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Citation for published version:
Munialo, CD, Kontogiorgos, V, Euston, SR & Nyambayo, I 2020, 'Rheological, tribological and sensory attributes of texture-modified foods for dysphagia patients and the elderly: A review', *International Journal of Food Science and Technology*, vol. 55, no. 5, pp. 1862-1871. https://doi.org/10.1111/ijfs.14483

Digital Object Identifier (DOI):
10.1111/ijfs.14483

Link:
Link to publication record in Heriot-Watt Research Portal

Document Version:
Peer reviewed version

Published In:
International Journal of Food Science and Technology

Publisher Rights Statement:
This is the peer reviewed version of the following article: Munialo, C.D., Kontogiorgos, V., Euston, S.R. and Nyambayo, I. (2020), Rheological, tribological and sensory attributes of texturemodified foods for dysphagia patients and the elderly: A review. Int J Food Sci Technol, which has been published in final form at https://doi.org/10.1111/ijfs.14483

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Download date: 20. Jun. 2021

Rheological, tribological and sensory attributes of texture-modified foods for dysphagia patients and the elderly: A review

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Abstract

Texture-modified foods (TMFs) and thickened fluids have been used as a therapeutic strategy in the management of food intake in the elderly and people with dysphagia. Despite recent advances in describing rheological features of TMFs for dysphagia management, there is still paucity of research regarding the sensory attributes, therapeutic thickness levels, and swallowing safety of these foods. Additionally, the relationship between mechanical and structural properties of TMFs throughout the oral processing are not yet fully understood. The present review discusses several properties of food boluses that are important during oral processing to allow for safe swallowing. Dynamic changes that occur during oral processing of TMFs will be reviewed. The use of hydrocolloids to improve the cohesiveness of TMFs and how this impacts the sensory properties of TMFs will be also discussed. Additionally, this review will suggest potential new research directions to improve textural and sensory properties of TMFs.

Key words: Texture-modified foods, Dysphagia, Oral processing, Rheology, Tribology, Sensory and Flavour perception

Introduction

Muscular disorders or ageing can result in structural or functional deficits of the oral cavity, larynx, pharynx, oesophagus, or oesophageal sphincters resulting in swallowing difficulties (Matsuo and Palmer, 2008). Difficulty with chewing or swallowing food or liquid due to the weakening of the muscles used for swallowing is referred to as dysphagia (Sukkar et al., 2018). Dysphagia impairs the autonomous and safe oral feeding and contributes to a reduced dietary intake (potentially results in malnutrition), aspiration, and asphyxiation (Logemann, 1998). Dysphagia can be divided into three categories namely; oral, oesophageal, and oropharyngeal. Oral dysphagia occurs in the mouth where there is chewing difficulties or problems transporting food around the mouth. Oesophageal dysphagia occurs when food stops in the oesophagus. Oropharyngeal dysphagia involves difficulty moving food to the back of the mouth and starting the swallowing process (Aslam and Vaezi, 2013).

Foods contain multiple phases and hierarchical structures that range from nanoscopic to microscopic length scales (Munialo, 2015). The presence of these structures provides certain functionality such as texture control and nutritional value or aid in processing and shelf-life stability (Stokes et al., 2013). Texture control and modification are a common strategy to manage dysphagia. Modified diets are hypothesised to reduce choking risk, and the need for chewing or oral processing of food (Sukkar et al., 2018). Consumption of thickened fluids is suggested to contribute to safe swallowing as the act of swallowing is slowed down due to the transit time of food products with modified consistency being usually higher than for unmodified foods. This allows more time for the glottis to close and prevent aspirations of food or liquids into the lungs (Steele, 2015).

Food texture may be modulated and modified to suit nutritional requirements of consumers. Texture modification and thickening of fluids forms a routine part of the assessment and treatment of dysphagia (Langmore and Miller, 1994). Texture-modified foods (TMFs) can be characterised based on several variables such as fluid flow rate, density, and viscosity. The use of viscosity to characterise thickened drinks for dysphagia management has however received criticism given that viscosity measurements are not accessible to most clinicians and care givers (IDDSI, 2017). As such, there is need to describe holistic characteristics of TMFs that give an insight as to how food is perceived e.g., in the initial stages of eating. This information should then be made accessible to clinicians and caregivers.

Mechanical and structural properties of foods have been related to texture perception. However, these relationships are still not fully understood, especially in TMFs. Mechanisms of oral processing that may result in dynamic changes in texture perception of TMFs may vary with physiological development of the oral cavity. The tongue has taste buds embedded in the papillae, which play an important role in taste senses and sensory perception of foods through taste receptors. Taste receptors are determined by genes which in turn code for different taste perceptions (Melis and Tomassini Barbarossa, 2017). Sensitivity of taste receptor cells is attributed to the physiology of saliva which is the principal fluid component of the external environment of the taste receptor cells (Matsuo, 2000). Saliva also plays an important role in lubricating the oral cavity, and breakdown of food. Quantity and quality of human saliva depends on medical conditions, gender, or age (Iorgulescu, 2009). Unstimulated saliva flow index of less than 0.1 ml/min in an adult characterises hyposalivation whereas 0.25-0.35 ml/min is considered normal (de Almeida et al., 2008). Elderly people have relatively low daily unstimulated saliva production linked to systemic diseases and prolonged use of medication (Lasisi et al., 2014). Reduction in unstimulated saliva flow index could contribute to the appearance of diseases in the oral mucosa, commonly identified in the elderly population.

Elderly people could have decreased oral processing capabilities which may present several problems with swallowing. Wang and Chen (2017) summarised eating and swallowing problems encountered by the elderly (**Table 1).**

Designing healthy foods for patients with dysphagia and the elderly

When designing healthy foods for the elderly there are important aspects to be considered (**Fig. 1**). TMFs recommended for dysphagia management and dietary intake of the elderly should be soft, moist, elastic, smooth, and easy to swallow (Sungsinchai et al., 2019). The International Dysphagia Diet Standardisation Initiative (IDDSI) framework provides standardised terminology and definitions to describe TMFs and thickened liquids for individuals with dysphagia (IDDSI, 2017). IDDSI framework is made up of a continuum of 8 levels (0-7) as illustrated in **Fig. 2**. An example of TMFs described within the IDDSI framework are pureed foods which are placed on the fourth level of the IDDSI framework. Pureed foods are usually ground and/or blended to a form that requires less chewing and oral manipulation. A cohesive swallowable mass that is referred to as “bolus” is made which is easy to push with the tongue into the pharynx (Hotaling, 1992). This could make swallowing easier and prevent bolus regurgitation which causes aspiration in dysphagics.

Use of thickeners (e.g. modified starch and xanthan gum) to increase bolus viscosity has been suggested in post-stroke oral dysphagia (OD) as a compensatory therapeutic strategy against aspiration. However, this approach has been criticised as the number of studies are small and the methodologies diverse. One study reported an increase in safe swallowing when modified starch and xanthan gum thickeners at “spoon thick” viscosity were administered to patients. The therapeutic effect of these thickeners was attributed to a compensatory mechanism without any massive change on swallow response timing (Vilardell et al., 2015). Another study suggests an increased bolus viscosity gives increased safety of swallowing and reduced mid-term pneumonia episodes in patients with OD (Kuhlemeier et al., 2001). Some authors report that an increase in viscosity impairs swallowing efficiency in OD by increasing oropharyngeal residue. Other researchers argue that the effect of thickeners on the physiology of swallow response is not yet fully understood (Vilardell et al., 2015). This provides a research challenge to further investigate the effect of increased bolus viscosity on the swallowing safety for patients with dysphagia.

Hydrocolloids are widely used in the food industry to improve the consistency and cohesiveness and reduce syneresis of TMFs. Improved consistency and cohesiveness of food makes it safe to swallow (Sharma and Duizer, 2019). Although all hydrocolloids can be used as thickeners, not all are able to form a cross-linked gel network that can be used for giving solidity to modified foods. Thickening of food mixtures using hydrocolloids mostly derives from polymer chains that entangle when their concentration increases. In dilute systems, entanglements are less likely, polymer chains move freely and viscosity is low. As such, after an intake of a thickened food mixture, saliva dilutes and breaks it up, resulting in a considerable decrease in viscosity. Decrease in viscosity becomes an issue especially when starch-based thickeners are used since saliva contains α-amylase that breaks down amylose and amylopectin (Butterworth et al., 2011). To mitigate against this, non-starch gums can be used even though this may not totally eliminate undesirable viscosity reduction. When non-starch biopolymer gums are used as thickeners, there can be non-specific entanglement that, above a certain concentration may result in an increase in stickiness that impairs the swallowing ability. Hydrocolloids in TMFs have been reported to impact the microstructure, particles breakdown, deformation force during mastication, bolus lubrication, and mouth coating (Sharma and Duizer, 2019). Each of these properties have an impact on oral processing and sensory perception of food. Furthermore, thickened liquids have been reported to be perceived as being significantly less palatable than their un-thickened counterparts (Yver et al., 2018). Thus, there is need for the development of new thickening agents that have been well characterised in terms of sensory properties that will be used to improve swallowing while maintaining palatability. This will provide a dysphagia management strategy that will prevent negative effects of increasing viscosity of residue and reduced palatability whilst being treatment compliant.

Rheological properties of TMFs for dysphagics and the elderly

Anatomical and physiological changes in feeding and swallowing occur as a result of dysphagia. For instance, impaired opening of the upper oesophageal sphincter can cause obstruction of the food way increasing risk of aspiration after swallowing (Matsuo and Palmer, 2008). To minimise the risk of aspiration for patients with OD, thickening agents to modify the viscosity of liquids is a commonly used strategy (Newman et al., 2016). Modifying viscosity of liquids does impact the flow properties which can be quantifiable. A 10 mL slip tip syringe is currently a recommended tool to quantify the liquid's flow category that measures a sample remaining from 10 mL after 10 sec of flow (IDDSI, 2017). This method has however some limitations as: (i) the flow of a liquid through a syringe is a broad representation of how a liquid will move during swallowing. Physiological process of swallowing a liquid *in vivo* involves a wide range of fluid deformations and rates, which differ from those *in vitro*, (ii) some syringes that are 10 mL have been reported to have a 12 mL capacity (IDDSI, 2017). A 10 mL syringe with a 12 mL capacity will give results that cannot reliably be used with the IDDSI framework, (iii) IDDSI test classifies consistency on the basis of the volume of the residual liquid in the syringe after a period of 10 s flow rather than measuring the required time for a sample to flow through the syringe. Thus, there is a need for IDDSI flow test to assess the flow rate as this will be more clinically relevant instead of classifying consistency based on residual liquid volume.

In terms of food texture, IDDSI suggests testing methods that use forks and spoons (IDDSI, 2017). As much as forks and spoons are inexpensive, easily accessible, and available, these tools are not reliable in providing detailed information on masticatory behaviour, bolus structure and perceived texture, mechanical and rheological properties throughout oral processing of foods. For these properties to be fully understood, advanced instruments such as texture analysers and rheometers need to be used. Measurements performed on these instruments can provide some insights that would be useful in the design of TMFs as opposed to instrumental swallowing assessment which are reported to bear little resemblance to eating in real life and swallowing ability at mealtimes (O'Keeffe, 2018).

To provide additional guidelines that can be used in designing modified foods for dysphagia management, further research to evaluate the properties of modified diets is needed. Examples of further studies may include variation, modulation, and modification of the consistency of TMFs and examining the impact of these modulations dysphagia management. Consistency in this context is defined as an attribute that relates to firmness or thickness of TMFs which can have an impact on the viscosity of the food products, and a subsequent impact on swallowing parameters. A texture-modified diet contains foods whose consistency may be more easily chewed and managed by people with dysphagia. Thickened fluids that have a honey-like, or pudding-like consistency and nutritionally enriched TMFs, such as, pureed and minced foods may be specially prepared for dysphagia management. Use of modified diets to manage dysphagia is mainly supported by the increasing dietary intake by elderly people with chronic dysphagia when diets with thickened and pureed food that have unspecified consistency have been administered (Taylor & Barr, 2006). Patients with OD are reported to be more likely to obtain a better dietary intake with TMFs rather than with normal foods (Sukkar et al., 2018). Conversely, a lack of evidence to support the significance of thickened fluids and TMFs in relation to the amount of dietary intake for adults with acute dysphagia has been reported (Foley et al., 2006, O'Keeffe, 2018). Kaneoka et al. reported the lack of evidence for thickened fluids and TMFs in prevention of aspiration pneumonia in patients with chronic dysphagia (Kaneoka et al., 2017). In a separate study, Andersen et al. found a lack of a strong evidence to support the use of thickened fluids and TMFs and suggested that more studies are needed to substantiate the use of modified diets for dysphagia management (Andersen, Beck, Kjaersgaard, Hansen, & Poulsen, 2013). Commercial thickened liquids with specific viscosities such as those with honey-like, or custard-like consistencies vary greatly with regards to viscoelastic properties. Variability in the consistency of thickened fluids prepared by staff within and between hospitals has also been reported (Cichero et al., 2000). This emphasises the importance of including other rheological characterisation that measures mechanical properties such as hardness, and cohesiveness in designing foods for dysphagics.

TMFs and thickened liquids were previously categorised based on quantified viscosity ranges (Association, 2002). In recent years, the flow of liquids is not solely quantified based on viscosity ranges. In fact IDDSI does not include viscosity in its descriptors given that the flow of a drink is influenced by many other variables including density, yield stress, and temperature (IDDSI, 2017). Viscosity and elasticity range are however still considered to be the two parameters used to classify foods and drinks that are formulated for people with swallowing disorders (Coster and Schwarz, 1987). These two parameters play an important role in the food sample, as a starting material, and the way they change within the entire oral manipulation cycle until a bolus is formed. Both viscosity and elasticity should be within a specific range and in specific relation to each other when food is ready to be swallowed. Thus, it is imperative to understand rheological and physical bolus properties that can affect swallowing performance. Relevant rheological properties that should be taken into consideration are yield stress, extensional viscosity, and shear viscosity. Shear viscosity is defined as the ability of liquids to resist flow under an applied force and is “calculated as the ratio of shear stress (the shear force required for flow) and shear rate (related to the flow rate)” (Newman et al., 2016).

Patients with dysphagia are susceptible low-viscosity fluids given that a bolus of too-high viscosity does demand exertion of extra force by the tongue and pharyngeal muscles to push the bolus through the oropharynx (Qazi et al., 2019). There is generally a lack of clear convention regarding the shear rates at which viscosities are measured despite the shear rate being used to describe the deformation rate of non-Newtonian stimuli as the fluid layers slide over each other once the bolus is placed under stress or force. Viscosity of 'thin' liquid stimuli is reported to be as high as 351 mPa s at a shear rate of 25s^{-1}. Viscosity of mildly thick or nectar-thick liquid is reported to be as high as 466 mPa s at 25s^{-1} or 325 mPa s at 45s^{-1}, while opaque liquids have viscosities of up to 863 mPa s at 25s^{-1}. Stimuli labelled as moderately thick is reported to have viscosities reaching 1541 mPa s at 25 s^{-1} for radio-opaque liquids or 785 mPa s at 45 s^{-1}for non-opaque stimuli (Steele, 2015). Even though it is suggested that a single oral shear rate could not be used to predict perceived viscosity (Ong et al., 2018), shear rate of 50 s^{-1} is reported to be a reasonable order of magnitude with respect to in-mouth handling of food boluses (Popa Nita et al., 2013). A shear rate of 50 s^{-1} corresponds to a range from low honey-thick to pudding-thick consistencies on the IDDSI scale.

When food is ingested, mastication usually starts with the "first bite" of solids or semi-solid food. Food is reduced to particulate form during chewing and saliva secreted from the oral cavity which helps with lubrication (Sungsinchai et al., 2019). Although increasing number of chewing cycles decreases hardness of food, hard semisolid food that has a reduced likelihood of disintegrating may present an aspiration risk for dysphagic patients (Nakagawa et al., 2014). Continual secretion of saliva into the oral cavity may alter the bolus rheology with time (Sungsinchai et al., 2019). During the swallowing process, the bolus is held on the tongue dorsal surface and is subsequently propelled into the oesophagus through the pharynx. Following the swallowing process, higher food bolus adhesiveness can increase the risk of pharyngeal residue due to its stickiness nature (Sungsinchai et al., 2019). Excessively lower food bolus cohesiveness is shown to raise the risk of aspiration (Nakagawa et al., 2014).

When developing foods for dysphagia management, it is important to consider the elastic modulus of the bolus. Cheng and colleagues studied the elastic modulus of a healthy human tongue and soft palate using magnetic resonance elastography under *in vivo* conditions. They showed the elastic modulus to be nearly 2.5 kPa (Cheng et al., 2011). In dysphagia, it is better for the bolus to be transported posteriorly with less pressure and this relates to hardness, adhesiveness and cohesiveness of the boluses. Dysphagia diets have been characterised based on these criteria into three classes (I, II, and III) and four levels as summarised in **Table 2** (Sungsinchai et al., 2019, Yoshioka et al., 2016). Easy to swallow foods have ben defined to have a texture that: (i) should be under 15000N/m^2 in hardness, (ii) under 1000J/m^2 adhesiveness, and (iii) cohesiveness in the range of 0.2 - 0.9 (Wada et al., 2017).

Wendin et al postulate that elasticity should be used to classify foods that are modified for dysphagia (Wendin et al., 2010). Equally, elasticity is important as a contributor to mechanical cohesiveness in non-Newtonian fluids (Funami et al., 2012). The significance of viscoelastic behaviour of boluses on swallowing and of thixotropic, shear thinning, and viscoelastic characteristics of commercial dysphagia foods for cluster classification has been corroborated (Casanovas et al., 2011). As such, optimisation of viscoelastic parameters is critical when designing foods for people with dysphagia so that bolus flow is cohesive (Funami et al., 2012). This provides a challenge to design foods that have optimum characteristics of TMFs for delivery of nutritional requirements for patient with dysphagia. This could be important for standardisation of food terminology, and facilitating product development for dysphagia management and meeting nutritional requirements of the elderly.

Tribological and Sensory attributes of TMFs for dysphagia management

Oral processing of food is a complex and dynamic pathway that involves mechano and chemo-receptors, mixing with saliva, temperature, and friction (Martínez et al., 2019). Oral processing of foods involves tribological processes that include friction, lubrication, and wear between surfaces that interact in relative motion. Soft and oral tribology refers to interactions between food and tissue in the mouth during food consumption which provides an underpinning knowledge on behaviour of foods under conditions relevant to swallowing and dysphagia (Stokes et al., 2013). Tribological properties of TMFs are however still not well understood or characterised, and more research is needed to try to connect these properties to actual oral sensations.

Oral lubrication is important in food texture perception towards the later stages of food oral processing (van Aken, 2010), and involves processes and mechanisms that result in the manipulation and dissipation of frictional forces that arise from the contact of two surfaces within the oral environment (Sarkar et al., 2019). The degree of lubrication is shown to influence bolus properties and contribute to "ease of swallowing" (de Lavergne et al., 2017). The ease of swallowing is a commonly used attribute in sensory profiling of food textures even though, the mechanisms by which this attribute maps to objective, quantifiable measures of bolus flow or physiology remains unclear. In the case of dysphagia, an understanding of oral lubrication in soft sliding interfaces informs strategies to overcome swallowing difficulties. As such, quantification of the friction coefficients between polymeric analogues of the tongue rolling/sliding against palate surfaces in model oral cavities are used; (i) to approximate the mechanical characteristics of these interactions in the mouth, and (ii) to establish correlations between oral perception and texture of food products characterised instrumentally (Sarkar and Krop, 2019). When the intricate features of biological surfaces in the oral cavity are examined, it is found that oral lubrication can occur between several surface types - hard-soft (hard palate-tongue), soft-soft (tongue-soft palate) and involve lubrication by food particles, saliva and other mucosal lubricants. The human tongue is however not smooth, and embedded with filiform papillae giving variable surface roughness in different areas (**Fig. 3**).

The critical link between taste perception and food ingestion is highlighted in patients with taste disorders. Taste sensitivity can be partially lost (hypogeusia) or entirely lost (ageusia) due to aging, disease states, and medical therapies. Taste is also lost in patients with dysphagia. Loss of taste sensitivity is associated with reduced food intake and reduced quality of life. A potential strategy to increase food intake and improving health status in the elderly is taste and flavour enhancement (Mathey et al., 2001).

The principal sensory systems involved in oral perception of food are:- (i) trigeminal, (ii) olfactory and (iii) gustatory systems (Running, 2016). Food texture is perceived initially outside the oral cavity by vision and hearing senses, and then inside the mouth during oral food processing which is mediated by sensations that include touch/pressure and joint position. When food is transformed to a bolus, a cognitive representation of food texture is formed, resulting in the release of flavours from the food (Doets and Kremer, 2016). A number of TMFs ranked based on a 3 point hedonic scale showed the flavour and appearance to play an important role in the liking of the food samples. Based on flavour, frozen, cold, and sweet foods (which were richest in fat and energy) were the most liked in-between-meals among old adults with dysphagia (Okkels et al., 2018). The preference of sweet foods is consistent with results that revealed an increase in age negatively affects perceived intensity for salt, sour and bitter tastes, although sweet tastes were not influenced (Barragán et al., 2018). There was no correlation between flavour liking and protein content of the in-between-meals which could have been attributed to the flavour of the in-between-meals with high protein content (Okkels et al., 2018). This provides a challenge to improve the flavour of in-between-meals with high protein content as a way of encouraging the likability of these meals. The need for further work in flavour improvement is supported by the higher preference for yoghurt and Quorn where flavour had been amplified (Griep et al., 2000). These findings provide insights on the interplay between flavour and acceptability of different macronutrients to be considered when formulating TMFs with specific consistency. Formulation of TMFs that are rich in various macronutrients may be used as a strategy to mitigate against malnutrition, a complication of dysphagia in older persons.

TMFs should be designed to give pleasurable meal experiences. During the design and development of new products it is vital to consider the impact of varying ingredients and processing conditions on the sensory or taste appeal. It is widely observed that pureed diets lack sensory or taste appeal and can lead to food refusal and reduced intake. Many elderly people suffer from a loss of taste and smell in addition to trigeminal stimuli, which has a negative impact on their enjoyment of meals and dietary habits. This provides a challenge to design TMFs that have attractive sensory properties. Vision and auditory perception are reported to be the dominant features in human perception of food (Gnaedinger et al., 2019). The appearance of a meal in terms of the colour, taste and smell, all perceived by the orbitofrontal cortex involved in processing pleasant stimuli, and how it is served is shown to play an important role in the evaluation of foods among the elderly and dysphagics (Ettinger et al., 2014). As such, oral sensation holds the potential for making sensory modified foods for dysphagia management.

Conclusion

The design of TMFs with specific consistencies for dysphagia management is a complex process that requires careful caveating and nuance. IDDSI framework has provided relevant specifications that are required for the standardisation of TMFs and thickened liquids with an aim of reducing penetration and aspiration. Development of an effective method for measuring flow behaviour that is assessed *in vivo* would be a valuable addition to the current method of describing the consistency of thickened fluid based on the volume of the residual liquid.

Literature findings suggests that there are several properties of food boluses that are important for safe swallowing. These include: hardness, adhesiveness, cohesiveness and viscosity. Apparent viscosities of different stimuli used in dysphagia management at varying shear rates have been reported. However, there is an absence of convention in terms of the shear rates used for reporting apparent viscosity. A 50 s^{-1} shear rate is reported to be a reasonable in-mouth handling of food boluses. However, TMFs may have similar apparent viscosity measured at 50 s^{-1} but have very different flow characteristics. Thus, more studies are needed to provide evidence to delineate convention shear rates that are used for reporting apparent viscosity.

The role that oral processing plays in the effective functioning of eating, and swallowing is documented. Mechanisms of oral processing are reported to vary with physiological development of the oral cavity processes. However, the mechanisms by which ease of swallowing maps to objective quantifiable measures of bolus flow or physiology needs further investigation. Additionally, there is a need to further characterise TMFs and thickened liquids in terms of rheological and tribological and to connect these properties to actual oral sensations.

Even though manipulation of texture remains to be a common strategy in dysphagia management, pureed diets are reported to lack sensory or taste appeal which can result in food refusal and reduced intake TMFs. To formulate TMFs that give pleasurable meal experiences, varying ingredients and processing conditions can be used improve taste, aroma and visual aspects of these foods. As such, sensory modified foods may be formulated and used to improve swallowing in dysphagics while maintaining palatability. A multidisciplinary collaboration involving food scientist, clinicians, and sensory scientists emerges as an important direction for future research in this respect.

Data Availability Statement

Research data are not shared

Ethical Guidelines

Ethics approval was not required for this research

Conflict of interest

None

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Table 1: Some common eating difficulties experienced by elderly people, possible causes and suggested solutions (Wang & Chen, 2017).

Difficulty	Likely causes	Suggested intervention
Chewing	Loss of functional teeth Reduction in biting force Decreased strength of tongue & jaw muscles	Reducing food particle sizes Use of TMFs
Dry mouth	Loss of ability to secrete saliva Reduction in saliva flow index Respiration via open mouth	Application of artificial saliva Use of liquidised/moisturised food Physical and bio-chemical saliva stimulation
Oral manipulation	Reduced lip sealing pressure Reduced strength of tongue muscle Reduced tactile (touching) sensitivity	Reducing food particle sizes Use of TMFs
Tasting	Drying of the mouth Reduced ability to secrete saliva Saliva composition changes	Application of artificial saliva Addition of flavouring compounds in food
Swallowing	Displacement of the tongue Reduced activity of facial and oral muscles	Use of TMFs
Aspiration or Suffocation risk	Reduced movement of the laryngeal	Increase in oral transit duration of food Intake of thickened rather than thin liquids
Choking risk	Intake of insufficiently processed food Reduced strength of laryngeal muscles	Use of TMFs
Appetite loss	Drying of the mouth or food becoming tasteless	Oral and aromatic multi-stimulations Addition of flavouring compounds in food

Table 2: Categories and hardness and viscosity levels for TMFs described by (Sungsinchai et al., 2019)

Category	Hardness and viscosity level	Description
I	$< 5 \times 10^4$ N/m^2 hardness level, viscosity not specified	Foods that are easy to chew but unsuitable for persons with impaired dental functions such as weakened muscles
II	$< 5 \times 10^4$ N/m^2, viscosity not specified	Foods that can break up by gums and thus are suitable for patients who lack natural teeth
III	$< 2 \times 10^4$ N/m^2 hardness level and viscosity >1500 mPa·s	Foods that can be broken up by tongue
IV	$< 5 \times 10^3$ N/m^2 and viscosity > 1500 mPa.s	Foods that do not require chewing

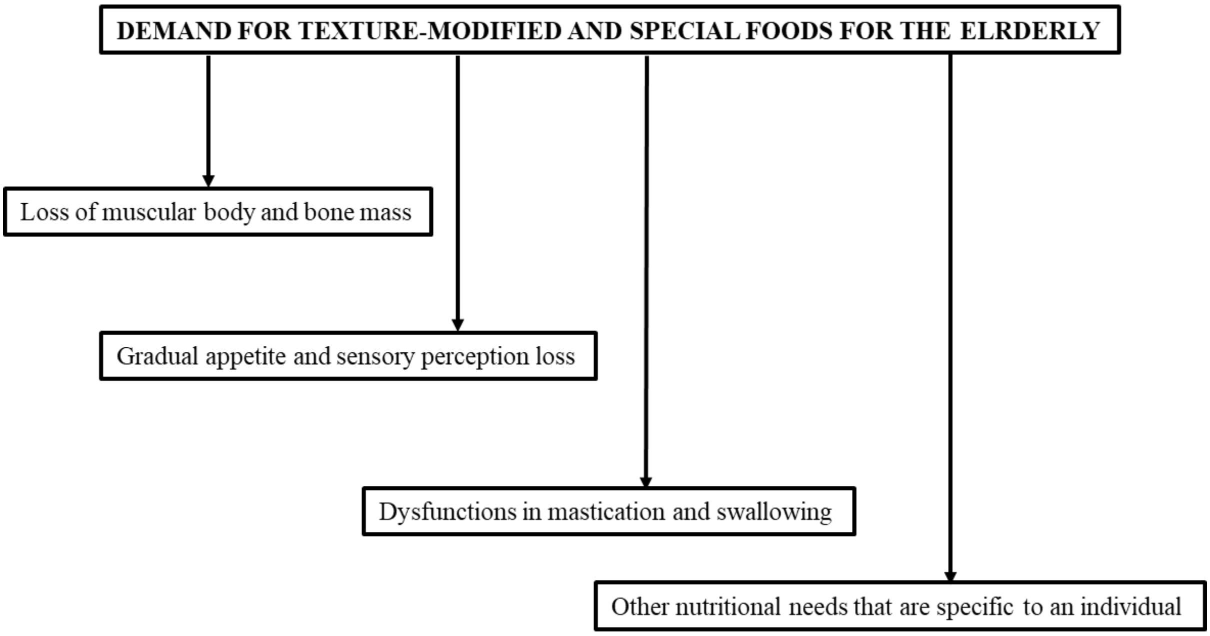

Figure 1: Important aspects to be considered when designing healthy foods for the elderly**.**

Figure 2: IDDSI terminology for TMFs and thickened liquids for people with dysphagia (© IDDSI 2016 @http://iddsi.org/framework/). The IDDSI Framework and Descriptors are licensed under the CreativeCommons Attribution Sharealike 4.0 Licence https://creativecommons.org/licenses/by-sa/4.0/legalcode. *Attribution is NOT PERMITTED for derivative works incorporating any alterations to the IDDSI Framework that extend beyond language translation.* *Supplementary Notice: Modification of the diagrams or descriptors within the IDDSI Framework is DISCOURAGED and NOT RECOMMENDED. Alterations to elements of the IDDSI framework may lead to confusion and errors in diet texture or drink selection for patients with dysphagia. Such errors have previously been associated with adverse events including choking and death.*

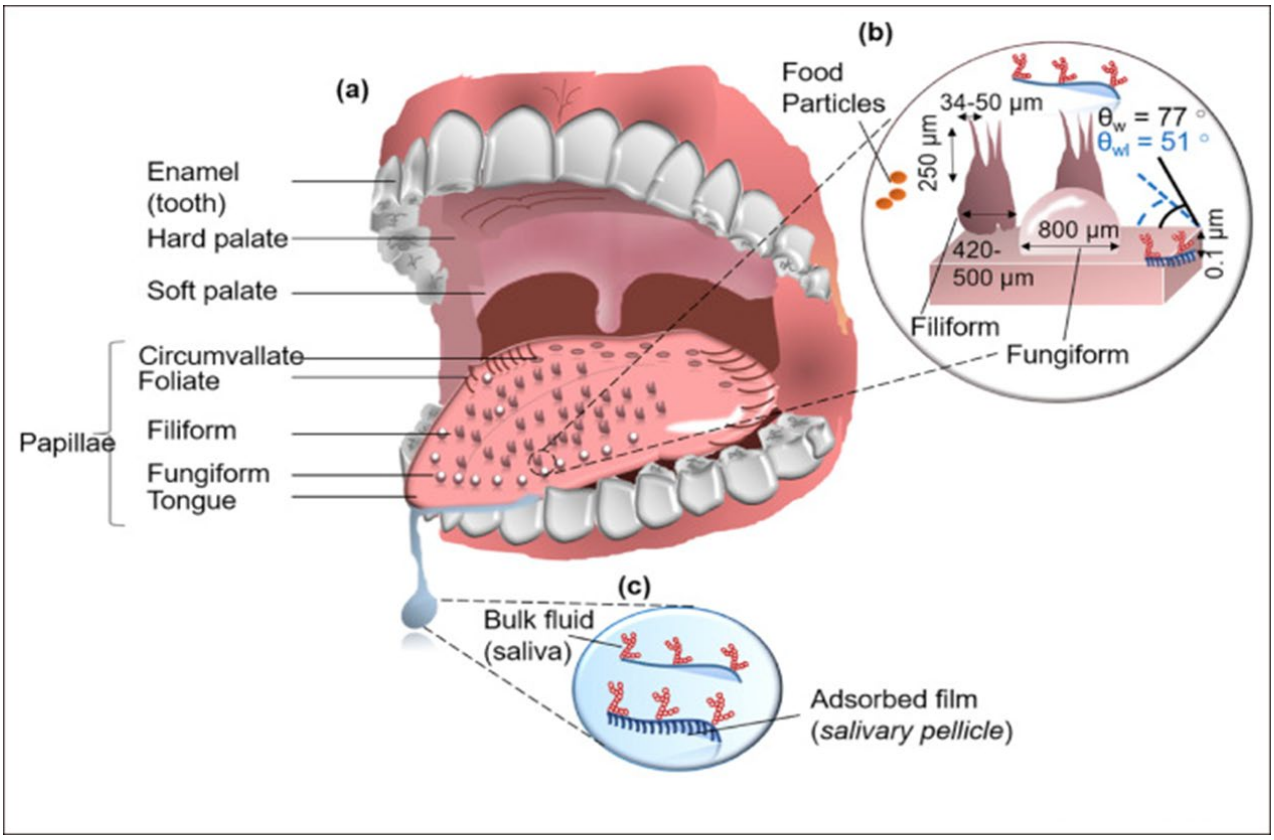

Figure 3: Building blocks of soft oral surfaces. (a) A schematic illustration of oral cavity (b) Building blocks of soft tongue surface at micron scale (Kullaa-Mikkonen & Sorvari, 1985) and its change in wettability. (c) Bulk saliva and adsorbed salivary pellicle (Sarkar et al., 2019). The use of this figure is allowed under CreativeCommons licence: https://creativecommons.org/licenses/by/4.0/.