focus groups were organized with 6 elderly people each (13 women, 5 men, mean age = 79.6 ± 5.0). Two focus groups were performed at our laboratory with independently living volunteers, and one was performed in a retirement home with frailer elderly people. The recruitment criteria were the following: older than 65 years old, no acute pathological episodes at the time of the experiment, no cognitive disorder and able to express themselves. To check these last criteria, participants completed the Mini Mental State Examination (MMSE). Only participants scoring at least 24 out of 30, meaning normal cognition, were included in the study (Folstein, Folstein, & McHugh, 1975).

For the two focus groups performed with independently living volunteers, we managed to have volunteers ranging from a poor to a good oral health in each group, based on the number of functional units (i.e. a pair of posterior antagonist teeth that had at least one contact area during chewing.) and salivary flow rates (Gupta, Epstein, & Sroussi, 2006; Leake, Hawkins, & Locker, 1994). For a first group (n = 6), the number of functional units varied from 2 to 9 and the salivary flow rates varied from 0.076 ml/min to 0.697 ml/min and 0.285 ml/min to 4.012 ml/min for the resting and stimulated salivary flows respectively. For a second group (n = 6), the number of functional units varied from 2 to 8 and the salivary flow rates varied from 0.049 ml/min to 0.631 ml/min and 0.295 ml/min to 2.182 ml/min for the resting and stimulated salivary flows respectively. In parallel, the ability to swallow was tested through the three following tests: measure of tongue pressure, ability to form a food bolus ready to be swallowed safely and glatzel mirror test to detect velopharyngeal insufficiency (Chow et al., 2015). Based on the tests' results, none of the volunteers presented swallowing disorders. However, it was not possible to carry out dental exams and salivary flow measurements for the volunteers living in nursing home, but it was checked with the nurses that none of the volunteers presented swallowing disorders.

During the focus groups, the moderator directed the flow of the discussion and ensured that all of the important issues were discussed. Before starting the discussion a short introduction about the subject of

Table 1
List of the selected foods for the focus group.

Started course	Main course	Cheese course	Dessert course
Sliced tomato	Steam cooked zucchini	Baguette	Apple
Red beetroot	Rice	White bread	Syrup peer
Minced carrots	Split pees puree	Rye bread	Banana
Curly endive	Green beans	Crispbread	White grapes
Crumbed tuna fish	Ground beef	Vanilla jelly	Waffle
Dry sausage	Turkey escalope	Comté cheese	Almond biscuit
White ham	Boiled beef	Vanilla cream	Madeleine
Raw ham	Roast beef	Light spread cheese	Shortbread biscuit

the focus group was given by the moderator and a self-introduction of the participants took place.

Each focus group consisted of three parts:

a) Brainstorming about oral comfort. The participants were asked the question "what comes to your mind when I say "oral comfort"?" and were invited to tell out loud the first words that popped-up to their minds. Every word that was cited was written on a paper-board in order to make the words visible to everyone.
b) Personal experience on most comfortable and most uncomfortable food. The volunteers were asked to express what were the most uncomfortable food and the most comfortable food for them, and describe what makes the food uncomfortable or comfortable during its consumption.
c) Tasting phase. Participants were served with 8 delicatessen and salads (starter course), 8 meat and veggie dishes (main course), 8 cheeses and breads (cheese course) and 8 sweet products (dessert course) (Table 1). For each course, they were asked to choose one uncomfortable and one comfortable food among the eight proposals, to taste it, to confirm or not their choice and to describe what makes the food uncomfortable or comfortable during its consumption.

The sessions lasted between 60 and 80 min. The three focus groups were videotaped and voice-recorded. A transcription of the focus groups was performed based on those tools. The analyses were performed in four stages:

a) Lemmatization: reduction of words to their root forms. This stage consisted in grouping together words with the same semantic origin. In most of the cases we grouped together masculine, feminine, singular and plural forms of adjectives;
b) Analysis of occurrence frequencies. This analysis consisted in determining which words were the most frequently cited by the participants throughout all the focus groups;
c) Semantic analysis. This analysis consisted in regrouping together the words that refer to the same dimension of the act of eating.

2.1.2. Results of the focus groups

During the brainstorming, 84 verbatims were cited comprising 46 different words. During the second step of the focus group, which consisted in telling a personal experience on what is the most comfortable and the most uncomfortable food, 93 words comprising 43 different words were generated. The final step of the focus group – the tasting session – generated 686 words comprising 109 different verbatims. On the whole, the volunteers cited 139 different words related to oral comfort with a number of citations varying from 1 to 63 throughout all the focus groups. The ten most cited words are: taste (cited 63 times), to masticate (cited 49 times), to swallow (cited 43 times), to chew (cited 43 times), cooked (cited 39 times), to eat (cited 33 times), hard (cited 29 times), dry (cited 29 times), tender (cited 24 times) and melting (cited 20 times).

It should be noted that each focus group included both elderlies with good and poor oral health. In such situation, it may be argued that the latter may have been embarrassed to talk about their oral troubles in front of the former. However, the volunteers were not informed that groups included people with a good oral health and people with a poor oral health, and actually, two women explicitly talked about their denture and problems encountered when eating a food during a focus group.

2.2. Development of a questionnaire

2.2.1. Selection of dimensions, items and scales

The authors of the present paper developed a questionnaire that aims at evaluating the oral comfort of different food for an elderly population, based on the analysis of the verbatim collected during the focus group.

A semantic analysis was carried out to select the dimensions to be included in the questionnaire. This analysis consisted in sorting together the words that refer to the same semantic dimension. This analysis highlighted 11 categories of words: mouth anatomy (i.e. taste papillae), bolus formation (i.e. to masticate), oral pain sensations (i.e. burning sensation), cooking (i.e. to grate), eating (i.e. to enjoy eating), body sensations (i.e. appetizing), meal environment (i.e. atmosphere), taste perception (i.e. sweet), odor (i.e. odor), texture perception (i.e. hard) and visual (i.e. aspect) (Table 2). Three categories (bolus formation, texture and taste perception) stand out from the others due to their important number of words and number of citations during the focus groups. As those categories of words were found to be largely represented, they were considered as essential to define the concept of oral comfort and were kept in the questionnaire. A fourth category was kept in the questionnaire as well: oral pain sensations. This category was poorly cited as it was only cited during the focus group organized in the retirement home and therefore concerns few elderly people. However, we hypothesized that when pain sensations occur during food consumption, oral comfort can be highly impacted. Indeed, during the focus group in the retirement home, one volunteer had the following reaction: "I have irritation problems, therefore [vinegar] burns me, I can't stand having it on my tongue".

Once the dimensions were chosen, we selected the most frequently cited words for each dimension. Accordingly, we selected 6 items for bolus formation (occurrence frequency ranged from 19% for masticating to 3% for humidification with saliva), 8 items for texture (occurrence frequency ranged from 9% for hard to 2% for sticky) and 5 items for taste (occurrence frequency ranged from 11% for sugary to 1% for bitter). For pain dimension, only the item "burning or spicy sensation" was mentioned during the focus group (occurrence frequency: 18%). Four additional items were chosen by asking a dentist of potential painful sensations that could occur when eating a food. Finally, a general question on food comfort was also added to the questionnaire.

Table 2
List of word categories resulting from the focus groups.

Categories	Occurrence frequencies (%)	Number of different words
Body sensations	3	11
Bolus formation	**30**	**23**
Cooking	5	11
Eating	1	4
Taste perception	**18**	**21**
Meal environment	0,2	2
Odor	1	1
Mouth anatomy	0,1	1
Oral pain sensations	1	7
Texture perception	**39**	**52**
Visual	2	6
TOTAL	100%	139

General question

This food is…

Very uncomfortable	Uncomfortable	Moderately comfortable	Comfortable	Very comfortable
☐	☐	☐	☐	☐

Bolus formation

To cut this food with your incisor is…

Impossible	Very difficult	Difficult	Moderately easy	Easy	Very easy
☐	☐	☐	☐	☐	☐

Same scale for cutting with premolars, masticating, humidification with saliva and swallowing the food bolus

The time needed to form the food bolus is…

Impossible to swallow	Very long	Long	Moderately brief	Brief	Very brief
☐	☐	☐	☐	☐	☐

Mouth pain

Does eating the food bring a burning or spicy sensation?

Not at all	Little	A lot	Extremely
☐	☐	☐	☐

Same scale for muscular pain, articular pain, dental pain and gum pain

Texture

Is this food sticky?

Not at all	Little	A lot	Extremely
☐	☐	☐	☐

Same scale for stringy, greasy, dry, doughy, melting, firm and hard

Taste

Is this food intense in taste?

Not at all	Little	A lot	Extremely
☐	☐	☐	☐

Same scale for salty, sweet, acidic and bitter

Fig. 1. Food comfortability questionnaire developed based on the results of focus groups organized with elderly people.

All the items of a given dimension were associated to the same scale. Scales were chosen to be consistent with the related question and to avoid any understanding ambiguity. The length of the scales varied depending on the dimensions (5-point for the general question; 6-point for bolus formation; 4-points for mouth pain, texture and taste). For the general question on food comfortability, we used the structure of the hedonic scale developed by Maître, Symoneaux, and Sulmont-Rossé (2014) for elderly people (i.e., a discrete scale including an odd number of 5 points, each point being associated with a label). We added the label "impossible" in the scales for the bolus formation items as some elderly people reported being incapable of biting and chewing some foods during focus groups. For mouth pain, texture and taste items, we selected a very simple intensity scale as recommended by Maître et al. (2014).

2.2.2. Presentation of the questionnaire

The questionnaire includes five sections (Fig. 1):

- A first general question on food comfort that the participants answered using a 5-point scale from "Very uncomfortable" to "Very comfortable."
- A second section on bolus formation included five items: the ability to cut the food with incisors, the ability to cut the food with premolars, the ability to masticate the food, the ability to humidify the food with saliva, and the ability to swallow the food. For each item, participants answered on 6-point scale from "Impossible" to "Very easy." This section also included an item on the time needed to form the food bolus; participants answered using a 6-point scale from "Impossible" to "Very brief."
- A third section on pain perception included five items: burning or

Table 3
Description of the tasted products.

	Name of the product	Description	Illustration	portion size
Meat-based products	Beef cheek	Slow cooked Beef cheek braised in a sauce with carrots		2 pieces About 50 g
	Beefsteak	Beefsteak		½ of a beefsteak About 70 g
	Ground beef	Ground beef		½ of a beefsteak About 50 g
	Chicken meatballs	Ground chicken reconstituted in meatballs shape		3 meatballs About 24 g
	Chicken aiguillette	Chicken breast sliced into an aiguillette shape		3 aiguillettes About 45 g
	Ground chicken reconstituted	Ground chicken breast reconstituted in an aiguillette shape		2 aiguillettes About 30 g
Cereal-based products	Crispbread	Flat and dry bread made of white bread dried and double cooked		1 slice About 8 g
	Financier	Small cake cooked in a mold, made of almond powder, flour, sugar, butter and eggs.		1 financier About 30 g
	Madeleine	Small cake cooked in a mold, made of flour, eggs, sugar and butter		1 madeleine About 15 h
	Sponge cake	Cake with a well-aerated crumb cooked in a cake mold, made of flour, sugar and eggs,		1/16 of the cake About 14 g
	Milk roll	Melting bread made of flour, milk, egg, sugar and butter		½ of the bread About 17 g
	Protein enriched milk roll	Milk roll enriched with vegetable protein		½ of the bread About 22 g

spicy sensation, muscular pain, articular pain, dental pain and gum pain. For each item, participants answered on a 4-point scale from "Extremely" to "Not at all."

- A fourth section on texture perception included eight items that were evaluated on their intensity: sticky, stringy, greasy, dry, doughy, melting, firm and hard. The items were rated on a 4-point scale from "Extremely" to "Not at all."
- A fifth section on taste perception included five items: taste intensity and the saltiness, sweetness, sour and bitter perceptions. For each item, participants answered on a 4-point scale from "Extremely" to "Not at all."

2.3. Validation of the questionnaire

The first version of the questionnaire was sent to 40 elderly people (older than 65 years old, independently living, 19 women and 21 men) in order to evaluate the feasibility of the questionnaire. The surveyed population received the questionnaire by post-mail and was asked to complete the questionnaire at home by eating a food to choose among a short list: a piece of Comté cheese (semi-hard cheese made of unpasteurized cow's milk), a cooked chicken escalope (thin boneless slice of chicken) or a madeleine (small cake cooked in a mold, made of flour, sugar, egg and butter). An evaluation sheet was added to the questionnaire in order to collect background information regarding the completion of the questionnaire. Thus, the time needed to complete the questionnaire and its evaluation (very long, long, moderate, short or very short), the easiness to answer the questions and any difficulty encountered during the completion were collected.

Of the 40 questionnaires sent, 31 were completed by the elderly people (14 women and 17 men) and sent back to the experimenter. The mean time of completion according to the elderly people was of 10 min which was considered as short or very short for all the respondents. Twenty-six respondents declared that they did not encounter any problem for completing the questionnaire, 4 declared that they encountered little problem and 1 respondent did not give his appreciation. The problems encountered while completing the questionnaire were the difficulty to differentiate firm to hard (texture descriptors) and bitter to sour (taste descriptors). Therefore, a decision was made to clarify those points at the beginning of each session using examples of common food such as Comté cheese vs crispbread or lemon vs grapefruit for the future utilization of the questionnaire.

3. Using the questionnaire to assess food comfortability (quantitative phase)

3.1. Materials and methods

3.1.1. Participants

A meat panel and a cereal panel were recruited for the tasting sessions. In the meat panel, 39 volunteers (21 women and 18 men) aged between 65 and 87 years old (M = 72.64 ± 1.0) were included whereas in the cereal panel 42 volunteers (21 women and 21 men) aged between 65 and 87 years old (M = 73.57 ± 0.9) were included. The recruitment criteria were the following: older than 65 years old, no acute pathological episodes at the time of the experiment, scoring at least 24 on the mini mental state evaluation (MMSE) (Folstein et al., 1975). In each group, we managed to have volunteers ranging from a poor to a good oral health, based on the number of functional units (i.e. a pair of posterior antagonist teeth that had at least one contact area during chewing) and salivary flows (Gupta et al., 2006; Leake et al., 1994). Overall the 81 volunteers, the number of functional units varied from 0 to 10 (M = 5.57; SEM = 0.019) and the resting salivary flow rate varied from 0.049 ml/min to 0.78 ml/min (M = 0.21; SEM = 0.005).

3.1.2. Products

Six meat-based products and six cereal-based products were chosen in order to have contrasted textures. The meat-based products included beef cheek, plain beef, ground beef, chicken meatballs, chicken aiguillette and ground chicken reconstituted in an aiguillette shape (Table 3). They were all provided by Terrena Innovation®. They were cooked just before serving according to the recipes provided by the supplier: beef cheek was received already cooked and needed a reheating in a water bath; the plain beef and ground beef were cooked in a frying pan at high temperature during 6 min (3 min for each side); the chicken meatballs, the chicken aiguillette and the ground chicken reconstituted were reheated in a micro-wave at 800 Watt during 5 min as recommended by the supplier. The products were served when the temperature in the heart of the product reached at least +65 °C. The cereal-based products included a crispbread (Heudebert®), a financier (Cerelab®), a madeleine (Saint-Michel®), a sponge cake (Cerelab®), a milk roll (Pasquier®) and a protein enriched milk roll (Cerelab®) (Table 3). They were served at room temperature (20.5 ± 0.5 °C). For both product categories, the served quantity of each product was calculated to be sufficient for answering the entire questionnaire (Table 3).

3.1.3. Procedure

The volunteers were invited to take part in one session where they had to taste 6 products, either the meat-based products or the cereal-based products. For each product, the volunteers were asked to answer the "food comfortability" questionnaire (Fig. 1). At the beginning of each session, the questionnaire was presented to the volunteers by the experimenter, with specific examples for defining the terms firm, hard, bitter and sour. No specific training was performed before the sessions. During the sessions, the volunteers were free to bite the products as many times as they wanted in order to answer the questions on the "food comfortability" questionnaire. The participants were given a 3-min rest time between samples, and they were free to drink as much water as they needed during the session. The sessions were conducted in a sensory room equipped with individual booths according to the AFNOR standard (AFNOR, 1987) and under white light. The room temperature was 20.5 ± 0.5 °C. The products were presented in an order determined by a William Latin square design; they were coded with a three digit number.

In order to check the questionnaire repeatability, participants from the cereal panel were invited to come back to the laboratory three months later for a second session. Thirty-eight volunteers out of the 42 who completed the first cereal session came back for the second cereal session (20 women, 18 men, mean age m = 73.7 ± 6.2). During this session, they were asked to rate the same cereal products using the same "food comfortability" questionnaire, under similar experimental conditions. The repeated session was not carried out on meat-based products because the supplier was not able to provide us with two batches (one for each replication) made of the same lot of meat and could not guarantee texture homogeneity between two batches produced with different lots of meat.

3.1.4. Data analysis

Participants' ratings were transformed on scores varying from 0 to 100 to facilitate further reading. Separate analyses were conducted for the meat products and for the cereal products. For each item of the "food comfortability" questionnaire, scores were submitted to an Analysis of Variance (ANOVA) with one fixed factor (product) and one random factor (participant). Post-hoc comparisons were performed using the Student Newman Keuls test. Means (M) were associated with their standard errors (SEM). The threshold for significance was set at 5 %. Statistical analyses were conducted using R-studio software version 3.3.1 with the "nlme" package for linear mixed models and the "agricolae" package for post hoc analyses (R Development Core Team, 2006). The significant attributes ($p = 0.05$) for the product effect were arranged in a FLASH table (Porcherot & Schlich, 2000; Schlich, 1998). The results of the repeated session of cereal-based products were compared to the results of the first cereal-based session. The data of both sessions were submitted to an ANOVA with two fixed factors, namely product and session, and one random factor (participant).

3.2. Results

3.2.1. Results on meat-based products

The results on the general question on food comfortability show that there is a difference of oral comfort perception between the products ($F(5,33) = 7.29$; $P < 0.001$). Indeed, the aiguillette, the beef cheek and the chicken balls are the most comfortable products while the plain beef is the most uncomfortable food.

The FLASH table presented in Table 4 highlights the differences between the meat-based products perceived by the volunteers. The ground and plain beef are the products perceived as less comfortable. For those two products, the food bolus is more difficult to form than for the other products. Both, the ground and the plain beef, are characterized by a harder and less melting texture than that of the comfortable products. Plain beef was associated with higher means for the pain items (i.e., muscle, articular, dental and gum pain) than the other products. However, as the means for pain sensations are very low, we determined the frequency of "no pain" answers (i.e., number of responses for "not at all" label on the pain scale) *versus* the frequency of "pain" answers (i.e., number of responses for "little" and "a lot" labels; no answer was observed for "extremely" label) for each products overall the pain items. Results showed a higher frequency of "pain" answers for the plain beef (13.3%) compared to the other products (chicken ball: 2.0%; beef cheek: 1.0%; chicken aiguillette: 2.0%; reconstituted chicken aiguillette: 3.6%; ground beef: 2.6%; $\chi^2 = 26.7$; $p < 0.001$).

The chicken balls, the aiguillette and the beef cheek are comfortable products. The food bolus is easy to form in mouth. Those three products have a low score on the hardness attribute.

Finally, the reconstituted aiguillette and the ground beef, judged as less comfortable than the beef cheek, are characterized by a dry, doughy and a little melting texture as well as a little intense taste. On the contrary, the beef cheek is characterized by a stringy texture but not dry nor doughy and melting. Its taste is more intense than the one of the reconstituted aiguillette or ground beef.

3.2.2. Results on cereal-based products

The results on the general question on food comfortability show that

Table 4
Flash table for the meat-based products.

	F-Prod	P(F)	GMEAN	Chicken balls	Beef cheek	Chicken aiguillette	Recon. Chicken aiguillette	Ground beef	Plain beef
General question									
comfort	14.46	***	70	**80+**	**80+**	**78+**	67	**61−**	**54−**
Bolus formation									
incisor	42.01	***	75	**87+**	**84+**	**86+**	**83+**	**70−**	**45−**
molar	35.26	***	83	**92+**	**89+**	**92+**	**89+**	**78−**	**59−**
masticate	37.45	***	82	**91+**	**90+**	**91+**	**86+**	**73−**	**59−**
humidify	8.45	***	76	**83+**	**85+**	79	74	**72−**	**68−**
swallow	20.34	***	81	**89+**	**90+**	**88+**	80	**77−**	**67−**
time	24.09	***	70	**81+**	**82+**	73	72	**64−**	**53−**
Pain encountered while eating									
muscle	5.89	***	2	1	1	**0−**	1	1	**7+**
articular	10.54	***	3	**0−**	1	1	1	3	**11+**
dental	4.06	**	2	1	1	0	2	0	**5+**
gum	2.28	*	1	0	1	0	1	1	**4+**
Texture (intensity)									
sticky	2.18		15	15	18	13	**20+**	17	**9−**
stringy	28.14	***	19	**3−**	**41+**	**11−**	**12−**	**12−**	**33+**
greasy	12.12	***	20	**28+**	**31+**	**7−**	17	**26+**	**8−**
dry	13.51	***	23	18	**4−**	**28+**	**36+**	**30+**	**17−**
doughy	12.94	***	21	**28+**	**12−**	17	**33+**	**25+**	**8−**
melting	24.31	***	27	29	**55+**	28	**19−**	**15−**	**15−**
firm	29.54	***	24	**7−**	**8−**	24	20	28	**53+**
hard	25.11	***	11	**0−**	**1−**	**6−**	**6−**	**17+**	**36+**
Taste (intensity)									
Taste intense	8.77	***	29	25	**38+**	32	**22−**	**17−**	**40+**
salty	5.69	***	18	**22+**	16	**22+**	**23+**	**8−**	17

The FLASH table gives the mean of every item of the questionnaire for each product, the results were transformed on a score varying from 0 to 100. The scales range from "very uncomfortable" to "very comfortable" for the general question; from "impossible" to "very easy" for the food oral processing dimension, from "very long" to "very short" for the time scale, from "not at all" to "a lot" for the last three dimensions (pain encountered while eating, texture intensity and flavor intensity). The sign "+" indicates that the product has a mean significantly higher than the general mean of the products for the related item. The sign "−" indicates that the product has a mean significantly lower than the general mean of the products for the related item.
The columns F-prod and P(F) correspond to the product effect ($^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$). The column GMEAN corresponds to the mean of every item all products taken together.

there is a difference of oral comfort perception between the products (F (5,36) = 5.95; $P < 0.001$). The sponge cake is the most comfortable food according to the student test while the crispbread and the enriched milk roll are the most uncomfortable foods.

The FLASH table presented in Table 5 highlights the differences between the cereal-based products perceived by the volunteers. The crispbread and the protein enriched milk roll are the two products judged as less comfortable. For both of them, the food bolus is more difficult to form than for the other products. The crispbread is characterized by a hard, firm, dry and a little melting texture. Its taste is a little intense. The protein enriched milk roll is characterized by a firm, dry, doughy and little melting texture. The two products are judged more salty than the other matrices. Finally, eating the crispbread provokes a slight gum and dental pain sensations while eating the protein enriched milk roll provokes a slight burning sensation.

The Madeleine and the sponge cake are judged as comfortable products. The food bolus is easy to form in the mouth. Those products have a texture that is not hard nor firm, but melting. The madeleine has a doughy, greasy but not dry texture. The two products are judged as a little salty.

Finally, the Financier and the milk roll are considered as moderately comfortable. The financier, as for the madeleine, has a doughy, greasy but not dry texture. Regarding the milk roll, compared to the protein enriched milk roll, it has a less firm, less dry and more melting texture.

3.2.3. Correlation between the general question on oral comfort and the other items

Table 6 displays the Pearson coefficient between the oral comfort and the other items for each product. Results highlight a strong correlation between oral comfort and the bolus formation item, for both products (Pearson coefficients vary from 0.77 to 0.99). Strong correlations are also observed between oral comfort and three texture items, namely melting, firm and hard. Finally, significant correlations are observed between oral comfort and mouth pain items for the meat product.

When looking at the correlations within each questionnaire section, all the bolus formation items correlate together (Pearson coefficients vary from 0.83 to 1 for the meat product and from 0.83 to 0.98 for the cereal products). Regarding mouth pain, only 5 correlations over the 10 possible correlations are significant for the meat and the cereal products (Pearson coefficients vary from 0.18 to 0.62 for the meat product and from 0.17 to 0.47 for the cereal products). Regarding texture, 18 and 20 correlations over the 28 possible correlations are respectively significant for the meat (range of Pearson coefficients: 0.16–0.62) and for the cereal (range of Pearson coefficients: 0.13–0.60). Regarding taste, 3 and 7 correlations over the 10 possible correlations are respectively significant for the meat (range of Pearson coefficients: 0.23–0.28) and for the cereal (range of Pearson coefficients: 0.13–0.39).

3.2.4. Results on the repeated session of cereal-based products

The results of the repeated session showed a significant *session* effect for five descriptors: ability to masticate the food ($t(1) = 12.22$; $P < 0.001$), ability to swallow the food ($t(1) = 4.69$; $P = 0.03$), stringy ($t(1) = 9.92$; $P = 0.002$), greasy ($t(1) = 4.75$; $P = 0.03$) and doughy ($t(1) = 6.51$; $P = 0.01$). Participants perceived the products as easier to masticate and swallow and they rated them as stringier and greasier during the second session than during the first session. A significant *product* × *session* interaction was observed for only the descriptor doughy: the financier belongs to the 'doughy' products in the first session (with the madeleine, the milk roll and the protein-enriched

Table 5
Flash table for the cereal-based products.

	F-Prod	P(F)	GMEAN	Sponge cake	Madeleine	Financier	Milk roll	Protein enriched milk roll	Crispbread
General question									
comfort	5.95	***	76	**85**+	**81**+	78	75	**70**−	69−
Bolus formation									
incisor	10.85	***	88	**93**+	**94**+	89	87	**83**−	**80**−
molar	13.49	***	89	**93**+	**93**+	**92**+	90	**84**−	**82**−
masticate	11.26	***	90	**94**+	**95**+	92	90	**84**−	**84**−
humidify	9.02	***	80	82	**85**+	**86**+	80	**72**−	**75**−
swallow	8.65	***	86	**90**+	89	**91**+	86	**78**−	**82**−
time	13.85	***	73	**77**+	**82**+	**76**+	74	**62**−	**68**−
Pain encountered while eating									
burn	2.01		1	0	1	**3**+	1	**3**+	0
dental	3.99	**	0	0	0	0	0	0	**3**+
gum	6.16	***	1	0	1	0	0	1	**5**+
Texture (intensity)									
sticky	7.15	***	23	20	**28**+	26	26	26	**10**−
stringy	2.83	*	2	1	1	1	**4**+	**5**+	2
greasy	26.64	***	18	**9**−	**25**+	**36**+	20	17	**4**−
dry	49.89	***	25	21	**13**−	**9**−	**13**−	**29**+	**63**+
doughy	25.90	***	26	**20**−	**31**+	**32**+	**34**+	**35**+	**6**−
melting	17.30	***	29	**37**+	**38**+	**40**+	31	**12**−	**16**−
firm	33.61	***	23	**9**−	**13**−	23	**7**−	**33**+	**50**+
hard	52.46	***	10	**1**−	**2**−	**4**−	**0**−	9	**41**+
Taste (intensity)									
Taste intense	15.38	***	30	29	**42**+	**40**+	31	29	**12**−
salty	15.77	***	10	**4**−	**6**−	**6**−	8	**12**+	**21**+
sugary	34.80	***	39	**44**+	**45**+	**51**+	42	37	**14**−
acidic	2.89	*	3	2	2	3	5	**6**+	**1**−
bitter	3.23	**	4	2	5	3	6	**9**+	**1**−

The FLASH table gives the mean of every item of the questionnaire for each product, the results were transformed on a score varying from 0 to 100. The scales range from "very uncomfortable" to "very comfortable" for the general question; from "impossible" to "very easy" for the food oral processing dimension, from "very long" to "very short" for the time scale, from "not at all" to "a lot" for the last three dimensions (pain encountered while eating, texture intensity and flavor intensity). The sign "+" indicates that the product has a mean significantly higher than the general mean of the products for the related item. The sign "−" indicates that the product has a mean significantly lower than the general mean of the products for the related item.
The columns F-prod and P(F) correspond to the product effect (*P < 0.05; **P < 0.01; ***P < 0.001). The column GMEAN corresponds to the mean of every item all products taken together.

milk roll) while it belongs to the "not doughy" products in the second session (with the crispbread) ($t(3) = 3{,}25$; $P = 0.02$). None of the other questionnaire items was associated with a significant *product × session* interaction providing that participants were quite repeatable when scoring the cereal-based products for food comfortability.

4. Discussion

As a reminder, expected results of these studies were i) to set up a definition of "oral comfort" when eating a food in the elderly population, ii) to propose a validated tool, suitable for elderly people, to evaluate the oral comfort when eating a food, and iii) to assess whether the "oral comfort" concept can differentiate food products. In the following discussion, we will consider each point and end by the limits and perspectives of our study.

4.1. Oral comfort: a multidimensional concept

Results of focus groups highlight that oral comfort when eating a food is a multi-dimensional concept which includes dimensions related to food oral processing (ability to form and swallow food bolus), food sensory properties (texture and taste) and to a lesser extent pain sensations. Results of the quantitative phase show that the less comfortable foods (plain beef, ground beef, crispbread, protein enriched milk roll) were systematically rated as more difficult to chew, to humidify and to swallow as well as firmer and/or harder than the most comfortable foods (chicken balls, chicken aiguillette, beef cheek, madeleine, sponge cake). Furthermore, the least comfortable food in the meat study (plain beef) induced slightly more pain sensations than the other products. Beyond these first dimensions (food oral processing, pain and hardness), ratings also revealed additional sensory properties or combinations of sensory properties that may contribute to oral comfort. Thus, foods which were perceived as dry and little melting also tend to be less comfortable than foods which were perceived as melting and a little dry (ground beef, reconstituted chicken aiguillette *versus* beef cheek; crispbread, protein enriched milk roll *versus* financier, madeleine). In the same way, taste intensity and saltiness (for meat products) or sweetness (for cereal product) tended to be rated lower in uncomfortable food than in comfortable food (ground beef *versus* beef cheek, chicken aiguillette and chicken balls; crispbread *versus* madeleine and financier), but this was not true for plain beef. However, it can be assumed that these dimensions (dryness, melting, taste intensity) play a secondary role in the definition of oral comfort. In fact, plain beef was rated as uncomfortable despite scoring lower on dryness and higher on taste intensity.

To sum up results from the qualitative and quantitative phases, the concept of "oral comfort" from the elderly perspective may be defined as the following: *When eating, oral comfort mainly depends on easiness to chew, to humidify and to swallow as well as on texture softness. Oral pain sensations that occur when eating decrease oral comfort. Beyond these first dimensions, oral comfort also tends to be lower for dry and little melting textures, as well as for low taste intensity foods.*

4.2. Development of a questionnaire to assess oral comfort

The "oral comfort" questionnaire developed in the present study proved to be easy to fill-up and repeatable. In fact, neither volunteers from the validation step (qualitative phase) nor volunteers from the

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Table 6
Pearson correlations between the general question of oral comfort and the other items of the questionnaire.

	Oral comfort on meat products	Oral comfort on cereal products
Bolus formation		
incisor	$0,59^{***}$	$0,45^{***}$
molar	$0,58^{***}$	$0,50^{***}$
masticate	$0,64^{***}$	$0,54^{***}$
humidify	$0,57^{***}$	$0,47^{***}$
swallow	$0,64^{***}$	$0,47^{***}$
time	$0,55^{***}$	$0,46^{***}$
Pain encountered while eating		
burn	−0,02 ns	$0,24^{***}$
muscle	$0,16^{*}$	0,10 ns
articular	$0,29^{***}$	0,11 ns
dental	$0,26^{***}$	$0,19^{**}$
gum	$0,19^{**}$	0,12 ns
Texture (intensity)		
sticky	$0,25^{***}$	$0,23^{***}$
stringy	$0,25^{***}$	0,12 ns
greasy	0,09 ns	$0,18^{**}$
dry	$0,33^{***}$	$0,21^{**}$
doughy	$0,24^{***}$	$0,17^{**}$
melting	$-0,35^{***}$	$-0,24^{***}$
firm	$0,41^{***}$	$0,20^{**}$
hard	$0,47^{***}$	$0,19^{**}$
Taste (intensity)		
Taste intense	$-0,13^{*}$	−0,01 ns
salty	−0,04 ns	$0,25^{***}$
sugary	0,06 ns	0,05 ns
acidic	0,04 ns	$0,14^{*}$
bitter	0,04 ns	0,05 ns

Correlation significance: $^{***}P < 0.001$, $^{**}P < 0.01$, $^{*}P < 0.05$, ns $P > 0.05$.

quantitative phase have reported problems when filling out the questionnaire. In particular, none of the respondents reported any difficulty for understanding the items and none of them complained about having different sizes of scales depending on questionnaire section. It should be noted that the average means on the pain scales were very low, and that none of the respondents ticked the label "extremely". A recommendation for further use of this questionnaire would be to simplify the pain scale into a "yes/no" ("presence"/"absence" of pain) question.

Developing sensory and consumer science methods specifically adapted to older adults is of crucial importance when considering this specific population (Methven, Jiménez-Pranteda, & Lawlor, 2016). Indeed, our questionnaire was developed *for* and *with* elderly people: items and scales were chosen from the verbatim collected during the focus groups carried out with elderly people. Furthermore, the test retest of the questionnaire carried out on the cereal products with three-month in-between revealed only one *product* × *session* interaction over 25 items (the interaction was observed for the doughy scale). Nevertheless, looking at the correlations between questionnaire items, a halo effect might have occurred from the general question to the other items. In fact, a halo effect happens when multiple attributes of a single product are evaluated at the same time (Nisbett & Wilson, 1977). Considering the strong correlations between the general question on oral comfort and the bolus formation items as well as the strong and significant correlations among the bolus formation items (all the Pearson coefficients observed between the bolus formation items are higher than 0.80), we can not rule out that the overall impression of oral comfort influenced respondent's judgement of bolus formation items. However, for the other sections (pain, texture and taste), correlations between the items were lower and not always significant (correlations observed between the items of each section ranged from 0.01 to 0.62).

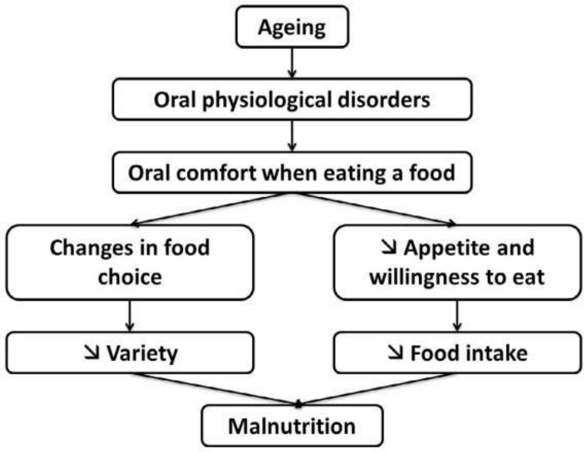

Fig. 2. Hypothesis on the relationship between oral health, oral comfort when eating a food and its consequences.

4.3. *Oral comfort: a "tool" to characterize food products*

On the whole, the elderly volunteers rated the food products as rather comfortable (the averages scores ranges from 54 for the plain beef to 85 over 100 for the sponge cake). However, volunteers discriminated the products with the oral comfort scale for both the meat-based and cereal-based products. Regarding the others items, they discriminated the products on 20 over 24 items for the meat products and on 22 over 24 items for the cereal products. Among others, the use of the present questionnaire highlighted some interesting results regarding two products supposed to fit with elderly people capacities and needs, namely the ground beef and the protein enriched milk roll.

In fact, some French nutritional guidelines recommend ground beef for elderly people suffering from chewing difficulties (*e.g.*, French Contract Catering Industry and Nutrition Study Group, 2015; French National Nutritional and Health Program, 2015). However, ground beef was rated as one of the less comfortable products among the five meat products that were assessed in the present study, with a score of 61 over 100 on the oral comfort scale. Participants rated this product as hard and difficult to chew, as well as dry and difficult to humidify. In parallel, the protein enriched milk roll was designed to improve the nutritional intake of malnourished elderly people. Again, this product was rated as one of the less comfortable products among the five cereal products (70 over 100 on the oral comfort scale). This product was perceived as difficult to humidify and swallow as well as dry, doughy and firm. It should be noted that cooking mode or tasting conditions may partly account for the lower comfort scores observed for these two products. Regarding the ground beef, it was prepared according to the good hygiene practice guidelines in mass catering. Accordingly, the meat was well cooked, which could have led to a quite hard and dry texture. Regarding the protein enriched milk roll, the volunteers did not have the opportunity to soak it in milk, tea or coffee during the tasting session, while it was observed as a common practice in daily life (Van Wymelbeke, Brondel, Bon, Martin-Pfitzenmeyer, & Manckoundia, 2016). Allowing older individuals to soak such product in a hot drink may be indeed an opportunity to reduce the dryness sensation associated with it. Nevertheless, the present results emphasize the fact that beyond nutritional requirements, it could be worth taking into account oral comfort when providing recommendations and/or developing food products tailored to oral capacities or nutritional needs of the elderly people, in order to ensure a good food acceptability.

4.4. Limits and perspectives of the present study

The present study allowed defining the concept of "oral comfort" and developing a repeatable and discriminative questionnaire to assess this concept when eating a food in the elderly population. Further work is needed to better understand the impact of "oral comfort" on eating pleasure and food intake. In fact, we can hypothesize that the cumulative effect of ageing and pathologies can induce oral disorders, which in turn might alter oral comfort perception. This decline in "oral comfort" might have a negative impact on i. food choice by leading older individuals to avoid certain foods because of oral discomfort when eating them, and ii. food intake by decreasing eating pleasure and willingness to eat because of uneasiness and unpleasant sensations when eating. Change in food choice and decrease in food intake may in turn impair dietary variety and nutrient intake, and consequently increase the risk of malnutrition in this population (Fig. 2). However, further work is needed to infirm or confirm this pathway. At the moment, a preliminary study on the impact of dental status (*i.e.*, the number of occlusal contact) and salivary flow on "oral comfort" perception when eating a food showed only little relationships. However, conclusions of the paper need to be reinforced on a larger number of subjects (Vandenberghe-Descamps, Sulmont-Rossé, Septier, Feron, & Labouré, 2017).

Regarding eating pleasure, the choice was made by the authors to not include any liking question in the present study to focus the participants on the oral sensations experienced when eating a food, and not on the affective component of food consumption. However, the link between oral comfort and food liking deserves more research as it was occasionally outlined in the focus groups.

Regarding product assortment, the products assessed in the present study displayed quite different texture properties. It would be interesting however to check questionnaire reliability and discrimination with products more alike such as different recipes for a given product. Indeed, it has been shown that consistency of products belonging to the same category of foods (jelly and custard) is positively correlated to the oral residence time and thus to the sensed difficulty of swallowing (Chen & Lolivret, 2011). Furthermore, as many authors highlighted a decrease of fruit and vegetable intake with oral disorders (Akpata, Otoh, Enwonwu, Adeleke, & Joshipura, 2011; Brodeur, Laurin, Vallee, & Lachapelle, 1993; De Marchi et al., 2011), it will be worse to assess "oral comfort" in this product category.

Finally, regarding the questionnaire, it can be argued that using scales with different lengths depending on the dimension (5-point for the general question; 6-point for bolus formation; 4-points for mouth pain, texture and taste) may have disturbed volunteers when rating the products. In fact, scales were chosen to be consistent with the related question and to avoid any understanding ambiguity. None of the respondents complained about having different sizes of scales depending on questionnaire section. Nevertheless, it could be worth harmonizing the scales between all the questionnaire items in future studies.

5. Conclusion

As a conclusion, the present study aimed at exploring the concept of "oral comfort" when eating a food in the elderly population through the running of focus groups and the development and validation of a questionnaire that evaluates the oral comfort when eating a food. As a result, the present study attempts to describe the oral sensations perceived by older adults when eating a food, taking into account the different dimensions that underlined the concept of "oral comfort". The concept of oral comfort perception during food consumption in the elderly population was defined as a multidimensional concept. **When eating, oral comfort mainly depends on easiness to chew, to humidify and to swallow as well as on texture softness. Oral pain sensations that occur when eating decrease oral comfort.** Beyond these first dimensions, oral comfort also tends to be lower for dry and little melting textures, as well as for low taste intensity foods. In line with this definition, we developed a repeatable and discriminable questionnaire suitable for elderly respondents to assess oral comfort. This questionnaire might be used by those who are willing to design food products tailored to the elderly population. However, further work is needed to explore the relationship between oral health, oral comfort and food intake in the elderly. Furthermore, it would be interesting to consider the impact of age-related impairment on the perception of foods which display smaller sensory difference than the ones in the present experiment.

Ethical statements

The authors declare that they do not have any conflicts of interest. The experimental protocol was approved by the French Ethics Committee for Research (CPP Est III, Nancy, #15.04.04, ANSM #2015-A00279-40). In accordance with ethical standards, all participants received written and oral information on the study before signing a consent form.

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References

Akpata, E., Otoh, E., Enwonwu, C., Adeleke, O., & Joshipura, K. (2011). Tooth loss, chewing habits, and food choices among older Nigerians in Plateau State: A preliminary study. *Community Dentistry and Oral Epidemiology, 39*(5), 409–415.

Bessadet, M., Nicolas, E., Sochat, M., Hennequin, M., & Veyrune, J. L. (2013). Impact of removable partial denture prosthesis on chewing efficiency. *J Appl Oral Sci, 21*(5), 392–396.

Brennan, D. S., Spencer, A. J., & Roberts-Thomson, K. F. (2008). Tooth loss, chewing ability and quality of life. *Quality of Life Research, 17*(2), 227–235.

Britton, D. (2016). The impact of aging and progressive neurological disease on swallowing: A concise overview. *Journal of Texture Studies, 47*(4), 257–265.

Brodeur, J. M., Laurin, D., Vallee, R., & Lachapelle, D. (1993). Nutrient intake and gastrointestinal disorders related to masticatory performance in the edentulous elderly. *Journal of Prosthetic Dentistry, 70*(5), 468–473.

Buettner, A. (2002a). Influence of human saliva on odorant concentrations. 2. aldehydes, alcohols, 3-alkyl-2-methoxypyrazines, methoxyphenols, and 3-hydroxy-4,5-dimethyl-2(5H)-furanone. *Journal of Agriculture and Food Chemistry, 50*(24), 7105–7110.

Buettner, A. (2002b). Influence of human salivary enzymes on odorant concentration changes occurring in vivo. 1. Esters and thiols. *Journal of Agriculture and Food Chemistry, 50*(11), 3283–3289.

Chen, C. C., Schilling, L. S., & Lyder, C. H. (2001). A concept analysis of malnutrition in the elderly. *Journal of Advanced Nursing, 36*(1), 131–142.

Chen, J., & Lolivret, L. (2011). The determining role of bolus rheology in triggering a swallowing. *Food Hydrocolloids, 25*(3), 325–332.

Chow, W., Brandt, M. G., Dworschak-Stokan, A., Doyle, P. C., Matic, D., & Husein, M. (2015). Validation of the Mirror-Fogging test as a screening tool for velopharyngeal insufficiency. *The Open Otorhinolaryngology Journal, 8*, 15–21.

de Castro, J. M., & de Castro, E. S. (1989). Spontaneous meal patterns of humans: influence of the presence of other people. *American Journal of Clinical Nutrition, 50*(2), 237–247.

De Marchi, R. J., Hugo, F. N., Padilha, D. M., Hilgert, J. B., Machado, D. B., Durgante, P. C., et al. (2011). Edentulism, use of dentures and consumption of fruit and vegetables in south Brazilian community-dwelling elderly. *Journal of Oral Rehabilitation, 38*(7), 533–540.

Ekberg, O., & Feinberg, M. J. (1991). Altered swallowing function in elderly patients without dysphagia: radiologic findings in 56 cases. *AJR. American Journal of Roentgenology, 156*(6), 1181–1184.

Engelen, L., van den Keybus, P. A., de Wijk, R. A., Veerman, E. C., Amerongen, A. V., Bosman, F., et al. (2007). The effect of saliva composition on texture perception of semi-solids. *Archives of Oral Biology, 52*(6), 518–525.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12*(3), 189–198.

Fontijn-Tekamp, F. A., Slagter, A. P., Van Der Bilt, A., Van, T. H. M. A., Witter, D. J., Kalk, W., et al. (2000). Biting and chewing in overdentures, full dentures, and natural dentitions. *Journal of Dental Research, 79*(7), 1519–1524.

Fontijn-Tekamp, F. A., van der Bilt, A., Abbink, J. H., & Bosman, F. (2004). Swallowing threshold and masticatory performance in dentate adults. *Physiology & Behavior, 83*(3), 431–436.

Fucile, S., Wright, P. M., Chan, I., Yee, S., Langlais, M. E., & Gisel, E. G. (1998). Functional oral-motor skills: Do they change with age? *Dysphagia, 13*(4), 195–201.

Gupta, A., Epstein, J. B., & Sroussi, H. (2006). Hyposalivation in elderly patients. *Journal/ Canadian Dental Association. Journal de l'Association Dentaire Canadienne, 72*(9), 841–846.

Hsu, K. J., Lee, H. E., Wu, Y. M., Lan, S. J., Huang, S. T., & Yen, Y. Y. (2014). Masticatory factors as predictors of oral health-related quality of life among elderly people in Kaohsiung City, Taiwan. *Qual Life Res, 23*(4), 1395–1405.

Ikebe, K., Matsuda, K., Kagawa, R., Enoki, K., Okada, T., Yoshida, M., et al. (2012). Masticatory performance in older subjects with varying degrees of tooth loss. *Journal of Dentistry, 40*(1), 71–76.

Iwasaki, M., Yoshihara, A., Ito, K., Sato, M., Minagawa, K., Muramatsu, K., et al. (2016). Hyposalivation and dietary nutrient intake among community-based older Japanese. *Geriatrics and Gerontology International, 16*(4), 500–507.

Keller, H. H. (1993). Malnutrition in institutionalized elderly: How and why? *Journal of the American Geriatrics Society, 41*(11), 1212–1218.

Kim, J.-M., Stewart, R., Prince, M., Kim, S.-W., Yang, S.-J., Shin, I.-S., et al. (2007). Dental health, nutritional status and recent-onset dementia in a Korean community population. *International Journal of Geriatric Psychiatry, 22*(9), 850–855.

Kimura, Y., Ogawa, H., Yoshihara, A., Yamaga, T., Takiguchi, T., Wada, T., et al. (2013). Evaluation of chewing ability and its relationship with activities of daily living, depression, cognitive status and food intake in the community-dwelling elderly. *Geriatrics and Gerontology International, 13*(3), 718–725.

Kohyama, K., Mioche, L., & Bourdiol, P. (2003). Influence of age and dental status on chewing behaviour studied by EMG recordings during consumption of various food samples. *Gerodontology, 20*(1), 15–23.

Leake, J. L., Hawkins, R., & Locker, D. (1994). Social and functional impact of reduced posterior dental units in older adults. *Journal of Oral Rehabilitation, 21*(1), 1–10.

Maître, I., Symoneaux, R., & Sulmont-Rossé, C. (2014). Sensory testing in new product development: Working with older people. In J. Delarue, B. Lawlor, & M. Rogeaux (Eds.). *Rapid sensory profiling techniques and related methods*Cambridge, UK: Woodhead Publishing Limited *485-208*.

Marcenes, W., Steele, J. G., Sheiham, A., & Walls, A. W. (2003). The relationship between dental status, food selection, nutrient intake, nutritional status, and body mass index in older people. *Cad Saude Publica, 19*(3), 809–816.

Marik, P. E., & Kaplan, D. (2003). Aspiration pneumonia and dysphagia in the elderly. *Chest, 124*(1), 328–336.

Methven, L., Jiménez-Pranteda, M. L., & Lawlor, J. B. (2016). Sensory and consumer science methods used with older adults: A review of current methods and recommendations for the future. *Food Quality and Preference, 48*(Part B), 333–344.

Mioche, L., Bourdiol, P., Monier, S., & Martin, J.-F. (2002). The relationship between chewing activity and food bolus properties obtained from different meat textures. *Food Quality and Preference, 13*(7–8), 583–588.

Mioche, L., Bourdiol, P., & Peyron, M. A. (2004). Influence of age on mastication: Effects on eating behaviour. *Nutrition Research Reviews, 17*(1), 43–54.

Muñoz-González, C., Vandenberghe-Descamps, M., Feron, G., Canon, F., Labouré, H., & Sulmont-Rossé, C. (In press). Does salivary hypofunction affect food consumption in the elderlies? A systematic literature review. The Journal of Nutrition, Health & Aging.

Nagler, R. M., & Hershkovich, O. (2005). Relationships between age, drugs, oral sensorial complaints and salivary profile. *Archives of Oral Biology, 50*(1), 7–16.

Ney, D. M., Weiss, J. M., Kind, A. J., & Robbins, J. (2009). Senescent swallowing: impact, strategies, and interventions. *Nutrition in Clinical Practice, 24*(3), 395–413.

Neyraud, E. (2014). Role of saliva in oral food perception. *Monographs in Oral Science, 24*, 61–70.

Nisbett, R. E., & Wilson, T. D. (1977). The halo effect: Evidence for unconscious alteration of judgments. *Journal of Personality and Social Psychology, 35*, 250–256.

Porcherot, C., & Schlich, P. (2000). FLASH table and canonical mapping of potato varieties. *Food Quality and Preference, 11*(1–2), 163–165.

Prinz, J. F., & Lucas, P. W. (1997). An optimization model for mastication and swallowing in mammals. *Proceedings of the Royal Society B: Biological Sciences, 264*(1389), 1715–1721.

Savoca, M. R., Arcury, T. A., Leng, X., Chen, H., Bell, R. A., Anderson, A. M., et al. (2010). Severe tooth loss in older adults as a key indicator of compromised dietary quality. *Public Health Nutrition, 13*(4), 466–474.

Schlich, P. (1998). What are the sensory differences among coffees? Multi-panel analysis of variance and FLASH analysis. *Food Quality and Preference, 9*(3), 103–106.

Sharma, J. C., Fletcher, S., Vassallo, M., & Ross, I. (2001). What influences outcome of stroke–pyrexia or dysphagia? *International Journal of Clinical Practice, 55*(1), 17–20.

Silva, A. E., Demarco, F. F., & Feldens, C. A. (2015). Oral health-related quality of life and associated factors in Southern Brazilian elderly. *Gerodontology, 32*(1), 35–45.

Sreebny, L. M., & Schwartz, S. S. (1997). A reference guide to drugs and dry mouth–2nd edition. *Gerodontology, 14*(1), 33–47.

Steele, J. G., Ayatollahi, S. M., Walls, A. W., & Murray, J. J. (1997). Clinical factors related to reported satisfaction with oral function amongst dentate older adults in England. *Community Dentistry and Oral Epidemiology, 25*(2), 143–149.

Tada, A., & Miura, H. (2014). Systematic review of the association of mastication with food and nutrient intake in the independent elderly. *Archives of Gerontology and Geriatrics, 59*(3), 497–505.

Takata, Y., Ansai, T., Soh, I., Akifusa, S., Sonoki, K., Fujisawa, K., et al. (2008). Relationship between chewing ability and high-level functional capacity in an 80-year-old population in Japan. *Gerodontology, 25*(3), 147–154.

Van Lancker, A., Verhaeghe, S., Van Hecke, A., Vanderwee, K., Goossens, J., & Beeckman, D. (2012). The association between malnutrition and oral health status in elderly in long-term care facilities: A systematic review. *International Journal of Nursing Studies, 49*(12), 1568–1581.

Van Wymelbeke, V., Brondel, L., Bon, F., Martin-Pfitzenmeyer, I., & Manckoundia, P. (2016). An innovative brioche enriched in protein and energy improves the nutritional status of malnourished nursing home residents compared to oral nutritional supplement and usual breakfast: FARINE+ project. *Clinical Nutrition ESPEN, 15*, 93–100.

Vandenberghe-Descamps, M., Labouré, H., Prot, A., Septier, C., Tournier, C., Feron, G., et al. (2016). Salivary flow decreases in healthy elderly people independently of dental status and drug intake. *Journal of Texture Studies, 47*(4), 353–360.

Vandenberghe-Descamps, M., Sulmont-Rossé, C., Septier, C., Feron, G., & Labouré, H. (2017). Using food comfortability to compare food's sensory characteristics expectations of elderly people with or without oral health problems. *Journal of Texture Studies* n/a-n/a.

Veyrune, J. L., & Mioche, L. (2000). Complete denture wearers: electromyography of mastication and texture perception whilst eating meat. *European Journal of Oral Sciences, 108*(2), 83–92.

Vissink, A., Spijkervet, F. K., & Van Nieuw Amerongen, A. (1996). Aging and saliva: A review of the literature. *Special Care in Dentistry, 16*(3), 95–103.

Wansink, B., Cheney, M. M., & Chan, N. (2003). Exploring comfort food preferences across age and gender. *Physiology & Behavior, 79*(4–5), 739–747.

Witter, D. J., De Haan, A. F., Kayser, A. F., & Van Rossum, G. M. (1994). A 6-year follow-up study of oral function in shortened dental arches. Part II: Craniomandibular dysfunction and oral comfort. *Journal of Oral Rehabilitation, 21*(4), 353–366.

2. THE EFFECT OF ORAL HEALTH ON ORAL COMFORT PERCEPTION

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FOOD ORAL PROCESSING SPECIAL ISSUE

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Using food comfortability to compare food's sensory characteristics expectations of elderly people with or without oral health problems

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Abstract

Food consumption is by far the most important point where food's organoleptic properties can be perceived and can elicit sensory pleasure. Ageing is often accompanied by oral impairments. Those impairments may impact food perception by changing texture perception and the release of flavor components, which have a significant impact on food acceptability. The present study aimed at evaluating the impact of oral health on the perception of food comfortability in an elderly population. This was achieved by asking elderly people with a good oral health and elderly people with poor oral health to rate six cereal products and six meat products using a food comfortability questionnaire. Thirty-seven and 35 elderly people (65–87 years old) underwent either a cereal or meat session, respectively. The present study showed very few effects of dental and saliva status on food perception. For the cereal products, a significant effect of dental status was observed for one texture descriptor and one flavor descriptor, and a significant effect of salivary status was observed for two texture descriptors and one flavor descriptor. For the meat products, a significant effect of dental status and a significant effect of salivary status were observed on one flavor descriptor. For both products, no significant impact of dental or salivary status was observed on the general perception of food oral comfort nor on food bolus formation. Future studies exploring the impact of a broader set of oral parameters and potential adapting factors are needed to further explore the results of the present study.

Practical applications

During oral food consumption, mastication, salivation, and swallowing play a key role in the acceptance of food and beverages by modulating the perception of texture, taste, and aroma, as well as providing eating comfort by assisting the food breakdown process into a bolus that can be safely swallowed. The age-related oral impairments such as loss of teeth, decrease in salivary flow or dysphagia are known to have an impact on food consumption. However, very few products are developed to skirt those impairments. Therefore, in the context of an ageing population, there is a need to develop functional foods that meet the specific nutritional needs of the elderly population, as well as a well-balanced flavor and texture framework. Considering the large interindividual variability observed on the elderly people, developing adapted functional foods is a major challenge for the food industry and society.

KEYWORDS
elderly, food comfortability, older adults, orosensory perception, texture

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1 | INTRODUCTION

When a food is put in the mouth, oral processes, namely, mastication, salivation, and swallowing, play a key role in texture and flavor perception, which have a significant impact on food acceptability (Yven, Bonnet, Cormier, Monier, & Mioche, 2006). As ageing is often accompanied by oral impairments, it is often assumed that age-related changes in oral health may therefore impact food perception by changing texture perception (Mioche, Bourdiol, Monier, & Martin, 2002; Veyrune & Mioche, 2000) and the release of flavor components (Duffy, Cain, & Ferris, 1999)

First, each tooth is connected to periodontal mechanoreceptors (up to 2,000 mechanoreceptors per tooth) that signal information about tooth loads in a temporal, spatial, and intensive aspect. Those mechanoreceptors are located in the ligaments that attach the tooth root to the alveolar bone, among the collagen fibers (Trulsson, 2006). When teeth are extracted, the remnants of the periodontal ligament break down. According to data from animal studies, this leads to changes in the neuro-muscular pattern and in periodontal sensitivity (Veyrune & Mioche, 2000). For instance, a study in cats has shown that after teeth extraction, the periodontal mechanoreceptor neurones no longer responded to mechanic stimulation (Linden & Scott, 1989). Those observations are also done in humans, and Devezeaux de Lavergne, Derks, Ketel, de Wijk, and Stieger (2015) highlighted the fact that passive tactile sensitivity depends largely on the presence of the periodontal ligament receptors. Indeed, in a denture wearing elderly population, the texture perception is altered compared to an elderly population with natural dentition (Mojet, Christ-Hazelhof, & Heidema, 2005). Consequently, it may be assumed that age-related tooth loss could have an impact on periodontal sensitivity and thus on texture perception in the elderly population. Second, ageing is also often accompanied by a decrease in muscle strength (Fontijn-Tekamp, van der Bilt, Abbink, & Bosman, 2004). It has been demonstrated that reduced strength in the jaw masticatory muscles and an alteration of dental status can have an impact on biting and chewing behavior (Mioche, Bourdiol, & Peyron, 2004). It may be assumed that these changes could have an impact on the perception of food rheological properties such as tenderness, elasticity, firmness, and melting, among others. Third, ageing may often be accompanied by a decrease in salivary flow (Vandenberghe-Descamps et al., 2016) or changes in salivary composition (Vissink, Spijkervet, & Amerongen, 1996), which in turn may have an impact on taste and texture perception. Indeed, it may be considered that an age-related decrease in salivary flow could modulate the perception of oral sensations such as viscosity, smoothness, juiciness, and astringency, among others (Neyraud, 2014). Furthermore, Engelen et al. (2007) demonstrated that subjects with high α-amylase activity had a decreased thickness perception of starch-based custard. Finally, mastication and saliva transform a food sample into a bolus that can be safely swallowed (Prinz & Lucas, 1997; Shaw & Martino, 2013). These food breakdown processes also lead to the release of chemical compounds responsible for taste and aroma perception. Age-related impairments have been demonstrated to have a significant impact on food bolus formation (Bessadet, Nicolas, Sochat, Hennequin, & Veyrune, 2013; Veyrune & Mioche, 2000). For instance, Bessadet et al. (2013) showed that denture wearers presented a decrease in the median particle size of food boluses in comparison to elderly people without removable denture prosthesis. In parallel, it may also be hypothesized that a decrease in food breakdown efficiency could lead to changes in flavor release.

In a recent study, we have explored the concept of "oral comfort" when eating a food in the elderly population (Vandenberghe-Descamps, Labouré, Septier, Feron & Sulmont-Rosse, in press). Three focus groups were conducted with elderly people. Each group included volunteers with poor oral health and volunteers with good oral health, in regards to dental status and salivary flow rate. The results of the focus groups, which included brainstorming (What is oral comfort for you?) and food tasting, revealed four dimensions underlying the concept of "oral comfort": the ability to form a food bolus, pain perception, texture perception, and flavor perception. The results were used to create a "food comfortability" questionnaire that included items on these four dimensions. This questionnaire was used in the present study to evaluate the impact of oral health status on food perception in elderly participants. Among the three identified oral health parameters (i.e., salivary status, dental health, and muscle strength), the first two were studied in the present experiment. Specifically, we asked elderly people with a good oral health and elderly people with poor oral health (poor dental status and/or low salivary flow) to rate six cereal products and six meat products using the food comfortability questionnaire.

2 | MATERIALS AND METHODS

2.1 | Participants

The data were collected as part of a programme that aimed at studying the relationship between oral health and eating behavior (AlimaSSenS project: toward an adapted and healthy food supply for elderly people). Among the 50 AlimaSSenS project's volunteers recruited at that time, 37 and 34 subjects were available for the cereal-based products and the meat-based products sessions, respectively. The recruitment criteria were as follows: older than 65 years old, living at home, no acute pathological episodes neither at the time of the experiment nor in the recent past, a score of at least 24 on the mini mental state evaluation (MMSE) (Folstein, Folstein, & Mchugh, 1975), and a number of functional units equal to seven or more (for non-oral health problems) and equal to four or less (for oral health problems). The thresholds of seven and four functional units to define good and bad dental status, respectively, were defined according to Leake, Hawkins, and Locker (1994). A functional unit was defined as a pair of posterior antagonist teeth that had at least one contact area during chewing. An interview and a dental examination were carried out with each volunteer to ensure that they met the inclusion criteria. In parallel, the resting salivary flow of every volunteer was measured by instructing the participant to spit out the saliva into a pre-weighed screw-cap cup every time they felt like swallowing over a period of 10 min. Salivary flow rate was expressed in ml/min, assuming that 1 g of saliva corresponds to 1 ml. As with the number of functional units, the participants were categorized into two groups depending on

General question

This food is…

Very uncomfortable	Uncomfortable	Moderately comfortable	Comfortable	Very comfortable
□	□	□	□	□

Bolus formation

To cut this food with your incisor is…

Impossible	Very difficult	Difficult	Moderately easy	Easy	Very easy
□	□	□	□	□	□

Same scale for cutting with premolars, masticating, humidification with saliva, swallowing and time needed to form the food bolus

Mouth pain

Does eating the food bring a burning or spicy sensation?

Extremely	A lot	Little	Not at all
□	□	□	□

Same scale for muscular pain, articular pain, dental pain and gum pain

Texture

Is this food sticky?

Extremely	A lot	Little	Not at all
□	□	□	□

Same scale for stringy, greasy, dry, doughy, melting, firm and hard

Flavour

Is this food intense in taste?

Extremely	A lot	Little	Not at all
□	□	□	□

Same scale for salty, sugary, acidic and bitter

FIGURE 1 Food comfortability questionnaire

their salivary flow. The cutoff value corresponds to the median resting salivary flow observed in 180 AlimaSSenS project's volunteers (65–92 years-old) and is equal to 0.26 ml/min. Therefore, elderly people with a salivary flow below 0.26 ml/min were considered as having a low salivary flow, and elderly people with a salivary flow over 0.26 ml/min were considered as having a high salivary flow.

2.2 | Products

Six cereal-based products and six meat-based products were chosen in order to have contrasted textures. The cereal-based products included a crispbread, a financier, a madeleine, a sponge cake, a milk roll, and a protein enriched milk roll. The meat-based products included stewed cheek, beefsteak, ground beef, chicken meatballs, chicken aiguillette, and ground chicken reconstituted in an aiguillette shape.

2.3 | Procedure

The volunteers were invited to take part in one session where they had to taste six products, either the cereal-based products or the meat-based products. For each product, the volunteers were asked to answer the "food comfortability" questionnaire (Figure 1). At the beginning of each session, the questionnaire was presented to the volunteers by the experimenter. No specific training was performed before the sessions. The questionnaire included five sections (Vandenberghe-Descamps et al., in press).

- A first general question on food comfort that the participants answered using a 5-point scale ranging from "Very uncomfortable" to "Very comfortable."
- A second section on bolus formation included five items: the ability to cut the food with incisors, the ability to cut the food with premolars, the ability to masticate the food, the ability to humidify the food with saliva, and the ability to swallow the food. For each item, participants answered on 6-point scale ranging from "Impossible" to "Very easy." This section also included an item on the time needed to form the food bolus; participants answered using a 6-point scale ranging from "Impossible" to "Very brief."
- A third section on pain perception included five items: burning or spicy sensation, muscular pain, articular pain, dental pain, and gum pain. For each item, participants answered on a 4-point scale ranging from "Extremely" to "Not at all."

TABLE 1 General characteristics of participants

		Cereal panel	Meat panel
Number of participants		37	34
Gender (% female)		54.05%	52.94%
Age	*m* (SEM)	73.49 (1.04)	72.15 (1.07)
	Range	65–87 years old	65–87 years old
Dental status	**Good dental status**		
	n	23	22
	m (SEM)	8.09 FU (0.53)	8.27 FU (0.64)
	Poor dental status		
	n	14	12
	m (SEM)	3.36 FU (0.69)	2.58 FU (0.84)
Saliva status	**High salivary flow**		
	n	17	18
	m (SEM)	0.53 ml/min (0.05)	0.51 ml/min (0.05)
	Low salivary flow		
	n	20	16
	m (SEM)	0.14 ml/min (0.05)	0.16 ml/min (0.05)

FU = Functional Units; SEM = Standard Error of the Mean.

- A fourth section on texture perception included eight items that were evaluated on their intensity: sticky, stringy, greasy, dry, doughy, melting, firm, and hard. The items were rated on a 4-point scale ranging from "Extremely" to "Not at all."
- A fifth section on flavor perception included five items: taste intensity and the salty, sugary, acidic, and bitter perceptions. For each item, participants answered on a 4-point scale ranging from "Extremely" to "Not at all."

During the sessions, the volunteers were free to bite the products as many times as they wanted in order to answer the questions on the "food comfortability" questionnaire. The participants were given a 3-min rest time between samples, and they were free to drink as much water as they needed during the session. Meat-based products were cooked right before serving according to the recipes provided by the supplier. They were served when the temperature in the heart of the product reached at least +65C. The sessions were conducted in a sensory room equipped with individual booths according to the AFNOR standard (AFNOR, 1987) and under white light. The room temperature was 20.5 ± 0.5C. The products were presented in an order determined by a William Latin square design; they were coded with a three-digit number.

2.4 | Data analysis

Separate analyses were conducted for the cereal products and for the meat products. For each item of the "food comfortability" questionnaire, scores were submitted to an analysis of variance (ANOVA) with three fixed factors (i.e., product, dental status [poor or good], salivary status [low or high]), and one random factor (participant). Post hoc comparisons were performed using the Student Newman Keuls test. Means (M) were associated with their standard errors (SEM). The threshold for significance was set at 5%. Statistical analyses were conducted using R-studio software version 3.3.1 with the "nlme" package for linear mixed models and the "agricolae" package for post hoc analyses (de Mendiburu, 2016).

3 | RESULTS

3.1 | Panel description

The general characteristics of participants recruited from the cereal testing and the meat testing are described in Table 1. Regarding dental status, we distinguished elderly people with good dental status (seven or more functional units) from elderly people with poor dental status (four or less functional units, possibly wearing denture). For both product categories the number of functional units of the elderly participants in the poor dental status group was significantly lower than that of the elderly participants in the good dental status group (cereal-based products: $t(36) = 13.17$; $p < .001$; meat-based products: $t(33) = 13.04$; $p < .001$). Regarding salivary status, we distinguished elderly people with a high salivary flow (higher than 0.26 ml/min) from elderly people with a low salivary flow (lower than 0.26 ml/min). The salivary flow of the elderly participants in the low salivary flow group was significantly lower than that of the elderly participants in the high salivary flow group (cereal-based products: $t(36) = 10.13$; $p < .001$; meat-based products: $t(33) = 10.54$; $p < .001$).

3.2 | Results on cereal-based products

The results on the dentition effect reveal that there was no effect of dental status on the general question of food comfortability (Table 2). Few effects were observed in the subdimensions of food comfortability. A significant dentition effect was observed on muscle pain and dental pain. Elderly people with a poor dentition reported feeling more muscle and dental pain while eating the food than elderly people with a good dentition. A dentition effect was also observed on the

TABLE 2 Results of the Anova on the dentition and saliva effect for both cereal-based and meat-based products

		Cereal-based products			Meat-based products		
	Variables	Dentition effect	Saliva effect	Interaction	Dentition effect	Saliva effect	Interaction
General perception	Comfort	0.490	0.856	0.641	0.569	0.872	0.815
Bolus formation	Incisor	0.894	0.379	0.716	0.270	0.949	0.840
	Molar	0.279	0.130	0.704	0.358	0.899	0.961
	Masticate	0.656	0.675	0.545	0.866	0.812	0.424
	Humidify	0.831	0.609	0.948	0.938	0.334	0.479
	Swallow	0.794	0.228	0.878	0.685	0.475	0.406
	Time	0.425	0.419	0.749	0.944	0.100	0.757
Pain	Burn	0.354	0.610	0.224	0.165	0.278	**.001*****
	Muscle	**.015***	**.053***	**.013***	**.012***	0.280	0.105
	Articular	0.134	0.680	**.038***	0.607	0.709	0.175
	Dental	**.012***	**.046***	**.006****	0.343	0.716	0.834
	Gum	0.565	0.150	0.916	0.839	0.797	0.416
Texture	Sticky	0.095	0.192	0.059	0.143	0.121	0.931
	Stringy	**.045***	**.048***	0.206	0.766	0.707	0.828
	Greasy	0.603	0.609	**.052***	0.204	0.277	0.585
	Dry	0.341	0.469	0.711	0.603	0.714	0.901
	Doughy	0.793	0.106	0.101	0.300	0.306	0.531
	Melting	0.391	0.206	0.660	0.730	0.474	0.540
	Firm	0.312	0.945	0.208	0.236	0.528	0.300
	Hard	0.784	**.046***	0.443	0.949	0.159	0.928
Flavor	Taste intense	0.547	0.316	0.565	0.478	0.876	0.877
	Salty	0.450	0.870	0.473	0.338	0.938	0.340
	Sweet	0.659	0.981	0.170	0.549	**.044***	0.464
	Acidic	0.712	0.211	**.034***	**.016***	0.610	0.648
	Bitter	0.871	0.313	0.078	0.455	0.505	0.805

Note. Presentation of the *p* value and significance levels (*$p < .05$; **$p < .01$; ***$p < .001$).

perception of a stringy texture. Elderly people with a poor dentition found the cereal-based products less stringy than elderly people with a good dentition.

The results on the saliva effect reveal that there was no effect of salivary status on the general question of food comfortability (Table 2). A significant salivary effect was observed on muscle and dental pain and on the stringiness and hardness of the food. The results showed that elderly people with a low salivary flow felt more muscle and dental pain and found the cereal-based products harder but less stringy than elderly people with a high salivary flow.

Moreover, a significant *dental status* × *saliva status* interaction was observed for muscle pain, articular pain, dental pain, greasiness, and acidic items; the volunteers with poor dental status and a low salivary flow found that eating the products resulted in more muscle, articular, and dental pain and considered the products less greasy but more acidic than the other groups.

3.3 | Results on meat-based products

The results on the dentition effect reveal that there was no effect of dental status on the general question of food comfortability (Table 2). Few effects were observed in the subdimensions of food comfortability. A significant dentition effect is observed on muscle pain. Elderly people with a poor dentition reported feeling more muscle pain during food consumption than elderly people with a good dentition. A dentition effect was also observed on the acidic perception. Elderly people with a poor dentition found the products more acidic than elderly people with a good dentition.

The results on saliva effect reveal that there was no effect of salivary status on the general question of food comfortability (Table 2). A significant effect was observed on the perception of sweetness. Elderly people with a poor dentition found the products less sweet than elderly people with a good dentition.

Moreover, a significant *dental status* × *saliva status* interaction was observed for the burning sensation; the elderly people with a poor dentition and a low salivary flow felt more burning sensations while eating than the other groups.

4 | DISCUSSION

Contrary to what was expected, we observed only few effects of dental or salivary status on cereal and meat products perception. For the cereal products, poor oral status induced slightly more muscular and dental pain. However, a significant effect of dental status was observed for only one texture descriptor and one flavor descriptor, and a significant effect of salivary status was observed for only two texture descriptors. A significant effect of the interaction *saliva* × *dental* status was also observed on three pain descriptors and one flavor descriptor. For the meat-based products, poor oral status induced slightly more muscular pain. A significant effect of dental status and a significant effect of salivary status were observed on one flavor descriptor. No significant impact of dental or salivary status was observed on the general perception of food oral comfort nor on food bolus formation.

Several methodological limitations can be initially considered to explain these inconclusive results.

First, the number of volunteers was relatively small. Therefore, the results need to be carefully considered, in particular those on saliva-dental status interaction, and studies with a higher number of volunteers are recommended. However, it is challenging to recruit elderly people with poor oral health at a good cognitive level to carry out the sensory tests. In fact, elderly people with poor oral health are usually frail and dependent, and therefore, they are less willing to take part in this type of study (Maître, Symoneaux, & Sulmont-Rossé, 2015).

Second, the recruited volunteers were naive in terms of sensory analysis and were therefore not used to rating food on sensory descriptors. Their inexperience might have led to a misunderstanding of the items and/or the misusing of the scales. These points were evaluated during the creation of the food comfortability questionnaire (Vandenberghe-Descamps et al., in press). To check rating repeatability, participants from the cereal panel were invited to come back to the laboratory three months later for a second session. During this session, they were asked to rate the same cereal products using the same "food comfortability" questionnaire under similar experimental conditions. The data from the first and the second session were submitted to an ANOVA with product and session as fixed factors. The results showed a significant *session* effect for five descriptors: ability to masticate the food, ability to swallow the food, stringy, greasy, and doughy. For all these descriptors, participants gave higher scores during the first session than during the second one. However, a significant *product* × *session* interaction was observed for only the descriptor doughy; the financier belonged to the "doughy" products in the first session (with the madeleine, the milk roll, and the protein-enriched milk roll), while it belonged to the "not doughy" products in the second session (with the crispbread). None of the other questionnaire items were associated with a significant *product* × *session* interaction, providing that the participants were quite repeatable when scoring the products for food comfortability.

Third, only two oral health parameters were used in the present study for assessing the oral status of the participant: the number of functional units and the resting salivary flow. Indeed, the number of functional units is known to be a key determinant of masticatory performance (Hatch, Shinkai, Sakai, Rugh, & Paunovich, 2001), and the resting salivary flow reflects an individual's basic physiological status rather than his/her immediate reflex response to stimulation. However, other oral parameters could have been taken into account. Regarding mastication, muscle mass and bite force are known to decrease with age and thus decrease masticatory performance (Hatch et al., 2001; Woda, Mishellany, & Peyron, 2006). However, Kohyama, Mioche, and Bourdiol (2003) demonstrated that elderly people cope relatively well with muscular weakness by extending the time cycle of mastication. Regarding salivation, previous studies have concluded that a value of 0.1 ml/min defines hyposalivation. However, most of these studies were conducted with frail, dependent, and highly medicated elderly people (Muñoz-González et al., in press). In the present study conducted with healthy elderly people living at home, only 6% of the participants displayed a resting salivary flow below 0.1 ml/min. Furthermore, the present study compared elderly people with low salivary flow versus high salivary flow, not necessarily elderly people with hyposalivation versus elderly without hyposalivation. Indeed, a person with hyposalivation can be defined as having a resting salivary flow rate below 0.1 ml/min; meanwhile, we limited our subjects having a resting salivary flow that was based on the median resting salivary flow observed in a large sample of healthy and autonomous elderly people (i.e., AlimaSSenS sample, $n = 180$). Furthermore, it could be argued that measuring *stimulated* salivary flow rather than *resting* salivary flow would be better representative of the saliva flow induced by the consumption of a food. Measuring stimulated salivary flow consists in collecting saliva either during a mechanical stimulation (chewing a piece of paraffin wax during collection) or a gustatory stimulation (application of citric acid on the anterior surface of the tongue). However, those two stimulations are a reduced representation of stimulated saliva during food eating, which involves a much more complex stimulation (Ekström, Khosravani, Castagnola, & Messana, 2012). Indeed, it has been shown in cereal products (toast and cake) that stimulated salivary flow during food consumption is significantly higher than mechanically stimulated salivary flow (Gavião, Engelen, & van der Bilt, 2004) Moreover, the authors observed a significant correlation between resting salivary flow and food-stimulated salivary flow, which suggested that resting salivary flow can be an indicator of the amount of saliva secreted during eating. Furthermore, the measure of stimulated salivary flow was associated with a large variability, whether between the different stimulations or even inside one stimulation but with different methods to collect saliva (Navazesh & Christensen, 1982).

To the best of our knowledge, the present experiment is the very first one that studied the impact of dental status and salivary flow on food perception, particularly texture and taste perception, in the elderly population. However, the absence of conclusive results observed in the present study is consistent with the results of the very few studies that investigated texture perception in older people. In fact, the research studies on meat texture produced by Mioche and collaborators showed no aged-related effects in terms of tenderness and juiciness perception when comparing young subjects and old adults with good dental health (Mioche, 2004). Veyrune and Mioche (2000) noticed that subjects with complete dentures were more sensitive to changes in juiciness of meat samples compared to dentate subjects, but the toughness perception of meat was similar between the two groups. Several hypotheses can be proposed to explain this lack of strong impact of age-related oral impairment on texture perception.

First, it may be assumed that the few remaining teeth of the elderly people with poor dental status are sufficient to discriminate the products, in particular, products that present large differences in terms of texture and/or flavor, as was the case in the present experiment. In fact, texture perception does not exclusively rely on periodontal mechanoreceptors. There are also mechanoreceptors in the other oral mucosa (tongue, palate, cheek) which may be sufficient to perceive food texture when the periodontal sensitivity is impaired due to tooth loss. Second, it is also possible that low saliva flow subjects had low saliva flow for a long time or that saliva flow had decreased progressively in time. In this case, they do not realize that it takes them longer to humidify the food with their saliva, and do not consider the food drier than elderly people with a high salivary flow. They probably adapted their food oral processing to this low saliva flow without any consequence in dry perception and food comfortability. Third, elderly people with poor oral health may have adapted their eating behavior, such as mouthful size, chewing time, or the amount of water drunk. Regarding mouthful size, Goto et al. (2015) suggested that a decrease in the mouthful size might assist with the formation of a bolus to cope with poor oral health. In the present experiment, we measured spontaneous mouthfuls of the cereal products during the second session that was organized to measure rating repeatability. For each product, five samples were served to the participants. Participants were asked to bite one time in each sample, and mouthful sizes were weighted by the experimenters. The results showed no difference between participants, whether they had oral impairments (poor dental status or low salivary flow rate) or not. They did not adapt the size of their mouthful according to their oral health. Regarding chewing time, it may be assumed that elderly people with oral impairment spend more time chewing food, particularly uncomfortable food, but they would not consciously realize it as it resulted from a progressive decline in oral health. The chewing time should be measured in further studies in order to confirm or infirm this hypothesis. Regarding the amount of water drunk, Shiozawa and Kohyama (2011) demonstrated that the addition of water in the mouth during mastication would facilitate the formation of a food bolus suitable for swallowing, regardless of the type of food. It may be assumed that elderly people with a low salivary flow drink a larger amount of water during food consumption. Measuring the amount of water drunk during the sessions in future studies will help in better understanding the eating behavior of this specific population.

5 | CONCLUSION

In conclusion, we observed very few effects of dental and saliva status on food perception for cereal-based and meat-based products. This is consistent with the results of the very few studies that investigated texture perception in older people. However, before drawing definitive conclusions, future studies should explore the impact of a broader set of oral parameters including muscle strength and measure potential adapting factors (mouthful size, chewing time, and water drunk…). Furthermore, it could be interesting to consider the impact of age-related impairment on the perception of food products, which displayed a smaller sensory difference than in the present experiment.

ETHICAL STATEMENTS

Conflict of Interest: The authors declare that they do not have any conflicts of interest.

Ethical Review: The experimental protocol was approved by the French Ethics Committee for Research (CPP Est III, Nancy, #15.04.04, ANSM #2015-A00279-40).

Informed Consent: In accordance with ethical standards, all participants received written and oral information on the study before signing a consent form.

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REFERENCES

AFNOR (Association française de normalisation) (1987). Bulletin des bibliothèques de France (BBF), n 4, p. 386–388. Available on line : <http://bbf.enssib.fr/consulter/bbf-1987-04-0386-001>. ISSN 1292-8399.

Bessadet, M., Nicolas, E., Sochat, M., Hennequin, M., & Veyrune, J. L. (2013). Impact of removable partial denture prosthesis on chewing efficiency. *Journal of Applied Oral Science: Revista FOB*, *21*, 392–396.

Devezeaux de Lavergne, M., Derks, J. A. M., Ketel, E. C., de Wijk, R. A., & Stieger, M. (2015). Eating behaviour explains differences between individuals in dynamic texture perception of sausages. *Food Quality and Preference*, *41*, 189–200.

Duffy, V. B., Cain, W. S., & Ferris, A. M. (1999). Measurement of sensitivity to olfactory flavor: Application in a study of aging and dentures. *Chemical Senses*, *24*, 671–677.

Ekström, J., Khosravani, N., Castagnola, M., & Messana, I. (2012). Saliva and the control of its secretion. In O. Ekberg (Ed.), *Dysphagia: Diagnosis and treatment* (pp. 19–47). Berlin, Heidelberg: Springer Berlin Heidelberg.

Engelen, L., van den Keybus, P. A., de Wijk, R. A., Veerman, E. C., Amerongen, A. V., Bosman, F., … van der Bilt, A. (2007). The effect of saliva composition on texture perception of semi-solids. *Archives of Oral Biology*, *52*, 518–525.

Folstein, M. F., Folstein, S. E., & Mchugh, P. R. (1975). "Mini-mental state." A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*, *12*, 189–198.

Fontijn-Tekamp, F. A., van der Bilt, A., Abbink, J. H., & Bosman, F. (2004). Swallowing threshold and masticatory performance in dentate adults. *Physiology & Behavior*, *83*, 431–436.

Gavião, M. B., Engelen, L., & van der Bilt, A. (2004). Chewing behavior and salivary secretion. *European Journal of Oral Sciences*, *112*, 19–24.

Goto, T., Nakamich, A., Watanabe, M., Nagao, K., Matsuyama, M., & Ichikawa, T. (2015). Influence of food volume per mouthful on chewing and bolus properties. *Physiology & Behavior*, *141*, 58–62.

Hatch, J. P., Shinkai, R. S., Sakai, S., Rugh, J. D., & Paunovich, E. D. (2001). Determinants of masticatory performance in dentate adults. *Archives of Oral Biology*, *46*, 641–648.

Kohyama, K., Mioche, L., & Bourdiol, P. (2003). Influence of age and dental status on chewing behaviour studied by EMG recordings during consumption of various food samples. *Gerodontology*, *20*, 15–23.

Leake, J. L., Hawkins, R., & Locker, D. (1994). Social and functional impact of reduced posterior dental units in older adults. *Journal of Oral Rehabilitation*, *21*, 1–10.

Linden, R. W. A., & Scott, B. J. J. (1989). The effect of tooth extraction on periodontal ligament mechanoreceptors represented in the mesencephalic nucleus of the cat. *Archives of Oral Biology*, *34*, 937–941.

Maître, I., Symoneaux, R. & Sulmont-Rossé, C. (2015). Sensory testing in new product development: working with older people. In J. Delarue, B. Lawlor & M. Rogeaux (Eds.), *Rapid sensory profiling techniques and related methods* (pp. 485–208). Cambridge, UK: Woodhead Publishing Limited.

de Mendiburu, F. (2016). Statistical Procedures for Agricultural Research. Version 1.2-4. URL : http://tarwi.lamolina.edu.pe/~fmendiburu

Mioche, L. (2004). Mastication and food texture perception: Variation with age. *Journal of Texture Studies*, *35*, 145–158.

Mioche, L., Bourdiol, P., Monier, S., & Martin, J. F. (2002). The relationship between chewing activity and food bolus properties obtained from different meat textures. *Food Quality and Preference*, *13*, 583–588.

Mioche, L., Bourdiol, P., & Peyron, M. A. (2004). Influence of age on mastication: Effects on eating behaviour. *Nutrition Research Reviews*, *17*, 43–54.

Mojet, J., Christ-Hazelhof, E., & Heidema, J. (2005). Taste perception with age: Pleasantness and its relationships with threshold sensitivity and supra-threshold intensity of five taste qualities. *Food Quality and Preference*, *16*, 413–423.

Muñoz-González, C., Vandenberghe-Descamps, M., Feron, G., Canon, F., Labouré, H., & Sulmont-Rossé, C. (in press). Does salivary hypofunction affect food consumption in the elderlies? A systematic literature review.

Navazesh, M., & Christensen, C. M. (1982). A Comparison of whole mouth resting and stimulated salivary measurement procedures. *Journal of Dental Research*, *61*, 1158–1162.

Neyraud, E. (2014). Role of saliva in oral food perception. *Monographs in Oral Science*, *24*, 61–70.

Prinz, J. F., & Lucas, P. W. (1997). An optimization model for mastication and swallowing in mammals. *Proceedings: Biological Sciences*, *264*, 1715–1721.

Shaw, S. M., & Martino, R. (2013). The normal swallow: Muscular and neurophysiological control. *Otolaryngologic Clinics of North America*, *46*, 937–956.

Shiozawa, K., & Kohyama, K. (2011). Effects of addition of water on masticatory behavior and the mechanical properties of the food bolus. *Journal of Oral Biosciences*, *53*, 148–157.

Trulsson, M. (2006). Sensory-motor function of human periodontal mechanoreceptors. *Journal of Oral Rehabilitation*, *33*, 262–273.

Vandenberghe-Descamps, M., Labouré, H., Prot, A., Septier, C., Tournier, C., Feron, G., & Sulmont-Rossé, C. (2016). Salivary flow decreases in healthy elderly people independently of dental status and drug intake. *Journal of Texture Studies*, *47*, 353–360.

Vandenberghe-Descamps, M., Labouré, H., Septier, C., Feron, G., & Sulmont-Rossé, C. (in press). Food comfortability: A new concept to understand elderlies' expectations in terms of food sensory characteristics. Food Quality and Preference.

Veyrune, J. L., & Mioche, L. (2000). Complete denture wearers: Electromyography of mastication and texture perception whilst eating meat. *European Journal of Oral Sciences*, *108*, 83–92.

Vissink, A., Spijkervet, F. K. L., & Amerongen, A. V. N. (1996). Aging and saliva: A review of the literature. *Special Care in Dentistry*, *16*, 95–103.

Woda, A., Mishellany, A., & Peyron, M. A. (2006). The regulation of masticatory function and food bolus formation. *Journal of Oral Rehabilitation*, *33*, 840–849.

Yven, C., Bonnet, L., Cormier, D., Monier, S., & Mioche, L. (2006). Impaired mastication modifies the dynamics of bolus formation. *European Journal of Oral Sciences*, 184–190.

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CHAPTER 4: DEVELOPMENT OF CULINARY TECHNIQUES TO IMPROVE MEAT TEXTURE

CHAPTER 4: DEVELOPMENT OF CULINARY TECHNIQUES TO IMPROVE MEAT TEXTURE

1. IDENTIFICATION OF CULINARY TECHNIQUES

IMPACT OF EASY-TO-DO CULINARY TECHNIQUES ON MEAT SHEAR FORCE AND WATER CONTENT

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Abstract:

Tenderness and juiciness are two essential characteristics for meat palatability, but seem to also have an impact on food bolus formation. Indeed, a tough or dry meat sample can be very difficult to eat, especially for elderly people who encounter oral health impairments due to ageing. The aim of the present study was to evaluate culinary techniques that elderly people could perform at home, in order to improve meat texture. This was achieved by measuring shear force and water content of beefsteak, roast beef and chicken breast samples that underwent either blade tenderization, marinade, or both treatments. Furthermore, roast beef and chicken breast samples were cooked either at low temperature or high temperature. The results showed a decrease in shear force and an increase in water content for blade tenderized and blade tenderized + marinated samples for both beef meats. In addition, the roast beef samples cooked at low temperature showed a significantly lower shear force and significantly greater water content. Future studies exploring a broader set of meat should be conducted to complete the results of the present study; the optimum conditions will be tested on an elderly panel to assess oral comfort when eating the samples.

Keywords: culinary techniques, marinade, blade tenderization, juiciness, tenderness, elderly people.

INTRODUCTION

Tenderness and juiciness are two essential characteristics for meat palatability (Robbins *et al.*, 2002; Huffman *et al.*, 1996; O'Quinn *et al.*, 2012). O'Quinn *et al.* (2012) have indeed highlighted that the overall liking of meat was associated to samples combining juiciness, tenderness and flavor intensity. Looking at the textural items, tenderness is a quality trait that ensures a softer meat, easy to chew while juiciness corresponds to the amount of juice that comes in mouth when biting in a sample of meat. Tenderness and juiciness can vary depending on several factors. First, tenderness can be influenced by meat treatments all along the processing chain, starting from the raising of the animal and ending in everyone's kitchen. Animals' characteristics such as breed, sex, age or its diet have an influence on meat quality and thus meat tenderness (Półtorak *et al.*, 2017; Guerrero *et al.*, 2013; Seideman and Crouse, 1986). Furthermore, the quality of slaughter also impacts meat tenderness. Killing the animal in a less stressful environment and performing an optimal cooling of the meat leads to a more tender meat at the end (Ferguson and Warner, 2008). Finally, meat tenderness can be increased using culinary techniques such as slice cutting, pounding, tumbling or poking (Pietrasik and Shand, 2004; Obuz *et al.*, 2014; for a review, see Bekhit *et al.*, 2013). Second, juiciness is associated to the level of liberated juice when biting a piece of meat. It is determined by the kind of sample, its quality, the time of maturation or any treatment such as marinade or brine (Robbins *et al.*, 2002; Burke and Monahan, 2003). Cooking condition can also improve tenderness and juiciness. When a meat is cooked, the collagen mesh gradually degrades and dissolves while muscle fibers retract. Cooking at low temperature leads to a better degradation of collagen which induces an increase of tenderness. In the meantime, the fibers retract less strongly which leads to a less strong compression of the meat and therefore decreases the quantity of juice liberated (Woolsey and Paul, 1969; Leander *et al.*, 1980; Bouton and Harris, 1981). Therefore, meat texture characteristics such as tenderness or juiciness can be impacted at any stage of meat process and controlling those stages is necessary as tenderness and juiciness remain essential for a consumer willing to eat meat. Indeed, a tough or dry meat sample can be very difficult to eat, especially for elderly people who encounter oral health impairments with ageing. Some elderly people can indeed be exposed to loss of teeth, a decrease in salivary secretion or even swallowing impairments, those impairments can induce eating difficulties. Thus, it would be interesting to give them tools to improve meat tenderness and juiciness at home in order to maintain pleasantness when eating meat. Many studies have already investigated techniques to improve meat tenderness and juiciness; however most of those techniques are not reproducible at home by average persons. First, injection is commonly used when working on beef tenderness. Made of phosphate, calcium chloride or a solution of both molecules, several authors have highlighted its impact on beef tenderness improvement (Pietrasik *et al.*, 2010; Pietrasik and Shand, 2004; Morgan *et al.*, 1991). However, those solutions are not made of ingredients commonly found in everyone's kitchen, furthermore it requires specific utensils that not everyone has. Finally, injecting meat cannot be well accepted by an elderly population willing to eat natural foods. Second, marinade was proven to increase tenderness. Several marinades were studied to investigate its impact of the different solutions on the physical characteristics of meats (Oreskovich *et al.*, 1992; Istrati *et al.*, 2015; Burke and Monahan, 2003). Some are made of uncommon ingredients; others are the result of a very complicated recipe with 8 or more items. In all cases the instructions are difficult to follow by an ordinary elderly person. Furthermore, marinade conditions are most of the time disconnected from what one can do at home to prepare a meat. Finally, several authors showed that cooking meat at low temperature could increase its tenderness (Bouton and Harris, 1981; Bouton and Harris, 1972; Obuz *et al.*, 2003). However, none of those studies use every day cooking conditions; while some cook their meat in water bath, others cooked the meat for many hours. An evaluation of non-expensive and easy-to-do culinary techniques should be performed in order to characterize meat texture after mechanical treatments.

Therefore, the aim of the present study was 1) to evaluate the impact of non-expensive and easy to do at home culinary techniques on meat tenderness and juiciness through physical measurements; 2) to select relevant culinary techniques for future studies that will ask a panel of elderly people to assess oral comfort when eating the meat samples in order to confront the results of the present study.

MATERIALS AND METHODS

Preparation of the products

Three meat products were chosen for the present study as they are commonly eaten in France: beefsteak, roast beef and chicken breast. All the products were provided by a butcher in the area of Dijon, each meat was provided from the same batch. The 3 meats were prepared following four different preparation modes: without any preparation, blade tenderized, marinated, or blade tenderized then marinated. In order to identify the optimum procedure for blade tenderization, marinade and cooking conditions, preliminary tests were conducted in the laboratory to select protocols that best improve meat texture. For those preliminary tests, shear force and water content of the samples (data not shown) were measured. Regarding blade tenderization, some tests were performed to evaluate the efficiency of one pass and two passes on the meat. The results of the preliminary tests showed that one pass on the meat lead to a decrease in shear force and an increase in water content compared to two passes or no blade tenderization. Therefore, the decision was made to perform one pass on each sample for the present study, on the top side for beefsteak and chicken breast samples and on both sides for the roast beef samples which were too thick for the blade tenderizer to pass through. Regarding the choice of marinade, some preliminary tests were performed using a marinade made of yogurt, soy sauce, vinegar or wine. The results showed that the marinade made of soy sauce was optimum for a decrease in shear force and an increase in water content of the meat. Therefore, the choice was made to select the marinade made of soy sauce for further tests. Finally, some cooking tests were performed to evaluate the impact of cooking conditions on meat texture for meat that need to be cooked in an oven, *i.e.* roast beef and chicken breast samples. Some commercially available products such as cooking bags are sold to improve meat tenderness and juiciness. Thus, the meat was cooked either in a cooking bag, "en papillotte", or with nothing. The results showed that cooking meat in cooking bags was in fact efficient; the choice was made to cook every meat that needed to be cooked in an oven in cooking bags for further tests.

Therefore, the following procedures were applied in the present study:

- Blade tenderization was performed using a blade tenderizer (Hendi Profi Line 51 blades). One pass was done on each sample, on the top side for beefsteak and chicken breast samples and on both sides for the roast beef samples which were too thick for the blade tenderizer to pass through
- The marinade was made of 6% soy sauce Suzi Wan® and 94% Evian® water, the beefsteak and chicken breast samples stayed in the marinade for 2 hours at +4°C; the roast beef stayed in the marinade for 4 hours at +4°C (Table 1).
- All roast beef and chicken breast samples were cooked in cooking bags

Table 1: Preparation and cooking of the products

	Preparation mode	Time of stay in the marinade	Cooking temperature
Beefsteak	None	-	Induction plaque at 160°C
	Blade tenderized	-	Induction plaque at 160°C
	Marinated	2 hours	Induction plaque at 160°C
	Blade tenderized + marinated	2 hours	Induction plaque at 160°C
Roast beef samples	None	-	Oven at 220°C
	Blade tenderized	-	Oven at 220°C
	Marinated	4 hours	Oven at 220°C
	Blade tenderized + marinated	4 hours	Oven at 220°C
	None	-	Oven at 110°C
	Blade tenderized	-	Oven at 110°C
	Marinated	4 hours	Oven at 110°C
	Blade tenderized + marinated	4 hours	Oven at 110°C

Cooking

Cooking on a frying pan: beefsteak samples

Beefsteak strips (80 x 40 x 15 mm) were cut parallel to the muscle fibre direction from muscle samples using a custom-made template (80 x 40 mm). The samples were cooked in a frying pan (Brabantia® 24cm frying pan non-stick) to an internal temperature of 45°C, then turned and cooked to a final internal temperature of 65°C. The temperature was controlled using a thermometer (Cooper Atkins® Cook'n Cool).The samples were cooled down at room temperature for Warner-Bratzler shear force and water content evaluation.

Cooking in the oven: roast beef and chicken breast samples

Roast beef were cut into pieces of approximately 298g (±29g), the muscle fibres direction corresponding to the length of the roast beef; chicken breast samples were of approximately 159g (±129g). The samples were all placed into a cooking bag (Albal®) in order to wrap the entire sample, the bags were closed using links at each end of the roast beefs. The samples were cooked on an oven (Brandt® 591E44) to an internal temperature of 65°C. The temperature of the sample was controlled using a thermometer (Cooper Atkins® Cook'n

Cool). The oven was either set-up to cook at 110°C (low cooking temperature) or 220°C (high cooking temperature) depending on the cooking condition (Table 1). The samples were cooled down at room temperature for Warner-Bratzler shear force and water content evaluation.

Shear test protocol

After cooking, the samples were cooled down at room temperature for 1 hour. The energy necessary to cut the samples was evaluated by a Warner-Bratzler (V-shaped cutting blade) attachment using an electronic testing machine (ttc® TA.XT plus) at a crosshead speed of 2mm/sec. The samples were cut into pieces of 1.5x8x1.2 cm (wide, length, thick) and placed in the Warner-Bratzler cell in order to shear meat perpendicular to the muscle fibres, six measures of each condition was performed. The remaining portions were kept for water content determination. The collected data was the area under the curve (g.sec), which corresponds to the total energy necessary for cutting meat samples.

Water content

After shear energy determination, the samples were cut into small pieces and approximately 2.16g (± 0.29g) were weighed into aluminium. The cells were let in an oven at 130°C for 24 hours for meat dehydration; the samples were weighed before and after dehydration for water content determination.

Statistical analysis

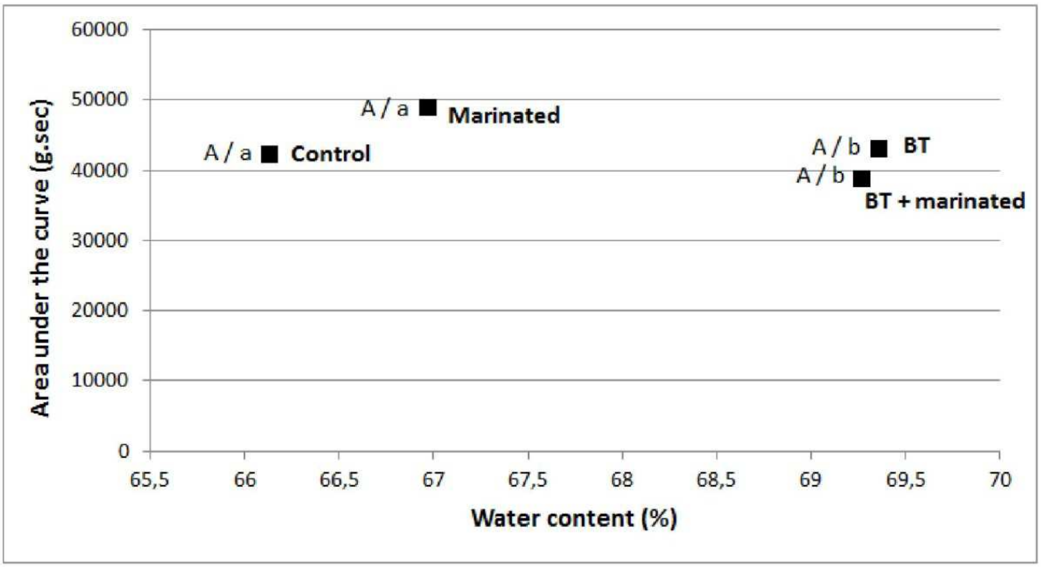
The results were submitted to an analysis of variance (ANOVA). Post hoc comparisons were performed using the Tuckey test. Means (M) were associated with their standard errors (SEM). The threshold for significance was set at 5%. Statistical analyses were conducted using R-studio software version 3.3.1 with the “multcomp” package for linear hypothesis.

RESULTS

Beefsteak

Figure 1 presents the area under the curve and water content for the four cooking conditions of beefsteak samples. The ANOVA revealed no significant difference between the four conditions for the area under the curve. However, the results show a non-significant but noticeable decrease of area under the curve value for the blade-tenderized + marinated sample. Regarding water content, the results show a significant condition effect ($F(3) = 18.39$; $P<0.01$). According to the post-hoc analyses, the control and marinated samples had a significantly lower amount of water compared to the blade-tenderized and blade-tenderized + marinated samples.

Fig. 1. Representation of the area under the curve and water content for control, marinated, blade-tenderized (BT) and blade-tenderized + marinated beefsteak samples



Area under the curve: $M_{Control}$ = 42147 g.sec ± 4361; $M_{Marinated}$ = 48799 g.sec ± 1074; $M_{Blade\text{-}tenderized}$ = 43142 g.sec ± 2457; $M_{Blade\ tenderized + Marinated}$ = 28277 g.sec ± 3578.

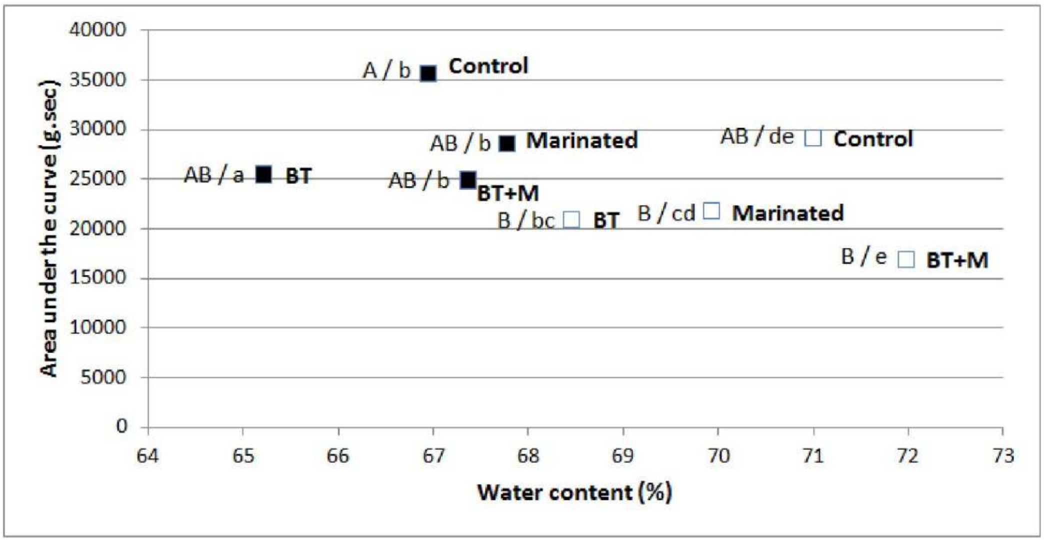
Water content: $M_{Control}$ = 66.6% ± 0.18; $M_{Marinated}$ = 66.5% ± 0.73; $M_{Blade\text{-}tenderized}$ = 70.0% ± 0.85; $M_{Blade\ tenderized + Marinated}$ = 69.2% ± 0.13.

A: results of the post-hoc analyses of the area under the curve
a, b: results of the post-hoc analyses of water content

Roast beef

Figure 2 presents the area under the curve and water content for the eight cooking conditions of roast beef samples. The ANOVA revealed a significant condition effect on the area under the curve and water content ($F(7) = 4.28$; $P<0.001$ and $F(7) = 20.76$; $P<0.001$ respectively). According to the post-hoc analyses, the blade-tenderized + marinated sample cooked at low temperature had a significantly lower area under the curve and a significantly greater amount of water. Furthermore, cooking at low temperature significantly decreased the sample's shear force and significantly increased water content.

Fig. 2. Representation of the area under the curve and water content for control, marinated, blade-tenderized (BT) and blade-tenderized + marinated (BT+M) roast beef samples cooked at high or low temperature



Area under the curve: High cooking temperature: $M_{Control}$ = 35662 g.sec ± 6791; $M_{Marinated}$ = 28585 g.sec ± 687; $M_{Blade\text{-}tenderized}$ = 25471 g.sec ± 2059; $M_{Blade\ tenderized + Marinated}$ = 24898 g.sec ± 1018. Low cooking temperature: $M_{Control}$ = 29126 g.sec ± 1066; $M_{Marinated}$ = 21754 g.sec ± 2202; $M_{Blade\text{-}tenderized}$ = 20933 g.sec ± 1007; $M_{Blade\ tenderized + Marinated}$ = 16940 g.sec ± 1939.

Water content: High cooking temperature: $M_{Control}$ = 66.9% ± 0.81; $M_{Marinated}$ = 67.8% ± 0.001; $M_{Blade\text{-}tenderized}$ = 65.2% ± 0.16; $M_{Blade\ tenderized + Marinated}$ = 67.4% ± 0.5. Low cooking temperature: $M_{Control}$ = 71.0% ± 0.29; $M_{Marinated}$ = 70.0% ± 0.69; $M_{Blade\text{-}tenderized}$ = 68.4% ± 0.65; $M_{Blade\ tenderized + Marinated}$ = 72.0% ± 0.19.

■: Samples cooked at high temperature

□: Samples cooked at low temperature

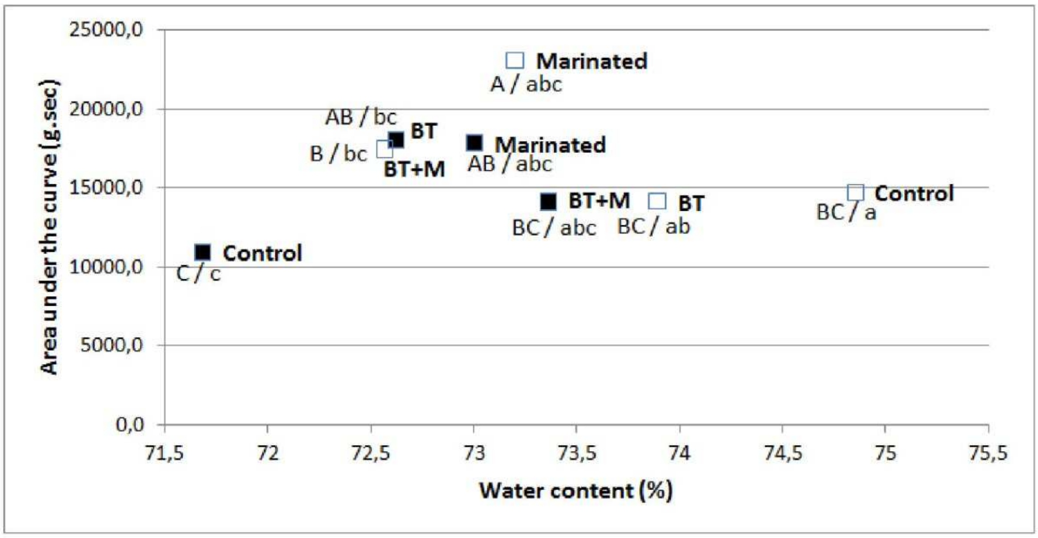
A: results of the post-hoc analyses of the area under the curve

a: results of the post-hoc analyses of water content

Chicken breast

Figure 3 presents the area under the curve and water content for the eight cooking conditions of chicken breast samples. The ANOVA revealed a significant condition effect on the area under the curve and water content ($F(7) = 8.84$; $P<0.001$ and $F(7) = 7.52$; $P<0.001$ respectively). The control sample cooked at high temperature had a significantly lower area under the curve but also a significantly lower amount of water. On the contrary, the control sample cooked at low temperature had a significantly greater amount of water compared to the other samples. While blade-tenderization seemed to improve meat texture for samples cooked at high temperature compared to the control sample cooked at high temperature, it did not improve meat texture when the chicken breast was cooked at low temperature. Furthermore, marinade does not seem to improve meat texture in both cooking conditions.

Fig. 3. Representation of the area under the curve and water content for control, marinated, blade-tenderized (BT) and blade-tenderized + marinated (BT+M) chicken breast samples cooked at high or low temperature



Area under the curve: High cooking temperature: $M_{Control}$ = 10949 g.sec ± 1490; $M_{Marinated}$ = 17830 g.sec ± 454; $M_{Blade\text{-}tenderized}$ = 18013 g.sec ± 1377; $M_{Blade\ tenderized\ +\ Marinated}$ = 14113 g.sec ± 1119. Low cooking temperature: $M_{Control}$ = 14717 g.sec ± 828; $M_{Marinated}$ = 23095 g.sec ± 1317; $M_{Blade\text{-}tenderized}$ = 14130 g.sec ± 820; $M_{Blade\ tenderized\ +\ Marinated}$ = 17444 g.sec ± 1846.

Water content: High cooking temperature: $M_{Control}$ = 71.7% ± 0.34; $M_{Marinated}$ = 73.0% ± 0.60; $M_{Blade\text{-}tenderized}$ = 72.6% ± 0.06; $M_{Blade\ tenderized\ +\ Marinated}$ = 73.4% ± 0.64. Low cooking temperature: $M_{Control}$ = 74.8% ± 0.06; $M_{Marinated}$ = 73.2% ± 0.23; $M_{Blade\text{-}tenderized}$ = 73.9% ± 0.11; $M_{Blade\ tenderized\ +\ Marinated}$ = 72.6% ± 0.05.

■: Samples cooked at high temperature

□: Samples cooked at low temperature

A: results of the post-hoc analyses of the area under the curve
a: results of the post-hoc analyses of water content

DISCUSSION

The present study aimed at comparing several easy-to do at home culinary techniques in order to improve meat tenderness and juiciness. The results showed a significant impact with the combination of blade tenderization and marinade on shear energy (area under the curve) and water content of beefsteak and roast beef samples; and a significant impact of blade tenderization on shear energy and water content of chicken breast cooked at high temperature. Furthermore, cooking roast beef at low temperature lead to a decrease in shear energy and an increase in water content.

The present study is one of the very first to consider practicability of culinary techniques feasible by an elderly population. Indeed, even though the effect of blade tenderization has been largely explored (Savell *et al.*, 1977; Seideman *et al.*, 1977; Pietrasik *et al.*, 2010; Obuz *et al.*, 2014), very few studies have investigated the impact of blade tenderization combined with an easy-to make marinade, and according to the results of the present study the combination of both techniques seem optimal in terms shear energy and water content. Furthermore, the impact of low cooking temperature on the energy necessary to cut meat samples and water content was scarcely explored in the literature as most of the study investigate the impact of pre-cooking treatments and omit the importance of cooking modes.

However, some methodological limitations can be considered and should be taken into account for future studies. First, six repetitions were performed for the measurements of shear energy and two repetitions were performed for the evaluation of water content which could be considered as weak. Indeed, (Honikel, 1998) specified that a minimum of eight to ten samples should be tested when describing the Warner-Bratzler shear test. However, the coefficient of variation was calculated and except for shear energy of the roast beef control sample cooked at high temperature, none of the coefficient of variation exceeded 30%, which is not considered as excessive taking into account the fact that in some studies, rheological measurements show a variation of around 30% on beef samples (Silva *et al.*, 2015; Novaković and Tomašević, 2017). Second, it would have been interesting to deeply investigate the meat structure in order to have a better understanding of structural changes due to mechanical treatments. Performing other rheological measurements could have brought specific information on meat deformation due to mechanical constraints. For example, Lepetit and Salé (1985) have developed a compression method to evaluate the myofibrillar resistance and the collagen resistance of meat using two compression thresholds. This method could have been used to investigate the impact of culinary techniques on meat physical properties. However, such level of information was not necessary to answer the objective of the present study.

As perspectives, several tracks should be considered. First, it would be interesting to investigate more meats in order to explore the impact of culinary techniques on every commonly consumed meat. Several authors have shown that mechanical treatments such as blade tenderization were not beneficial for every kind of meat (see Bekhit *et al.* (2013) for a review). Jeremiah *et al.*, (1999) have for example studied the impact of blade tenderization on different bovine muscles and showed that blade tenderization did not improve meat tenderness on half of the studied muscles. Savell *et al.* (1977) draw similar conclusions on their study. Therefore, studying a larger amount of meat muscles from different species would lead to a wider investigation of the impact of culinary techniques on meat texture, which would help elderly people or catering professionals to identify the best way to improve meat texture. Second, it is not guaranteed that culinary techniques do not impact meat's nutritional composition. It is indeed well known that cooking temperature has an impact on meat mechanical properties, as soluble collagen in meat increases with greater cooking temperature and soluble proteins decreases when cooking temperature increases (Murphy and Marks, 2000; Davey and Gilbert, 1974). Furthermore, several authors showed an increase of cook loss i.e. the amount of meat juice exudate during cooking, with the increase of coking temperature (Bouton and Harris, 1972; Barbanti and Pasquini, 2005). One hypothesis would be that these differences observed due to cooking temperature lead to nutritional composition modifications. Future studies should perform nutritional analysis on cooked samples in order to ensure that culinary techniques do not have a negative impact on meat nutritional quality. Finally, it would be interesting to investigate the impact of these culinary techniques on food acceptability in an elderly population. Indeed, even though these techniques seem promising to soften and/or moisten meat products, they were never tested for acceptability in an elderly population yet human textural evaluation may be different from physical measurements. At the moment, a study on the impact of culinary techniques on oral comfort when eating meat in an elderly population is being held. The results will be analysed and compared to the results of the present study.

CONCLUSION

As a conclusion, the study aimed at identifying easy-to-do at home culinary techniques to improve meat texture. The cumulative effect of blade tenderization + marinade seems a good option to decrease shear energy and increase water content in beef samples; while blade tenderization seems a good option to decrease shear energy and water content in chicken breast samples cooked at high temperature. Furthermore, cooking roast beef and chicken breast at low temperature had a significant effect on shear energy and water content. The optimum conditions will be tested on an elderly panel to assess oral comfort when eating the samples. Furthermore, future studies exploring a broader set of meat should be conducted to complete the results of the present study. In terms, advices will be given to elderly people and catering professionals in order to help them to perform the best treatments to meat before eating.

Ethical Statements

The authors declare that they do not have any conflicts of interest. The experimental protocol was approved by the French Ethics Committee for Research (CPP Est III, Nancy, #15.04.04, ANSM #2015-A00279-40). In accordance with ethical standards, all participants received written and oral information on the study before signing a consent form.

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References

BARBANTI, D., and PASQUINI, M. 2005. Influence of cooking conditions on cooking loss and tenderness of raw and marinated chicken breast meat. LWT - Food Science and Technology 38, 895-901.

BEKHIT, A.E.-D.A., CARNE, A., HA, M., and FRANKS, P. 2013. Physical Interventions to Manipulate Texture and Tenderness of Fresh Meat: A Review. International Journal of Food Properties 17, 433-453.

BOUTON, P.E., and HARRIS, P.V. 1972. The effect of cooking temperature and time on some mechanical properties of meat. Journal of Food Science 37, 140-144.

BOUTON, P.E., and HARRIS, P.V. 1981. Changes in the Tenderness of Meat Cooked at 50–65°C. Journal of Food Science 46, 475-478.

BURKE, R.M., and MONAHAN, F.J. 2003. The tenderisation of shin beef using a citrus juice marinade. Meat Sci 63, 161-168.

DAVEY, C.L., and GILBERT, K.V. 1974. Temperature-dependent cooking toughness in beef. J Sci Food Agric 25, 931-938.

FERGUSON, D.M., and WARNER, R.D. 2008. Have we underestimated the impact of pre-slaughter stress on meat quality in ruminants? Meat Sci 80, 12-19.

GUERRERO, A., VELANDIA VALERO, M., CAMPO, M.M., and SAÑUDO, C. 2013. Some factors that affect ruminant meat quality: from the farm to the fork. Review. Acta Scientiarum. Animal Sciences 35, 335-347.

HONIKEL, K.O. 1998. Reference methods for the assessment of physical characteristics of meat. Meat Sci 49, 447-457.

HUFFMAN, K.L., MILLER, M.F., HOOVER, L.C., WU, C.K., BRITTIN, H.C., and RAMSEY, C.B. 1996. Effect of beef tenderness on consumer satisfaction with steaks consumed in the home and restaurant. J Anim Sci 74, 91-97.

ISTRATI, D., SIMION CIUCIU, A.-M., VIZIREANU, C., IONESCU, A., and CARBALLO, J. 2015. Impact of Spices and Wine-Based Marinades on Tenderness, Fragmentation of Myofibrillar Proteins and Color Stability in BovineBiceps FemorisMuscle. Journal of Texture Studies 46, 455-466.

JEREMIAH, L.E., GIBSON, L.L., and CUNNINGHAM, B. 1999. The influence of mechanical tenderization on the palatability of certain bovine muscles. Food Research International 32, 585-591.

LEANDER, R.C., HEDRICK, H.B., BROWN, M.F., and WHITE, J.A. 1980. Comparison of structural changes in bovine long and semitendinosus muscles during cooking. Journal of Food Science 45, 1-6.

LEPETIT, J., and SALÉ, R. 1985. Analyse du comportement rhéologique de la viande par une méthode de compression sinusoïdale. Sci. Alim 5, 521-540.

MORGAN, J.B., MILLER, R.K., MENDEZ, F.M., HALE, D.S., and SAVELL, J.W. 1991. Using calcium chloride injection to improve tenderness of beef from mature cows. J Anim Sci 69, 4469-4476.

MURPHY, R.Y., and MARKS, B.P. 2000. Effect of meat temperature on proteins, texture, and cook loss for ground chicken breast patties. Poult Sci 79, 99-104.

NOVAKOVIĆ, S., and TOMAŠEVIĆ, I. 2017. A comparison between Warner-Bratzler shear force measurement and texture profile analysis of meat and meat products: a review. IOP Conference Series: Earth and Environmental Science 85, 012063.

O'QUINN, T.G., BROOKS, J.C., POLKINGHORNE, R.J., GARMYN, A.J., JOHNSON, B.J., STARKEY, J.D., RATHMANN, R.J., and MILLER, M.F. 2012. Consumer assessment of beef strip loin steaks of varying fat levels. J Anim Sci 90, 626-634.

OBUZ, E., AKKAYA, L., GÖK, V., and DIKEMAN, M.E. 2014. Effects of blade tenderization, aging method and aging time on meat quality characteristics of Longissimus lumborum steaks from cull Holstein cows. Meat Sci 96, 1227-1232.

OBUZ, E., DIKEMAN, M.E., and LOUGHIN, T.M. 2003. Effects of cooking method, reheating, holding time, and holding temperature on beef longissimus lumborum and biceps femoris tenderness☆☆Contribution no. 03-15-J from the Kansas Agricultural Experiment Station. Meat Sci 65, 841-851.

ORESKOVICH, D.C., BECHTEL, P.J., MCKEITH, F.K., NOVAKOFSKI, J., and BASGALL, E.J. 1992. Marinade pH Affects Textural Properties of Beef. Journal of Food Science 57, 305-311.

PIETRASIK, Z., AALHUS, J.L., GIBSON, L.L., and SHAND, P.J. 2010. Influence of blade tenderization, moisture enhancement and pancreatin enzyme treatment on the processing characteristics and tenderness of beef semitendinosus muscle. Meat Sci 84, 512-517.

PIETRASIK, Z., and SHAND, P.J. 2004. Effect of blade tenderization and tumbling time on the processing characteristics and tenderness of injected cooked roast beef. Meat Sci 66, 871-879.

PÓŁTORAK, A., MOCZKOWSKA, M., WYRWISZ, J., and WIERZBICKA, A. 2017. Beef tenderness improvement by dietary vitamin D3 supplementation in the last stage of fattening of cattle. Journal of Veterinary Research 61.

ROBBINS, K., JENSEN, J., RYAN, K.J., HOMCO-RYAN, C., MCKEITH, F.K., and BREWER, M.S. 2002. Consumer attitudes towards beef and acceptability of enhanced beef.

SAVELL, J.W., SMITH, G.C., and CARPENTER, Z.L. 1977. Blade tenderization of four muscles from three weight-grade groups of beef. Journal of Food Science 42, 866-870.

SEIDEMAN, S.C., and CROUSE, J.D. 1986. The effects of sex condition, genotype and diet on bovine muscle fiber characteristics. Meat Sci 17, 55-72.

SEIDEMAN, S.C., SMITH, G.C., CARPENTER, Z.L., and MARSHALL, W.H. 1977. Blade tenderization of beef psoas major and semitendinosus muscles. Journal of Food Science 42, 1510-1512.

SILVA, D.R., TORRES FILHO, R.A., CAZEDEY, H.P., FONTES, P.R., RAMOS, A.L., and RAMOS, E.M. 2015. Comparison of Warner-Bratzler shear force values between round and square cross-section cores from cooked beef and pork Longissimus muscle. Meat Sci 103, 1-6.

WOOLSEY, A.P., and PAUL, P.C. 1969. External Fat Cover Influence on Raw and Cooked Beef 2. Cooking Time, Losses, Press Fluid and Shear Force Values. Journal of Food Science 34, 568-569.

2. EVALUATION OF THE CULINARY TECHNIQUES BY THE ALIMASSENS PANEL USING THE FOOD COMFORTABILITY QUESTIONNAIRE

Impact of blade tenderization, marinade and cooking temperature on oral comfort when eating meat in an elderly population

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Keywords: older adult; food bolus; texture; oral health; denture; saliva

Abstract

Several studies demonstrated that oral health impairment, such as tooth loss or a decrease in salivary flow decrease might lead elderly people to reduce their meat intake. The present study assessed the impact of culinary processes liable to improve meat texture and smooth down meat oral processing, in order to fulfil the oral capacities of elderly people. Four culinary processes were selected: cooking bag, blade tenderizer, marinade and low-temperature cooking. A panel of 40 elderly participants included participants with a good and a poor dental status were asked to assess 5 chicken breast samples, 5 roast beef samples and 4 beefsteak samples prepared according to different process conditions by using an "oral comfort" questionnaire. Results highlighted the fact that oral impairment may alter food bolus formation as well as texture perception while eating meat in elderly people. Furthermore, they revealed that easy-to-do culinary processes may improve meat tenderness and juiciness as well as smooth down food bolus formation, in particular for the roast beef.

INTRODUCTION

With aging, oral health impairments can occur and lead to difficulties in masticating, humidifying food with saliva or even swallowing foods. Oral health degradation such as tooth loss (Auvray, Doussin, & Le Fur, 2003; Hoffmann et al., 2006), wearing of dentures (Asakawa, Fueki, & Ohyama, 2005), decrease in muscle strength (Goodpaster et al., 2006; Peyron, Blanc, Lund, & Woda, 2004), lack of saliva (Mathilde Vandenberghe-Descamps et al., 2016) and impaired swallowing (Humbert & Robbins, 2008; Tracy et al., 1989) can alter food consumption (Cousson et al., 2012; Geissler & Bates, 1984; Joshipura, Willett, & Douglass, 1996; Lee et al., 2004; Marcenes, Steele, Sheiham, & Walls, 2003; Muñoz-González et al., 2017; Sura, Madhavan, Carnaby, & Crary, 2012). Regarding meat consumption, Lee et al. (2004) highlighted that edentate participants had lower intake in hard-to-chew foods, including fried chicken and beef, compared to dentate elderly participants. Another study led by Marcenes et al. (2003) showed that edentulous elderly people had significantly greater difficulty eating well-done steaks compared to dentate elderly participants. However, consuming an appropriate amount of meat according to the body's needs, thereby having a sufficient intake of proteins, is essential for preventing muscle loss and in the end malnutrition in elderly people (Beasley, Shikany, & Thomson, 2013; Paddon-Jones, Short, Campbell, Volpi, & Wolfe, 2008). Therefore, it is of crucial importance to develop meat products that have an adapted texture for the elderly's masticatory ability.

Many studies have investigated the improvement of meat texture through the use of culinary processes (Aktaş, Aksu, & Kaya, 2003; Burke & Monahan, 2003; Davis, Smith, & Carpenter, 1977; Hayward, Hunt, Kastner, & Kropf, 1980; Jeremiah, Gibson, & Cunningham, 1999; Oreskovich, Bechtel, McKeith, Novakofski, & Basgall, 1992; Savell, Smith, & Carpenter, 1977). Among the techniques are blade tenderization and marinating, which are largely represented in the literature. Cooking temperature is also known to have an impact on meat characteristics.

Blade tenderization consists of perforation of the meat with sharp edged blades that are closely spaced to cut muscle fibers (Pietrasik & Shand, 2004) and is one of the most effective interventions currently used to ensure tenderness (King et al., 2009). Many authors have reported that one or two passages depending on the meat category and muscle type were sufficient to increase meat tenderness and overall meat palatability (King et al., 2009; Obuz, Akkaya, Gök, & Dikeman, 2014; Pietrasik, Aalhus, Gibson, & Shand, 2010). Obuz et al. (2014) have for example studied the impact of a blade tenderizer on meat characteristics using shear force evaluation and sensory analysis. The authors showed a decrease in the shear force value and an increase in the tenderness assessment with the use of a blade tenderizer passed two times on the meat. Regarding marinade, many authors have highlighted its impact on meat palatability. Made of red wine, citrus juice or even soy sauce, the effects of marinade on meat texture characteristics have been largely explored (Aktaş et al., 2003; Burke & Monahan, 2003; Kim et al., 2013; Oreskovich et al., 1992). Kim et al. (2013) have for example investigated the impact of a soy sauce marinade on meat tenderness using rheological measurements. The results showed a decrease in shear force with increasing soy sauce concentration in the marinades. Finally, cooking temperature is known to have an impact on mechanical properties, as soluble collagen in meat increases with greater cooking temperature and soluble protein decreases when cooking temperature increases (Davey & Gilbert, 1974; Murphy & Marks, 2000). Furthermore, several authors have shown an increase in cooking loss, *i.e.* the amount of meat juice exudate during cooking, with increasing cooking temperature (Barbanti & Pasquini, 2005; Bouton & Harris, 1972).

Even though these processes seem promising to soften and/or moisten meat products, they have never been tested for acceptability in an elderly population, members of which are known to be less sensitive to texture perception than younger adults (Conroy, O' Sullivan, Hamill, & Kerry, 2017). Consequently, the aim of the present experiment was to test culinary processes and ask an elderly panel to assess oral comfort when eating the samples. In addition, the elderly's oral health was characterized to investigate the impact of oral health on meat acceptability. To this end, we asked elderly people to rate the oral comfort of 3 meat products prepared according to different process conditions using the "oral comfort" questionnaire developed in a previous study (Mathilde Vandenberghe-Descamps, Labouré, Septier, Feron, & Sulmont-Rossé, 2017).

MATERIALS AND METHODS

Participants

Two groups of 20 older adults (≥ 65 years old) were recruited, one group with a good dental status (10 women and 10 men; age mean: 72.8 yo; age range: 66-87) and one group with a poor dental status (11 women and 9 men; age mean: 74.7 yo; age range: 67-89). According to Leake, Hawkins, and Locker (1994), the number of functional units was used to characterize elderly people's dental status. A functional unit was defined as a pair of posterior antagonist teeth that had at least one contact area during chewing. The number of functional units was evaluated by asking the participants to chew 1–2 cycles on 200-mm thick articulating paper; the number of teeth on the mandibular arch that had at least one color mark provided the number of functional units. Elderly people with at least 7 functional units and not wearing a removable denture were considered as having a good dental status; elderly people with 4 or less functional units and possibly wearing a removable denture were considered as having a poor dental status. The other recruitment criteria were the following: older than 65 years old, living at home, no acute pathological episodes neither at the time of the experiment nor in the recent past, a score of at least 24 on the mini mental state evaluation (MMSE) (Folstein,

Folstein, & McHugh, 1975). An interview was carried out with each volunteer to ensure that they met the inclusion criteria. In parallel, the resting and stimulated salivary flows of every volunteer were measured by instructing the participant to spit out the saliva into a pre-weighed screw-cap cup every time they felt like swallowing. The measurement of resting salivary flow was over a period of 10 min and the measurement of stimulated salivary flow lasted 5 minutes during which the participants were asked to masticate a piece of pre-weighted parafilm while spitting saliva. The salivary flow rate was expressed in ml/min, assuming that 1 g of saliva corresponded to 1 ml.

Products

Three meat products were chosen for the present study: chicken breast, roast beef and beefsteak. All the products were provided by a butcher and each meat was provided from the same batch. Four culinary processes were selected: cooking bag (Albal®), blade tenderizer, marinade and low-temperature cooking. These processes were chosen because they are easy to implement in everyone's kitchen (they do not need expensive or complex devices) and/or because they proved to have a positive impact on meat tenderness and/or juiciness in the scientific literature. As it was not possible to ask the elderly participants to taste all the possible combinations made with these four culinary processes, preliminary tests were conducted *i.* to select the most promising processes and/or combinations of processes, and *ii.* to set up the protocol for each culinary processes. For these preliminary tests, several assays were achieved and evaluated through two physical measurements: the shear force evaluation, which was demonstrated to be correlated with meat tenderness (Obuz et al., 2014; Pietrasik et al., 2010) and water content. Shear force, which corresponds to the force necessary to cut the sample, was measured by using a Warner-Bratzler (V-shaped cutting blade) attachment positioned on an electronic testing machine (ttc® TA.XT plus) at a crosshead speed of

2mm/sec. Water content was evaluated by weighing a sample before and after dehydration in an oven at 130°C for 24 hours.

Based on the results of these preliminary tests (Vandenberghe-Descamps, Sulmont-Rossé, Feron, & Labouré, submitted), five "process" conditions were selected for chicken breast and roast beef and four conditions were selected for beefsteak (Table 1).

Table 1: For each product, characterization of the samples.

	Culinary processes				Physical characterization	
Sample	**Cooking bag**	**Blade tenderizer**	**Marinade**	**Low-temperature cooking**	**Shear force (g.sec)**	**Water content (%)**
Chicken breast						
Control	√				10949	71.7
BT	√	√			18013	72.6
BT - M	√	√	√		14113	73.4
LT	√			√	14717	74.8
BT - LT	√	√		√	14130	73.9
Roast beef						
Control	√				35662	66.9
LT	√			√	29126	71.0
BT - LT	√	√		√	20933	68.4
M – LT	√		√	√	21754	70.0
BT - M - LT	√	√	√	√	16940	72.0
Beefsteak						
Control	NA			NA	42147	66.6
BT	NA	√		NA	43142	70.0
M	NA		√	NA	48799	66.5
BT + M	NA	√	√	NA	28277	69.2

Cooking bag. The meat was put in a tightly closed cooking bag (Albal®). Such cooking bags can be easily found in supermarket and more or less mimic stewing condition.

Blade tenderizer. Blade tenderization (BT) consists in the perforation of the meat with sharpened edged blades being closely spaced in order to cut muscle fibers (Figure 1). In the present experiment, it was performed by using a blade tenderizer Hendi Profi Line 51 blades. One pass was done on each sample, on the top side for chicken breast and beefsteak samples and on both sides for the roast beef samples which were too thick for the blade tenderizer to pass through. No visual difference could be made between control and blade-tenderized samples by the participants.

Figure 1. Blade tenderizer

Marinade. The marinade (M) was made of 6% of soy sauce and 94% of water. The chicken breast and beefsteaks stayed in the marinade for 2 hours at +4°C and the roast beef stayed for 4 hours at +4°C. For blade tenderizer and marinade samples (BT-M), blade tenderization was made before plunging the meat in the marinade.

Low-temperature cooking. Low-temperature (LT) samples for chicken breast and roast beef were cooked in an oven at 110°C until reaching +65°C at the center of the product. The time needed to cook the meat at low-temperature was approximatively 60 minutes for chicken breast and 77 minutes for roast beef.

The samples were cooked right before serving. The beefsteak samples were cooked on a frying pan heated at 160°C. The chicken breast and roast beef samples cooked under standard condition (*i.e.* not a low-temperature cooking) were put in an oven at 220°C until reaching +65°C at the center of the product. The time needed to cook the meat under standard condition was approximatively 25 minutes for chicken breast, 31 minutes for roast beef and 6 minutes for beefsteak. The temperature was controlled by using a cooking thermometer which measuring tube was sank to reach the center of the product.

Oral comfort assessment

In a recent study, we conducted focus groups asking elderly people to define the concept of oral comfort during food consumption (Mathilde Vandenberghe-Descamps et al., 2017). The results highlighted five important categories to consider when evaluating the easiness to eat: food bolus formation, time needed to form the food bolus, pain sensations felt when eating, texture perception and taste perception. Inside the texture category, 10 attributes were considered relevant to characterizing food oral processing: sticky, stringy, greasy, dry, doughy, melting, firm, hard, tender and juicy. A questionnaire aimed at evaluating oral comfort when eating a food was developed using the results of the focus groups. This questionnaire was used in the present study to assess oral comfort when eating meats (Figure 2).

Figure 2. Oral comfort questionnaire

GENERAL QUESTION	Very uncomfortable	Uncomfortable	Moderately Comfortable	Comfortable	Very comfortable
This food is...					

BOLUS FORMATION	Impossible	Very difficult	Difficult	Moderately easy	Easy	Very easy
To cut this food with your incisor is...						
To cut this food with your molar is...						
To masticate this food is...						
To humidify this food with saliva is...						
To swallow this food is...						

TIME TO FORM FOOD BOLUS	Impossible to swallow	Very long	Long	Moderately brief	Brief	Very brief
Time needed to form the bolus is...						

MOUTH PAIN	Not at all	Little	A lot	Extremely
Does eating the food bring a burning or spicy sensation?				
Does eating the food bring muscular pain?				
Does eating the food bring articular pain?				
Does eating the food bring dental pain?				
Does eating the food bring gum pain?				

TEXTURE	Not at all	Little	A lot	Extremely
Is this food sticky?				
Is this food stringy?				
Is this food greasy?				
Is this food dry?				
Is this food doughy?				
Is this food melting?				
Is this food firm?				
Is this food hard?				
Is this food tender?				
Is this food juicy?				

FLAVOR	Not at all	Little	A lot	Extremely
Is this food intense in taste?				
Is this food salty?				
Is this food sweet?				
Is this food sour?				
Is this food bitter?				

Procedure

The participants were invited to take part in three tasting sessions, one for each type of meat. The sessions either took place at 11 AM or at 6 PM (*i.e.*, close to French lunch and dinner hours). At the beginning of each session, the oral comfort questionnaire was presented to the participants by the experimenter. Then the participants were served with the five (chicken breast, roast beef) or the four (beefsteak) samples. After tasting a product, the participants were asked to complete the oral comfort questionnaire. They were free to bite the products as many times as they wanted in order to answer the questions. After each sample, they were given a 3-minutes rest time; participants were free to drink as much water as they needed.

The sessions were conducted in a sensory room equipped with individual booths according to the AFNOR standard (AFNOR, 1987) and under white light. The room temperature was 20.5 ± 0.5°C. The products were presented in an order determined by a William Latin square design and they were coded with a three-digit number. Portion size were 70g for chicken breast, 50g for roast beef and 40g for beefsteak (portion size were determined to be sufficient for answering the entire questionnaire).

Data analysis

Separate analyses were conducted for the chicken breast, roast beef and beefsteak to study the impact of culinary processes on oral comfort. For each item of the oral comfort questionnaire, scores were submitted to Analysis of Variance (ANOVA) with one factor (sample) after checking for normality. A global analysis was conducted to investigate the impact of oral health on oral comfort. For each item of the oral comfort questionnaire, scores were submitted to an Analysis of Covariance (ANCOVA) with three factors: product (chicken breast, roast beef and beefsteak), dental status (poor; good) and salivary flow. As the interaction *product x dental status* was not significant, the results of the interaction were not described below. Post hoc comparisons were performed using the Student Newman Keuls test. Means (M) were associated with their standard errors (SEM). The threshold for significance was set at 5 %. Statistical analyses were conducted using R-studio software version 3.3.1 with the "nlme" package for linear mixed models and the "agricolae" package for post hoc analyses (de Mendiburu, 2017).

RESULTS

Impact of culinary processes on oral comfort assessment

Table 2: Impact of culinary processes: results of the one-way ANOVAs performed for each product and for each attribute of the oral comfort questionnaire (F-value of the sample effect and significance level: * p<0.05; **p<0.01; ***p<0.001).

	Attributes	Chicken breast	Roast beef	Beefsteak
General question	Comfort	0.578	**<0.001*** **	0,629
Bolus formation	Incisor	0.584	**0,038***	0,460
	Molar	0.338	**0,035***	**0,037***
	Masticate	0.506	**0,006****	0,052
	Humidify	0.132	**0,021***	0,548
	Swallow	0.152	0,070	0,481
Time to form food bolus	Time	0.436	0,064	0,696
Mouth pain	Burning	0.261	0,475	0,400
	Muscular	0.765	0,176	0,829
	Articular	0.960	0,149	0,725
	Dental	0.700	0,259	0,572
	Gum	1.000	0,124	0,891
Texture	Sticky	0.565	0,096	0,350
	Stringy	0.341	0,055	0,718
	Greasy	0.962	0,995	0,144
	Dry	**0.024***	**<0.001*** **	0,282
	Doughy	0.281	0,418	0,356
	Melting	**0.010****	**0,045***	0,248
	Firm	0.208	**0,041***	0,310
	Hard	0.287	**0,021***	0,271
	Tender	0.086	**0,001*** **	0,142
	Juicy	0.888	**0,012***	0,624
Flavor	Taste intense	0.642	0,234	0,506
	Salty	0.730	0,817	0,291
	Sweet	0.901	0,904	0,731
	Sour	0.442	0,950	0,357
	Bitter	0.888	0,412	0,569

Results on chicken breast

There was no significant difference between the samples regarding the general question of oral comfort (Table 2). However, the samples were rated as significantly different on the texture attributes dry and melting ($p<0.05$ and $p<0.01$ respectively) (Figure 3). According to post hoc analysis, the sample that was blade-tenderized and cooked at low-temperature was rated as less dry and less melting than the control sample. Blade-tenderization alone (BT) or low-temperature cooking alone did not significantly improve product texture compared to the control sample.

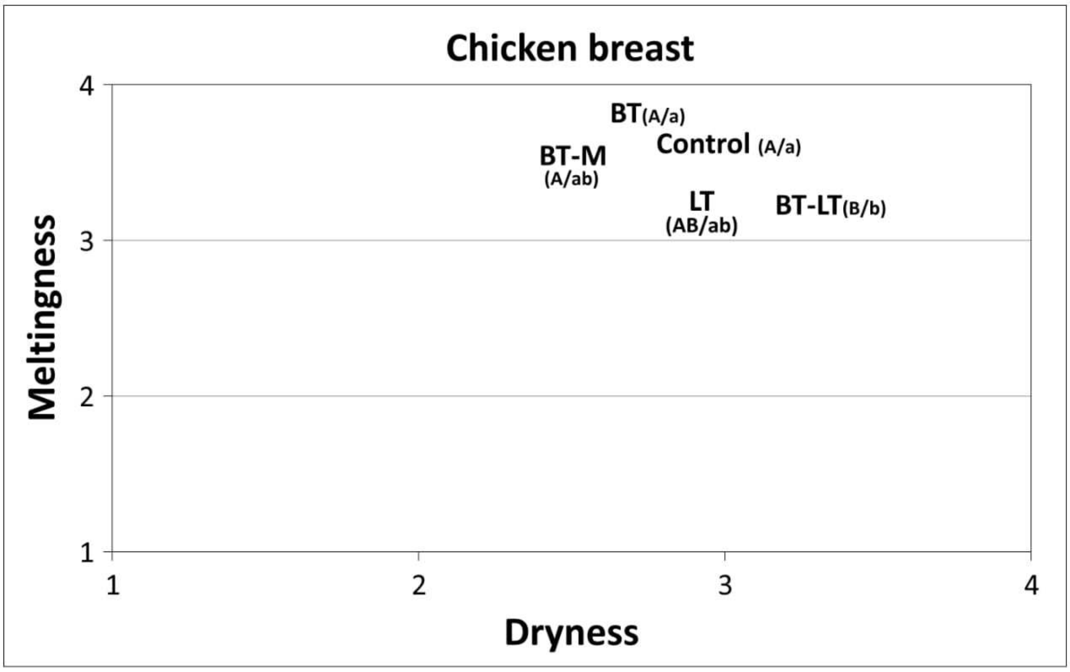

Figure 3. Impact of culinary techniques on chicken meltingness and dryness

Results on roast beef

A significant sample effect was observed for the general question on oral comfort as well as on several attributes related to food bolus formation and product texture (Table 2). Regarding the general question, low-temperature cooking alone was not enough to increase oral comfort compared to the control sample cooked at high-temperature. However, the combination of low-temperature cooking with at least one other culinary process (blade tenderizer and/or marinade) led to a significant increase in oral comfort while eating roast beef (Figure 4a). Regarding food bolus formation, the combination of low-temperature cooking and marinade (M-LT and BT-M-LT) led to meat samples significantly easier to masticate and easier to humidify than the control sample (Figure 4b). Finally, regarding texture attributes, all the processed samples (LT, BT-LT, M-LT and BT-M-LT) were rated as less dry, more juicy and tenderer than the control sample (Figure 4c). In addition, the BT-M-LT sample was rated as more melting as well as less firm and hard than the control sample.

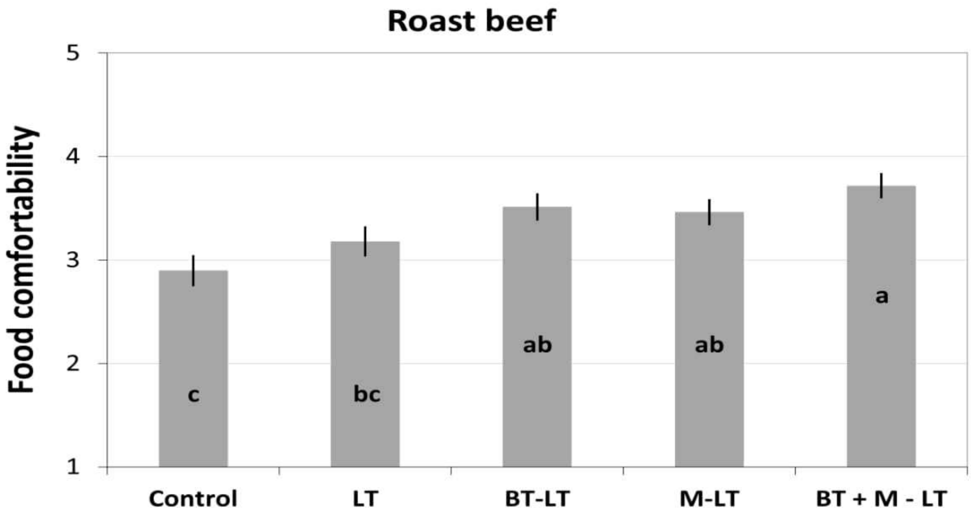

Figure 4a. Impact of culinary technniques on Roast beef comfortability

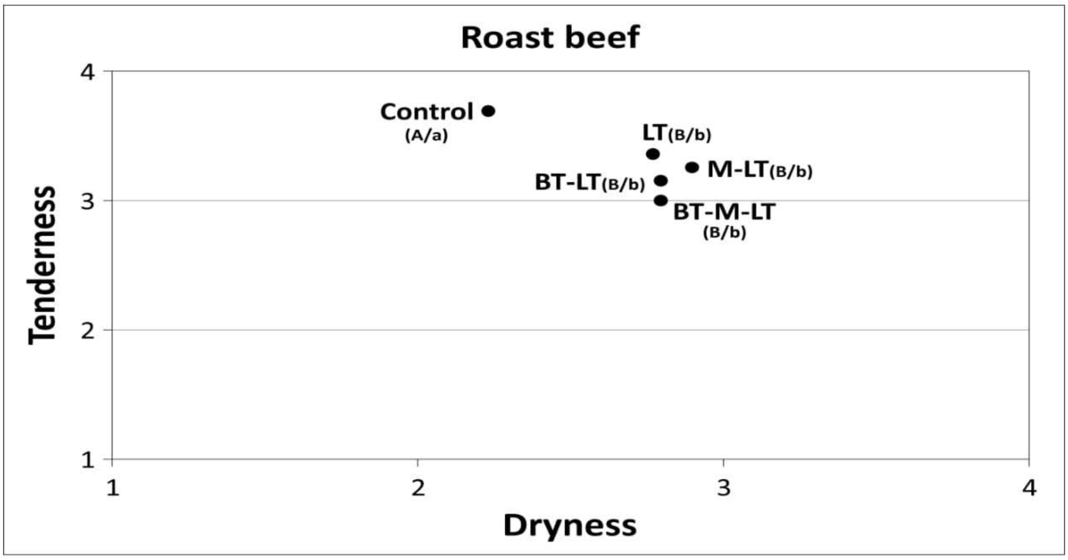

Figure 4b. Impact of culinary techniques on Roast beef tenderness and dryness

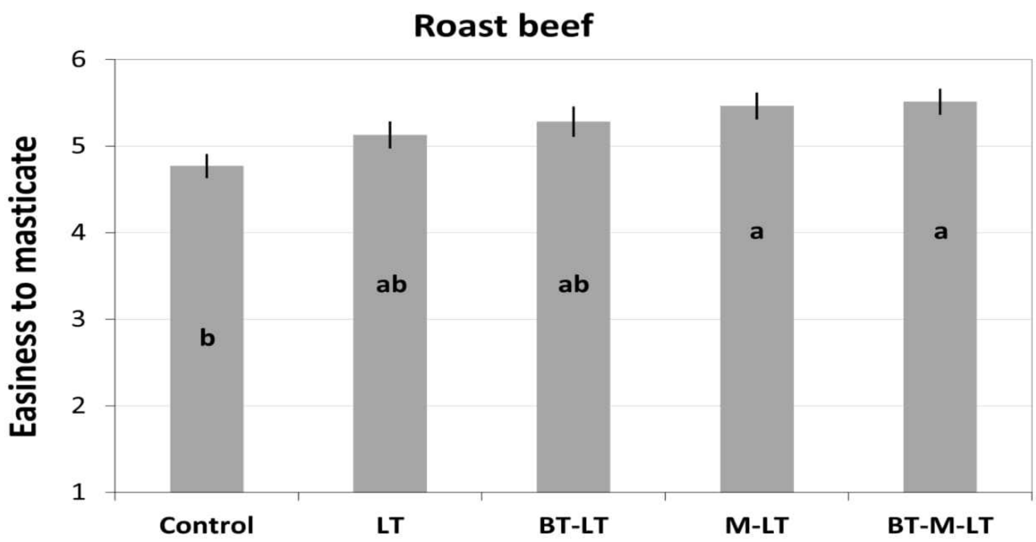

Figure 4c. Impact of culinary techniques on Roast beef easiness to masticate

Results on beefsteak

There was no significant difference between the samples regarding the general question of oral comfort (Table 2). Only the attribute *easiness to cut with the molars* was associated with a significant sample effect, but none of the processed samples (*i.e.*, BT, M, BT-M) were significantly different from the control sample (Figure 5).

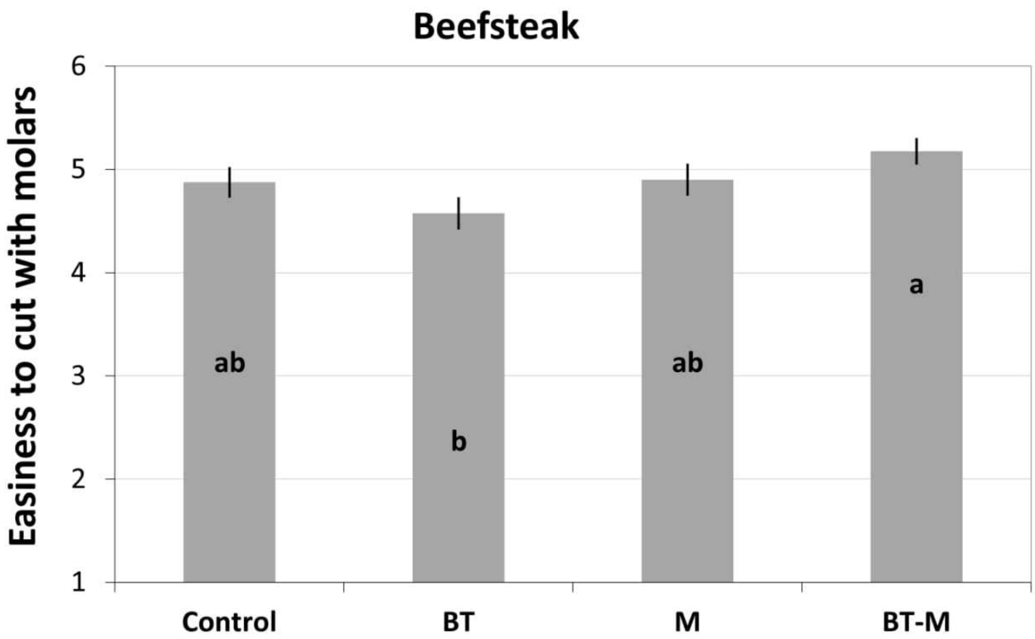

Figure 5. Impact of culinary techniques on Beefsteak easiness to cut with molars

Impact of oral health on the oral comfort assessment

No impact of oral health parameters (dental status, resting and stimulated salivary flow) was observed on the general question of oral comfort (Table 3). However, several significant effects were observed on the attributes related to food bolus formation and pain sensations as well as on texture and flavor perception. The interaction *product x dental status* was never significant, meaning that the two groups rated the products in the same order whatever the attribute. The stimulated salivary flow of elderly people with a good dental status group (M=1.9 ml/sec; SEM=0.8) was significantly higher than the one of elderly people with a poor dental status group (M=1.3 ml/sec; SEM=0.6; $t(38)=-2.70$; p=0.01). Not such difference was observed for the resting salivary flow ($t(38) = -0.14$; p=0.9).

Regarding dental status, elderly people with a good dental status found the food bolus easier to humidify with saliva and to swallow and they needed less time to form the food bolus than elderly people with a poor dental status. They also rated the samples as tenderer and juicier as well as saltier and more intense in flavor than the latter. Finally, elderly people with a good dental status felt slightly less muscle and articular pain but slightly more gum pain than elderly with a poor dental status.

Regarding resting salivary flow, elderly people with a greater resting salivary flow found the food bolus easier to form than elderly people with a lower resting salivary flow. They also felt slightly less muscular pain but slightly more articular and dental pain than the latter. Finally, elderly people with a greater resting salivary flow rated the product as less sticky, less greasy, less hard, and less intense in flavor than elderly people with a lower resting salivary flow.

Regarding stimulated salivary flow, elderly people with a greater stimulated salivary flow found the food easier to cut with molar but more difficult to humidify, to swallow and needed more time to form the food bolus than elderly people with a lower stimulated salivary flow. Nevertheless, they felt slightly less articular and gum pain than the latter. Finally, elderly people with a greater resting salivary flow rated the product as less doughty, less firm and less bitter than elderly people with a lower resting salivary flow.

Table 3: Impact of oral health: result of the three-way ANCOVA performed for each attribute of the oral comfort questionnaire (normalized coefficients and significance levels: * p<0.05; **p<0.01; ***p<0.001).

	Attributes	Sample effect	Dentition effect	Resting saliva effect	Stimulated saliva effect
General question	Comfort	***	0.015	0.045	0.027
Easiness to form food bolus	Incisor	***	0.113	**0.208*** **	-0.098
	Molar	***	0.021	0.002	**0.110***
	Masticate	***	0.059	**0.115***	-0.066
	Humidify	***	**0.117****	**0.201*****	**-0.233*****
	Swallow	***	**0.139****	**0.194*****	**-0.242*****
Time to form food bolus		***	**0.172*****	**0.176*****	**-0.197*****
Pain	Burning	NS	-0.022	-0.059	-0.014
	Muscular	NS	**-0.191*****	**-0.116***	-0.051
	Articular	**	**-0.180*****	**0.109***	**-0.155****
	Dental	NS	-0.019	**0.129***	-0.105
	Gum	NS	**0.133****	0.087	**-0.171****
Texture	Sticky	***	0.40	**-0.142****	0.004
	Stringy	***	0.075	-0.074	-0.065
	Greasy	NS	-0.060	**-0.162****	0.017
	Dry	***	**-0.156*****	-0.033	-0.006
	Doughy	***	**0.105***	-0.054	**-0.184*****
	Melting	***	**0.139****	-0.045	0.076
	Firm	***	-0.017	0.001	**-0.156****
	Hard	***	-0.016	**-0.178*****	-0.005
	Tender	***	**0.139****	**0.132****	-0.109
	Juicy	***	**0.115****	0.052	-0.076
Flavor	Taste intense	***	**0.116****	**-0.171*****	0.073
	Salty	NS	**0.133****	0.024	-0.167
	Sweet	NS	-0.059	-0.043	-0.046
	Sour	NS	-0.066	0.002	-0.106
	Bitter	NS	-0.041	-0.002	**-0.191****

Regarding dental status, a positive coefficient means that good dental status group rated the item higher compared to the poor dental status group. Regarding resting and stimulated salivary flow, a positive coefficient reflects a positive correlation between the item score and the salivary flow.

DISCUSSION

The present study demonstrates that using easy-to-do culinary processes could improve oral comfort, easiness to form food bolus and food texture while eating meat in the elderly population. Regarding chicken breast, blade tenderization and low-temperature cooking decreased dryness compared to a control sample cooked at high-temperature without preliminary culinary processes. Regarding roast beef, the cumulative effect of blade tenderization, marinade and low-temperature cooking were the optimal conditions to obtain meat sample easy to chew, to humidly with saliva and to swallow, as well as to a tender and juicy product. Finally, regarding beefsteak, blade tenderization and marinade tended to improve easiness to form food bolus by increasing easiness to break down the meat in mouth. It should be noted that stronger effects of culinary processes were observed for chicken breast and roast beef than for beefsteak. This could be explained by the fact that beefsteak samples were made from high-quality beef meat (Charolais local production). This meat may not have needed any improvement to be easy to chew and swallow, and in fact, the control beefsteak sample scored higher on the general comfort item (*M*=3,1; *SEM=0.1*) than the control chicken breast (*M*=2.8; *SEM*=0.1) and the control roast beef (*M*=1.9; *SEM*=0.1). Conversely, the present results support the fact that easy-to-do culinary processes may have a significant impact on medium-quality meat, namely products that are affordable by the majority of the population. This is all the more important as elderly people with a lower socioeconomic status – and who are the less likely to afford high-quality meat – also present poorer dental status and are less likely to get dental care (Bernabé & Marcenes, 2011; Gilbert, Duncan, & Shelton, 2003; Marcus, Kaste, & Brown, 1994).

The present study also highlights that oral health impairments may have a significant impact on food bolus formation and on texture perception, in line with previous authors (Mese & Matsuo, 2007; Solemdal, Sandvik, Willumsen, Mowe, & Hummel, 2012; Veyrune & Mioche, 2000). Regarding food bolus perception, when considering both dental and salivary status, it is interesting to note that a poor dental status mainly alters elderly people's ability to humidify and swallow food bolus, while low resting salivary flow impairs elderly people's ability to break down food products as well as to humidify and swallow food bolus. In addition, elderly people with poorer dental status and lower resting saliva flow needed more time to form food bolus, and elderly people with poorer dental status and lower stimulated salivary flow experienced more pain sensations. Regarding texture perception, elderly people with poor dental status rated the products as dryer and less juicy than elderly people with good dental status, which is in line with the previous results on the impact of dental status on easiness to humidify the food. Aside, elderly people with a good dental status and a higher resting salivary flow rated the products as tenderer than elderly people with poor dental status and lower resting salivary flow. These results emphasize the fact that both dentition and saliva may impact food oral processing and thus should be considered when looking at the impact of oral health on eating behavior in an elderly population (actually, previous studies often considered dental status while they seldom considered salivary status; for a review, see Kiesswetter et al., in press; Tada & Miura, 2014). However, the present experiment also highlights some odd results. In particular, participants with lower stimulated salivary flow reported less difficulty to humidify and swallow food bolus than participants with higher stimulated salivary flow. In fact, elderly people may have adapted their drinking behavior to cope with the lack of saliva when eating a food. In the present study, the participants were free to drink as much water as they wanted during the sessions. It could be hypothesized that elderly people with a low stimulated salivary flow drunk more water during meat consumption, which could have smoothen and even reverse the impact of low stimulated salivary flow rate on food bolus formation.

The present study stands out from previous ones as processed meat samples were evaluated by a non-trained elderly panel, using an “oral comfort” questionnaire. In fact, previous studies on the impact of culinary processes on meat texture used rheological measurements (Barbanti & Pasquini, 2005; King et al., 2009) or rely on a trained sensory panel (Obuz et al., 2014; Pietrasik et al., 2010). However, the complex dynamics of food deformation in the mouth, responsible of texture sensation cannot be easily included in any single mechanical test (Dransfield, 1996 cited by Mathoniere et al., 2000). Actually, instrumental techniques do not mimic the dynamics of oral motion, rate of force application and salivation and can give low correlations with subjectives assessments (Peyron et al., 1994). Furthermore, trained panels generally include young or middle-aged adults who cannot account for the oral impairments frequently observed in an elderly population such as tooth loss, decrease in saliva flow or even swallowing disorders. The aim of the present study was to develop culinary processes liable to improve meat texture and smooth down meat oral processing, in order to fulfil the oral capacities of elderly people. Consequently, the choice was made to recruit the target population – namely elderly people – for sample assessment. However, recruiting elderly people, and in particular elderly people suffering from oral impairment, is quite challenging. In fact, elderly people with poor oral heath are often frail and dependent, and thus less willing to take part in experimental studies (Maître, Symoneaux, & Sulmont-Rossé, 2015). In order to avoid an over-representation of elderly people with a good oral health (the easiest to recruit), efforts were made during the recruitment to have half participants with a good dental status and half participants with a poor dental status. However, with such criterion, it was not possible to recruit more than 40 participants, because of time constraints (the study had to be made within one month to ensure homogeneity of meat batches and avoid seasonality effect).

CONCLUSION

In agreement with scientific literature, the present study highlighted the fact that oral impairment such as a poor dental status or low salivary flow may impair food bolus formation as well as texture perception while eating meat in elderly people. Furthermore, the present study also revealed that easy-to-do culinary processes such as blade tenderization, marinade or low-temperature cooking may improve elderly people's ability to break down the food, to humidify the particles and to swallow food bolus. These techniques may also increase meat tenderness and juiciness. However, the impact of these techniques varied depending on the meat. The most conclusive effects was observed on roast beef and the least conclusive effects on beefsteak. Further research should explore a broader set of culinary processes for a broader set of meat products (various types of meat, and for a given meat, various types of muscle) in order to identify the optimum combinations in term of "oral comfort" for elderly people. Anyways, the present study proved that there are easy-to-do culinary solutions to sustain meat intake in elderly people suffering from oral impairment, a key-factor to prevent sarcopenia and malnutrition in these population.

Ethical statements

The authors have no conflicts of interest to declare. The experimental protocol was approved by the French Ethics Committee for Research (CPP Est III, Nancy, #15.04.04, ANSM #2015-A00279-40). In accordance with ethical standards, all participants received written and oral information on the study before signing a consent form.

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References

AFNOR. (1987). (Association française de normalisation). Bulletin des Bibliothèques de France (BBF). *Available on line : <http://bbf.enssib.fr/consulter/bbf-1987-04-0386-001>. ISSN 1292-8399., 4*, 386-388.

Aktaş, N., Aksu, M. I., & Kaya, M. (2003). The effect of organic acid marination on tenderness, cooking loss and bound water content of beef. *Journal of Muscle Foods, 14*(3), 181-194. doi: 10.1111/j.1745-4573.2003.tb00699.x

Asakawa, A., Fueki, K., & Ohyama, T. (2005). Detection of improvement in the masticatory function from old to new removable partial dentures using mixing ability test. *Journal of Oral Rehabilitation, 32*(9), 629-634. doi: 10.1111/j.1365-2842.2005.01480.x

Auvray, L., Doussin, A., & Le Fur, P. (2003). Santé, soins et protection sociale en 2002, CREDES.

Barbanti, D., & Pasquini, M. (2005). Influence of cooking conditions on cooking loss and tenderness of raw and marinated chicken breast meat. *LWT - Food Science and Technology, 38*(8), 895-901. doi: http://dx.doi.org/10.1016/j.lwt.2004.08.017

Beasley, J. M., Shikany, J. M., & Thomson, C. A. (2013). The role of dietary protein intake in the prevention of sarcopenia of aging. [Research Support, N I H , Extramural Review]. *Nutr Clin Pract, 28*(6), 684-690.

Bernabé, E., & Marcenes, W. (2011). Income inequality and tooth loss in the United States. *J Dent Res, 90*(6), 724-729.

Bouton, P. E., & Harris, P. V. (1972). The effect of cooking temperature and time on some mechanical properties of meat. *Journal of Food Science, 37*(1), 140-144. doi: 10.1111/j.1365-2621.1972.tb03404.x

Burke, R. M., & Monahan, F. J. (2003). The tenderisation of shin beef using a citrus juice marinade. *Meat Sci, 63*(2), 161-168.

Conroy, P. M., O' Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2017). Sensory capability of young, middle-aged and elderly Irish assessors to identify beef steaks of varying texture. *Meat Science, 132*, 125-130. doi: https://doi.org/10.1016/j.meatsci.2017.05.020

Cousson, P. Y., Bessadet, M., Nicolas, E., Veyrune, J.-L., Lesourd, B., & Lassauzay, C. (2012). Nutritional status, dietary intake and oral quality of life in elderly complete denture wearers. *Gerodontology, 29*(2), e685-e692. doi: 10.1111/j.1741-2358.2011.00545.x

Davey, C. L., & Gilbert, K. V. (1974). Temperature-dependent cooking toughness in beef. *J Sci Food Agric, 25*(8), 931-938. doi: 10.1002/jsfa.2740250808

Davis, G. W., Smith, G. C., & Carpenter, Z. L. (1977). Effect of blade tenderization on storage life, retail case life and palatability of beef. *Journal of Food Science, 42*, 330-337.

de Mendiburu, F. (2017). Statistical Procedures for Agricultural Research. *Version 1.2-8.*

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. *J Psychiatr Res, 12*(3), 189-198.

Geissler, C. A., & Bates, J. F. (1984). The nutritional effects of tooth loss. *American Journal of Clinical Nutrition, 39*, 478-489.

Gilbert, G. H., Duncan, R. P., & Shelton, B. J. (2003). Social determinants of tooth loss. [Research Support, U S Gov't, P H S]. *Health Serv Res, 38*(6 Pt 2), 1843-1862.

Goodpaster, B. H., Park, S. W., Harris, T. B., Kritchevsky, S. B., Nevitt, M., Schwartz, A. V., . . . Newman, A. B. (2006). The loss of skeletal muscle strength, mass, and quality in older adults: the health, aging and body composition study. [Research Support, N I H , Intramural]. *J Gerontol A Biol Sci Med Sci, 61*(10), 1059-1064.

Hayward, L. H., Hunt, M. C., Kastner, C. L., & Kropf, D. H. (1980). Blade tenderization effects on beef longissimis sensory and instron textural measurements. *Journal of Food Science, 45*(4), 925-935. doi: 10.1111/j.1365-2621.1980.tb07480.x

Hoffmann, T., John, M., Kerschbaum, T., Micheelis, W., Potthoff, P., Reich, E., . . . Schroeder, E. (2006). Vierte Deutsche Mundgesundheitsstudie (DMS IV). *Köln. Mikrozensus: Fragen zur Gesundheit (2009a): Verteilung der Bevölkerung auf Body-Mass-Index-Gruppen in.*

Humbert, I. A., & Robbins, J. (2008). Dysphagia in the elderly. [Review]. *Phys Med Rehabil Clin N Am, 19*(4), 853-866, ix-x. doi: 10.1016/j.pmr.2008.06.002

Jeremiah, L. E., Gibson, L. L., & Cunningham, B. (1999). The influence of mechanical tenderization on the palatability of certain bovine muscles. *Food Research International, 32*(8), 585-591.

Joshipura, K. J., Willett, W. C., & Douglass, C. W. (1996). The impact of edentulousness on food and nutrient intake. *The Journal of the American Dental Association, 127*(4), 459-467. doi: http://dx.doi.org/10.14219/jada.archive.1996.0237

Kiesswetter, E., Donini, L., Migliaccio, S., Poggiogalle, E., Sulmont-Rossé, C., Feart, C., . . . Volkert, D. (in press). Functional determinants of dietary intake in community-dwelling older adults - a DEDIPAC systematic literature review. *Public Health Nutr.*

Kim, H. W., Choi, Y. S., Choi, J. H., Kim, H. Y., Lee, M. A., Hwang, K. E., . . . Kim, C. J. (2013). Tenderization effect of soy sauce on beef M. biceps femoris. [Evaluation Studies
Research Support, Non-U.S. Gov't]. *Food Chem, 139*(1-4), 597-603. doi: 10.1016/j.foodchem.2013.01.050

King, D. A., Wheeler, T. L., Shackelford, S. D., Pfeiffer, K. D., Nickelson, R., & Koohmaraie, M. (2009). Effect of blade tenderization, aging time, and aging temperature on tenderness of beef longissimus lumborum and gluteus medius. [Research Support, N.I.H., Extramural
Research Support, Non-U.S. Gov't]. *J Anim Sci, 87*(9), 2952-2960. doi: 10.2527/jas.2009-1803

Leake, J. L., Hawkins, R., & Locker, D. (1994). Social and functional impact of reduced posterior dental units in older adults. *J Oral Rehabil, 21*(1), 1-10.

Lee, J. S., Weyant, R. J., Corby, P., Kritchevsky, S. B., Harris, T. B., Rooks, R., . . . Newman, A. B. (2004). Edentulism and nutritional status in a biracial sample of well-functioning, community-dwelling elderly: the health, aging, and body composition study. [Research Support, U S Gov't, P H S]. *Am J Clin Nutr, 79*(2), 295-302.

Maître, I., Symoneaux, R., & Sulmont-Rossé, C. (2015). Sensory testing in new product development: working with older people. *Maître I, Symoneaux R & Sulmont-Rossé C (2015). Sensory testing in new product development: working with older people. In*

Delarue J, Lawlor B & Rogeaux M (eds), Rapid sensory profiling techniques and related methods (pp. 485-208). Woodhead Publishing Limited, Cambridge, UK.

Marcenes, W., Steele, J. G., Sheiham, A., & Walls, A. W. (2003). The relationship between dental status, food selection, nutrient intake, nutritional status, and body mass index in older people. *Cadernos de Saude Publica, 19*(3), 809-816.

Marcus, S. E., Kaste, L. M., & Brown, L. J. (1994). Prevalence and demographic correlates of tooth loss among the elderly in the United States. [Comparative Study]. *Spec Care Dentist, 14*(3), 123-127.

Mathonière, C., Mioche, L., Dransfield, E., Culioli, J. (2000) Meat texture characterisation: comparison of chewing patterns, sensory and mechnical measures. *Journal of Texture Study*, *31*, 183-203.

Mese, H., & Matsuo, R. (2007). Salivary secretion, taste and hyposalivation. *Journal of Oral Rehabilitation, 34*(10), 711-723.

Muñoz-González, C., Vandenberghe-Descamps, M., Feron, G., Canon, F., Labouré, H., & Sulmont-Rossé, C. (2017). Association between salivary hypofunction and food consumption in the elderlies. A systematic literature review. [journal article]. *The journal of nutrition, health & aging*. doi: 10.1007/s12603-017-0960-x

Murphy, R. Y., & Marks, B. P. (2000). Effect of meat temperature on proteins, texture, and cook loss for ground chicken breast patties. [Research Support, Non-U S Gov't]. *Poult Sci, 79*(1), 99-104.

Obuz, E., Akkaya, L., Gök, V., & Dikeman, M. E. (2014). Effects of blade tenderization, aging method and aging time on meat quality characteristics of Longissimus lumborum steaks from cull Holstein cows. *Meat Sci, 96*(3), 1227-1232. doi: https://doi.org/10.1016/j.meatsci.2013.11.015

Oreskovich, D. C., Bechtel, P. J., McKeith, F. K., Novakofski, J., & Basgall, E. J. (1992). Marinade pH Affects Textural Properties of Beef. *Journal of Food Science, 57*(2), 305-311. doi: 10.1111/j.1365-2621.1992.tb05482.x

Paddon-Jones, D., Short, K. R., Campbell, W. W., Volpi, E., & Wolfe, R. R. (2008). Role of dietary protein in the sarcopenia of aging. *Am J Clin Nutr, 87(suppl)*, 1562S-1566S.

Peyron, M.A., Mioche, L. and Culioli, J. (1994). Bite force and sample deformation during hardness assessment of viscoelastic models of food. Journal of Texture Studies 24, 59-76.

Peyron, M. A., Blanc, O., Lund, J. P., & Woda, A. (2004). Influence of age on adaptability of human mastication. *Journal of Neurophysiology, 92*(2), 773-779.

Pietrasik, Z., Aalhus, J. L., Gibson, L. L., & Shand, P. J. (2010). Influence of blade tenderization, moisture enhancement and pancreatin enzyme treatment on the processing characteristics and tenderness of beef semitendinosus muscle. [Research Support, Non-U.S. Gov't]. *Meat Sci, 84*(3), 512-517. doi: 10.1016/j.meatsci.2009.10.006

Pietrasik, Z., & Shand, P. J. (2004). Effect of blade tenderization and tumbling time on the processing characteristics and tenderness of injected cooked roast beef. *Meat Sci, 66*(4), 871-879. doi: https://doi.org/10.1016/j.meatsci.2003.08.009

Savell, J. W., Smith, G. C., & Carpenter, Z. L. (1977). Blade tenderization of four muscles from three weight-grade groups of beef. *Journal of Food Science, 42*(4), 866-870. doi: 10.1111/j.1365-2621.1977.tb12625.x

Solemdal, K., Sandvik, L., Willumsen, T., Mowe, M., & Hummel, T. (2012). The impact of oral health on taste ability in acutely hospitalized elderly. [Research Support, Non-U S Gov't]. *PLoS One, 7*(5), 3.

Sura, L., Madhavan, A., Carnaby, G., & Crary, M. A. (2012). Dysphagia in the elderly: management and nutritional considerations. [Review]. *Clin Interv Aging, 7*, 287-298. doi: 10.2147/CIA.S23404

Tada, A., & Miura, H. (2014). Systematic review of the association of mastication with food and nutrient intake in the independent elderly. [Review]. *Arch Gerontol Geriatr, 59*(3), 497-505.

Tracy, J. F., Logemann, J. A., Kahrilas, P. J., Jacob, P., Kobara, M., & Krugler, C. (1989). Preliminary observations on the effects of age on oropharyngeal deglutition. [Research Support, U S Gov't, P H S]. *Dysphagia, 4*(2), 90-94.

Vandenberghe-Descamps, M., Labouré, H., Prot, A., Septier, C., Tournier, C., Feron, G., & Sulmont-Rossé, C. (2016). Salivary Flow Decreases in Healthy Elderly People Independently of Dental Status and Drug Intake. *Journal of Texture Studies, 47*(4), 353-360. doi: 10.1111/jtxs.12191

Vandenberghe-Descamps, M., Labouré, H., Septier, C., Feron, G., & Sulmont-Rossé, C. (2017). Oral comfort: A new concept to understand elderly people's expectations in terms of food sensory characteristics. *Food Quality and Preference*. doi: http://dx.doi.org/10.1016/j.foodqual.2017.08.009

Vandenberghe-Descamps, M., Sulmont-Rossé, C., Feron, G., & Labouré, H. (submitted). Impact of easy-to-do culinary techniques on meat shear force and water content. Journal of Texture Study.

Veyrune, J. L., & Mioche, L. (2000). Complete denture wearers: electromyography of mastication and texture perception whilst eating meat. *Eur J Oral Sci, 108*(2), 83-92.

GENERAL DISCUSSION

GENERAL DISCUSSION

The general objective of the present thesis was to understand what oral health factors have an impact on the physiological and psychological dimensions of eating a food, in order to identify culinary techniques that could preserve food intake in elderly people having a poor oral health. Three secondary objectives were brought up from this general objective, corresponding to the three chapters developed previously:

1) To recruit a panel of independently living elderly people; to characterize them in terms of oral health status, food oral processing, food behavior and nutritional status; to analyze data in order to identify the relationships between oral health and eating dimensions;
2) To define the concept of oral comfort when eating a food for elderly people; to develop a tool in order to assess oral comfort among the elderly population with or without oral health impairments; to use the questionnaire to assess oral comfort when eating cereal-based or meat-based products;
3) To prospect culinary technics that could improve food texture; to evaluate the culinary techniques using physical measurement and asking elderly people to rate oral comfort using the food comfortability questionnaire.

1. OBJECTIVES AND MAIN RESULTS

1.1. ORAL HEALTH CHARACTERIZATION

The first objective, developed in chapter 2, was i. to recruit a panel of independently living elderly people; ii. to characterize them in terms of oral health status, food oral processing, food behavior and nutritional status; iii. to analyze data in order to identify the relationships between oral health and eating dimensions.

The main results of this chapter were:

- A large variability was observed in salivary flow rates of elderly people but on average, a 38.5% reduction in the resting salivary flow and a 38.0% reduction in the stimulated salivary flow were observed in healthy elderly people compared with young adults;

- Every component of the oral sphere has its importance in food oral processing, ones should not consider teeth by themselves when investigating the impact of oral health on food oral processing in elderly people.

While most of the papers that investigate the relationship between oral health and eating behavior focus on dental status, the present thesis underlines the importance of other parameters of oral health. Mastication showed indeed to be a complex process that involves the different components of the oral apparatus including salivation. According to the results, dental status had an impact on raw vegetable consumption while salivary status had an impact on protein, carbohydrate, fiber and calcium intake. Furthermore, masticatory ability had an impact on protein, calcium and vitamin D intake.

To go further on this work, it would be interesting to deeper investigate the collected data and perform a rigorous data analysis on both data issued from the oral health characterization and data issued from the 5-day dietary record. A large amount of data was indeed collected during this thesis, and an in depth analysis could not be performed due to lack of time. Analyzing deeper the eating behavior of the AlimaSSenS panel could bring some interesting information on eating habits of elderly people in general. Furthermore, as hypothesized in the article "Impact of oral health and chemosensory perception on food oral processing and food intake in healthy elderly people" presented in Chapter 2 Part 2 of the present thesis, analysis of food and nutrient intake might not be accurate enough to detect differences between poor and good oral health volunteers in terms of food behavior. A different categorization of foods, such as categorizing food into two groups representing "easy to chew" and "hard to chew" foods, could be more appropriate and give indices in the difficulties encountered when eating. Indeed, inside the meat category for example, some elderly people will eat a hard to chew beef steak while some other will eat ground meat knowing that they are not able to chew plain meat. This difference might be perceived as slight but could have its importance as it is not brought out when food is categorized based on its standard classification *i.e.* meat, fruits, vegetables etc. Therefore, using a different classification of food using its physical properties might lead to some different and very interesting results.

1.2. ORAL COMFORT WHEN EATING A FOOD

The second objective, developed in chapter 3, was i. to define the concept of oral comfort when eating a food for elderly people; ii. to develop a tool in order to assess oral comfort among the elderly population with or without oral health impairments; iii. to use the questionnaire to assess oral comfort when eating cereal-based or meat-based products.

The main results of this chapter were:

- Oral comfort when eating a food is a multidimensional concept that includes food bolus formation, painful sensations as well as a texture and flavor appreciations;
- Considering oral comfort when eating a food seems essential when developing food tailored for elderly people.
- Oral health does not seem to play a crucial role when assessing oral comfort when eating a food.

Through the running of focus groups and the development and validation of a questionnaire that evaluates the oral comfort when eating a food, the oral comfort concept was defined as the following: "When eating, oral comfort mainly depends on easiness to chew, to humidify and to swallow as well as on texture softness. Oral pain sensations that occur when eating decrease oral comfort. Beyond these first dimensions, oral comfort also tends to be lower for dry and little melting textures, as well as for low taste intensity foods". Furthermore, the use of the oral comfort questionnaire on every-day products revealed interesting results: some foods supposed to fit with elderly peoples capacities and needs (ground beef and protein enriched milk roll) did not appear as being the most comfortable products among the tested food. Thus, the oral comfort questionnaire will be a precious tool when improving or developing new products for the elderly people, as taking into account elderly people's considerations might help in developing well adapted products. In addition, very few effects of dental status were observed on the assessment of oral comfort, which could be explained by the fact that elderly people may have adapted their food oral processing as oral health deterioration is a long acting process.

To go further on this work, it could be interesting to better control the parameters during tasting sessions such as the amount of water drunk during food consumption, the number of chews necessary to form a swallowable food bolus or even muscle activity when chewing the foods. In that way, masticatory pattern differences between elderly people with a good oral health and elderly people with a poor oral health might be highlighted and the complex mechanic of mastication could be better understood. In addition, the matrices that were used in the present work were very different in terms of texture characteristics. It could be interesting to investigate foods which display a smaller sensory difference. This work was performed on meat-based products (presented in chapter 4) and on meat-based, cereal-based and dairy products in the work package 4 of the AlimaSSenS project

1.3. DEVELOPMENT OF CULINARY TECHNIQUES TO IMPROVE MEAT TEXTURE

Finally the third objective, developed in chapter 4, was to prospect culinary technics that could improve food texture; to evaluate the culinary techniques using physical measurement and asking elderly people to rate oral comfort using the food comfortability questionnaire.

The main results of this chapter were:

- Some easy-to-do at home culinary techniques, *i.e.* blade tenderization, marinade and cooking temperature, improve meat texture significantly;
- Similar results were observed when asking a panel of elderly people to assess oral comfort when eating the meats.

This study was the very first one investing the impact of easy-to-do at home culinary techniques on meat texture, asking elderly consumers to assess oral comfort. The results showed that there is no need to invest into expensive cooking utensils or tire ourselves cooking for hours as simple technics showed a significant improvement on meat texture and oral comfort. As an example, roast-beef samples were significantly improved in terms of shear force, water content and oral comfort when they were blade-tenderized, marinated then cooked at low temperature.

As a first perspective, it would be interesting to investigate a broader set of culinary techniques, on a various number of foods. Several authors have indeed shown that elderly people with dental impairments eat less fruits and vegetables (Lee *et al.*, 2004; Kim *et al.*, 2007; Ervin and Dye, 2009; De Marchi *et al.*, 2011; Tsai and Chang, 2011; Inomata *et al.*, 2014), nuts (Marcenes *et al.*, 2003; Lee *et al.*, 2004; Kimura *et al.*, 2013) or even meat (Lee *et al.*, 2004; Savoca *et al.*, 2010). Therefore, exploring the culinary techniques that could have an impact on those foods' texture could be helpful for elderly people not being able to eat them as it is commonly prepared.

Finally, it is important to keep in mind that this project was created and performed with and for the elderly population. Therefore, it seems necessary to communicate towards them in order to make visible the obtained results. As a first step, it would be very interesting to contact the French national program for nutrition and health and help them updating their guidebook. They indeed created a series of guidebooks, each of them adapted to one segment of the French population. One of them concerns independently living elderly people and aims at helping them to maintain themselves in good health thanks to food and nutrition. This guidebook is unfortunately incomplete when talking about oral health impairments as no advice was given on how to adapt food in that case. Therefore, setting up a partnership with them could be interesting to enrich their guidebook for independently living elderly people. As a second step, it would be interesting to communicate towards catering professionals that work for elderly people, such as cooks working in retirement homes. Nowadays, very few options exist for elderly people that have dental or salivary impairments but no swallowing disorders; therefore for those who are not supposed to eat pureed food. Most of the culinary techniques identified in the present work could be performed in institutions' kitchens, do not require a large amount of work, and could help elderly people with oral impairments but not willing to eat pureed food to keep eating all kind of food thanks to texture improvement. A communication strategy should therefore be set up in order to help enhancing quality of life in retirement homes.

2. CONSIDERATIONS AND PERSPECTIVES

2.1. IS DENTAL STATUS REPRESENTATIVE OF ORAL HEALTH?

Many studies investigated the impact of oral health on food behavior in an elderly population, however very few simultaneously evaluated masticatory, salivary and chemosensory functions in the same sample. Thus, the results of the present thesis showed that it is essential to consider oral health as a multidimensional entity, including dental status but also salivation and masticatory ability. Furthermore, while some studies have investigated the impact of oral components (*e.g.* dental status, salivary flow) on the efficiency of oral processes (*e.g.* chewing performance, bolus formation) and others investigated the impact of oral components on nutritional variables (*e.g.* food or nutrient intake), none considered oral components, oral processes and nutritional variables in one experiment (see Tada and Miura (2014); Muñoz-González *et al.* (2017) and Kiesswetter *et al.* (in press) for reviews). Once again, the results of the present thesis tend to demonstrate that oral health status and food oral processing should be considered as a whole when exploring elderly people's food behavior.

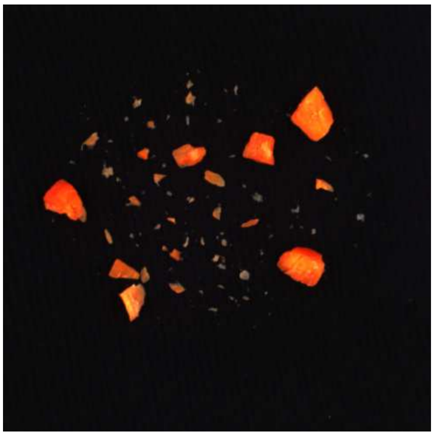
Indeed, when investigating the impact of oral health on food oral processing and food intake, the results showed that each oral health factor had its importance in the food oral process. While a dental status effect was observed on olfactory capacities and on raw vegetables consumption, saliva effects were observed on food bolus formation and on some nutrient intakes. Furthermore, other parameters such as tongue strength, odor perception or masticatory ability were observed on nutrient intakes. Therefore, each oral factor seems to play a role in food oral processing and food consumption. In addition, when developing the concept of oral comfort when eating a food, the impact of dental status and salivation on food comfort perception was investigated. The results showed some dentition effect as well as some saliva effect on some texture descriptors. Even though few effects were observed in total, the results still highlight the importance of both oral health factors on oral comfort when eating a food. Finally, the study on culinary techniques highlighted some dentition effect as well as some resting and stimulated saliva effects on the subdimensions of oral comfort when eating a food. As for the previous study, the dental status and the salivary status did not impact on the same oral comfort descriptors. These results prove again that salivary status is as important as dental status in food oral processing.

Therefore, studying dental status only is not sufficient to fully understand the complex mechanism of mastication, when investigating the impact of oral health on food consumption.

To go further on the exploration on oral health, three main perspectives can be considered and could be set-up for future research.

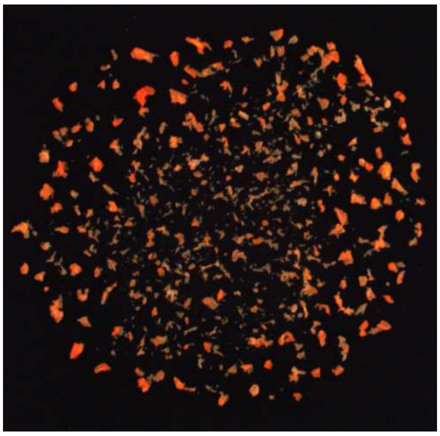
2.1.1. *Specific tests for the evaluation of elderly people's oral health*

Some of the measurements performed in the present study were not developed for the elderly population specifically. As an example, the masticatory ability test was developed on the adult population in general. It was created assuming that people masticate food with their pre-molars and molars; the test was indeed based on the masticatory pattern of a normo-dentate population. In the AlimaSSenS panel, some of the elderly people do not have or have very few remaining pre-molars and molars. Therefore, they do not masticate food using these teeth but using other teeth such as incisors or canines or using their gum. Thus, it was decided to adopt a new strategy in terms of data analysis in order to optimize the representations of bolus structures. Indeed, the median particle size – used as the determinant data for masticatory ability classification (Woda *et al.*, 2010) – was sometimes similar for two elderly persons who formed very different food bolus (Figure 8). While some persons formed a bolus with many median size particles, others formed a bolus made of some very small particles and some very big particles, which leads to a median particle size close to the first ones. In order to adapt this test to our population, we had to take into account other parameters to highlight food bolus heterogeneity, not initially included in the test.



Subject 031: 0 functional units

- **91** particles
- Time of mastication : **77** sec
- D50 = **1.16** mm



Subject 032: 4 functional units

- **526** particles
- Time of mastication : **26** sec
- D50 = **1.35** mm

Figure 8. Two carrot bolus with a similar D50 but with different number of particles and time of mastication.

2.1.2. *ORAL HYGIENE AND MASTICATORY PATTERN, SOME ADDITIONAL INTERESTING MEASUREMENTS*

Some other measurements that can be found in the literature could be performed to complete the oral health characterization. For example, the analysis of oral hygiene has not been performed in the present study but could be a good indicator for oral health characterization. Indeed, several authors have shown that dental plaque on tooth surfaces contains bacteria, leukocytes, desquamated oral epithelial cells and food debris, those malodors result in anaerobic fermentation which can have an impact on taste perception (Langan and Yearick, 1976; Hughes and McNab, 2008). In the study conducted by Langan and Yearick (1976), institutionalized elderly people were recruited to evaluate the impact of oral hygiene on taste perception; the authors concluded on a positive impact of oral hygiene treatment on taste perception. Regarding the presence of mucosal lesions, very few studies were conducted but in their study, Smith and Sheiham (1979) reported that difficulty of chewing was observed in 30% of the elderly having oral lesions. Regarding the presence of in-mouth mycosis, only one study investigated its relation to nutritional status (Paillaud *et al.*, 2004). The authors showed that elderly people with oral candidiasis had lower daily energy and protein intakes compared to elderly people without oral candidiasis. Finally, the oral microbiome could play a role in food behavior, directly or indirectly. Solemdal *et al.* (2012) studied the influence of oral bacteria on taste perception on an elderly population and showed that the patients with high growth of oral bacteria had impaired sour taste. Furthermore, there is a well-known relationship between oral microbiome and caries and periodontitis, which are bacterial diseases (Wade, 2013; Costalonga and Herzberg, 2014); those diseases being related to loss of tooth (McFall, 1982; Desvarieux *et al.*, 2003). Therefore, investigating the elderly's oral hygiene could have brought some new information regarding oral health and food behavior.

A second example of measurement that could be performed in future studies is the electromyography. It is well known that electromyography parameters evolve with ageing and can depend on dental status but also on food characteristics (Veyrune and Mioche, 2000; Mioche *et al.*, 2002; Kohyama *et al.*, 2003; Peyron *et al.*, 2004). Investigating the electromyography activity of our elderly panel might bring some information on masticatory pattern and should strengthened data already obtained on masticatory ability.

2.1.3. A FOCUS ON A SINGLE PRODUCT UNIVERSE

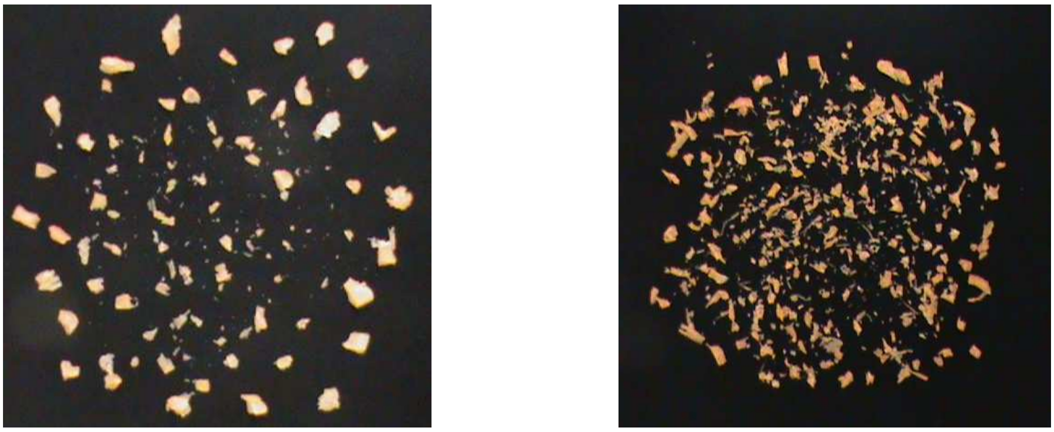
The present study aimed at characterizing an elderly panel in terms of oral health, therefore the choice was made to use validated tests for oral health assessment. However, those tests seemed to be too general to predict the intake of one food in particular, as few effects of oral health were observed on food and nutrient intake. Therefore, to complete this data it could be interesting to investigate a single product universe in order to fully understand food oral processing of one specific food. Indeed, the different measurements performed in the present study used several devices a piece of parafilm® for stimulated salivary flow measurement, a piece of raw carrot for the evaluation of masticatory ability and a mint pastille for aroma release measurement. Even though the retrieved data allowed an oral health characterization, it does not give information on food oral processing and food consumption of a food matrix in particular. Thus, the idea would be for example to investigate meat products, and to perform tests when eating a piece of meat such as measuring muscle activity and salivary flows, studying bolus structure, evaluating the aroma perception or assessing oral comfort. When confronting to the oral health data, these results might bring relevant information on difficulties encounter when eating hard to chew food. This data should also be confronted to the information we retrieved on food consumption such as meat frequency consumption or the daily meat consumption in quantity.

2.2. WHY IS THERE ONLY FEW EFFECT OF ORAL HEALTH ON FOOD CONSUMPTION AND ORAL COMFORT PERCEPTION?

Fewer effects of oral health than expected were observed on oral comfort perception in the present thesis. Indeed, when assessing oral comfort on cereal-based and meat-based products, the results showed that dental effect and saliva effect were observed on very few descriptors of the subdimensions of oral comfort. In addition, few effects of oral health were observed on food and nutrient intake. Similar results can be found in the literature, which were highlighted in a recent literature review (Kiesswetter *et al.*, in press). As an example, the literature review highlighted that among the included studies, 1 and 8 observed an impact of oral health on meat and protein intake respectively out of the 9 and 15 studies which investigated these relationships (Österberg and Steen, 1982; Sheiham and Steele, 2001; Marshall *et al.*, 2002; Österberg *et al.*, 2002; Marcenes *et al.*, 2003; Lee *et al.*, 2004; Yoshihara *et al.*, 2005; Inomata *et al.*, 2014; Iwasaki *et al.*, 2014). Some of the studies that have investigated the impact of oral health on food behavior recruited thousands of volunteers, performed a great amount of measurements, but in most cases very few effects of oral health was observed on food behavior.

One explanation to these results could be that the present study, as well as the studies included in the literature review, recruited healthy elderly people only. Indeed, the inclusion criteria of the present study were: living at home, no acute pathological episodes neither at the time of the experiment nor in the recent past, scoring at least 24 on the Mini Mental State Evaluation. Therefore, even though part of the studied population had a poor dental status, all of the volunteers were in general good health with no acute pathologies and not in critical mental state.

It could be hypothesized that elderly people in good general health are able to compensate better their poor oral health. Interestingly, the elderly people of our panel that were in poor oral health did not consider themselves as having a poor oral health. This hypothesis results from four considerations. First, in a complementary AlimaSSenS study, some focus groups were organized in order to investigate food consumption among elderly people. Some volunteers had a good oral health and some other had a poor oral health, but all of them were in good general health following the same recruitment criteria as previously described. During the focus group with elderly people in poor oral health, none of the volunteers evoked oral health difficulties when eating food, whether during the consumption of dairy, cereal-based or meat-based products. Second, an interview of an AlimaSSenS volunteer was organized as a communication strategy; the production manager recruited specifically a lady with a poor oral health in order to ask her some questions about difficulties encountered when eating food. Contrary to what was expected, when the lady was asked what the most difficult food to eat was for her, she answered that she could not eat grape seed anymore due to digestion troubles. At any time she mentioned difficulties during food oral processing while we knew she had a very poor oral health with few teeth left in the mouth. Third, when assessing oral health self-perception among the panel, the results showed that the scores varied from 34 to 60 out of 60. All the participants, whether they had a good or a poor oral health, evaluated their oral health as good. When comparing oral health self-assessment and masticatory ability, the results showed that some elderly people were in the poor masticatory ability group (production of a carrot bolus with few and big particles) but evaluated their oral health as good (60/60 on the Good Oral Health Assessment Index). On the contrary, others had a Good Oral Health Assessment Index score of 48/60 and were in the good masticatory ability group (Production of a carrot bolus with many and small particles) (Figure 9).



Subject 115: 2 functional units

- **143** particles
- D50 = **2.28** mm
- GOHAI score = 60/60
- Poor masticatory group

Subject 193: 3 functional units

- **313** particles
- D50 = **1.82** mm
- GOHAI score = 48/60
- Good masticatory group

Figure 9. Two carrot bolus of an elderly volunteer in the poor masticatory group and an elderly volunteer in the good masticatory group.

Finally, the results of the present study showed no correlation between the assessment of dry mouth and salivary flow rates, either for resting or stimulated salivary flow rated. Only one volunteer rated himself as having a dry mouth (score of xerostomia = 27.2/80); none of the other volunteers seemed to be complaining about dry mouth while some very low salivary flow rates were measured.

To conclude, the hypothesis would be that the oral health self-perception might be overestimated when people are in good general health; the burden of a poor oral health is greater in elderly people presenting a poor general health compared to elderly in a good general health. Maybe, compensation mechanisms that occur when ones is in good oral health are less efficient with a poor general health, which highlights difficulties encountered when eating.

In addition, it is to be noted that no information was retrieved regarding volunteers past in terms of oral health. Most of the volunteers in poor oral health have probably had a continuous oral degradation, which is less traumatic than experiencing oral impairments all of a sudden due to a particular event. They may have had the time to adopt an adapted behavior in terms of food consumption.

Therefore, a perspective would be to recruit frailer volunteers: 1) elderly people with a poor general health but in good mental health, 2) elderly people with a good general health but in poor mental health, 3) elderly people in poor general health and in poor mental health. Interviewing frailer elderly people might bring some new interesting information regarding oral health self-perception and its relationship with food oral processing and food and nutrient intake, and observing this recruitment order would help understanding the impact of general health and mental health in compensation mechanisms. However, it may be challenging to recruit elderly people in poor general health as they are less movable and less willing to invest themselves into research studies. Furthermore, it would require a different strategy in terms of measurements as an at-home recruitment might be needed. In addition, collecting information using questionnaire may be challenging as elderly people with an impaired mental status are usually not able to answer properly and it is difficult to assess the veracity of the answers. The only way to evaluate food consumption among this population is to perform an interventional study in order to weigh the plates before and after food consumption to estimate the eaten quantities. These kinds of studies are very time and resource consuming, which could explain why very few studies have been performed on this specific population.

2.3. IS IT REALLY NECESSARY TO DEVELOP FOOD WITH A TEXTURE ADAPTED TO ELDERLY PEOPLE'S ORAL HEALTH?

The aim of the present thesis was to identify oral health factors that have an impact on food oral processing and food behavior. Having investigating this topic, one can wonder whether it is necessary to develop a food offering adapted to elderly people's oral health or not. In other words, can the elderly people deal with the oral impairments that occur with ageing or would it be easier for them to eat food with an adapted texture?

The results of the present study lead to think that developing a food offering for the elderly population is really important. During the assessment of oral comfort on cereal-based and meat-based products, whether the volunteers had a good or a poor oral health status, elderly people rated the plain and the ground beefsteaks as less comfortable than the other products. The first one was rated as harder than the other samples; the second was rated as drier than the other samples. While the samples with a melting texture and that were easy to moisten with saliva and to masticate were considered as the most comfortable products, the ones with a dry and hard texture were rated as the less comfortable products due to the difficulties encountered when forming the food bolus.

These results are the proof that texture acceptability is essential when eating food. Unfortunately, texture evaluation is often left aside in sensory analysis compared to flavor perception; very few studies have indeed investigated the impact of ageing on texture perception (Veyrune and Mioche, 2000; Mioche, 2004) while studies having investigated the impact of ageing on taste and flavor perception are profuse (Stevens and Lawless, 1981; Stevens and Cain, 1993; Rawson, 2006). Therefore, the impact of ageing on texture perception remains unclear while texture perception is probably a crucial aspect during food consumption in all ages; but may be even more important for the elderly population as food oral processing ability decreases with ageing whether is it due to dental, saliva or other oral health impairments. While some solutions are developed to partially compensate the loss of teeth, nothing exists to fight against the decrease in salivary flow rate; thus the present study highlighted a 38.5% reduction in the resting salivary flow and a 38.0% reduction in the stimulated salivary flow in healthy elderly people compared with young adults.

Therefore, developing products with an adapted texture to meet elderly people's expectations in terms of texture properties seem to be a priority in the context of the ageing population in developed countries; and researches are needed to define elderly's needs for each food category.

However, to make sure the development of new products will reach its main objective, which is to say being consumed by the elderly population in order to improve mealtime, it seems necessary to develop a marketing strategy to make sure the concerned population will understand the purpose of the products.

According to a complementary study lead in the AlimaSSenS project, reaching elderly people with advice seems more challenging than expected. Some focus groups were performed in order to investigate the commercial messages that could be written on products tailored for elderly people, among the recruited volunteers, some had a good oral health and others had a poor oral health. The results of the focus groups showed that elderly people were not concerned by the theme "senior". When asking them whether or not they would buy a product with the mention "adapted to seniors' needs", the answer was no. However, they easily think of the utility of those products for their older relatives such as institutionalized or hospitalized parents. “I am still young, I do not consider myself as a senior”, “I don’t know what the word senior means, it does not mean anything to me” and “for me, senior is an administrative word, it’s good for having discount on the train but anyhow I am not senior” are common sentences that could be heard during the focus groups. Consequently, there is a real concern on how to reach elderly people that do not think they are being affected by oral health problems but might be anyway, and how to deliver the message in order to improve meal time.

GENERAL CONCLUSION

GENERAL CONCLUSION

The present thesis aimed at understanding what oral health factors (dental, salivary, muscular) have an impact on the physiological and psychological dimensions of eating a food, in order to identify culinary techniques that could preserve food intake in elderly people having a poor oral health. The results showed that food and nutrient intake are influenced by oral factors, however dental status, tongue muscular strength or salivary status do not play the same role on food intake and elderly's corpulence. From that data, culinary techniques to improve meat texture were investigated and blade-tenderization, marinade and low cooking temperature were identified as pertinent culinary techniques to improve meat texture according to physical measurements and oral comfort assessment by an elderly panel; oral comfort being defined as a multidimensional concept that includes food bolus formation, painful sensations as well as texture and flavor appreciations. Those results will allow enhancing elderly's quality of life when eating meat, whether or not they encounter oral health impairments. Other culinary techniques should be explored in order to offer a broader set of advices to elderly people that encounter difficulties when eating foods. Finally, the attention should be brought on communication strategies in order to make the results visible and help elderly people with oral impairments to enhance their mealtime both in terms of nutrition efficiency and also in pleasure.

RÉSUMÉ SUBSTANTIEL

RÉSUMÉ SUBSTANTIEL

INTRODUCTION

La proportion de personnes âgées est en constante augmentation dans le monde. Représentant 8.5% de la population en 2016, le taux devrait atteindre 17% en 2050 ; soient 1.6 billion de personnes (He *et al.*, 2016). Si les personnes âgées vivent de plus en plus longtemps et en meilleur santé dans la plupart des pays développés, ces derniers voient apparaître de nouveaux problèmes de santé publique qui y sont liés. Un de ces problèmes, déjà rencontré dans bon nombre de pays développés, est la dénutrition. La dénutrition résulte d'un déséquilibre entre les besoins du corps humain et les apports nutritionnels. Chez la personne âgée, elle est souvent liée à une consommation insuffisante d'aliments et se traduit par une perte de poids, en particulier de masse musculaire. Trop souvent ignorée, la dénutrition induit ou aggrave un état de fragilité et/ou de dépendance chez la personne âgée. Elle affecte sa qualité de vie et son espérance de vie. Le développement de produits alimentaires adaptés aux séniors se profile donc comme étant une des solutions pour lutter contre la dénutrition, c'en est même une recommandation du World Health Organisation. C'est dans ce contexte qu'est né le projet AlimaSSenS : vers une offre alimentaire adaptée et saine à destination des populations séniors. Le principal objectif du projet AlimaSSenS est de développer et de fournir une offre alimentaire adaptée spécifiquement à la population âgée (au moins 65 ans) vivant à domicile. Les objectifs spécifiques sont les suivants :

- Connaître le lien entre physiologie orale, sensibilité sensorielle et confort à consommer des aliments chez le sujet âgé
- Comprendre l'importance des facteurs socio-économiques dans les choix alimentaires de la personne âgée en lien avec ses difficultés à manger
- Elaborer des aliments afin de procurer du plaisir à manger mais aussi de fournir des apports nutritionnels suffisants
- Proposer une offre alimentaire de qualité accessible à toutes et à tous

Cette thèse fait partie intégrante du projet AlimaSSenS, et plus spécifiquement du Work Package 1 qui a pour objectif de comprendre l'impact de la santé orale sur la dégradation de l'aliment en bouche et leurs conséquences sur le plaisir à manger et la prise alimentaire, chez la personne âgée.

CHAPITRE 1. ETAT DE L'ART

Afin de mieux comprendre l'impact de l'âge sur la dégradation des aliments en bouche, il semble nécessaire d'identifier les différents paramètres oraux impliqués lors de la mastication d'aliments, paramètres qui peuvent être impactés avec l'âge.

LA MASTICATION

La fonction masticatoire joue un rôle déterminant dans la dégradation de l'aliment en bouche, il participe en effet de manière clé à la formation d'un bol alimentaire prêt à être avalé (Mioche, 2004). Premièrement, chaque dent a un rôle spécifique dans la déstructuration de l'aliment : les incisives ou les canines coupent l'aliment lorsqu'il est mis en bouche, puis les molaires le cisaillent ou le broient afin de le réduire en bol alimentaire. De plus, ces dents sont chacune reliées à des mécanorécepteurs qui envoient un signal au cerveau sur les caractéristiques de l'aliment à mastiquer (Trulsson, 2006). Enfin, les muscles masticatoires permettent à la mâchoire de s'ouvrir et de se fermer, régulant les forces de mastication (Wood, 1987).

Avec l'âge, les différentes entités de la mastication peuvent être affectées, entraînant des modifications dans le comportement masticatoire. La perte de dents, le port de dentier mais également le déclin des forces musculaires peuvent induire des changements lors de la dégradation des aliments en bouche. De plus, certains auteurs ont mis en évidence le fait qu'avec l'âge, les cycles masticatoires pouvaient être impactés (Karlsson and Carlsson, 1990; Peyron *et al.*, 2004).

Ces modifications physiologiques peuvent perturber la perception des aliments, et donc la prise alimentaire de manière plus générale. En effet, certains auteurs ont montré que la perception de la texture mais également la perception des flaveurs pouvaient être perturbés avec le déclin de la capacité masticatoire (Manly *et al.*, 1952; Burdach and Doty, 1987; Duffy *et al.*, 1999; Veyrune and Mioche, 2000; Nalcaci and Baran, 2008). De plus, des études ont montré que la perte de dents ou le port de dentier pouvait affecter le comportement alimentaire (Geissler and Bates, 1984; Brodeur *et al.*, 1993; Joshipura *et al.*, 1996; Kagawa *et al.*, 2013). En effet, la plupart des études ont mis en évidence le fait qu'un mauvais état bucco-dentaire était lié à une diminution d'apports en nutriments par rapport à une population en bonne santé bucco-dentaire (Ernest, 1993; Sahyoun *et al.*, 2003; Hung *et al.*, 2005; Yoshihara *et al.*, 2005; Cousson *et al.*, 2012).

LA SALIVATION

La salive est un fluide physiologique qui joue un rôle crucial dans la préservation et le maintien de la santé orale ainsi que dans le confort en bouche (Carpenter, 2012). La salive est sécrétée par trois glandes salivaires majeures et une multitude de glandes salivaires mineures à travers la cavité orale (Christensen, 1986). Lors de la consommation d'un aliment, la salive permet la perception de sensations orales (le goût, la viscosité, la jutosité, astringence, etc.) mais également la libération des arômes en bouche (Fischer *et al.*, 1994; Engelen *et al.*, 2007; Dsamou *et al.*, 2012). De plus, la salive, conjointement à la mastication, transforme l'aliment en un bol prêt à être avalé (Prinz and Lucas, 1997). En effet, la salive humidifie les particules d'aliment et les mucines salivaires permettent d'agglomérer les particules entre elles. Enfin, la salive dilue et enlève les substances de la cavité orale après déglutition, jouant ainsi un rôle de nettoyant (Lagerlof and Oliveby, 1994; Lenander-Lumikari and Loimaranta, 2000).

Il a été démontré que l'effet cumulé de l'âge de de facteurs associés tels que la perte de dents, la prise de médicaments ou encore certaines pathologies pouvait avoir un impact sur le flux salivaire (Dormenval *et al.*, 1998; Bardow *et al.*, 2001; Chu *et al.*, 2015). Cependant, il a été récemment montré que l'âge lui-même pouvait induire une diminution du flux salivaire (Vandenberghe-Descamps *et al.*, 2016).

Il se peut que cette diminution du flux salivaire entraîne des modifications du comportement alimentaire chez la personne âgée. Une récente revue systématique de la littérature résume la littérature existante sur le lien entre faible salivation et prise alimentaire chez la personne âgée (Muñoz-González *et al.*, 2017). Cette revue systématique de la littérature montre qu'il existe un lien entre le manque de salive et les capacités à mastiquer et à avaler, la perception des flaveurs, la perte d'appétit, la prise alimentaire mais également le statut nutritionnel. Cependant, la littérature sur le sujet reste minime, des études longitudinales seraient nécessaires pour confirmer les résultats publiés à ce jour.

LA DEGLUTITION

La déglutition est l'acte d'avaler un aliment, une boisson ou sa salive. Composée de 4 phases (phase orale, phase de transit oral, phase pharyngée, phase œsophagienne), chacune participe à son tour à l'envoi du bol alimentaire vers l'estomac (Schindler and Kelly, 2002; Lambert and Ménage, 2013).

Avec l'âge, chacune des phases de la déglutition peut être impactée, principalement dû à une diminution de la force musculaire. Durant la phase orale, la diminution de la force musculaire peut entraîner une mauvaise préparation du bol alimentaire, ce qui peut mener à des troubles de la déglutition. En revanche, peu d'effet des mobilités linguale et labiale sur la formation du bol ont été observés à ce jour (Baum and Bodner, 1983; Crow and Ship, 1996). Lors de la phase pharyngée, il peut être observé un ralentissement du réflexe de déglutition avec l'âge, mais également une diminution de l'amplitude et de la vitesse du mouvement péristaltique (Tracy *et al.*, 1989; Robbins *et al.*, 1992; Lesourd, 2006), ce qui réduit la vitesse de passage du bol et pourrait augmenter le risque de fausse route. Enfin, la phase œsophagienne semble moins affectée par l'âge mais pourrait présenter des disfonctionnements au niveau du sphincter supérieur (Shaker and Lang, 1994; Ren *et al.*, 1995; Achem and Devault, 2005).

Si très peu d'études ont étudié le lien entre ces modifications physiologiques et la perception des aliments (Bisch *et al.*, 1994), il est avéré que les modifications physiologiques liées à l'âge peuvent avoir des conséquences sur la prise alimentaire (Sura *et al.*, 2012). Lorsque les personnes âgées rencontrent des troubles de la déglutition, il leur est proposé une alimentation à texture modifiée telle que l'alimentation hachée ou encore mixée. Cependant, ce changement drastique d'alimentation peut avoir de graves conséquences sur le statut nutritionnel des personnes. En effet, certaines études ont mis en évidence un lien entre consommation d'aliments mixés et perte d'appétit mais également entre consommation d'aliments mixés et risque de dénutrition (Cabre *et al.*, 2010; Rofes *et al.*, 2011; Serra-Prat *et al.*, 2012).

TRAVAIL PERSONNEL MENE DANS LE CADRE DE LA THESE

Les sections précédentes mettent en avant le fait qu'avec l'âge, la mastication, la salivation mais également la déglutition peuvent être affectés, ce qui peut entraîner des modifications de comportement alimentaire (diminution de l'appétit, diminution de la prise alimentaire, évitement de certains aliments, diminution du plaisir à manger). L'objectif de ma thèse est d'identifier les facteurs bucco-dentaires qui ont un impact sur les dimensions physiologiques et psychologiques de l'acte alimentaire, afin d'étudier des techniques culinaires permettant d'améliorer la texture des aliments dans un but de préserver l'apport alimentaire des personnes âgées ayant un mauvais état bucco-dentaire. Trois axes se dégagent de cet objectif :

Premier axe. Caractériser la population âgée en termes de santé orale. Pour cela, un panel d'environ 100 personnes âgées (>65 ans) a été recruté à Dijon sur la base du volontariat. Ce panel est venu au laboratoire à 3 reprises, pendant lesquelles 6 catégories de mesures ont été réalisées :

- Examen bucco-dentaire (statut dentaire, statut salivaire, force musculaire de la langue, force de morsure) ;
- Auto-évaluation de la santé orale via l'utilisation d'un questionnaire ;
- Evaluation des capacités chimiosensorielles (capacité à percevoir les saveurs, capacité à percevoir les odeurs, quantification des arômes libérés en bouche) ;
- Capacité à former un bol alimentaire ;
- Etude du comportement alimentaire (questionnaire de fréquence de consommation, relevé de consommation du 5 jours) ;
- Evaluation du statut nutritionnel (mesure d'impédance, utilisation d'un questionnaire).

Deuxième axe. Développer le concept de confort en bouche lors de la consommation d'un aliment. Afin de comprendre ce concept jusqu'alors inexistant, nous en avons discuté avec des personnes âgées autour de groupes focus. Sur la base de la retranscription des groupes focus, un questionnaire a été développé ayant pour objectif d'évaluer le confort en bouche lors de la consommation d'un aliment. Le questionnaire est divisé en 5 parties afin d'évaluer : le confort en bouche de manière générale, la difficulté à former le bol alimentaire, les éventuelles douleurs ressenties mais également les propriétés texturales et de flaveur de l'aliment consommé. Ce questionnaire a été validé auprès d'un panel de personnes âgées lors de la consommation de produits céréaliers et de produits carnés.

Troisième axe. Identification de techniques culinaires permettant d'améliorer la texture de la viande. Le choix de l'aliment s'est porté sur la viande car cet aliment représente une source de protéines intéressante pour la population âgée qui en a besoin. Trois techniques culinaires facilement réalisables chez soi ont été identifiées : l'attendrisseur, la marinade et la température de cuisson. Ces trois techniques ont été testées sur du blanc de poulet, du rôti de bœuf et du steak de bœuf ; des mesures physiques ont été réalisées afin d'évaluer la force de cisaillement et la teneur en eau des viande préparées et cuites, un panel de 40 personnes âgées a été sollicité afin d'évaluer le confort en bouche de ces viandes.

Les trois sections suivantes détaillent ces trois axes et en présentent les principaux résultats.

CHAPITRE 2. CARACTERISATION ORALE D'UN PANEL DE PERSONNES AGEES

CARACTERISTIQUES SALIVAIRES DE LA POPULATION

INTRODUCTION

Chez l'homme, la mise en bouche d'un aliment est la phase ultime de la chaîne alimentaire et le début de l'étape de digestion. Concernant l'influence de l'âge sur la dégradation de l'aliment en bouche, le processus a été largement étudié d'un point de vue mastication mais très peu d'un point de vue salivation. En effet, à notre connaissance, très peu d'études ont étudié l'impact d'un vieillissement normal sur le flux salivaire, en considérant le statut dentaire et le nombre de comprimés ingérés par jour. De plus, ces études ont utilisé des méthodes différentes pour évaluer le flux salivaire, ce qui rend les résultats difficilement comparables. Enfin, aucune de ces études n'a étudié le lien entre le statut dentaire et le flux salivaire chez les personnes âgées.

En conséquence, l'objectif de cette étude est d'étudier l'impact d'un vieillissement normal sur le flux salivaire tout en considérant le statut dentaire et le nombre de comprimés ingérés chez les personnes âgées. Pour cela, les flux salivaires au repos et stimulés d'adultes jeunes et de personnes âgées autonomes ont été comparés.

MATERIEL ET METHODE

Participants. 93 adultes jeunes et 84 personnes âgées autonomes ont été recrutés. Les critères de recrutement étaient les suivants : pour les adultes jeunes : avoir un âge compris entre 20 et 55 ans, avoir un bon statut dentaire (aucune dent manquante à l'exception des troisièmes molaires, pas de trouble d'occlusion dentaire) et ne pas prendre de médicament au moment de l'étude. Pour les personnes âgées autonomes : avoir au moins 70 ans, ne pas présenter de pathologie sévère au moment de l'étude, avoir un score supérieur ou égal à 24 au test d'évaluation du statut cognitif (Mini Mental State Evaluation, Folstein *et al.* (1975)). Une interview a été menée avec chacun des volontaires afin de vérifier les critères d'inclusion.

Procédure. Les participants ont réalisé des mesures de flux salivaires au repos et stimulé. Le flux salivaire au repos a été mesuré en demandant aux participants de déposer la salive accumulée dans la bouche dans un tube préalablement pesé à chaque fois que nécessaire, pendant 5 minutes (pour les adultes jeunes) ou 10 minutes (pour les personnes âgées). Le flux salivaire stimulé a été mesure en demandant aux participants de mastiquer un morceau de parafilm préalablement pesé tout en déposant la salive accumulée dans la bouche dans un tube préalablement pesé pendant 5 minutes. Une fois la mesure effectuée, les tubes ont été pesés afin d'évaluer le flux salivaire (en ml/min), assumant qu'un gramme de salive correspond à un millilitre de salive.

En parallèle, le nombre de dents ainsi que le nombre d'unités fonctionnelles de chaque volontaire a été évalué. Une unité fonctionnelle correspond à une paire de dents antagoniste qui se touche pendant la mastication, cette mesure a été réalisée en demandant aux volontaires de mastiquer un papier à articuler, les zones de contact entre les dents se colorant en bleu lors de la mastication.

RESULTATS

Impact de l'âge sur le flux salivaire. Les résultats ont montré que les deux flux (au repos et stimulé) étaient significativement inférieurs chez les personnes âgées par rapport aux adultes jeunes (flux au repos: $t(175)=6.00$; $p<0.001$; flux stimulé: $t(164)=6.91$; $p<0.001$).

Impact de l'âge versus du statut dentaire et de la prise de comprimés sur le flux salivaire. Afin d'étudier l'impact du statut dentaire sur le flux salivaire, la population âgée a été classée en deux groupes : un groupe ayant un bon statut dentaire (au moins 7 unités fonctionnelles postérieures) et un groupe ayant un mauvais statut dentaire (4 unités fonctionnelles postérieurs ou moins). Les résultats ont montré qu'il n'y avait pas de différence significative des flux entre les deux groupes. Afin d'étudier l'impact de la prise de médicaments sur le flux salivaire, la population âgée a été classée en deux groupes : un groupe ne prenant aucun médicament et un groupe ayant au moins 4 comprimés par jour. Les résultats ont montré qu'il n'y avait pas de différence significative des flux entre les deux groupes.

CONCLUSION

Cette étude a montré que le flux salivaire diminue avec l'âge, indépendamment du statut dentaire et de la prise de médicament. Ceci pourrait être expliqué par les modifications physiologiques des glandes salivaires avec l'âge, qui deviennent moins efficaces en termes de production de salive. Davantage d'études sont nécessaires afin de mieux comprendre les liens entre ces changements physiologiques et la sécrétion de salive chez les personnes âgées.

CARACTERISTIQUES ORALES DU PANEL ALIMASSENS

INTRODUCTION

Avec l'âge, la santé orale évolue et consommer un aliment peut parfois devenir un challenge. En effet, avec l'âge, des modifications physiologiques apparaissent dans la sphère orale telles que la perte de dents, la diminution du flux salivaire, ou encore la diminution de la force musculaire ; ceci pouvant entraîner des difficultés à mastiquer, humidifier avec la salive, ou encore à avaler certains aliments. Parmi les études ayant analysé l'impact de la santé orale sur la prise alimentaire des personnes âgées, certaines ont mis en évidence des liens entre certains troubles oraux et le comportement alimentaire. Cependant, les résultats des différentes études ne sont pas toujours consensuels. De plus, la plupart de ces études n'ont pris en compte qu'un ou deux facteurs oraux dans leurs analyses.

En conséquence, l'objectif de cette étude est d'étudier les liens entre la santé orale et l'alimentation des personnes âgées autonomes en prenant en compte les facteurs de mastication, de salivation et de perceptions sensorielles, tout en considérant les paramètres appartenant à la sphère orale (statut dentaire, flux salivaire, force de la langue, force masticatoire, perception des odeurs et des saveurs) ainsi que les paramètres issus de la dégradation des aliments en bouche (formation du bol alimentaire, libération des arômes en bouche).

MATERIEL ET METHODE

Participants. 61 personnes âgées autonomes ont été recrutées. Les critères de recrutement étaient les suivants : avoir au moins 65 ans, ne pas présenter de pathologie sévère au moment de l'étude, avoir un score supérieur ou égal à 24 au test d'évaluation du statut cognitif (Mini Mental State Evaluation, Folstein *et al.* (1975)), avoir un nombre d'unités fonctionnelles postérieures inférieur ou égal à 4, ou supérieur ou égal à 7. Une unité fonctionnelle correspond à une paire de dents antagoniste qui se touche pendant la mastication. Une interview a été menée avec chacun des volontaires afin de vérifier les critères d'inclusion.

Procédure. Les participants sont venus au laboratoire à 4 reprises pour réaliser les examens suivants : comptage de dents, comptage du nombre d'unités fonctionnelles postérieures, mesure de la force de mastication (utilisation de la méthode du chewing-gum bicolore), mesure de la force musculaire de la langue (utilisation du matériel IOPO®), mesure des flux salivaires au repos et stimulés, évaluation des seuils de perception des saveurs sucrée et salée, évaluation du seuil de perception des odeurs, évaluation de la capacité à former un bol alimentaire lors de la consommation d'une rondelle de carotte crue, mesure des arômes de menthe libérés en bouche lors de la consommation d'une pastille de menthe. En parallèle, un questionnaire d'auto-évaluation de la santé orale (Geriatric Oral Health Assessment Index), une enquête alimentaire de 5 jours, un questionnaire de fréquence de consommation ainsi que des mesures de corpulence (poids, taille, impédance) ont été réalisés.

RESULTATS

Concernant les données de santé orale des participants, les résultats ont montré que la diminution du nombre de dents était associée à un déclin au niveau des perceptions olfactives, et que l'auto-évaluation de la santé orale était corrélée au nombre de dents. Concernant les liens entre santé orale et dégradation de l'aliment en bouche, les résultats ont montré que le nombre de particules de carotte était lié au nombre de dents, à la force musculaire de la langue ainsi qu'au flux salivaire. De plus, le nombre de particules ainsi que la taille de la plus grosse particule formée était liés à l'auto-évaluation de la santé orale. Concernant les liens entre santé orale, dégradation de l'aliment en bouche et le comportement alimentaire, les résultats ont mis en évidence un lien entre la consommation de crudités et le statut dentaire. En revanche, aucun lien n'a été observé entre la consommation de viande et les facteurs de santé orale. Les résultats ont également montré un lien entre la faculté à percevoir les odeurs et la consommation de protéines et de calcium. Enfin, seules les variables de statut dentaire étaient liées au statut pondéral des personnes âgées.

CONCLUSION

Cette étude met en avant le fait que s'intéresser uniquement au statut dentaire ne suffit pas pour comprendre le comportement alimentaire. En effet, le flux salivaire mais également la force musculaire de la langue ont montré des liens significatifs avec des variables du comportement alimentaire. Il semble donc nécessaire de considérer la sphère orale dans son ensemble lorsque l'on étudie l'impact de la santé orale sur le comportement alimentaire des personnes âgées autonomes.

CHAPITRE 3. CONFORT EN BOUCHE

DEFINITION DU CONFORT EN BOUCHE ET DEVELOPPEMENT D'UN OUTIL PERMETTANT D'EVALUER LE CONFORT EN BOUCHE

INTRODUCTION

Chez la population âgée, les changements physiologiques de la sphère orale liés à l'âge peuvent avoir des conséquences non négligeables sur la faculté à manger les aliments. Dans un contexte de population vieillissante, il semble crucial de développer des aliments adaptés aux troubles oraux que peuvent rencontrer les personnes âgées. Or pour développer des produits alimentaires adaptés, il est nécessaire d'interroger les personnes elles-mêmes sur leur perception des aliments et leur évaluation en termes de confort en bouche. Il n'existe, à ce jour, aucune définition du confort en bouche et encore moins d'outils pour permettre à un panel de l'évaluer.

En conséquence, l'objectif de cette étude est d'explorer le concept de confort en bouche chez la population âgée afin de développer un outil permettant aux personnes âgées d'évaluer le confort en bouche lors de la consommation d'un aliment (étude 1), puis de valider ce questionnaire à travers des dégustations de produits carnés et de produits céréaliers (étude 2).

ETUDE 1 : MATERIEL ET METHODE

Trois groupes focus ont été mis en place avec 6 personnes âgées dans chaque groupe. Les critères d'inclusion étaient les suivants : avoir au moins 65 ans, ne pas présenter de pathologie sévère au moment de l'étude, avoir un score supérieur ou égal à 24 au test d'évaluation du statut cognitif (Mini Mental State Evaluation, Folstein *et al.* (1975)). Chaque groupe focus était constitué de trois étapes : un brainstorming sur le confort en bouche ; un partage d'expérience sur ceux que sont les aliments les plus confortables et les plus inconfortables, une dégustation 8 aliments parmi 32 propositions afin de discuter de leur aspect confortable ou inconfortable.

ETUDE 1 : RESULTATS

L'analyse des groupes focus a permis de développer un questionnaire, outil visant à évaluer le confort en bouche lors de la consommation d'un aliment : le questionnaire « confort en bouche ». Le questionnaire est composé de 5 parties : une partie générale sur l'évaluation du confort en bouche et de sa facilité à manger, une partie évaluant la difficulté à former le bol alimentaire, une partie permettant d'évaluer les éventuelles douleurs ressenties lors de la consommation de l'aliment, une partie portant sur les caractéristiques texturales de l'aliment, et une partie portant sur les caractéristiques de flaveur des aliments.

ETUDE 2 : MATERIEL ET METHODE

Participants. Deux panels de personnes âgées ont été constitués, l'un pour les produits carnés (n=39), l'autre pour déguster les produits céréaliers (n=42). Les critères d'inclusion étaient les suivants : avoir au moins 65 ans, ne pas présenter de pathologie sévère au moment de l'étude, avoir un score supérieur ou égal à 24 au test d'évaluation du statut cognitif (Mini Mental State Evaluation, Folstein *et al.* (1975)).

Produits. Six produits carnés et 6 produits céréaliers ont été choisis dans le but de présenter des produits à texture contrastée. Les produits carnés étaient constitués de steak de bœuf, steak haché de bœuf, joue de bœuf, boulettes de poulet, aiguillette de poulet et nuggets de poulet. Les produits étaient cuits ou réchauffés quelques minutes avant la dégustation, et servis à 65°C à cœur. Les produits céréaliers étaient constitués de biscotte, financier, madeleine, génoise, pain au lait et pain au lait enrichi en protéines végétales. Les produits étaient servis à température ambiante.

Dégustations. Les volontaires étaient invités à goûter chacun des six produits (produits carnés ou produits céréaliers selon le panel), ils pouvaient manger autant de produit qu'ils le souhaitaient afin de répondre au questionnaire confort en bouche. Ils pouvaient également boire de l'eau librement pendant la dégustation.

ETUDE 2 : RESULTATS

Concernant les produits carnés, les résultats ont montré que le steak et le steak haché étaient les produits les moins confortables selon les personnes âgées. A l'inverse, les boulettes de poulet, les aiguillettes de poulet ainsi que la joue de bœuf étaient les produits évalués comme étant les plus confortables. Concernant les produits céréaliers, la biscotte et le pain au lait enrichi en protéines végétales étaient les produits considérés comme étant les moins confortables. A l'inverse, la madeleine et la génoise étaient évalués comme étant confortables. Enfin, le pain au lait et le financier étaient considérés comme étant modérément confortables.

CONCLUSION

Cette étude a permis de définir le concept de confort en bouche, sa définition est la suivante : un aliment confortable est un aliment facile à mastiquer, à humidifier avec la salive et à avaler, Sa texture doit être tendre. Les douleurs ressenties lors de la consommation d'un aliment diminuent la perception du confort de l'aliment. Cette étude a également permis de mettre en évidence le fait que certains aliments, développés spécifiquement pour la population sénior ou recommandés lors de problèmes bucco-dentaires (pain au lait enrichi, steak haché) ne font pas partie des aliments les plus confortables. Or un aliment évalué comme étant inconfortable par la population âgée ne sera pas consommé. Il semble donc essentiel, lors de développement de nouveaux produits à destination de la population sénior, de recueillir leur évaluation du confort en bouche desdits produits avant toute commercialisation.

IMPACT DE LA SANTE ORALE SUR LA PERCEPTION DU CONFORT EN BOUCHE CHEZ LES PERSONNES AGEES

INTRODUCTION

Avec l'âge, la sphère orale présente des modifications physiologiques qui peuvent impacter sur la formation du bol et la perception sensorielle des aliments. Dans une récente étude, nous avons exploré le concept de confort en bouche, et développé un outil permettant aux personnes âgées d'évaluer le confort en bouche lors de la consommation d'un aliment. Ce questionnaire a été utilisé dans cette étude afin d'évaluer quels paramètres oraux (état dentaire et salivaire) avaient un impact sur la perception du confort en bouche. Plus particulièrement, nous avons demandé à un panel de personnes âgées ayant un bon ou un mauvais état bucco-dentaire d'évaluer le confort en bouche de 6 produits carnés et 6 produits céréaliers.

MATERIEL ET METHODE

Participants. Deux panels de personnes âgées ont été constitués, l'un pour les produits carnés (n=34), l'autre pour déguster les produits céréaliers (n=37). Les critères d'inclusion étaient les suivants : avoir au moins 65 ans, ne pas présenter de pathologie sévère au moment de l'étude, avoir un score supérieur ou égal à 24 au test d'évaluation du statut cognitif (Mini Mental State Evaluation, Folstein *et al.* (1975)), avoir au moins 7 unités fonctionnelles postérieurs ou 4 unités fonctionnelles postérieures ou moins. Une unité fonctionnelle correspond à une paire de dents antagoniste qui se touche pendant la mastication. Une interview a été menée avec chacun des volontaires afin de vérifier les critères d'inclusion. Lors de cette interview, le flux salivaire au repos a été mesuré en demandant aux participants de déposer la salive accumulée dans la bouche dans un tube préalablement pesé pendant 10 minutes. Le tube était ensuite collecté puis pesé afin de déterminer le flux salivaire en ml/min.

Produits. Six produits carnés et 6 produits céréaliers ont été choisis dans le but de présenter des produits à texture contrastée. Les produits carnés étaient constitués de steak de bœuf, steak haché de bœuf, joue de bœuf, boulettes de poulet, aiguillette de poulet et nuggets de poulet. Les produits étaient cuits ou réchauffés quelques minutes avant la dégustation, et servis à 65°C à cœur. Les produits céréaliers étaient constitués de biscotte, financier, madeleine, génoise, pain au lait et pain au lait enrichi en protéines végétales. Les produits étaient servis à température ambiante.

Dégustations. Les volontaires étaient invités à goûter chacun des six produits (produits carnés ou produits céréaliers selon le panel), ils pouvaient manger autant de produit qu'ils le souhaitaient afin de répondre au questionnaire confort en bouche. Ils pouvaient également boire de l'eau librement pendant la dégustation.

RESULTATS

Concernant les produits carnés, les résultats n'ont pas montré d'effet du statut dentaire ni de la salivation sur la perception du confort en bouche. En revanche, un effet de la dentition a été observé sur l'apparition de douleurs musculaires et sur la perception acide des produits ; un effet de la salivation a été observé sur la perception sucrée des produits. Concernant les produits céréaliers, les résultats n'ont pas montré d'effet du statut dentaire ni de la salivation sur la perception du confort en bouche. En revanche, des effets de la dentition et de la salivation ont été observés sur l'apparition de douleurs musculaires et dentaires, ainsi que sur l'évaluation du descripteur filandreux.

CONCLUSION

Très peu d'effets des facteurs oraux ont été observés sur l'évaluation du confort en bouche. Les produits ont donc été notés de manière similaire quelle que soit la santé orale des dégustateurs.

CHAPITRE 4. DEVELOPPEMENT DE TECHNIQUES CULINAIRES PERMETTANT D'AMELIORER LA TEXTURE DE LA VIANDE

IMPACT DE TECHNIQUES CULINAIRES SUR LA FORCE DE CISAILLEMENT ET LA TENEUR ET EAU DE LA VIANDE

INTRODUCTION

La tendreté et la jutosité sont deux caractéristiques essentielles pour la palatabilité d'une viande. Ces deux paramètres semblent également avoir un impact sur la formation d'un bol de viande. De nombreux auteurs ont étudié l'impact de méthodes physiques d'améliorer la texture de la viande. Cependant, la majorité des études utilise des méthodes difficilement reproductibles chez soi. Or dans un contexte de population vieillissante, il serait intéressant de pouvoir proposer des solutions aux personnes âgées autonomes afin qu'elle puisse améliorer la texture des viandes qu'elles cuisinent à travers la mise en place de techniques culinaires simples.

En conséquence, l'objectif de cette étude est d'étudier l'impact de techniques culinaires simples à réaliser sur la teneur en eau et la force de cisaillement de viandes. Les techniques utilisées sont l'attendrissement, la marinade ainsi que la température de cuisson.

MATERIEL ET METHODE

Trois viandes ont été sélectionnées car elles sont consommées majoritairement en France : le steak de bœuf, le rôti de bœuf et le blanc de poulet. Les trois viandes ont été préparées et cuites selon le tableau ci-dessous (Table 1).

Table 1. Mode de préparation, temps de marinade et mode de cuisson des viandes

	Mode de préparation	Temps de marinade	Mode de cuisson
Steak de bœuf	Aucune préparation	-	Plaque à induction à 160°C
	Attendri	-	Plaque à induction à 160°C
	Mariné	2 heures	Plaque à induction à 160°C
	Attendri + mariné	2 heures	Plaque à induction à 160°C
Rôti de bœuf	Aucune préparation	-	Four à 220°C
	Attendri	-	Four à 220°C
	Mariné	4 heures	Four à 220°C
	Attendri + mariné	4 heures	Four à 220°C
	Aucune préparation	-	Four à 110°C
	Attendri	-	Four à 110°C
	Mariné	4 heures	Four à 110°C
	Attendri + mariné	4 heures	Four à 110°C
Blanc de poulet	Aucune préparation	-	Four à 220°C
	Attendri	-	Four à 220°C
	Mariné	2 heures	Four à 220°C
	Attendri + mariné	2 heures	Four à 220°C
	Aucune préparation	-	Four à 110°C
	Attendri	-	Four à 110°C
	Mariné	2 heures	Four à 110°C
	Attendri + mariné	2 heures	Four à 110°C

L'attendrissement a été réalisé à l'aide d'un attendrisseur à viande, constitué de 51 lames tranchantes permettant de couper les fibres les plus importantes du morceau de viande. Un passage d'attendrisseur a été réalisé sur chaque morceau, sur une face pour le steak et le poulet, sur les deux faces pour le rôti afin de transpercer la viande dans son intégralité. La marinade était composée de sauce soja Suzi Wan® (6%) et d'eau Evian® (94%), la viande étaient mises à mariner pendant 2h (steak et poulet) ou 4h (rôti) à +4°C. Suite à des pré-tests, il a été décidé de cuire tous les morceaux allant au four dans des sachets cuisson, les résultats des pré-tests ayant mis en évidence une diminution de la force de cisaillement et une augmentation de la teneur en eau de des viandes lorsqu'elles étaient cuites en sachet cuisson. L'évaluation de la force de cisaillement a été réalisée à l'aide de la cellule de Warner-Bratzler (ttc® TA.XT plus) ; l'évaluation de la teneur en eau été réalisée en pesant environ 2g de viande avant et après passage à l'étuve à 130°C permettant un dessèchement total de la viande.

RESULTATS

Les résultats ont montré que les techniques culinaires avaient un impact sur la force de cisaillement et la teneur en eau des trois viandes. Si la combinaison attendrisseur + marinade semble être optimal pour améliorer la texture des deux viandes de bœuf (steak et rôti), l'attendrisseur seul semble optimiser la texture du blanc de poulet. De plus, la cuisson à basse température réduit significativement la force de cisaillement et augmente de manière significative la teneur en eau des deux viandes cuites au four, le rôti de bœuf et le blanc de poulet.

CONCLUSION

L'étude a permis de mettre en évidence le fait que la mise en place de techniques culinaires faciles à réaliser chez soi pouvait améliorer significativement la texture de la viande. Il serait intéressant d'interroger un panel de personnes âgées sur leur perception du confort en bouche lors de la consommation de ces viandes afin de valider l'intérêt des techniques culinaires étudiées.

IMPACT DE L'ATTENDRISSEUR, DE LA MARINADE ET DE LA TEMPERATURE DE CUISSON SUR LA PERCEPTION DU CONFORT EN BOUCHE CHEZ LES PERSONNES AGES

INTRODUCTION

De nombreuses études ont étudié l'impact de techniques culinaires sur la tendreté et la jutosité de la viande. Cependant, la plupart d'entre elles ont utilisé des techniques difficilement réalisables chez soi. De plus, toutes les études ont utilisé des techniques de mesures physiques ou ont fait appel à un panel expert en analyse sensorielle de la viande pour évaluer les propriétés texturales des viandes ; aucune d'entre elle n'a fait appel à un panel de consommateurs lambda. Enfin, la majorité des études n'a évalué que deux descripteurs de texture (tendreté et jutosité) ; or une précédente étude portant sur le concept de confort en bouche a mise en évidence le fait que plusieurs dimensions rentraient dans la définition du confort en bouche : la faculté à former le bol alimentaire, les douleurs ressenties en bouche lors de la consommation d'un aliment ainsi que certains paramètres de texture et de flaveur.
En conséquence, l'objectif de cette étude est d'évaluer l'impact des techniques culinaires sur la perception du confort en bouche chez des personnes âgées. Les techniques évaluées sont l'attendrissement, la marinade ainsi que la température de cuisson.

MATERIEL ET METHODE

Participants. 40 personnes âgées ont été recrutées
Les critères d'inclusion étaient les suivants : avoir au moins 65 ans, ne pas présenter de pathologie sévère au moment de l'étude, avoir un score supérieur ou égal à 24 au test

d'évaluation du statut cognitif (Mini Mental State Evaluation, Folstein *et al.* (1975)), avoir au moins 7 unités fonctionnelles postérieurs ou 4 unités fonctionnelles postérieures ou moins. Une unité fonctionnelle correspond à une paire de dents antagoniste qui se touche pendant la mastication. Une interview a été menée avec chacun des volontaires afin de vérifier les critères d'inclusion. Lors de cette interview, les flux salivaires au repos et stimulé ont été mesurés. Le flux salivaire au repos a été évalué en demandant aux participants de déposer la salive accumulée dans la bouche dans un tube préalablement pesé pendant 10 minutes. Le tube était ensuite collecté puis pesé afin de déterminer le flux salivaire en ml/min. Le flux salivaire stimulé a été évalué en demandant aux participants de mastiquer un morceau de parafilm préalablement pesé tout en déposant la salive accumulée dans la bouche dans un tube préalablement pesé pendant 5 minutes. Une fois la mesure effectuée, les tubes ont été pesés afin d'évaluer le flux salivaire (en ml/min), assumant qu'un gramme de salive correspond à un millilitre de salive.

Produits. Trois viandes ont été sélectionnées car elles sont consommées majoritairement en France : le steak de bœuf, le rôti de bœuf et le blanc de poulet. Les trois viandes ont été préparées et cuites selon le tableau ci-dessous (Table 2).

Table 2. Mode de préparation, temps de marinade, mode de cuisson et portion servie des viandes à la dégustation

	Mode de préparation	Temps de marinade	Mode de cuisson	Portion servie
Blanc de poulet	Aucune préparation	-	Four à 220°C	Environ 70g
	Aucune préparation	-	Four à 110°C	Environ 70g
	Attendri	-	Four à 220°C	Environ 70g
	Attendri	-	Four à 110°C	Environ 70g
	Attendri + mariné	2 heures	Four à 220°C	Environ 70g
Rôti de bœuf	Aucune préparation	-	Four à 220°C	Environ 50g
	Aucune préparation	-	Four à 110°C	Environ 50g
	Attendri	-	Four à 110°C	Environ 50g
	Mariné	4 heures	Four à 110°C	Environ 50g
	Attendri + mariné	4 heures	Four à 110°C	Environ 50g
Steak de bœuf	Aucune préparation	-	Plaque à induction à 160°C	Environ 38g
	Attendri	-	Plaque à induction à 160°C	Environ 38g
	Mariné	2 heures	Plaque à induction à 160°C	Environ 38g
	Attendri + mariné	2 heures	Plaque à induction à 160°C	Environ 38g

Le choix des conditions testées résulte des résultats de l'étude précédemment présentée, les conditions de préparation sont identiques.

Dégustation. La dégustation était organisée en trois séances, chacune correspondant à un type de viande. Les volontaires étaient invités à goûter chacun des morceaux de viandes, ils pouvaient manger autant de produit qu'ils le souhaitaient afin de répondre au questionnaire confort en bouche. Ils pouvaient également boire de l'eau librement pendant la dégustation.

RESULTATS

Les résultats ont montré un effet significatif des techniques culinaires sur la perception du confort en bouche. Concernant les blancs de poulet, l'utilisation d'un attendrisseur ainsi que la cuisson à basse température produit une viande moins sèche et plus fondante que les autres conditions. Concernant le rôti de bœuf, la combinaison de l'attendrisseur, de la marinade et de la cuisson à basse température entraîne une viande plus facile à mastiquer, à humidifier avec la salive et à avaler. La viande est en effet évaluée comme étant plus fondante, plus tendre et plus juteuse que les autres conditions. Concernant le steak de bœuf, très peu d'effets ont été observés, ceci peut s'expliquer par le fait que la viande était déjà très tendre initialement. Concernant l'impact de la santé orale sur la perception du confort en bouche, un effet dentition a été observé sur la difficulté à former le bol de viande ; un effet du flux salivaire au repos a été observé sur la difficulté à former le bol de viande ainsi que sur la perception de la texture collante ; un effet du flux salivaire stimulé a été observé sur la perception des textures pâteuse et dure.

CONCLUSION

Cette étude est la première ayant investigué l'impact de techniques culinaires réalisables facilement chez soi sur la perception du confort en bouche chez les personnes âgées. Elle met en avant le fait qu'en connaissant certaines astuces, les personnes âgées pourraient significativement améliorer la texture de leur viande en la préparant différemment, et ainsi prendre davantage de plaisir en la mangeant.

DISCUSSION GENERALE

Cette thèse a permis de montrer que :

- Chaque élément de la sphère orale est important lors de la dégradation d'aliment en bouche chez la personne âgée ;
- Le confort en bouche est un concept multidimensionnel qui comprend la formation du bol alimentaire, les douleurs ressenties en bouche, la perception de la texture et la perception de la flaveur ;
- Il semble essentiel de prendre en compte le confort en bouche des personnes âgées lorsque l'on souhaite développer des produits alimentaires spécifiques à cette population ;
- La santé orale ne semble pas impacter la perception du confort en bouche ;
- Des techniques culinaires facilement réalisables chez soi peuvent améliorer de façon significative la texture de la viande et la perception du confort en bouche.

En perspective, il semblerait intéressant d'étudier la validité de certaines mesures de paramètres oraux pour des populations spécifiques telles que la population âgée. En effet, certains tests réalisés dans la présente étude se sont révélés être peu adaptés à la population âgée, une stratégie d'analyse a donc été mise en place. Il se peut que certains autres tests ne soient pas adaptés non plus à cette population, investiguer de manière systématique permettrait de gagner du temps lors d'études comme celles-ci.

Ensuite, étudier davantage de paramètres oraux tels que l'hygiène buccale ou l'activité musculaire des muscles masticatoire permettrait de compléter les informations de santé orale collectées auprès du panel AlimaSSenS. L'hygiène buccale par exemple est connue pour avoir un impact sur la perception des aliments mais également sur la formation du bol alimentaire (Smith and Sheiham, 1979; Hughes and McNab, 2008). De plus, l'étude de l'activité musculaire des muscles masticatoires permettrait de mettre en évidence différents comportements masticatoires au sein de la population étudiée (Mioche *et al.*, 2002).

De plus, investiguer un univers produit spécifique et en étudier sa déstructuration en bouche jusqu'à la déglutition permettrait de mieux comprendre les liens avec sa consommation au quotidien. Suivre un morceau de viande par exemple depuis sa mise en bouche jusqu'à la déglutition en relevant la libération des arômes, le comportement masticatoire mais également la perception du confort en bouche, tout en enquêtant sur ses habitudes de consommation, pourrait révéler de nouvelles informations intéressantes.

Ensuite, il serait intéressant de recruter un panel de personnes âgées plus fragiles afin d'élargir la population étudiée et de potentiellement mettre en évidence davantage de liens entre santé orale et alimentation. Le panel AlimaSSenS est en effet en bonne santé générale, ne présente pas de pathologie sévère, et n'est pas dénutrie. Il est probable que l'étude d'une population plus fragile mette en évidence d'autres liens entre santé orale et comportement alimentaire.

Enfin, il semble nécessaire de communiquer largement sur les résultats de cette thèse concernant l'identification de techniques culinaires. Donner aux personnes âgées des clés pour mieux manger est aujourd'hui un défi, et pour cela il faudrait développer une stratégie de communication afin de toucher le plus grand nombre de personnes concernées par les problèmes de santé orale liés à l'âge.

CONCLUSION GENERALE

L'objectif de cette thèse était de comprendre quels facteurs bucco-dentaires ont un impact sur les dimensions physiologiques et psychologiques de l'acte alimentaire, afin d'identifier des techniques culinaires permettant d'améliorer la texture des aliments dans un but de préserver l'apport alimentaire des personnes âgées ayant un mauvais état bucco-dentaire. Les résultats ont montré que le processus de dégradation de l'aliment en bouche est complexe et multidimensionnel, il inclut des paramètres physiologiques tels que les dents, la salive ou encore les muscles masticatoires, mais également des paramètres fonctionnels tels de la capacité à former un bol alimentaire ou la libération des arômes en bouche. A partir de ces données, des techniques culinaires ont été identifiées permettant d'améliorer la texture de la viande : l'attendrisseur, la marinade et la température de cuisson. Ces techniques permettent d'améliorer de façon significative la dureté et la teneur en eau de la viande, ainsi que le confort en bouche perçu par les personnes âgées. Il serait maintenant intéressant de communiquer ces résultats auprès de la population âgée pour leur donner des conseils sur les façons de préparer la viande afin de faciliter la mastication, améliorer leur confort à manger et augmenter le plaisir ressenti lors du repas.

BIBLIOGRAPHY

BIBLIOGRAPHY

ACHEM, S.R., and DEVAULT, K.R. 2005. Dysphagia in aging. J Clin Gastroenterol *39*, 357-371.

AKPATA, E., OTOH, E., ENWONWU, C., ADELEKE, O., and JOSHIPURA, K. 2011. Tooth loss, chewing habits, and food choices among older Nigerians in Plateau State: a preliminary study. Community Dent Oral Epidemiol *39*, 409-415.

ANGELINI, V., CAVAPOZZI, D., CORAZZINI, L., and PACCAGNELLA, O. 2012. Age, Health and Life Satisfaction Among Older Europeans. Social Indicators Research *105*, 293-308.

ASAKAWA, A., FUEKI, K., and OHYAMA, T. 2005. Detection of improvement in the masticatory function from old to new removable partial dentures using mixing ability test. Journal of oral rehabilitation *32*, 629-634.

AUVRAY, L., DOUSSIN, A., and LE FUR, P. 2003. Santé, soins et protection sociale en 2002, CREDES.

BARDOW, A., NYVAD, B., and NAUNTOFTE, B. 2001. Relationships between medication intake, complaints of dry mouth, salivary flow rate and composition, and the rate of tooth demineralization in situ. Archives of oral biology *46*, 413-423.

BATISSE, C., BONNET, G., ESCHEVINS, C., HENNEQUIN, M., and NICOLAS, E. 2017. The influence of oral health on patients' food perception: a systematic review. Journal of oral rehabilitation *44*, 996-1003.

BAUM, B.J., and BODNER, L. 1983. Aging and oral motor function: evidence for altered performance among older persons. J Dent Res *62*, 2-6.

BÉNARD, C., and DOITSIDOU, M. 2017. Nervous System Ageing. In *Ageing: Lessons from C. elegans*. A. Olsen and M.S. Gill, eds. Springer International Publishing, Cham pp. 163-189.

BISCH, E.M., LOGEMANN, J.A., RADEMAKER, A.W., KAHRILAS, P.J., and LAZARUS, C.L. 1994. Pharyngeal effects of bolus volume, viscosity, and temperature in patients with dysphagia resulting from neurologic impairment and in normal subjects. J Speech Hear Res *37*, 1041-1059.

BRADBURY, J., THOMASON, J.M., JEPSON, N.J.A., WALLS, A.W.G., MULVANEY, C.E., ALLEN, P.F., and MOYNIHAN, P.J. 2008. Perceived chewing ability and intake of fruit and vegetables. Journal of Dental Research *87*, 720-725.

BRENNAN, D.S., SPENCER, A.J., and ROBERTS-THOMSON, K.F. 2008. Tooth loss, chewing ability and quality of life. Qual Life Res *17*, 227-235.

BRODEUR, J.M., LAURIN, D., VALLEE, R., and LACHAPELLE, D. 1993. Nutrient intake and gastrointestinal disorders related to masticatory performance in the edentulous elderly. J Prosthet Dent *70*, 468-473.

BURDACH, K.J., and DOTY, R.L. 1987. The effects of mouth movements, swallowing, and spitting on retronasal odor perception. Physiol Behav *41*, 353-356.

BURNSTOCK, G. 1990. Changes in expression of autonomic nerves in aging and disease. Journal of the Autonomic Nervous System *30*, S25-S34.

CABRE, M., SERRA-PRAT, M., PALOMERA, E., ALMIRALL, J., PALLARES, R., and CLAVE, P. 2010. Prevalence and prognostic implications of dysphagia in elderly patients with pneumonia. Age Ageing *39*, 39-45.

CARLOS, J.P., and WOLFE, M.D. 1989. Methodological and nutritional issues in assessing the oral health of aged subjects. Am. J. Clin. Nutr. *50*, 1210-1218.

CARPENTER. 2012. Role of Saliva in the Oral Processing of Food. Food Oral Processing, Wiley-Blackwell, pp. 45-60.

CHRISTENSEN, C.M. 1986. Role of saliva in human taste perception. In *Clinical Measurement of Taste and Smell*. M.L. Meiselman and R.S. Rivlin, eds. Macmillan, New York, United-States pp. 414-428.

CHU, C.H., NG, A., CHAU, A.M., and LO, E.C. 2015. Oral health status of elderly chinese with dementia in Hong Kong. Oral Health Prev Dent *13*, 51-57.

COLLINS, K.J., EXTON-SMITH, A.N., JAMES, M.H., and OLIVER, D.J. 1980. Functional changes in autonomic nervous responses with agenig. Age and Ageing *9*, 17-24.

COSTALONGA, M., and HERZBERG, M.C. 2014. The oral microbiome and the immunobiology of periodontal disease and caries. Immunology Letters *162*, 22-38.

COUSSON, P.Y., BESSADET, M., NICOLAS, E., VEYRUNE, J.-L., LESOURD, B., and LASSAUZAY, C. 2012. Nutritional status, dietary intake and oral quality of life in elderly complete denture wearers. Gerodontology *29*, e685-e692.

CROW, H.C., and SHIP, J.A. 1996. Tongue strength and endurance in different aged individuals. J Gerontol A Biol Sci Med Sci *51*, M247-250.

DE MARCHI, R.J., HUGO, F.N., PADILHA, D.M., HILGERT, J.B., MACHADO, D.B., DURGANTE, P.C., and ANTUNES, M.T. 2011. Edentulism, use of dentures and consumption of fruit and vegetables in south Brazilian community-dwelling elderly. Journal of oral rehabilitation *38*, 533-540.

DESVARIEUX, M., DEMMER, R.T., RUNDEK, T., BODEN-ALBALA, B., JACOBS, D.R., JR., PAPAPANOU, P.N., and SACCO, R.L. 2003. Relationship between periodontal disease, tooth loss, and carotid artery plaque: the Oral Infections and Vascular Disease Epidemiology Study (INVEST). Stroke *34*, 2120-2125.

DORMENVAL, V., BUDTZ-JORGENSEN, E., MOJON, P., BRUYERE, A., and RAPIN, C.H. 1998. Associations between malnutrition, poor general health and oral dryness in hospitalized elderly patients. Age Ageing *27*, 123-128.

DOTY, R.L. 1991. Olfactory capacities in aging and Alzheimers-disease - psychophysical and anatomic considerations. Ann.NY Acad.Sci. *640*, 20-27.

DOTY, R.L., and BROMLEY, S.M. 2004. Effects of drugs on olfaction and taste. Otolaryngologic clinics of North America *37*, 1229-1254.

DSAMOU, M., PALICKI, O., SEPTIER, C., CHABANET, C., LUCCHI, G., DUCOROY, P., CHAGNON, M.C., and MORZEL, M. 2012. Salivary protein profiles and sensitivity to the bitter taste of caffeine. Chem Senses *37*, 87-95.

DUFFY, V.B., CAIN, W.S., and FERRIS, A.M. 1999. Measurement of Sensitivity to Olfactory Flavor: Application in a Study of Aging and Dentures. Chemical Senses *24*, 671-677.

EDGAR, W.M., and O'MULLANE, D.M. 1996. *Saliva and Oral Health*. British Dental Association.

ENGELEN, L., VAN DEN KEYBUS, P.A., DE WIJK, R.A., VEERMAN, E.C., AMERONGEN, A.V., BOSMAN, F., PRINZ, J.F., and VAN DER BILT, A. 2007. The effect of saliva composition on texture perception of semi-solids. Archives of oral biology *52*, 518-525.

ERICSSON, Y. 1953. Clinical determination of salivary buffering. Swedish Dental Journal *46*, 379-386.

ERNEST, S.L. 1993. Dietary intake, food preferences, stimulated salivary flow rate, and masticatory ability in older adults with complete dentitions. Spec Care Dentist *13*, 102-106.

ERVIN, R.B., and DYE, B.A. 2009. The effect of functional dentition on Healthy Eating Index scores and nutrient intakes in a nationally representative sample of older adults. J Public Health Dent *69*, 207-216.

EVANS, C. 2005. Malnutrition in the Elderly: A Multifactorial Failure to Thrive. The Permanente Journal *9*, 38-41.

FISCHER, U., BOULTON, R.B., and NOBLE, A.C. 1994. Physiological factors contributing to the variability of sensory assessments: Relationship between salivary flow rate and temporal perception of gustatory stimuli. Food Quality and Preference *5*, 55-64.

FOLSTEIN, M.F., FOLSTEIN, S.E., and MCHUGH, P.R. 1975. "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res *12*, 189-198.

FONTIJN-TEKAMP, F.A., SLAGTER, A.P., VAN DER BILT, A., M.A., V.T.H., WITTER, D.J., KALK, W., and JANSEN, J.A. 2000. Biting and chewing in overdentures, full dentures, and natural dentitions. Journal of Dental Research *79*, 1519-1524.

GALO, R., VITTI, M., MATTOS MDA, G., and REGALO, S.C. 2007. Masticatory muscular activation in elderly individuals during chewing. Gerodontology *24*, 244-248.

GARCIA, R.I., PERLMUTER, L.C., and CHAUNCEY, H.H. 1989. Effects of dentition status and personality on masticatory performance and food acceptability. Dysphagia *4*, 121-126.

GEISSLER, C.A., and BATES, J.F. 1984. The nutritional effects of tooth loss. Am. J. Clin. Nutr. *39*, 478-489.

GIERCZYNSKI, I., GUICHARD, E., and LABOURE, H. 2011. Aroma perception in dairy products: the roles of texture, aroma release and consumer physiology. A review. Flavour and Fragrance Journal *26*, 141-152.

GOODPASTER, B.H., PARK, S.W., HARRIS, T.B., KRITCHEVSKY, S.B., NEVITT, M., SCHWARTZ, A.V., SIMONSICK, E.M., TYLAVSKY, F.A., VISSER, M., and NEWMAN, A.B. 2006. The loss of skeletal muscle strength, mass, and quality in older adults: the health, aging and body composition study. J Gerontol A Biol Sci Med Sci *61*, 1059-1064.

GRIEP, M.I., COLLYS, K., METS, T.F., SLOP, D., LASKA, M., and MASSART, D.L. 1996. Sensory detection of food odour in relation to dental status, gender and age. Gerodontology *13*, 56-62.

GUPTA, A., EPSTEIN, J.B., and SROUSSI, H. 2006. Hyposalivation in elderly patients. J Can Dent Assoc *72*, 841-846.

HAMOSH, M., and BURNS, W.A. 1977. Lipolytic activity of human lingual glands (Ebner). Lab Invest *37*, 603-608.

HANDELMAN, S.L., BARIC, J.M., SAUNDERS, R.H., and ESPELAND, M.A. 1989. Hyposalivatory drug use, whole stimulated salivary flow, and mouth dryness in older, long-term care residents. Spec Care Dentist *9*, 12-18.

HE, W., GOODKIND, D., and KOWAL, P. 2016. An Aging World: 2015. U.S. Census Bureau, International Population Reports *U.S. Government Publishing Office, Washington, DC*, P95/16-91.

HENKIN, R.I., and CHRISTIANSEN, R.L. 1967. Taste thresholds in patients with dentures. The Journal of the American Dental Association *75*, 118-120.

HILDEBRANDT, G.H., DOMINGUEZ, B.L., SCHORK, M.A., and LOESCHE, W.J. 1997. Functional units, chewing, swallowing, and food avoidance among the elderly. Journal of Prosthetic Dentistry *77*, 588-595.

HOFFMANN, T., JOHN, M., KERSCHBAUM, T., MICHEELIS, W., POTTHOFF, P., REICH, E., REIS, U., REITER, F., SCHIFFNER, U., and SCHROEDER, E. 2006. Vierte Deutsche Mundgesundheitsstudie (DMS IV). Köln. Mikrozensus: Fragen zur Gesundheit (2009a): Verteilung der Bevölkerung auf Body-Mass-Index-Gruppen in.

HSU, K.J., LEE, H.E., WU, Y.M., LAN, S.J., HUANG, S.T., and YEN, Y.Y. 2014. Masticatory factors as predictors of oral health-related quality of life among elderly people in Kaohsiung City, Taiwan. Qual Life Res *23*, 1395-1405.

HUGHES, F.J., and MCNAB, R. 2008. Oral malodour--a review. Archives of oral biology *53*, 70002-70005.

HUMBERT, I.A., and ROBBINS, J. 2008. Dysphagia in the elderly. Physical medicine and rehabilitation clinics of North America *19*, 853-866, ix-x.

HUNG, H.C., COLDITZ, G., and JOSHIPURA, K.J. 2005. The association between tooth loss and the self-reported intake of selected CVD-related nutrients and foods among US women. Community Dentist. Oral Epidemiol. *33*, 167-173.

IKEBE, K., MATSUDA, K., KAGAWA, R., ENOKI, K., OKADA, T., YOSHIDA, M., and MAEDA, Y. 2012. Masticatory performance in older subjects with varying degrees of tooth loss. J Dent *40*, 71-76.

IKEBE, K., MORII, K., MATSUDA, K., and NOKUBI, T. 2007. Discrepancy between satisfaction with mastication, food acceptability, and masticatory performance in older adults. Int J Prosthodont *20*, 161-167.

IMOSCOPI, A., INELMEN, E.M., SERGI, G., MIOTTO, F., and MANZATO, E. 2012. Taste loss in the elderly: epidemiology, causes and consequences. Aging Clin Exp Res *24*, 570-579.

INOMATA, C., IKEBE, K., KAGAWA, R., OKUBO, H., SASAKI, S., OKADA, T., TAKESHITA, H., TADA, S., MATSUDA, K., KURUSHIMA, Y., KITAMURA, M., MURAKAMI, S., GONDO, Y., KAMIDE, K., MASUI, Y., TAKAHASHI, R., ARAI, Y., and MAEDA, Y. 2014. Significance of occlusal force for dietary fibre and vitamin intakes in independently living 70-year-old Japanese: from SONIC Study. J Dent *42*, 556-564.

ISHIKAWA, Y., WATANABE, I., HAYAKAWA, I., MINAKUCHI, S., and UCHIDA, T. 2007. Evaluations of masticatory performance of complete denture wearers using color-changeable chewing gum and other evaluating methods. J Med Dent Sci *54*, 65-70.

IWASAKI, M., TAYLOR, G.W., MANZ, M.C., YOSHIHARA, A., SATO, M., MURAMATSU, K., WATANABE, R., and MIYAZAKI, H. 2014. Oral health status: relationship to nutrient and food intake among 80-year-old Japanese adults. Community Dentist. Oral Epidemiol. *42*, 441-450.

JOHANSON, C.N., OSTERBERG, T., LERNFELT, B., EKSTROM, J., and BIRKHED, D. 2015. Salivary secretion and drug treatment in four 70-year-old Swedish cohorts during a period of 30 years. Gerodontology *32*, 202-210.

JOSHIPURA, K.J., WILLETT, W.C., and DOUGLASS, C.W. 1996. The impact of edentulousness on food and nutrient intake. The Journal of the American Dental Association *127*, 459-467.

KAGAWA, R., IKEBE, K., ENOKI, K., MURAI, S., OKADA, T., MATSUDA, K., and MAEDA, Y. 2013. Influence of hypertension on pH of saliva in older adults. Oral Dis *19*, 525-529.

KARLSSON, S., and CARLSSON, G.E. 1990. Characteristics of mandibular masticatory movement in young and elderly dentate subjects. J Dent Res *69*, 473-476.

KELLER, H., CHAMBERS, L., NIEZGODA, H., and DUIZER, L. 2012. Issues associated with the use of modified texture foods. The journal of nutrition, health & aging *16*, 195-200.

KIESSWETTER, E., DONINI, L., MIGLIACCIO, S., POGGIOGALLE, E., SULMONT-ROSSÉ, C., FEART, C., SUWALSKA, A., WIECZORKOWSKA-TOBIS, K., PAŁYS, W., ŁOJKO, D.,

SABA, A., SINESIO, F., POLITO, A., MONETA, M., CIARAPICA, D., BRUG, J., and VOLKERT, D. in press. Functional determinants of dietary intake in community-dwelling older adults - a DEDIPAC systematic literature review. Public health nutrition.

KIKUTANI, T., TAMURA, F., NISHIWAKI, K., KODAMA, M., SUDA, M., FUKUI, T., TAKAHASHI, N., YOSHIDA, M., AKAGAWA, Y., and KIMURA, M. 2009. Oral motor function and masticatory performance in the community-dwelling elderly. Odontology *97*, 38-42.

KIM, J.M., STEWART, R., PRINCE, M., KIM, S.W., YANG, S.J., SHIN, I.S., and YOON, J.S. 2007. Dental health, nutritional status and recent-onset dementia in a Korean community population. International journal of geriatric psychiatry *22*, 850-855.

KIMURA, Y., OGAWA, H., YOSHIHARA, A., YAMAGA, T., TAKIGUCHI, T., WADA, T., SAKAMOTO, R., ISHIMOTO, Y., FUKUTOMI, E., CHEN, W., FUJISAWA, M., OKUMIYA, K., OTSUKA, K., MIYAZAKI, H., and MATSUBAYASHI, K. 2013. Evaluation of chewing ability and its relationship with activities of daily living, depression, cognitive status and food intake in the community-dwelling elderly. Geriatrics & gerontology international *13*, 718-725.

KOHYAMA, K., and MIOCHE, L. 2004. Chewing behavior observed at different stages of mastication for six foods, studies by electromyography and jaw kinetics in young and elderly subjects. Journal of Texture Studies *35*, 395-414.

KOHYAMA, K., MIOCHE, L., and BOURDIOL, P. 2003. Influence of age and dental status on chewing behaviour studied by EMG recordings during consumption of various food samples. Gerodontology *20*, 15-23.

LAGERLOF, F., and OLIVEBY, A. 1994. Caries-protective factors in saliva. Adv Dent Res *8*, 229-238.

LAMBERT, C., and MÉNAGE, A.-L. 2013. La presbyphagie : le vieillissement de la déglutition : plainte et vécu des personnes concernées. Sciences cognitives *<dumas-00868599>*.

LANGAN, M.J., and YEARICK, E.S. 1976. The effects of improved oral hygiene on taste perception and nutrition of the elderly. J Gerontol *31*, 413-418.

LEAKE, J.L., HAWKINS, R., and LOCKER, D. 1994. Social and functional impact of reduced posterior dental units in older adults. Journal of oral rehabilitation *21*, 1-10.

LEE, J.S., WEYANT, R.J., CORBY, P., KRITCHEVSKY, S.B., HARRIS, T.B., ROOKS, R., RUBIN, S.M., and NEWMAN, A.B. 2004. Edentulism and nutritional status in a biracial sample of well-functioning, community-dwelling elderly: the health, aging, and body composition study. Am J Clin Nutr *79*, 295-302.

LENANDER-LUMIKARI, M., and LOIMARANTA, V. 2000. Saliva and dental caries. Adv Dent Res *14*, 40-47.

LESOURD, B. 2006. Dysphagia in the elderly. Acta Endoscopica *36*, 623-638.

LEVKOFF, S.E., CLEARY, P.D., and WETLE, T. 1987. Differences in the Appraisal of Health Between Aged and Middle-aged Adults. Journal of gerontology *42*, 114-120.

LORET, C. 2015. Using sensory properties of food to trigger swallowing: a review. Crit Rev Food Sci Nutr *55*, 140-145.

MANLY, R.S., PFAFFMAN, C., LATHROP, D.D., and KEYSER, J. 1952. Oral sensory thresholds of persons with natural and artificial dentitions. J Dent Res *31*, 305-312.

MARCENES, W., STEELE, J.G., SHEIHAM, A., and WALLS, A.W. 2003. The relationship between dental status, food selection, nutrient intake, nutritional status, and body mass index in older people. Cadernos de Saude Publica *19*, 809-816.

MARSHALL, T.A., WARREN, J.J., HAND, J.S., XIE, X.-J., and STUMBO, P.J. 2002. Oral health, nutrient intake and dietary quality in the very old. The Journal of the American Dental Association *133*, 1369-1379.

MCFALL, W.T., JR. 1982. Tooth loss in 100 treated patients with periodontal disease. A long-term study. J Periodontol *53*, 539-549.

MICHEELIS, W., and SCHIFFNER, U. 2006. Fourth German oral health study (DMS IV). Institut der Deutschen Zahnärzte (IDZ, Materialienreihe Band 31).

MIOCHE, L. 2004. Mastication and food texture perception: Variation with age. Journal of Texture Studies *35*, 145-158.

MIOCHE, L., BOURDIOL, P., MONIER, S., and MARTIN, J.F. 2002. The relationship between chewing activity and food bolus properties obtained from different meat textures. Food Quality and Preference *13*, 583-588.

MIOCHE, L., BOURDIOL, P., and PEYRON, M.A. 2004. Influence of age on mastication: effects on eating behaviour. Nutrition Research Reviews *17*, 43-54.

MISHELLANY-DUTOUR, A., RENAUD, J., PEYRON, M.A., RIMEK, F., and WODA, A. 2008. Is the goal of mastication reached in young dentates, aged dentates and aged denture wearers? Br J Nutr *99*, 121-128.

MUÑOZ-GONZÁLEZ, C., VANDENBERGHE-DESCAMPS, M., FERON, G., CANON, F., LABOURÉ, H., and SULMONT-ROSSÉ, C. 2017. Association between salivary hypofunction and food consumption in the elderlies. A systematic literature review. The journal of nutrition, health & aging.

MURPHY, C., SCHUBERT, C.R., CRUICKSHANKS, K.J., KLEIN, B.E., KLEIN, R., and NONDAHL, D.M. 2002. Prevalence of olfactory impairment in older adults. JAMA *288*, 2307-2312.

NALCACI, R., and BARAN, I. 2008. Factors associated with self-reported halitosis (SRH) and perceived taste disturbance (PTD) in elderly. Arch Gerontol Geriatr *46*, 307-316.

ÖSTERBERG, T., and STEEN, B. 1982. Relationship between dental state and dietary intake in 70-year-old males and females in Göteborg, Sweden: a population study*. Journal of oral rehabilitation *9*, 509-521.

ÖSTERBERG, T., TSUGA, K., ROTHENBERG, E., CARLSSON, G.E., and STEEN, B. 2002. Masticatory ability in 80-year-old subjects and its relation to intake of energy, nutrients and food items. Gerodontology *19*, 95-101.

PAILLAUD, E., MERLIER, I., DUPEYRON, C., SCHERMAN, E., POUPON, J., and BORIES, P.N. 2004. Oral candidiasis and nutritional deficiencies in elderly hospitalised patients. Br J Nutr *92*, 861-867.

PEDERSEN, A.M., BARDOW, A., JENSEN, S.B., and NAUNTOFTE, B. 2002. Saliva and gastrointestinal functions of taste, mastication, swallowing and digestion. Oral Dis *8*, 117-129.

PEYRON, M.A., BLANC, O., LUND, J.P., and WODA, A. 2004. Influence of age on adaptability of human mastication. Journal of Neurophysiology *92*, 773-779.

PFEIFER, M.A., WEINBERG, C.R., COOK, D., BEST, J.D., REENAN, A., and HALTER, J.B. 1983. Differential changes of autonomic nervous system function with age in man. The American Journal of Medicine *75*, 249-258.

PRINZ, J.F., and LUCAS, P.W. 1997. An optimization model for mastication and swallowing in mammals. Proc Biol Sci *264*, 1715-1721.

RAWSON, N.E. 2006. Olfactory Loss in Aging. Sci. Aging Knowl. Environ. *2006*, pe6-.

REN, J., SHAKER, R., KUSANO, M., PODVRSAN, B., METWALLY, N., DUA, K.S., and SUI, Z. 1995. Effect of aging on the secondary esophageal peristalsis: presbyesophagus revisited. Am J Physiol *268*, G772-779.

ROBBINS, J., HAMILTON, J.W., LOF, G.L., and KEMPSTER, G.B. 1992. Oropharyngeal swallowing in normal adults of different ages. Gastroenterology *103*, 823-829.

ROFES, L., ARREOLA, V., ALMIRALL, J., CABRE, M., CAMPINS, L., GARCIA-PERIS, P., SPEYER, R., and CLAVE, P. 2011. Diagnosis and management of oropharyngeal Dysphagia and its nutritional and respiratory complications in the elderly. Gastroenterology research and practice *2011*.

SAHYOUN, N.R., LIN, C.L., and KRALL, E. 2003. Nutritional status of the older adult is associated with dentition status. J Am Diet Assoc *103*, 61-66.

SALT, W.B., and SCHENKER, S. 1976. Amylase--its clinical significance: a review of the literature. Medicine *55*, 269-289.

SATO, S., FUEKI, K., SATO, H., SUEDA, S., SHIOZAKI, T., KATO, M., and OHYAMA, T. 2003. Validity and reliability of a newly developed method for evaluating masticatory function using discriminant analysis. Journal of oral rehabilitation *30*, 146-151.

SAVOCA, M.R., ARCURY, T.A., LENG, X., CHEN, H., BELL, R.A., ANDERSON, A.M., KOHRMAN, T., FRAZIER, R.J., GILBERT, G.H., and QUANDT, S.A. 2010. Severe tooth loss in older adults as a key indicator of compromised dietary quality. Public health nutrition *13*, 466-474.

SCHIFFMAN, S.S. 1991. Drugs influencing taste and smell perception. In *Smell and taste in health and disease*. T.V. Getchell, R.L. Doty, L.M. Bartoshuk, and J.B. Snow, eds. Raven Press, New York pp. 845-850.

SCHINDLER, J.S., and KELLY, J.H. 2002. Swallowing Disorders in the Elderly. The Laryngoscope *112*, 589–602.

SERRA-PRAT, M., PALOMERA, M., GOMEZ, C., SAR-SHALOM, D., SAIZ, A., MONTOYA, J.G., NAVAJAS, M., PALOMERA, E., and CLAVE, P. 2012. Oropharyngeal dysphagia as a risk factor for malnutrition and lower respiratory tract infection in independently living older persons: a population-based prospective study. Age Ageing *41*, 376-381.

SHAKER, R., and LANG, I.M. 1994. Effect of aging on the deglutitive oral, pharyngeal, and esophageal motor function. Dysphagia *9*, 221-228.

SHEIHAM, A., and STEELE, J. 2001. Does the condition of the mouth and teeth affect the ability to eat certain foods, nutrient and dietary intake and nutritional status amongst older people? Public health nutrition *4*, 797-803.

SHIP, J.A. 1992. Oral health of patients with Alzheimer's disease. J Am Dent Assoc *123*, 53-58.

SHIP, J.A., DECARLI, C., FRIEDLAND, R.P., and BAUM, B.J. 1990. Diminished submandibular salivary flow in dementia of the Alzheimer type. J Gerontol *45*, M61-66.

SHIP, J.A., and PUCKETT, S.A. 1994. Longitudinal study on oral health in subjects with Alzheimer's disease. J Am Geriatr Soc *42*, 57-63.

SILVA, A.E., DEMARCO, F.F., and FELDENS, C.A. 2015. Oral health-related quality of life and associated factors in Southern Brazilian elderly. Gerodontology *32*, 35-45.

SLADE, G.D., and SPENCER, A.J. 1994. Development and evaluation of the Oral Health Impact Profile. Community Dent Health *11*, 3-11.

SMITH, J.M., and SHEIHAM, A. 1979. How dental conditions handicap the elderly. Community Dent Oral Epidemiol *7*, 305-310.

SOLEMDAL, K., SANDVIK, L., WILLUMSEN, T., MOWE, M., and HUMMEL, T. 2012. The impact of oral health on taste ability in acutely hospitalized elderly. PLoS One *7*, 3.

SRINIVASULU, G., FAREED, N., SUDHIR, K.M., and KRISHNA KUMAR, R.V. 2014. Relationship between stimulated salivary factors, dental caries status and nutritional condition among institutionalized elderly people. Oral Health Dent Manag *13*, 49-53.

STEELE, J.G., AYATOLLAHI, S.M., WALLS, A.W., and MURRAY, J.J. 1997. Clinical factors related to reported satisfaction with oral function amongst dentate older adults in England. Community Dent Oral Epidemiol *25*, 143-149.

STEVENS, D.A., and LAWLESS, H.T. 1981. Age-related changes in flavor perception. Appetite *2*, 127-136.

STEVENS, J.C., and CAIN, W.S. 1993. Changes in taste and flavor in aging. Critical Reviews in Food Science and Nutrition *33*, 27-37.

SURA, L., MADHAVAN, A., CARNABY, G., and CRARY, M.A. 2012. Dysphagia in the elderly: management and nutritional considerations. Clinical interventions in aging *7*, 287-298.

TADA, A., and MIURA, H. 2014. Systematic review of the association of mastication with food and nutrient intake in the independent elderly. Arch Gerontol Geriatr *59*, 497-505.

TAKATA, Y., ANSAI, T., SOH, I., AKIFUSA, S., SONOKI, K., FUJISAWA, K., YOSHIDA, A., KAGIYAMA, S., HAMASAKI, T., NAKAMICHI, I., AWANO, S., TORISU, T., and TAKEHARA, T. 2008. Relationship between chewing ability and high-level functional capacity in an 80-year-old population in Japan. Gerodontology *25*, 147-154.

THOMSON, W.M. 2015. Dry mouth and older people. Aust Dent J *1*, 54-63.

TRACY, J.F., LOGEMANN, J.A., KAHRILAS, P.J., JACOB, P., KOBARA, M., and KRUGLER, C. 1989. Preliminary observations on the effects of age on oropharyngeal deglutition. Dysphagia *4*, 90-94.

TRULSSON, M. 2006. Sensory-motor function of human periodontal mechanoreceptors. Journal of oral rehabilitation *33*, 262-273.

TRULSSON, M., and JOHANSSON, R.S. 1996. Encoding or tooth loads bu human periodontal afferents and their role in jaw motor control. Progress in Neurobiology *49*, 267-284.

TSAI, A.C., and CHANG, T.L. 2011. Association of dental prosthetic condition with food consumption and the risk of malnutrition and follow-up 4-year mortality risk in elderly Taiwanese. J Nutr Health Aging *15*, 265-270.

TSUGA, K., CARLSSON, G.E., OSTERBERG, T., and KARLSSON, S. 1998. Self-assessed masticatory ability in relation to maximal bite force and dental state in 80-year-old subjects. Journal of oral rehabilitation *25*, 117-124.

TUBERT-JEANNIN, S., RIORDAN, P.J., MOREL-PAPERNOT, A., PORCHERAY, S., and SABY-COLLET, S. 2003. Validation of an oral health quality of life index (GOHAI) in France. Community Dent Oral Epidemiol *31*, 275-284.

VANDENBERGHE-DESCAMPS, M., LABOURÉ, H., PROT, A., SEPTIER, C., TOURNIER, C., FERON, G., and SULMONT-ROSSÉ, C. 2016. Salivary Flow Decreases in Healthy Elderly People Independently of Dental Status and Drug Intake. Journal of Texture Studies *47*, 353-360.

VEYRUNE, J.L., and MIOCHE, L. 2000. Complete denture wearers: electromyography of mastication and texture perception whilst eating meat. Eur J Oral Sci *108*, 83-92.

WADE, W.G. 2013. The oral microbiome in health and disease. Pharmacological Research *69*, 137-143.

WAYLER, A.H., and CHAUNCEY, H.H. 1983. Impact of complete dentures and impaired natural dentition on masticatory performance and food choice in healthy aging men. J Prosthet Dent *49*, 427-433.

WODA, A., NICOLAS, E., MISHELLANY-DUTOUR, A., HENNEQUIN, M., MAZILLE, M.N., VEYRUNE, J.L., and PEYRON, M.A. 2010. The masticatory normative indicator. J Dent Res *89*, 281-285.

WOOD, W.W. 1987. A review of masticatory muscle function. The Journal of Prosthetic Dentistry *57*, 222-232.

WRIGHT, L., COTTER, D., HICKSON, M., and FROST, G. 2005. Comparison of energy and protein intakes of older people consuming a texture modified diet with a normal hospital diet. Journal of Human Nutrition and Dietetics *18*, 213-219.

YOSHIHARA, A., WATANABE, R., NISHIMUTA, M., HANADA, N., and MIYAZAKI, H. 2005. The relationship between dietary intake and the number of teeth in elderly Japanese subjects. Gerodontology *22*, 211-218.