CHAPTER EIGHT

Nutritional Aspects of Dysphagia Management

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Abstract

This chapter describes the nutritional aspects of dysphagia management by starting with the definition of these two conditions (dysphagia and malnutrition) that share three main clinical characteristics: (a) their prevalence is very high, (b) they can lead to severe complications, and (c) they are frequently underrecognized and neglected conditions. From an anatomical standpoint, dysphagia can result from oropharyngeal and/or esophageal causes; from a pathophysiological perspective, dysphagia can be caused by organic or structural diseases (either benign or malignant) or diseases causing impaired physiology (mainly motility and/or perception disorders). This chapter gathers up-to-date information on the screening and diagnosis of oropharyngeal dysphagia, the consequences of dysphagia (aspiration pneumonia, malnutrition, and dehydration), and on the nutritional management of dysphagic patients. Concerning this last topic, this chapter reviews the rheological aspects of swallowing and dysphagia (including shear and elongational flows) and its influence on the characteristics of the enteral

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nutrition for dysphagia management (solid/semisolid foods and thickened liquids; ready-to-use oral nutritional supplements and thickening powders), with special focus on the real characteristics of the bolus after mixing with human saliva.

1. INTRODUCTION

This chapter describes the nutritional aspects of dysphagia management by starting with the definition of these two conditions (dysphagia and malnutrition) that share three main clinical characteristics: (a) their prevalence is very high, (b) they can lead to severe complications, (c) they are frequently underrecognized and most patients do not receive an appropriate treatment, and frequently they are neglected conditions.

The word "dysphagia" derives from the Greek terms *dys* meaning "disordered" or "ill," and *phago* meaning "eat" or "swallow." Swallowing is defined as "the function of clearing food and drink through the oral cavity, pharynx, and esophagus into the stomach at an appropriate rate and speed defined by the International Classification of Functioning, Disability and Health (ICF, code b5105) promoted by the World Health Organization (WHO). Dysphagia is classified under "digestive symptoms and signs" in the International Classification of Diseases (ICD-10, code R13), also promoted by WHO. However, the term is often used, not fully appropriately, to mean a disorder or disease. In addition, patients affected can be unaware of their swallow dysfunction.

From an anatomical standpoint, dysphagia can result from oropharyngeal and/or esophageal causes; from a pathophysiological perspective, dysphagia can be caused by organic or structural diseases (either benign or malignant) or diseases causing impaired physiology (mainly motility and/or perception disorders). Oropharyngeal, head, neck, and esophageal structural causes (such as tumors, webs, pouches, and rings) of dysphagia are reviewed elsewhere (Feldman, Friedman, & Brandt, 2010; Shaker, Belafsky, Postma, & Easterling, 2013). This chapter focuses on advances in understanding dysphagia caused by diseases that impair oropharyngeal physiology.

Oropharyngeal dysphagia (OD) is a symptom of a swallow dysfunction that provokes difficulty or inability to form or move the alimentary bolus safely from the mouth to the esophagus. It can include oropharyngeal aspiration (the entry of secretions, food, or drink from the oropharynx into the trachea or the lungs) and choking (the subsequent mechanical obstruction of pulmonary air flow) (Clavé, Terre, de Kraa, & Serra, 2004). OD should be differentiated from globus pharyngis, a specific somatoform disorder consisting of the continuous feeling of having a "lump in the throat," phlegm, or some sort of obstruction when there is none. Despite the severity of OD complications, the standard of care for the majority of these patients is very poor as most are not diagnosed or treated (Barczi, Sullivan, & Robbins, 2000; Clavé & Shaker, 2015).

Prevalence of OD is extremely high. The phenotype of patients in which OD develops varies significantly and includes three main groups: elderly people, patients with neurological and neurodegenerative diseases (NDGD), and patients with head and neck diseases. In a recent consensus document developed between the European Society for Swallowing Disorders (ESSD) and the European Union Geriatric Medicine Society (EUGMS), OD matches the definition of a geriatric syndrome as it is a highly prevalent clinical condition in old age, as well as being multifactorial, associated with multiple comorbidities and bad prognosis and is only treatable when a multidimensional approach is used (Baijens et al., 2016). These societies concluded that OD should be given more importance and attention and thus be included in all standard screening protocols. In addition, it should be treated and regularly monitored to prevent its main complications. More research is needed to develop and standardize new treatments and management protocols for older patients with OD, this being a challenging mission for those societies. OD is highly prevalent among older people (Robbins, Bridges, & Taylor, 2006), which affects approximately between 15% and 40% of them (Barczi et al., 2000). Data related to prevalence of OD in NDGD varies greatly. For instance, in Parkinson's disease, prevalence of OD ranges between 52% and 82% (Kalf, de Swart, Bloem, & Munneke, 2012); in Alzheimer's, between 57% and 84% (Horner, Alberts, Dawson, & Cook, 1994; Langmore, Olney, Lomen-Hoerth, & Miller, 2007), and in motor neuron disease, depending on the stage of the disease, between 30% and 100% (Haverkamp, Appel, & Appel, 1995). Prevalence of OD following stroke varies between 37% and 78%, depending on the diagnostic method used (Daniels et al., 1998; Martino et al., 2005), whereas the incidence of OD in traumatic brain injury is approximately 25% (Mackay, Morgan, & Bernstein, 1999). Between 44% and 50% of head and neck cancer patients are reported to present OD, either as a symptom of their disorder or following chemotherapy (Clavé & Shaker, 2015; García-Peris et al., 2007; Lazarus, 2009). Table 1 summarizes the prevalence

Table 1 Prevalence of Oropharyngeal Dysphagia in Several Target Populations and Phenotypes of Patients

Phenotype	Target Population	Evaluation Method	Prevalence (%)
Elderly			
	Independently living older people	Screening (questionnaires)	11.4–33.7
		Clinical exploration (V-VST)	23
	Hospitalized in an acute geriatric unit	Not specified/clinical exploration (water swallow test or V-VST)	29.4–47.0
	Hospitalized with community-acquired pneumonia	Clinical exploration (water swallow test or V-VST)	55.0–91.7
	Hospitalized with community-acquired pneumonia	Instrumental exploration	75
	Institutionalized	Screening (questionnaires)	40
		Clinical exploration (water swallow test)	38
		Screening and clinical exploration	51
	Stroke: acute phase	Screening (questionnaires)	37–45
		Clinical exploration	51–55
		Instrumental exploration	64–78
	Stroke: chronic phase	Clinical exploration	25–45
		Instrumental exploration	40–81
Neurodegenerative disease			
	Parkinson disease	Reported by patients	35
		Instrumental exploration	82
	Alzheimer disease	Instrumental exploration	57–84
	Dementia	Reported by caregivers	19–30
		Instrumental exploration	57–84
	Multiple sclerosis	Screening (questionnaires)	24
		Instrumental exploration	34.3

Table 1 Prevalence of Oropharyngeal Dysphagia in Several Target Populations and Phenotypes of Patients—cont'd

Phenotype	Target Population	Evaluation Method	Prevalence (%)
Amyotrophic lateral sclerosis		Clinical and instrumental exploration	47–86
Structural			
Head and neck cancer		Clinical exploration	50.6
		Instrumental exploration	38.5
Zenker diverticulum		Instrumental exploration	86
Osteophytes		Screening	17–28

Abbreviation: *V-VST*, volume–viscosity swallowing test.

Adapted from Newman, R., Vilardell, N., Clavé, P., & Speyer, R. (2016). Effect of bolus viscosity on the safety and efficacy of swallowing and the kinematics of the swallow response in patients with oropharyngeal dysphagia: White paper by the European Society for Swallowing Disorders (ESDD). *Dysphagia*, *31*, 232–249; Clavé, P., & Shaker, R. (2015). Dysphagia: Current reality and scope of the problem. *Nature Reviews Gastroenterology & Hepatology*, *12*, 259–270.

of OD in different phenotypes of patients or diseases according to the evaluation method used for OD.

The pathophysiology of swallowing dysfunction in neurological patients and elderly people is characterized by a slow swallow response with delayed closure of the laryngeal vestibule and opening of the upper esophageal sphincter (UES) and aspiration may also result from insufficient hyoid and laryngeal elevation, which would fail to protect the airway (Carrión et al., 2015; Serra-Prat et al., 2012). In frail elderly patients, OD is associated to delayed and prolonged swallow response, weak tongue thrust, and weak and delayed impaired hyoid motion (Clavé et al., 2006). Aspirations and penetrations into the airways during the pharyngeal phase are specifically related to delayed laryngeal vestibule closure. Impaired efficacy is mainly characterized by oropharyngeal residue caused by weak tongue bolus propulsion forces and slow vertical hyoid motion (Kahrilas, Lin, Rademaker, & Logemann, 1997). Moreover, a decreased sensitivity of the pharyngeal and supraglottic areas, associated to a decrease of myelinated nerve fibers of the superior laryngeal nerve, has been described in older patients and strongly contributes to the pathophysiology of their swallow dysfunction (Aviv, 1997; Aviv et al., 1994; Rofes, Arreola, Romea, et al., 2010). In patients with poststroke OD, it was found that several impairments in pharyngeal sensitivity and cortical activation are associated to stroke severity. Specifically, these sensory deficits have been related to an impaired safety of swallow and aspirations in both elderly people and poststroke patients (Rofes, Ortega, Vilardell, Mundet, & Clavé, 2016). OD associated with head and neck malignancy is caused by the combination of disrupted normal anatomy secondary to mass effect, nerve involvement, soft tissue tethering, or tumor-induced pain and the sequelae of treatments.

Other head and neck conditions associated with dysphagia are trauma to the throat or larynx or posttracheal intubation, use of tracheostomy tubes, and cervical spine surgery. Congenital malformations (cleft lip, cleft palate), Zenker's diverticulum, and cricopharyngeal muscle dysfunction can also cause OD. Cervical osteophytes, primarily with large lesions below the level of C3 and cervical hyperostosis (Forestier–Rotes syndrome) can produce dysphagia due to both obstruction of the cervical esophagus from the mass of the osteophyte or to inflammation around osteophyte formation (Sifrim, Vilardell, & Clavé, 2014).

On the other hand, there is no universally accepted definition of malnutrition, as evidenced by the many attempts to do so. One of the most widely accepted is the one proposed by Elia, Stratton, Russell, Green, and Pang (2006): malnutrition is the state of nutrition in which a deficiency of energy, protein, and other nutrients causes measurable adverse effects on the composition and function of tissues/organs and clinical outcome. It is also possible to consider malnutrition as a pathological condition resulting from a relative or absolute absence of one or more essential nutrients. One of the major challenges for clinicians is to assess malnutrition in a sick patient and evaluate its specific effects on patient outcomes. Indeed, the clinical manifestations of the disease may confuse the detection of malnutrition and vice versa, being recognized the interaction between them. Therefore, it is a challenge to show that malnutrition independently worsens the prognosis of a disease, which is merely improved by nutritional therapy. Malnutrition (MN) is also a geriatric syndrome related to increased healthcare costs and impaired health outcomes as it increases hospital stay and risk of infections, impairs recovery, and increases mortality (Bonnefoy et al., 2015). MN is also underestimated and underdiagnosed among elderly hospitalized patients despite being classified in the International Classification of Diseases. A resolution of the Council of Europe claimed that undernutrition among hospital patients was highly prevalent and identified OD as a major contributor to MN. The overall prevalence of MN among older persons admitted to general hospitals for acute diseases is estimated to be 38.7% (Carrión et al., 2015).

A recent study from the Hospital of Mataró (Barcelona, Spain) found OD is a prevalent risk factor for malnutrition in a cohort of older patients admitted with an acute disease to a general hospital. In this study, it was shown that prevalence of dysphagia was higher than malnutrition in the older patients, OD was an independent risk factor for malnutrition, and both conditions were related to poor outcome.

Despite its enormous impact on functional capacity, health, and quality of life (Jensen et al., 2010), OD is underestimated and underdiagnosed as a cause of major nutritional and respiratory complications in many patients admitted to hospitals, and the level of healthcare resources dedicated to dysphagic patients is very low. The relationship between OD and pneumonia is well recognized and gives rise to the term "aspiration pneumonia" for those patients with abnormal swallowing function and pneumonia. In contrast, the association between OD and MN is less recognized, probably because the nutritional complication develops slowly and insidiously.

The aim of this chapter is to describe the methods and strategies for diagnosis of OD, the nutritional (malnutrition, dehydration) and respiratory (aspiration pneumonia) complications of this condition, and the nutritional management basis of dysphagic patients.

2. SCREENING AND DIAGNOSIS OF OD

The goal of the diagnostic strategy for dysphagia is to evaluate two deglutition-defining characteristics: (a) *efficacy*, the patient's ability to ingest all the calories and water he/she needs to remain adequately nourished and hydrated and (b) *safety*, the patient's ability to ingest all needed calories and water with no respiratory complications (Clavé et al., 2006). To assess both characteristics of deglutition, two groups of diagnostic methods are available: (a) clinical methods such as deglutition-specific medical history and clinical examination, usually used as screening methods and (b) the exploration of deglutition using specific complementary studies such as fiberoptic endoscopic evaluation of swallowing (FEES) or videofluoroscopy (VFS). Clinical screening for OD should be low risk, quick, and low cost and aim at selecting the highest risk patients who require further clinical or instrumental assessment, and can include:

(a) *Deglutition-specific questionnaires*: The Eating Assessment Tool (EAT-10) is a self-administered, symptom-specific outcome instrument for dysphagia. The EAT-10 has displayed excellent internal consistency, test–retest reproducibility, and criterion-based validity. The normative data from the original study suggest that an EAT-10 score of 3 or higher is abnormal. The instrument may be utilized to document the initial dysphagia severity in persons with swallowing disorders (Belafsky et al., 2008). There is also a validated specific symptom inventory to assess the severity of OD in patients with neuromyogenic dysphagia. The inventory consisted in 17 questions each answered on a 100-mm visual analog scale. Applied to patients with neuromyogenic dysphagia, the 17-question inventory shows strong test–retest reliability over 2 weeks. Also, content, construct validity, and score are highly correlated with an independent global assessment severity score (Wallace, Middleton, & Cook, 2000).

(b) *Clinical assessment*: Current methods for clinical screening of dysphagia are, for example, the water swallow test (Gordon, Hewer, & Wade, 1987), the 3-oz water test developed in the Burke Rehabilitation Center (DePippo, Holas, & Reding, 1992), the timed swallow test (Nathadwarawala, Nicklin, & Wiles, 1992), and the standardized bedside swallow assessment (SBSA) (Smithard et al., 1998; Westergren, 2006). Patients are asked to drink different amounts of water from a glass without interruption. Coughing during or after completion or the presence of a postswallow wet-hoarse voice quality, or swallow speed of less than 10 mL/s are scored as abnormal and the test is reported as "failed." These clinical bedside methods can detect dysphagia, although with differing diagnostic accuracy. The Burke's 3-oz water swallow test identified 80% of patients aspirating during subsequent VFS examination (sensitivity 76%, specificity 59%) (DePippo et al., 1992). The SBSA showed a variable sensitivity (47–68%) and specificity (67–86%) in detecting aspiration when used by speech swallow therapists or doctors (Smithard et al., 1998; Westergren, 2006). Note that these screening procedures involve continuous swallowing of quite large amounts of liquid and may place the patient at high risk for aspiration. Furthermore, many of these studies on bedside screening lack methodological quality and, therefore, the psychometric properties of the screening procedure being studied cannot be determined accurately (Bours, Speyer, Lemmens, Limburg, & de Wit, 2009). Clavé et al. (2008) developed a safer clinical method (the volume–viscosity swallow test, V-VST) using a series of 5–20 mL nectar, liquid, and pudding boluses sequentially administered in a progression of increasing difficulty. Cough, fall in oxygen saturation $\geq$3%, and changes in quality of voice were considered clinical signs of impaired safety, whereas piecemeal deglutition and oropharyngeal residue were considered signs of impaired efficacy. The V-VST is a safe, quick, and accurate clinical method with 88.2% sensitivity for impaired safety, 100% sensitivity for aspiration, and up to 88.4% sensitivity for impaired efficacy of swallows. Fig. 1 shows the algorithm for management (screening, diagnosis, and treatment) of OD at the Hospital de Mataró (Barcelona, Spain).

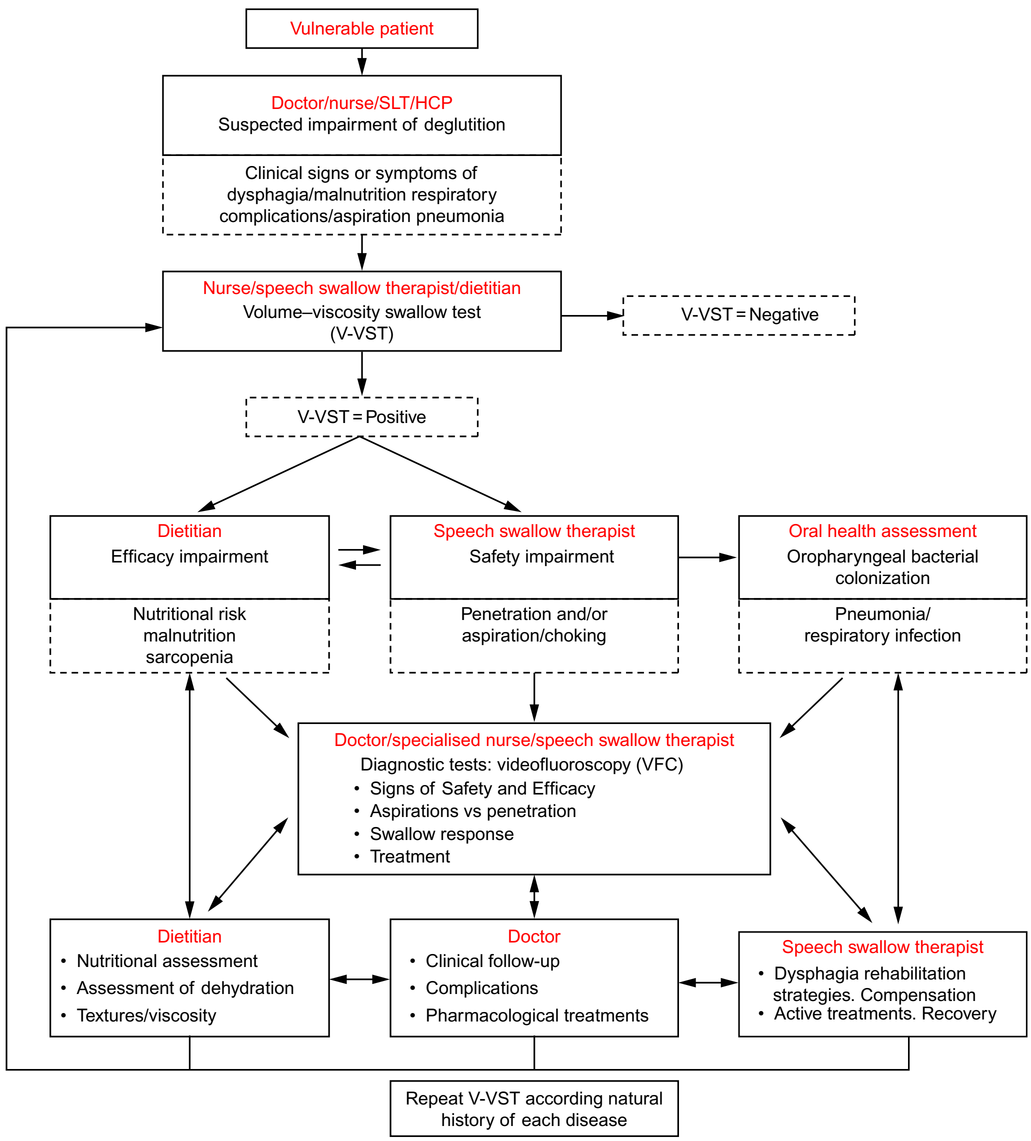

Fig. 1 Proposed algorithm for diagnosis and treatment of oropharyngeal functional dysphagia using the V-VST for screening and VFS studies for patient assessment. Note the involvement of several professional domains of the dysphagia multidisciplinary team and the flows of information.

The V-VST is considered to be a highly adequate instrument for screening of dysphagia and agrees with the recommendations stated in the systematic review on bedside screening for dysphagia by Bours et al. (2009), which combine a water test and pulse oxymetry and use coughing, choking, and voice alteration as endpoints. The use of different viscosities in the V-VST can be considered to be an improvement compared to a simple water test using only liquid. In a recent study, some of the authors determined the accuracy of the EAT-10 and the V-VST for clinical evaluation of OD by using a new xanthan gum thickener and using VFS as gold standard. According to VFS, prevalence of OD was 87%, 75.6% with impaired efficacy and 80.9% with impaired safety of swallow including 17.6% aspirations. The EAT-10 showed a diagnostic accuracy of 0.89 for OD with an optimal cut-off at 2 (0.89 sensitivity and 0.82 specificity). The V-VST showed 0.94 sensitivity and 0.88 specificity for OD, 0.79 sensitivity and 0.75 specificity for impaired efficacy, 0.87 sensitivity and 0.81 specificity for impaired safety, and 0.91 sensitivity and 0.28 specificity for aspirations. It was concluded that clinical methods for screening (EAT-10) and assessment (V-VST) of OD offer excellent psychometric properties that allow adequate management of OD. Their universal application among at-risk populations will improve the identification of patients with OD at risk for malnutrition and aspiration pneumonia. A recent systematic review further confirms these data and provides an update of currently available bedside screenings to identify OD in neurological patients (Rofes, Arreola, Mukherjee, & Clavé, 2014).

(c) *Instrumental explorations*: Following initial screening and clinical assessment, further assessment by means of instrumental techniques are performed to obtain a more accurate and objective diagnosis. The instrumental techniques considered to be the *gold standard* in the examination of the swallowing mechanism are VFS and FEES. VFS is the gold standard to study the oral and pharyngeal mechanisms of dysphagia (Cook & Kahrilas, 1999). VFS is a dynamic exploration that evaluates the safety and efficacy of deglutition, characterizes the alterations of deglutition in terms of videofluoroscopic symptoms, and helps to select and assess specific therapeutic strategies. Technical requirements for clinical VFS are an X-ray tube with fluoroscopy and a videotape recorder; additionally, there are computer-assisted methods of analysis of images allowing quantitative temporal and spatial measurements. Main observations during VFS are done in the lateral plane while swallowing 5–20 mL boluses of at least three consistencies: liquid, nectar, and pudding. The patient is kept at a minimal risk for aspiration by starting the study with low volumes and thick consistencies, and continuing with liquids and high volumes as tolerated (Clavé et al., 2006). Major signs of impaired efficacy during the oral stage include apraxia and decreased control and bolus propulsion by the tongue. Many older patients present deglutitional apraxia (difficulty, delay, or inability to initiate the oral stage) following a stroke. This symptom is also seen in patients with Alzheimer's, dementia, and patients with diminished oral sensitivity. Impaired lingual control (inability to form the bolus) or propulsion results in oral or vallecular residue when alterations occur at the base of the tongue.

The main sign regarding safety during the oral stage is glossopalatal (tongue-soft palate) seal insufficiency, a serious dysfunction that results in the bolus falling into the hypopharynx before triggering the oropharyngeal swallow response and while the airway is still open, which causes predeglutitive aspiration (Logemann, 1993). Videofluoroscopic signs of safety during the pharyngeal stage include penetrations and/or aspirations. Penetration refers to the entering of contrast into the laryngeal vestibule within the boundaries of the vocal cords. When aspiration occurs, contrast goes beyond the cords into the tracheobronchial tree (Fig. 2B).

The potential of VFS regarding image digitalization and quantitative analysis currently allows accurate swallow response measurements in patients with dysphagia (Fig. 2). A slow closure of the laryngeal vestibule and a slow aperture of the UES (as seen in Fig. 2B) are the most characteristic aspiration-related parameters (Clavé et al., 2006; Kahrilas et al., 1997). Penetration and aspiration may also result from an insufficient or delayed hyoid and laryngeal elevation, which fail to protect the airway. A high, permanent postswallow residue may lead to postswallow aspiration, since the hypopharynx is full of contrast when the patient inhales after swallowing, and then contrast passes directly into the airway. Thereafter, VFS can determine whether aspiration is associated with impaired glossopalatal seal (predeglutitive aspiration), a delay in triggering the pharyngeal swallow or impaired deglutitive airway protection (laryngeal elevation, epiglottic descent, and closure of

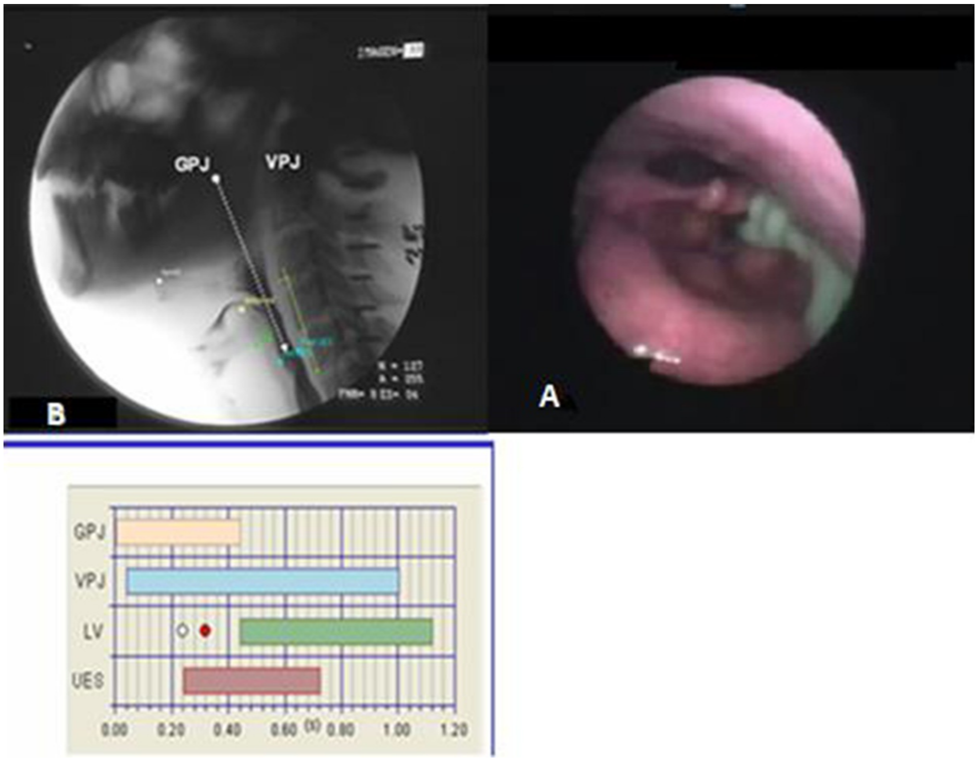

Fig. 2 Instrumental explorations used for OD. The main signs of impaired safety (aspiration) of swallow can be observed by FEES (A, *right*) or VFS (B, *left*).

vocal folds during swallow response), or an ineffective pharyngeal clearance (postswallowing aspiration).

FEES involves a nasoendoscopic evaluation by means of a fiberoptic rhinolaryngoscope passed through the nares to the pharynx to obtain images of the base of the tongue, pharynx, and larynx. Colored boluses are administered to visualize the events before and after swallowing. Variables studied during FEES are related to efficacy (pharyngeal residue) and safety (penetration and aspiration) of swallow (Diniz, Vanin, Xavier, & Parente, 2009; Leder, Judson, Sliwinski, & Madson, 2013). Both VFS (Choi, Ryu, Kim, Kang, & Yoo, 2011) and FEES (Langmore, 2006) enable comparisons between subjects with and without OD and allow the effects of therapeutic strategies to be assessed, including the use of thickening agents (Clavé et al., 2006). The recommendation of the ESSD is to develop an agreement on the metrics (VFS/FEES signs and measurements of swallow response) that describe the normal/impaired swallow response.

3. CONSEQUENCES OF DYSPHAGIA

OD causes two groups of severe complications depending on the etiology of the problem. If the patient presents impaired efficacy of swallow, he/she will suffer from malnutrition and dehydration; however, if the patient presents impaired safety of swallow and aspirations, he/she will develop respiratory infections and aspiration pneumonia (AP) with increased morbidity and mortality. It has been also found that OD is a very prevalent and relevant risk factor associated with hospital readmission for both aspiration and nonaspiration pneumonia in elderly persons (Cabré et al., 2014).

3.1 Aspiration Pneumonia

The pathophysiology of aspiration pneumonia (AP) can be explained as the combination of risk factors that alter swallowing function, cause aspiration, and predispose the oropharynx to bacterial colonization (Fig. 3) (Almirall, Cabré, & Clavé, 2007; Marik & Kaplan, 2003). They include medication, altered conscience, NDGD, stroke, esophageal diseases, aging, malnutrition, antibiotics, dry mouth, impaired immune system, dehydration, and smoking (Almirall, Cabre, & Clavé, 2012).

They can be classified into three types of risk: (1) OD with impaired safety of swallow (aspirations); (2) frailty and impaired health status (malnutrition, sarcopenia, impaired immunity, comorbidities, low functionality); and (3) poor oral health and hygiene with bacterial colonization by respiratory pathogens (Ortega et al., 2013; Tada & Miura, 2012). Prevention of complications of OD and AP should be directed at all the three risk groups. The incidence and the prevalence of aspiration pneumonia (AP) in the community are poorly defined. They increase in direct relation with age and underlying diseases.

The risk of AP is higher in older patients because of the high incidence of dysphagia (Cabré, 2009). In elderly nursing home residents with OD, AP occurs in 43–50% during the first year, with a mortality of up to 45% (Almirall et al., 2007). Cabré et al. (2009) studied 134 older patients (>70 years) consecutively admitted with pneumonia in an acute geriatric unit in a general hospital. Of the 134 patients, 53% were over 84 years old and 55% presented clinical signs of OD; the mean Barthel score was 61 points, indicating a frail population. Patients with dysphagia were older,

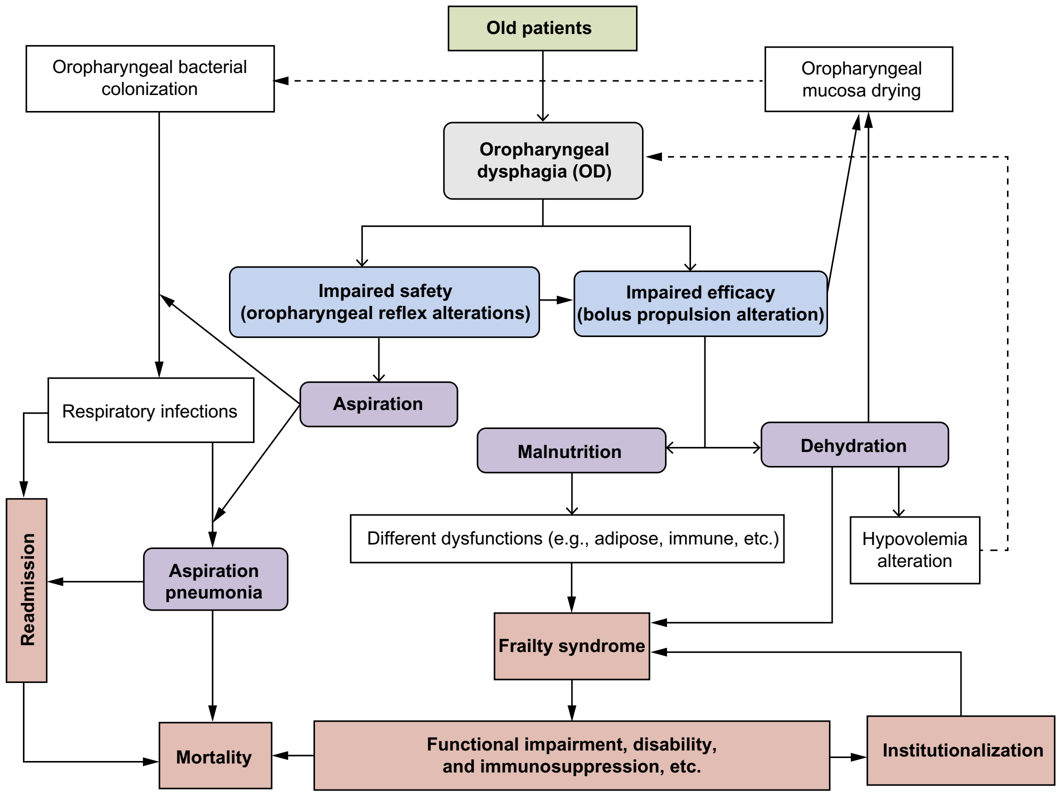

Fig. 3 Pathophysiology of nutritional and respiratory complications of OD in elderly people. *Adapted from Ortega, O., Cabré, M., & Clavé, P. (2014). Oropharyngeal dysphagia: Aetiology & effects of ageing*. Journal of Gastroenterology and Hepatology Research, 3, *1049–1054.*

showed lower functional status, higher prevalence of malnutrition and comorbidities, and higher Fine's pneumonia severity scores. Patients with dysphagia had higher mortality at 30 days (22.9% vs 8.3%, $p = 0.033$) and at 1 year of follow-up (55.4% vs 26.7%, $p = 0.001$). Therefore, OD is a highly prevalent clinical finding and an indicator of disease severity in older patients with pneumonia.

The pathogenesis of aspiration pneumonia has been revised (Almirall et al., 2007; Marik & Kaplan, 2003). Aspiration observed at VFS is associated with a 5.6- to 7-fold increase in risk of pneumonia (Schmidt, Holas, Halvorson, & Reding, 1994). Up to 45% of older patients with dysphagia presented penetration into the laryngeal vestibule and 30% aspiration, half of them without cough (silent aspiration); and 45%, oropharyngeal residue (Clavé et al., 2005). It is accepted that detection of aspiration by VFS is a predictor of pneumonia risk and/or probability of rehospitalization

(Cook & Kahrilas, 1999). It is also well known that not all patients who aspirated during VFS develop pneumonia. Impairment in host defenses such as abnormal cough reflex (Marik & Kaplan, 2003), impaired pharyngeal clearance (Palmer et al., 2001), amount and bacterial concentration of aspirate, and weakened immune system also strongly contributed to the development of AP (Almirall et al., 2007). Impairment of cough reflex increases the risk of AP in stroke patients (Addington, Stephens, & Gilliland, 1999). Several risk factors contribute to oropharyngeal colonization such as: (1) older age, (2) malnutrition, (3) smoking status, (4) poor oral hygiene, (5) antibiotics, (6) dry mouth, (7) immunity, and (8) feeding tubes. Increased incidence of oropharyngeal colonization with respiratory pathogens is also caused by impairment in salivary clearance (Palmer et al., 2001). The microbial etiology of AP involves *Staphylococcus aureus*, *Haemophilus influenzae*, and *Streptococcus pneumoniae* for community-acquired AP and Gram-negative aerobic bacilli in nosocomial pneumonia. It is worth bearing in mind the relative unimportance of anaerobic bacteria in AP (Almirall et al., 2007). Surprisingly, in the clinical setting, OD and aspiration are usually not considered etiologic factors in older patients with pneumonia (Almirall et al., 2007; Marik & Kaplan, 2003).

Ortega et al. (2014) have recently found two groups of results further linking poor oral health, oral colonization of respiratory pathogens, frailty, and aspiration with the pathophysiology of aspiration pneumonia (Fig. 4). In one study, they assessed oral health in patients with OD and found older patients with OD presented polymorbidity and impaired health status, high prevalence of VFS signs of impaired safety of swallow, and poor oral health

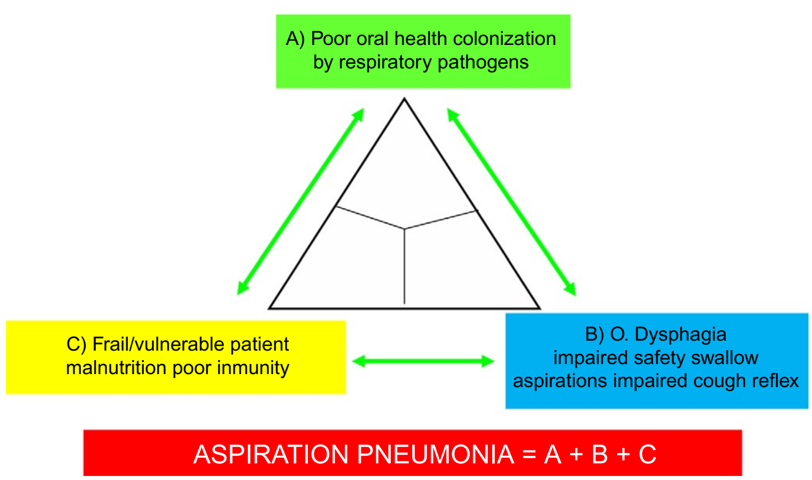

Fig. 4 Pathophysiology of aspiration pneumonia.

status with high prevalence of periodontal diseases and caries. These patients are at great risk of developing AP. Ortega et al. (2015) also explored the oral and nasal microbiota and the colonization of oral cavity by respiratory pathogens in frail older patients with OD and found: (a) oral health was poor in all groups, 90% presented periodontitis and 72% caries; (b) total bacterial load was similar in all groups, but higher in the oropharynx (>10^8 CFU/mL) than in the nose (<10^6 CFU/mL) ($p < 0.0001$); and (c) colonization by respiratory pathogens was very high: 93% in OD patients ($p < 0.05$), and lower in controls (67%). They concluded frail older patients with OD had impaired health status, poor oral health, high oral bacterial load, and prevalence of oral colonization by respiratory pathogens and VFS signs of impaired safety of swallow, and were, therefore, at risk for contracting AP. A policy of systematic oral health assessment in elderly patients with OD is recommended.

3.2 Malnutrition and Dehydration

There is a strong relationship between prevalence and severity of dysphagia and incidence of malnutrition (MN) (Clavé et al., 2006). Up to 50% of nursing home residents and up to 70% of geriatric patients in hospital show signs of malnutrition. However, the true prevalence of malnutrition among patients with OD, the pathophysiology of malnutrition associated to OD, the relevance of OD as a cause of malnutrition, and the type of malnutrition associated with diseases also causing OD is not fully settled. The ESSD position statements establish that OD is a risk factor for MN and a nutritional examination should be performed regularly using validated nutritional screening tools. In addition, the ESPEN guidelines on nutrition in older people recognized OD as a major cause of impaired nutritional intake among this population. Despite all these recommendations, both conditions continue to be underestimated and underdiagnosed and can be considered neglected conditions among older people and neurological patients.

Three types of malnutrition have been described: starvation-related malnutrition, chronic disease-related malnutrition, and acute disease or injury-related malnutrition (Jensen et al., 2010). Starvation-related malnutrition develops in situations of chronic energy and protein deficiency while maintaining a ratio between the amount of energy and protein. It is characterized by absence of inflammation, and loss of the body's muscle mass and subcutaneous fat, eventually leading to emaciation. Chronic disease-related malnutrition is characterized by the presence of chronic inflammation of mild to moderate degree, and by a variable degree of reduced food intake because of disease-associated anorexia. Acute disease or injury-related malnutrition is characterized by acute and severe inflammation, which impairs the ability to use nutrients introduced by the diet or infused by artificial nutrition. Critically ill patients frequently develop this type of malnutrition. Chronic disease-related malnutrition is the most common form of malnutrition in hospital. The existence of disease-associated malnutrition is very common and the prevalence may range between 20% and 50% of patients, depending on the variability of the diagnostic criteria used (Norman, Richard, Lochs, & Pirlich, 2008). The etiology and prevalence of malnutrition in different diseases and settings are extensively discussed in the recently published ESPEN guidelines on enteral nutrition (Volkert et al., 2006).

The European Working Group on Sarcopenia in Older People (EWGSOP) has recently developed a practical clinical definition and consensus diagnostic criteria for age-related sarcopenia (Cruz-Jentoft et al., 2010). They define sarcopenia as a syndrome characterized by progressive and generalized loss of skeletal muscle mass and strength with a risk of adverse outcomes such as physical disability, poor quality of life, and death (Delmonico et al., 2007; Goodpaster et al., 2006). Depending on the literature definition used for sarcopenia, the prevalence in 60–70 years old is reported as 5–13%, while the prevalence ranges from 11% to 50% in people >80 years (Morley, 2008). Even with a conservative estimate of prevalence, sarcopenia affects >50 million people today and will affect >200 million in the next 40 years. The impact of sarcopenia on older people is far reaching; its substantial tolls are measured in terms of morbidity (Sayer et al., 2005), disability (Janssen, Heymsfield, & Ross, 2002), high costs of health care (Janssen, Shepard, Katzmarzyk, & Roubenoff, 2004), and mortality (Gale, Martyn, Cooper, & Sayer, 2007). The EWGSOP recommends using the presence of both low muscle mass and low muscle function (strength or performance) for the diagnosis of sarcopenia. The rationale for use of two criteria is muscle strength does not depend solely on muscle mass, and the relationship between strength and mass is not linear (Goodpaster et al., 2006). The tongue plays a key role in bolus propulsion. Different authors have found elderly patients with dysphagia showed impaired tongue propulsion (Rofes, Arreola, Romea, et al., 2010), and decreased tongue volume due to sarcopenia (Robbins et al., 2005). Older adults present lingual weakness, a finding that has been related to sarcopenia of the head and neck musculature and frailty (Robbins et al., 2005), and one of the major causes for dysphagia in the elderly, associated with impairment in efficacy and safety of swallow (Rofes, Arreola, Almirall, et al., 2010).

Clavé et al. (2006) have studied the prevalence, risk factors, and characteristics of malnutrition among different phenotypes of patients with OD. First, they studied the prevalence of malnutrition among patients with chronic dysphagia caused by nonprogressive brain disorders (NPBD, e.g., stroke, brain injury) or by NDGD patients (e.g., ALS, multiple sclerosis). Prevalence and type of malnutrition were studied using the SGA (Subjective Global Assessment), anthropometric measures, and biochemical markers. They found that prevalence and type of malnutrition were similar between NPDB and NDGD patients with neurogenic dysphagia. Malnutrition was found in 16–24% NPBD patients and 22–23.5% NDGD patients. Their study also found a strong correlation between clinical severity of dysphagia and malnutrition and the type of malnutrition in both groups of patients with neurogenic dysphagia was uniformly of the chronic type with a strong reduction in skeletal muscle and fat mass; in contrast, measurements of visceral protein (albumin and lymphocytes) were found to be within the normal range in most patients with neurogenic dysphagia and malnutrition.

More recently, Carrión et al. (2015) also explored the relationship between OD, nutritional status, and clinical outcome in a cohort of 1662 patients $\geq$70 years consecutively hospitalized with acute diseases to an acute geriatric unit. They found that 47.4% patients presented OD and 30.6% malnutrition. Both conditions were significantly associated with polymorbidity, multiple geriatric syndromes, and poor functional capacity. However, patients with dysphagia presented increased prevalence of malnutrition regardless of their functional status and comorbidities and lower albumin and cholesterol levels. Otherwise, patients with malnutrition presented an increased prevalence of dysphagia (68.4%). Patients with dysphagia and patients with malnutrition presented increased intrahospital, 6-month and 1-year mortality rates, and the poorest outcome was for patients with both conditions (1-year mortality was 65.8%). So, prevalence of dysphagia was higher than malnutrition in the elderly patients and dysphagia was found an independent risk factor for malnutrition, and both conditions were related to poor outcome. Therefore, they recommended systematic and integrated management of OD and MN among hospitalized elderly patients. They also explored the nutritional status in older patients with OD in a chronic and an acute clinical situation. Prevalence of impaired nutritional status (malnutrition risk, and sarcopenia) among older patients with OD associated with either chronic or acute conditions was very high. They also found, in patients with OD and chronic diseases, poor nutritional status that further impairs OD with an increase in oropharyngeal residue at spoon-thick viscosity. In the acute setting, there is inflammation and an additional protein deficiency. These findings will help develop specific products both for OD and nutritional status in each specific clinical situation.

Finally, OD has been shown to cause dehydration in older people, although the real prevalence of dehydration in patients with OD is unknown because of the different methods used and the lack of a gold standard for its assessment (Armstrong, 2007). Studies suggested that bioimpedance was a good technique to study hydration status in older adults in the community (Goldberg et al., 2014). Patients with OD and in a chronic situation showed a general decrease in intracellular water compartment. Intracellular dehydration is a consequence of a loss of body fluids with a lower osmolality in relation to plasma secondary to low intake caused by OD or fluid restriction. Low intake increases the osmotic pressure of the extracellular space and the necessity for osmotic equilibrium between the two spaces causes transmembrane flow of water from the intracellular space to the extracellular space (Cheuvront & Kenefick, 2014). Considering the bioimpedance results, and taking as a reference that intracellular water is $0.4\ \mathrm{L\ kg^{-1}}$ of body mass, it has been found that most patients have reduced intracellular water, suggesting some degree of dehydration. Despite these results and taking into account some of the limitations of the bioimpedance, it is clear that more studies are needed to clarify the real hydration status of elderly patients with OD.

4. NUTRITIONAL MANAGEMENT OF DYSPHAGIC PATIENTS

4.1 Rheological Aspects of Swallowing and Dysphagia

Deglutition is the act or process of swallowing. It is a complex operation that involves a highly coordinated activity of many muscles and nerves of the oral cavity, oropharynx, and esophagus. The whole process is partially under voluntary control (e.g., oral or mastication phase) and partially reflexive in nature (e.g., oropharyngeal and esophageal phases). By definition, deglutition involves the passage of a food bolus (solid or liquid) from the oral cavity to the stomach via the pharynx and then to the esophagus. During the oral phase, the food is prepared for swallowing. In this first phase, mastication is involved with the main target to grind or to comminute food with the teeth, thus reducing its size, in preparation for deglutition and then digestion, and food is put in contact with saliva that brings a lubrication effect to the mechanical forces applied by the jaws, teeth, and tongue. In addition, an enzymatic reaction due to the presence of α-amylase in the saliva may modify the flow properties (i.e., viscosity) of starch-rich meals (Pedersen, Bardow, Beier-Jensen, & Nauntofte, 2002). Once mastication is voluntarily finished, bolus is propelled by the tongue from the oral cavity to the oropharynx.

The oropharyngeal phase is critical to ensure a safe swallowing. It is during this phase that the alimentary and ventilator streams cross each other. In healthy individuals, a dynamic separation of these streams is possible due to the high coordination of muscles and nerves involved in this complex process. It is an extremely fast flow process that takes around a second for the bolus to traverse the pharynx and reach the cricopharyngeal area, also known as UES. At this stage, the breathing stops for a split second before the soft palate is closed, preventing the passage of the bolus to the nasopharynx; glottis closes epiglottis and vocal cords. The esophageal phase begins when the bolus passes through the UES. The lower esophageal sphincter (LES) muscle acts as a valve that opens to allow the passage of the bolus to the stomach.

In summary, a safe swallowing has two essential physiological aspects: (1) passage of food from the oral cavity to the stomach and (2) airway protection to prevent contamination of the trachea. Swallowing and respiration (expiration) have tight temporal coordination in healthy individuals but not in people with swallowing or deglutition disorders also known as dysphagia (Matsuo & Palmer, 2009). On the other hand, it is well known that the swallow-respiratory temporal coordination is a function of the method of ingestion, body position, and food bolus consistency. This last clearly suggests that swallowing processes can be analyzed from a fluid kinematics/dynamics point of view (Engmann & Burbidge, 2013), where food bolus flow properties (e.g., food bolus rheology) are an important tool to better understand swallowing disorders.

A kinematic/dynamic analysis of dysphagia aims to gain insight into the mechanisms of bolus and liquids flow during swallowing. As rheology is the study of the deformation and flow of matter, the connection between the dysphagia world and rheology is clear.

4.1.1 Food Bolus Rheology

Food bolus rheology is related to the study of flow and deformation of the food bolus. The rheological characterization of the bolus is highly relevant, as it is linked to the performance of the deglutition or swallowing process.

The rheological properties of foods entering into the mouth are fundamentally a function of the food composition. However, once in the mouth, the rheological behavior is modified during the formation of the bolus, which is largely influenced by subjective sensorial perceptions. Thus, rheological properties play an important role in perceptions of food textures or consistencies (Chen & Rosenthal, 2015; Coster & Schwarz, 1987; Smith, Logemann, Burghardt, Zecker, & Rademaker, 2006).

For the oral or mastication phase, food bolus rheological/textural properties, such as for instance elasticity and viscosity, cohesiveness, brittleness, chewiness, and gumminess, are important as they are involved in the sensorial perception that describe human swallowing (De Araujo & Rolls, 2004). For example, Jestrović, Coyle, and Sejdić (2014), using electroencephalography (EEG) systems, showed specific brain activity patterns related to eating, in particular to bolus viscosity stimuli. The authors explained the nonstationary values of the EEG signals by the modulation of the response from neurons to changes (i.e., increase or decrease) in food bolus viscosity. These results confirm the influence of food texture/rheology properties and sensorial perception of food bolus in the brain that are involved in human body adaptation to bolus stimuli during swallowing (De Araujo & Rolls, 2004). Surface electromyography (sEMG) has been used to measure laryngeal physiology for diagnostic and treatment purposes of swallowing disorders. Watts and Kelly (2015) showed a significant effect of bolus consistency on sEMG measurements, in particular on the peak contraction amplitude, but not on contraction duration. The results from this study revealed that, as bolus consistency moved from less to more solid, sEMG amplitude increased. The authors hypothesized the recruitment of larger motor neuron pools to move more solid bolus toward the UES, as the mechanisms involved in the bolus stimuli reaction. In spite of the relevance of these bolus properties, it is not well established yet which of these food bolus mechanical–sensorial properties are necessary to assess or to diagnose an efficient oral preparatory or food mastication step during bolus formation, and how human body reacts to bolus stimuli, in preparation for the next swallowing step, the oropharyngeal phase. Today, the only clear evidence is that human brain systems are activated by the oral perception of viscosity as well as other rheological properties. The main challenge in this area is to translate lab-based mechanical properties, like food texture/rheology, into the sensorial-physiological domain associated to swallowing.

Food textural and rheological properties are used to describe the solid-like behavior of food bolus. Elasticity is a material property representative of the solid-like behavior of food boluses that, together with other textural properties, like hardness, gumminess, springiness, creaminess, crispness, brittleness, chewiness, adhesiveness, and cohesiveness, is commonly associated to sensorial perceptions. The classical "in vitro" texture profile analysis (TPA) is the main experimental technique used for the assessment of the solid-like behavior of foods and its relation with sensorial dimensions. This technique is well established and gives important information to better understand the mastication process (Chen & Rosenthal, 2015).

However, the "in vivo" investigation of the effect of mechanical properties on food bolus formation and, thus, safe swallowing has been quite limited due to the difficulty to perform "in vivo" experiments (Van der Bilt, Engelen, Pereira, van der Glas, & Abbink, 2006). In this sense, the translation of TPA information to the whole swallowing process still is an area where additional research is needed.

On the other hand, the basic rheological property that characterizes the flow behavior of fluid-like materials is the viscosity. Food bolus flow is a dynamic process that depends on the characteristics of the applied force (e.g., magnitude and direction). Thus, the bolus during the swallowing process is submitted to shear and extensional flow (Chen, 2009; Ekberg et al., 2009). However, the focus is usually centered on the measurement of shear viscosity (Brito-de la Fuente, Ekberg, & Gallegos, 2012). For most liquid and semiliquid food boluses, their shear viscosity decreases as shear rate increases and this behavior is known as non-Newtonian shear thinning (Partal & Franco, 2010). The spectrum of food bolus shear-thinning behavior is very wide. Thus, in many occasions, their viscous flow curves exhibit Newtonian regions at low and/or high shear rates. Consequently, the apparent viscosity of these boluses may decrease from a constant value at low shear rates down to another constant value, orders of magnitude lower, at high shear rates. Taking into account, the still limited knowledge concerning the shear rate at which the bolus is submitted during the swallowing process, it is of remarkable relevance the viscous characterization of the boluses in a very wide range of shear rates.

Quite often, structured food systems exhibit both a fluid- and solid-like behavior. In this case, more sophisticated rheological studies should be used to describe these materials (Brito-de la Fuente, Ekberg, et al., 2012).

There are several guidelines from different dysphagia professional associations around the world (see Section 4.3). All of them are referring to viscosity as the only rheological property involved in diet modification for dietary management of dysphagia. However, only one of these guidelines proposes objective viscosity borders and ranges for thickened liquids or food boluses. In this case, the classification and ranges are based on shear viscosities measured at one single shear rate of 50 s^{-1} and at a temperature of 25°C (National Dysphagia Diet Task Force, 2002). There is no scientific evidence or rationale given by the NDDTF on the temperature and shear rate chosen for this scale. In fact, a wide range of shear rates ranging from 5 to 1000 s^{-1} are feasible, being 50 s^{-1} the value most frequently cited, perhaps, because it was adopted by the NDDTF. These conditions have been challenged recently by some authors (Brito-de la Fuente, Staudinger-Prevost, et al., 2012; Chen et al., 2012; O'Leary, Hanson, & Smith, 2010; Quinchia et al., 2011).

Consequently, it is quite clear that more research needs to be conducted to determine normative values for the complex swallowing process. Regarding a more close to reality estimation of shear rates and, thus, shear viscosity, there are data from different experimental "in vivo" techniques that allow some estimation of shear rate ranges during the different steps of swallowing. In this sense, the velocity spectrum of food bolus flow in the pharynx and esophagus has been determined by using different "in vivo" techniques. So far, the "golden standard" VFS has been the most frequently used (Bardan, Kern, Arndorfer, Hofmann, & Shaker, 2006). Other nonradiological techniques, like high-resolution manometry (Williams, Pal, Brasseur, & Cook, 2001) and intraluminal impedance (Nguyen et al., 1997), have been also used to generate bolus transit velocity data and then conduct a swallowing kinematic analysis. Ultrasonic pulse Doppler method has been added to this list (Hasegawa, Otoguro, Kumagai, & Nakazawa, 2005). Regardless of the technique used for the kinematic analysis of dysphagia, it is clear that bolus transit time and thus velocity is highly dependent on patient's medical conditions and food bolus rheological properties. Thus, healthy subjects present high bolus velocity (>35 cm/s). In contrast, neurological patients show slow bolus velocity (<22 cm/s) and weak bolus propulsion forces, causing postswallow residue. Older people with OD present even more impaired tongue propulsion forces and slower bolus velocity (<10 cm/s). Brito-de la Fuente, Ekberg, et al. (2012) reviewed the available information on this subject and used "in vivo" information on food bolus kinematics and dimensions of the pharynx to estimate the shear rates associated to the food bolus flows in both the oropharyngeal and the esophageal phases. Thus, Battagel, Johal, Smith, and Kotecha (2002) reported that the maximum liquid bolus kinematics velocity of a bolus head in the oropharyngeal phase was 35.5 cm/s and the estimated shear rate of 932 s^{-1}. On the other hand, the bolus tail had a much lower average kinematics velocity (10 cm/s) and an estimated shear rate of 262 s^{-1} (Srinivasan et al., 2001). Finally, bolus kinematics velocity (2.94 cm/s) and shear rate (4.7 s^{-1}) values in the esophageal phase, estimated from bolus transfer time, were much lower than in the oropharyngeal phase.

Concerning numerical analysis of the swallowing process, limited information about the flow behavior through the pharynx has been reported in the literature. Most of them are focused on 2D simulations (McMahon, Odie, Moloney, & Gregersen, 2007; Meng, Rao, & Datta, 2005). However, different authors (Gallegos, Quinchia, Ascanio, Salinas-Vázquez, & Brito-de la Fuente, 2012; Salinas-Vázquez et al., 2014) have developed a 3D simulation of Newtonian and non-Newtonian bolus peristaltic flow along the pharynx, from the glossopalatal junction (GPJ) to the UES. Shear rates of up to 1000 s^{-1} can be reached, which is in agreement with the results obtained by Battagel et al. (2002). It was also observed that the bolus head travels faster than the bolus tails, which indicates that the bolus is also subjected to extensional flow.

Finally, two recent systematic reviews on the role of rheology and texture modification in patients with OD have been published (Newman, Vilardell, Clavé, & Speyer, 2016; Steele et al., 2015). In both cases, the conclusions around this complex flow process are quite similar and are summarized here:

- There is clinical evidence showing that increasing food bolus viscosity reduces the risk of airway invasion (i.e., penetration and aspiration) and that this practice is a valid management strategy for OD.
- Modifying food textures by modifying food rheological properties (i.e., like viscosity), may induce a postswallow risk by increasing residue in the pharynx, in particular with specific thickening powders at high consistency levels. Thus, new products in this category should be designed to avoid these negative effects. Furthermore, new thickening agents should also consider reductions in viscosity associated to the salivary alpha-amylase reaction occurring during mastication.
- There is no enough clinical evidence that allows defining objective viscosity levels and thus stages that may predict a safe swallowing process and thus clinical outcomes. In those cases where objective viscosity levels are proposed, there is no consensus in terms of shear rates that should be used for reporting food bolus shear viscosities. New randomized controlled clinical trials should be performed aiming to identify viscosity levels or stages, ideally for each phenotype of dysphagic patients.

- Consensus on descriptors, terminology, and use of objective rheological food bolus properties, which may also consider the physiological behavior that is observed when ingesting different stimuli, is an unmet medical need. Once this step is solved, then the next step will be the development of clinical guidelines that will close the current gap and provide the best practice.

4.2 Enteral Nutrition for Dysphagia Patients: Minimal-Massive Intervention

It is important to recognize that many illnesses and complications secondary to the primary disease state are associated with a reduction in nutritional weight loss. Thus, it has been reported that, once 7 days have elapsed without the patient being able to achieve a sufficient oral intake of aliments or if the patient has been unable to take at least 60% of the estimated daily nutrient demands, nutritional support with modified texture products should be initiated without delay (Arends et al., 2006; Jayarajan & Daly, 2011; Stene & Jeppsson, 2012). Thus, enteral nutrition support is indispensable for patients who cannot achieve full supply of energy and substrate demand. Therefore, appropriate and timely nutritional intervention can play a vital role in the prevention of malnutrition and promoting recovery (Penman & Thomson, 1998).

In agreement to this, it has been reported that increasing bolus viscosity from liquid to pudding significantly reduces the prevalence of laryngeal penetration and aspiration in 98.9% of patients (Newman et al., 2016; Rofes, Arreola, Mukherjee, Swanson, & Clavé, 2014). On the other hand, safe swallowing of solid or semisolid foods may require greater strength in terms of the tongue propulsive forces and pharyngeal muscles that are used to drive material through the oropharynx. A risk of aspiration from residual materials in the pharynx will be prevalent if a person has reduced tongue or pharyngeal muscle strength to properly clear the food bolus from the pharynx. In addition, solid foods that require chewing may prove challenging for people with dental issues or weakness in the masticatory muscles. Alteration of the properties of solid foods (by dicing, chopping, mincing, or pureeing) is a common approach to making these materials easier for oral processing and swallowing (Clavé et al., 2006, 2012; Huckabee & Steele, 2006; Steele et al., 2015; Steele & Huckabee, 2007).

Diet modification has been used as a management strategy for dysphagia irrespective of the phenotype of the dysphagic patients and the specific impairment in the swallow physiology. In addition, the term "diet modification" contains many definitions and terminologies of modified liquids and solids, which varies considerably from country to country or even from hospital to hospital. These variations in definitions and terminologies of thickened liquids and texture-modified foods mean that dysphagia patients with the same phenotype as well as swallowing impairment may receive different treatments in terms of the viscosity levels of thickened liquids and textures of solid foods.

Recently, a study performed by some of the authors proved the therapeutic effect of the so-called minimal-massive intervention (MMI) in elderly people with OD. This MMI included fluid adaptation using starch-based thickening powders provided at a specific level of viscosity according the V-VST, texture adaptation for solids according the descriptors of the BDA applied to traditional alimentation, caloric and protein supplementation using traditional food, and oral health care. Main results of this intervention showed that MMI decreased hospital readmissions and respiratory infections, and increased survival after the follow-up period.

4.2.1 Solid and Semisolid Foods

Modified solid and semisolid foods are prescribed to promote safe swallowing and adequate nutrition in dysphagia patients. Solids and semisolids are modified such that their textures are suited to the swallowing ability and palatability of a patient. However, it is evident that there is still lack of strong, universally standardized guidelines to describe the most appropriate modification of foods. A lack of standardized guidelines and definitions has a number of implications that ranges from reduced food intake to complete rejection of a meal, which in turn may result in increased risk of malnutrition for some patients with dysphagia.

The following food texture properties have been considered as the most significant to characterize the modification of solid and semisolid foods for dysphagia patients, for instance, adhesiveness, cohesiveness, firmness, fracturability, hardness, springiness, viscosity, and yield stress (National Dysphagia Diet Task Force, 2002).

The understanding of the above textural properties is paramount in order to develop standardized terminologies and characteristics of modified solid and semisolid foods for dysphagia patients. The need for standardization of texture-modified foods is an area that needs greater focus. In an attempt toward standardization, different studies and organizations have grouped texture-modified solid and semisolid foods into different dysphagia levels.

Table 2 Texture-Modified Foods Classification System for Individuals With Dysphagia

Levels	Food Examples
Texture C: smooth pureed	Pureed meat/fish (pureed with sauce/gravy to achieve a thick moist texture), gelled bread, mashed potato, pureed fruits, smooth jams, smooth puddings, and gelled cakes
Texture B: minced and moist	Coarsely minced, tender, meats with a sauce, breakfast cereal with small moist lumps, mashed soft fresh fruits, milkshakes, smoothies, and yogurt
Texture A: soft	Casseroles with small pieces of tender meat, well-cooked legumes (the outer skin must be soft), soft canned vegetables, soft sandwiches, fruit juice, puddings, dairy desserts, and creamed rice
Unmodified: regular foods	All food and textures can be included

Adapted from Dietitians Association of Australia and the Speech Pathology Association of Australia Limited (2007). Texture-modified foods and thickened fluids as used for individuals with dysphagia: Australian standardized labels and definitions. *Nutrition & Dietetics*, *64*, S53–S76.

Table 2 shows a selected example from the Dietitians Association of Australia and The Speech Pathology Association of Australia Limited (2007). Other examples can be found elsewhere (National Dysphagia Diet Task Force, 2002; The British Dietetic Association, 2009).

Although these classifications of texture-modified foods for dysphagia give a promising start toward standardization, the lack of clear cut boundaries and objective assessment among the different levels leave them to an open interpretation and this might still have an impact on the treatment of dysphagia using a common language.

Wendin et al. (2010) studied objective definition of texture-modified foods using rheological measurements and sensory analyses. As part of rheological characterization, they used penetration test to measure the texture of solid foods and small amplitude oscillatory shear (SAOS) to measure viscoelasticity of the foods. Based on their studies, they have grouped texture-modified solid and semisolid foods into three different categories (see Table 3).

4.2.2 Thickened Liquids

Thickened liquids are prescribed for dysphagia patients for the purpose of maintaining adequate hydration and preventing aspiration during swallowing (Sura, Madhavan, Carnaby, & Crary, 2012). The mechanism of this strategy is that increasing the bolus consistency changes both the flow

Table 3 Definition of Texture-Modified Solids and Semisolids—Summary of Sensory and Rheological Analyses

	Texture Measurement	
Category	**Parameters**	**Determination Method**
Patés	Maximum load: 0.6–2.4 N	Penetration test
	Strain at max load: 16–34%	Penetration test
	Elastic modulus: 11,000–20,000 Pa	SAOS
	Loss angle: 7.4–7.9 degree	SAOS
Timbales	Maximum load: 0.5–0.8 N	Penetration test
	Strain at max load: 25–33%	Penetration test
	Elastic modulus: 15,000–17,000 Pa	SAOS
	Loss angle: 6.6–7.2 degree	SAOS
Jellied products	Maximum load: 0.1–0.3 N	Penetration test
	Strain at max load: 18–28%	Penetration test
	Elastic modulus: 800–1600 Pa	SAOS
	Loss angle: 4.4–8.4 degree	SAOS

Adapted from Wendin, K., Ekman, S., Bülow, M., Ekberg, O., Johansson, D., Rothenberg, E., et al. (2010). Objective and quantitative definitions of modified food textures based on sensory and rheological methodology. *Food & Nutritional Research*, *54*, 5134.

behavior of the bolus and the physiology of swallowing in dysphagia patients. These changes include higher oral phase flow time of the bolus, significantly shorter pharyngeal delay time, longer pharyngeal response time, significantly shorter pharyngeal transit time, and longer duration of cricopharyngeal opening. These changes help dysphagia patients to properly manipulate the bolus and allow them enough time for laryngeal vestibule closure, hence increasing airway protection. Newman et al. (2016) showed on their review that an increase in viscosity from thin liquid to spoon-thick viscosity significantly decreases the prevalence of laryngeal penetration and aspiration. However, the optimal viscosity of boluses that ensures safe swallowing for the different dysphagia severity, dysphagia phenotype, and for the different swallowing impairment is less established (Bakheit, 2001; Newman et al., 2016).

In addition to this, the required bolus viscosity is often judged subjectively and recorded using descriptive terms, such as mildly thick or custard consistency. This has the disadvantage that thinner liquids might be served that lead to aspiration. On the other hand, thicker liquids are unpalatable and often rejected by patients, which lead to reduced fluid intake and an increased risk of hydration (Bakheit, 2001; Newman et al., 2016; Sura et al., 2012).

Newman et al. (2016) also mentioned that, in addition to the bolus viscosity, bolus volume plays an important role in the safety of swallowing. Increasing bolus volume in the pyriform sinuses leads to greater potential of overspill into the airway as well as leads to increased postswallow residue.

Penman and Thomson (1998) conducted a detailed review of terminologies, definitions, and levels of dysphagia diets for the period 1981–1996. In their review, they mentioned a wide variety of degrees of modification and numerous descriptions of the thickened liquids. In addition to this, the descriptions were solely based on subjective assessment of the modified liquids.

In an attempt toward standardization, different societies and professional organizations have defined different levels of thickened liquids for dysphagia treatment. Most of these definitions of levels are still based on one criterion "how thick they appear" and there is still no detailed study of the effect of a specific thickness of a fluid on the different phenotypes of dysphagia, age, and swallowing impairment. As an example, The Dietitians Association of Australia and the Speech Pathology Association of Australia Limited (2007) have defined four qualitative thickened liquid levels for dysphagia management: Regular; Level 150, Mildly thick; Level 400, Moderately tick; and Level 900, Extremely thick (see this reference for further details).

The National Dysphagia Diet Task Force (2002) defined four levels of thickened liquids based on objective measurement of shear viscosity at a standard temperature of 25°C and a shear rate of 50 s^{-1}. In this sense, they proposed four consistency levels: (i) *Thin* for viscosities lower than 50 mPa·s; (ii) *Nectar-like* for viscosities in the range of 51–350 mPa·s; (iii) *Honey-like* for viscosities in the range of 351–1750 mPa·s; and (iv) *Spoon-thick* for viscosities above 1750 mPa·s. Even though the definition of these levels is a good step toward standardization, there is still a lack of evidence on the definitions. For instance, viscosity dependence of temperature and shear rate for the numerous thickened liquids available in the market is very different. Taking in to account the lack of scientific basis for defining 50 s^{-1} as the relevant shear rate for the swallowing process, establishing thickened liquid levels at a single shear rate and temperature does not guarantee rheological similarity of the boluses inside the mouth where they are submitted to "in vivo" temperatures and shear rates.

It is very important to consider that, for safe and efficient treatment as well as to maintain adequate nutrition and hydration of patients with dysphagia, standardization is of paramount significance. In light to this, the word standardization should include many factors into consideration such as dysphagia phenotype, age, gender, detailed rheological characterization, measurement protocol, and preparation protocol (Newman et al., 2016; Wendin et al., 2010).

Recently, Newman et al. (2016) conducted a detailed review of articles published until July 2015 on the effect that bolus modification has upon the physiology, efficacy, and safety of swallowing in adults with OD. In their review, they mentioned that, although increasing liquid viscosity reduces the prevalence of penetrations and aspirations, there is still lack of proper understanding of the rheological properties of boluses and their effect on OD based on their phenotype. In addition, rheological characterization of boluses has been conducted mainly based on their shear viscosity.

Other less-studied physical properties, such as density and more complex rheological features such as viscoelasticity, plastic flow, and slip flow may also play an important role in the swallowing process. Based on their review, Newman et al. (2016) suggested that further research on intensive rheological characterization of boluses, standardized protocols, definitions, and measurements are necessary in order bolus modification to be an evidence-based treatment for various phenotypes of patients with dysphagia.

4.3 Thickening Powders

Thickening powders are widely added to drinks to slow bolus flow speed during swallowing. The main reason for using thickening powders for dysphagia management is the relative simplicity of the preparation of the thickened fluids, convenience, and reasonable cost.

Although the use of a thickening agent would be beneficial for dysphagic patients with delayed swallow, due to the decreased velocity of bolus flow in comparison to thin liquid, however, other studies have found that increasing bolus viscosity does not affect bolus velocity (Clavé et al., 2006; Rofes, Arreola, Mukherjee, Swanson, et al., 2014). In addition, the results from these studies may also give rise to the need for consideration of the type of thickener used in patients with impaired swallowing function and the effect of other intrinsic bolus properties. A recent review shows a summary of these physiological changes in swallowing and also changes in bolus velocity associated with increased viscosity (Newman et al., 2016).

As previously mentioned, current practice often relies on subjective evaluation of viscosity using verbal descriptors. However, in the absence of quantified viscosity measurements, subjective evaluation of the viscosity of thickened drinks has shown poor repeatability for safe and efficient dysphagia treatment. This is due to the fact that many variables may affect the consistency of a thickened liquid prepared from thickening powders, such as thickener nature, beverage type, fluid temperature, human saliva, shear rate, and time. Thus, for instance, several brands of thickening powders are available in the market with differences in constituent ingredients (mainly starch, gums, or their blends) and instructions for use, which may complicate attempts for objective judgment.

On the other hand, it is worth pointing out that manufacturer guidelines for each of the thickeners usually determine the exact amount of thickening agent required to achieve the desired consistency level for a target liquid although a standardization of the consistency levels is still missing. This limitation significantly affects the safety and efficiency of dysphagia management. As a consequence, there is a motivation for the development of an objective evaluation of viscosity, which can effectively and efficiently handle the variation of viscosity with the above-mentioned parameters.

Thickened fluids for dysphagia management show complex response to an applied deformation (Mackley et al., 2013). At sufficiently large deformations, they show nonlinear viscoelastic behavior, whereas, at a sufficiently low deformation, a linear viscoelastic response is apparent. The viscous response of these complex fluids is characterized by a non-Newtonian shear-thinning viscous behavior.

Some of the authors (Assegehegn, 2012) have quantitatively studied the viscous behavior of fluids thickened with commercial thickening powders. Thus, three different thickness (viscosity) levels were prepared according to the stage definitions of the National Dysphagia Diet Task Force (2002). The viscosity of the resulting thickened fluids has been found to be strongly dependent on the properties of the medium in which the thickener was dissolved, such as pH, temperature, fat content, and density (O'Leary et al., 2010).

Fig. 5 shows a representative graph of the shear-thinning behavior of a starch-based, a gum-based thickener, and a mixture of both thickeners dispersed in water for different levels of dysphagia, prepared according to manufacturer's guidelines (Assegehegn, 2012). It has been proven that the values of the flow index, n, and the consistency index, K, differ significantly depending on the thickener composition for all the stages of dysphagia studied. The degree of shear-thinning behavior is closely related to the swallowing of thickened products. A thickened product with low flow index reduces its viscosity to rather low values as shear rate increases, and this may increase the risk of aspiration in dysphagia patients. On the other

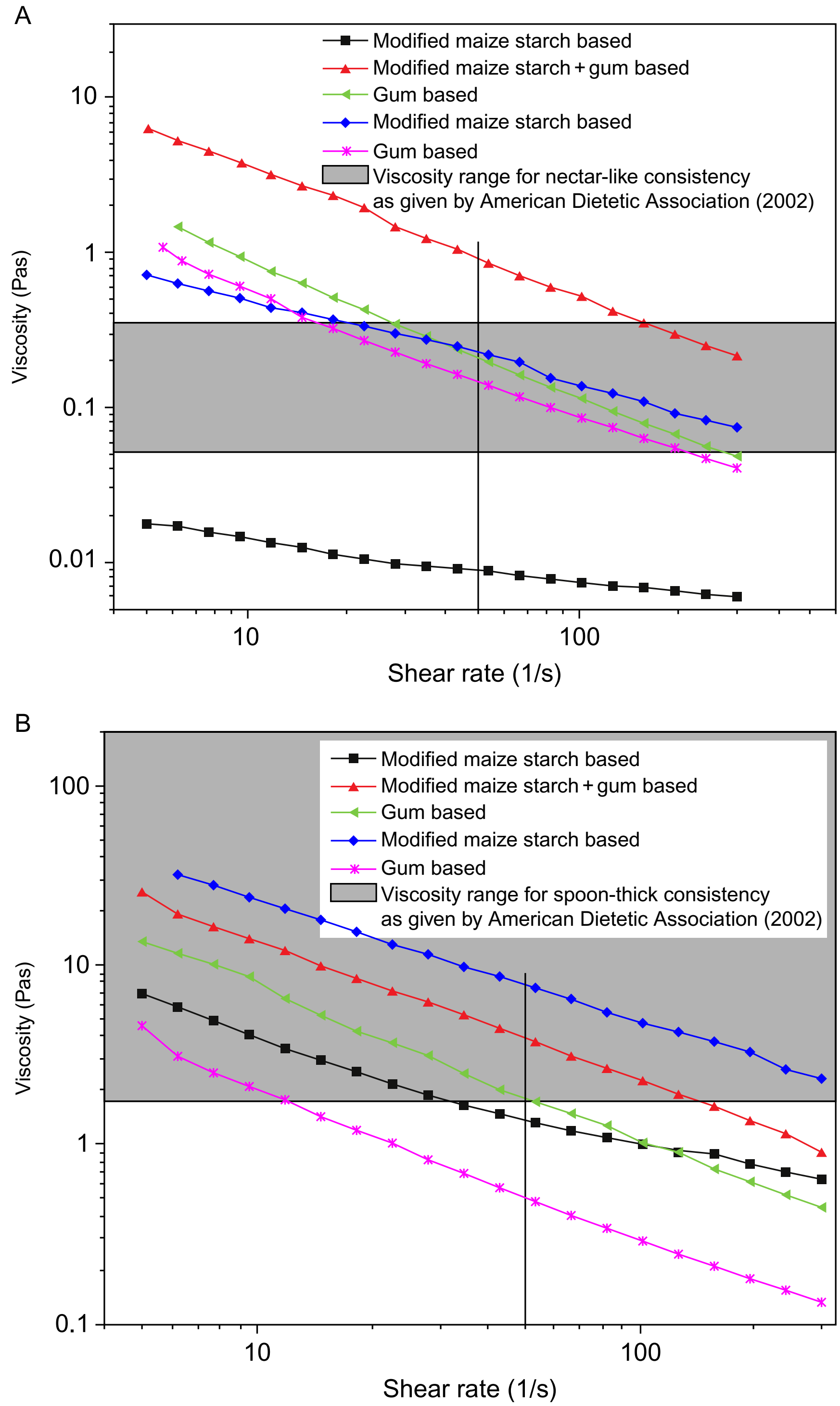

Fig. 5 Viscous flow curves of fluids thickened with different thickening powders ((A) nectar-like and (B) pudding).

hand, a thickened product with a high flow index remains relatively viscous at high shear rates, and thus may facilitate the safe swallowing process. In general, since the variation in degree of shear thinning may affect the swallowing safety of dysphagia patients, manufacturers of thickener products should comply with suitable and narrow ranges of flow indexes. In addition, the big variation in consistency index (viscosity level) of the different thickened fluids significantly affects standardized management of dysphagia. It is, therefore, highly recommended that standardized objective definitions, in terms of viscosity level, shear-thinning behavior, and elasticity of each dysphagia stages, taking into account dysphagia phenotype, swallowing impairment, gender, and age of the patients, are set. Manufacturers should strictly follow these definitions to manufacture thickening powders as well as ready-to-use (RTU) oral nutritional supplements (ONS). Finally, proper randomized control trials should prove its therapeutic efficacy in each dysphagia patient phenotype.

Thickened fluids, as often practiced in dysphagia management, may be consumed over a long period of time. In this relatively long period of time, the rheological properties of the thickened fluids may change and this change may worsen the safety of dysphagia patients. To study the viscous behavior of these thickened fluids during aging after mixing, repeated shear rate-sweep measurements were performed by Assegehegn (2012). The results obtained demonstrated a significant increase in viscosity during aging for starch-based thickened fluids. Even if the consequences of this viscosity variation are unlikely to have negative effects on patients with dysphagia, a thickened fluid with a stable viscosity should always be preferred. In this sense, Leonard, White, McKenzie, and Belafsky (2014) have remarked the advantages of using gums instead of starch as thickeners for dysphagia management. A recent study with starch- and gum-based thickened fluids in poststroke OD found that the penetration–aspiration scale score was significantly reduced with increased viscosity for both types of thickeners. However, starch-based thickeners increased oral and pharyngeal residues for nectar and spoon-thick viscosities (Vilardell, Rofes, Arreola, Speyer, & Clavé, 2016).

4.3.1 Hydrolysis of Starch-Based Thickeners by Human Saliva

As mentioned before, starch is a thickener that has been traditionally used to increase the viscosity of liquids for dysphagia management. Thus, many commercial thickeners use starch as the active agent to increase viscosity, usually in the form of granulated modified maize starch (Hanson, O'Leary, & Smith, 2012).

Saliva is a complex heterogeneous clear fluid consisting of roughly 98% water and 2% organic and inorganic substances, such as enzymes, electrolytes, mucus, glycoproteins, proteins, and antibacterial compounds (Chen, 2009). α-Amylases (α-1,4-glucan-4-glucanohydrolases) are the major component of the enzymes found in human saliva and catalyze the hydrolysis of internal α-1,4-glucosidic bonds in starch and related polysaccharides (De Sales, de Souza, Simeoni, & Silveira, 2012).

During ingestion of starch-based drinks, saliva is mixed into the bolus in the mouth. Saliva can also mix with the thickened drinks in the cup. This is likely to occur with individuals who may have difficulty in swallowing their saliva and who may have excessive saliva collecting in the mouth. In either case, the presence of α-amylase plays an important role in an early breakdown of starch components. The interaction of α-amylase enzyme with starch produces its immediate hydrolysis. However, this hydrolysis of starch components by α-amylase has a negative effect on the treatment of dysphagia, as it reduces the viscosity of the thickened drinks prior to swallowing. This reduction in viscosity is due to the breaking down of the long starch chain into smaller chains or simple sugars. It was found that, in less than 10 s after mixing with saliva (or α-amylase), honey consistency shows almost a 10-fold decrease of its original viscosity (Chen, 2009). When foods made with unmodified starch are mixed with α-amylase, their viscosity can reduce by more than half within 1–10 s (Ferry, Hort, & Mitchell, 2004).

The activity and stability of the enzyme are very important in determining the extent of starch hydrolysis and depends on temperature, pH, pressure, substrate concentration, and additives (Baks, Bruins, Matser, Janssen, & Boom, 2008). α-Amylase is stable at high temperature (up to 90°C) and high pressure (up to 450 MPa). The pH dependency, on the other hand, is significant. It has an optimum pH of approximately from 6.8 to 7.5 (Chen, 2009). This effect can be demonstrated because saliva reduces the viscosity of thickened water very significantly and very rapidly; however, the effect was almost negligible when saliva was added to thickened fluids with acidic pH ($pH < 4$) (Hanson, Cox, Kaliviotis, & Smith, 2012).

In the case of the reaction of starch and α-amylase, mixing is a very important operation as it controls reaction efficiency and reaction rate. Its importance is related to blending components for the reaction to take place, reaction kinetics of the starch degradation, and rheological evolution of the reaction mixture. Hanson, O'Leary, et al. (2012) and Hanson, Cox, et al. (2012) studied the effect of α-amylase on starch-based thickened fluids. Their procedure consisted of mixing the thickened fluid and α-amylase manually prior to loading it in the rheometer. The disadvantage of this procedure is that it does not allow studying the kinetics of the reaction as well as the change in their rheological properties throughout the reaction. It only gives a single point measurement, which corresponds to the final viscosity due to the reaction. The kinetics of the reaction is extremely important to compare the effect of different concentrations of saliva and different shear rates on the reduction of the viscosity of thickened fluids.

For this reason, a mixing rheometer has been used by some of the authors (Assegehegn, 2012) to study the effect of human saliva on the thickened fluids used in dysphagia management. The mixing system used for this purpose is a helical ribbon mixer coupled to a standard rotational rheometer.

Besides increasing the mixing efficiency of the reaction, the mixing rheometer was also used to study the rheological evolution and the reaction kinetics of the reaction mixture. Assegehegn (2012) studied the influence of the addition of 1 mL of saliva solution to 10 mL of a starch-based thickened solution with the above-mentioned mixing rheometer. A fast and dramatic reduction (up to 99%) in viscosity occurred for any of the three dysphagia stages.

As an action to minimize the effect of α-amylase on the starch-based thickeners, some commercially available thickener products are also formulated with gums (i.e., xanthan, tara, and guar gums with or without the addition of modified maize starch). In the case of fluids thickened with a mixture of starch and gums, the kinetics of the hydrolysis was as fast as for starch-based thickeners, but the final reduction in viscosity was lower. This was mainly due to the presence of the gums, which are not hydrolysable by α-amylase. No reduction in viscosity was shown for gum-based thickened fluids. This is shown in Fig. 6, where the behaviors of a fluid thickened with starch-based, gum-based, and a mixture of both types of thickeners, for a honey-like consistency, are compared.

4.3.2 Inhibition of the Hydrolysis of Starch-Based Thickeners by Human Saliva

The above-mentioned viscosity reduction poses a tremendous disadvantage on the safety and efficiency of the starch-based thickened fluids for dysphagia

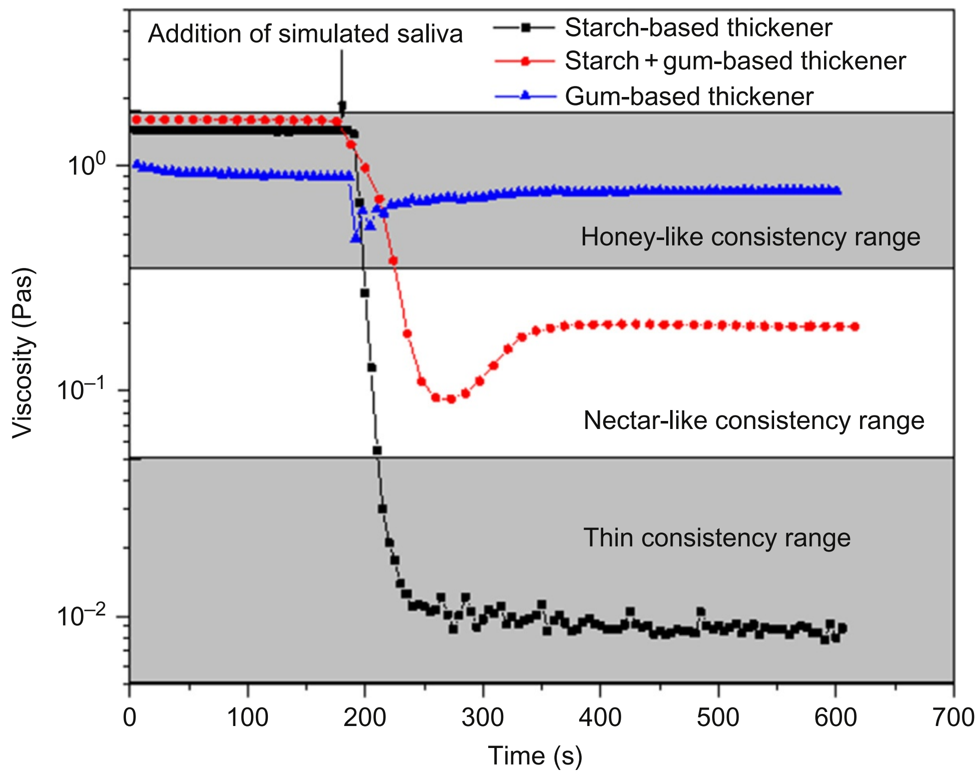

Fig. 6 Comparative effect of simulated saliva on the viscosity of fluids thickened with starch, gums, or mixtures of starch + gums (saliva concentration, 1 mL saliva/10 mL sample; shear rate, 50 s^{-1}; pH, 6.5; *T*, 25°C).

management. A possible solution to this problem is to inhibit the activity of salivary α-amylase, thus keeping the viscosity of the thickened fluids fairly constant throughout the swallowing process, by decreasing the pH of the drink (3.6 or lower) (Hanson, Cox, et al., 2012).

Gallegos et al. (2014) have tested different molecules (i.e., well-known antioxidants, such as tannic acid), which are able to inhibit the hydrolysis of starch by salivary α-amylase, so that the resulting viscosity of the starch-based thickened fluids after the addition of saliva remains within the range of viscosities given by the American Dietetic Association (National Dysphagia Diet Task Force, 2002). This result was observed for all the three consistencies. This important achievement is crucial for the safety of dysphagia patients during consumption of drinks and/or foods. The action mechanism for the inhibitory capacity of these molecules is related to the number of hydroxyl groups on the ring of the molecule skeleton with the formation of hydrogen bonds between the hydroxyl groups, the molecule ligands and the catalytic residues of the binding site of the enzyme, which differs from inhibitor to inhibitor (De Sales et al., 2012).

4.3.3 Elongational Flow of Thickened Fluids for Dysphagia Management

As mentioned in Section 4.1.1, it is now acknowledged that extensional rheology may also play an important role in the development of dysphagia-oriented products, since the elongational properties of thickened fluids may affect the characteristics of the swallowing process (Ekberg et al., 2009; Nyström, Stading, Qazi, Bülow, & Ekberg, 2015). With this aim, different authors (Mackley et al., 2013) have studied the extensional behavior of starch- and gum-based thickened fluids and the effect of salivary α-amylase on the extensional properties of these thickened fluids. In all cases, a capillary break-up extensional rheometer was used. Some representative pictures of the extensional process obtained with nectar-like starch- (SBTS) and gum-based (GB1TS) thickened fluids, as well as the influence of salivary α-amylase, are presented in Fig. 7 (unpublished results).

The results obtained demonstrate a dramatic decrease in filament breakup time of starch-based thickeners in the presence of α-amylase, while gum-based thickeners show a much longer filament breakup time, regardless of the presence of α-amylase. On the other hand, the filament deformation is nonuniform for highly viscous thickened fluids (i.e., pudding-like), related to the nonuniform nature of the samples (Mackley et al., 2013). In any case, the values of both breakup and longest relaxation times depend on the viscosity stage of the thickened fluid, as well as on the nature of the gums (i.e., xanthan or xanthan/guar blend) used as thickener.

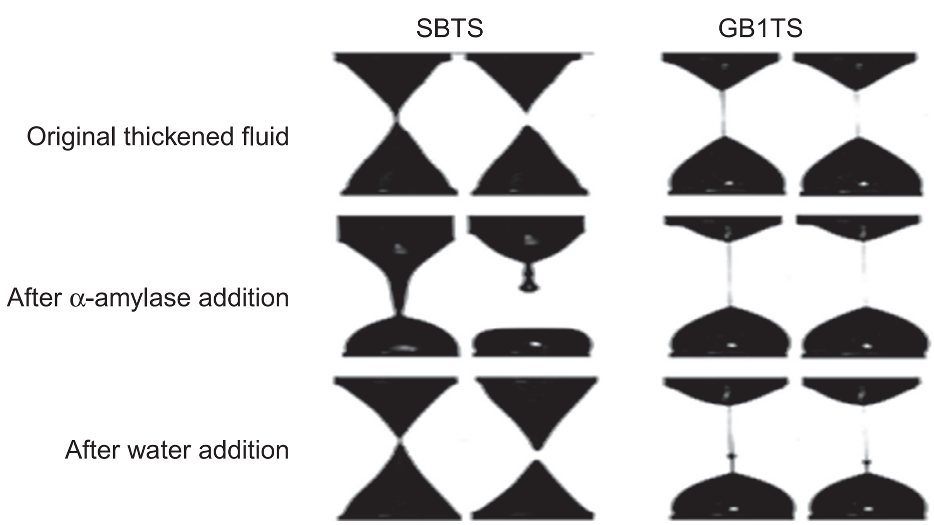

Fig. 7 Influence of α-amylase addition on the filament evolution, during extensional tests, for starch- (SBTS) and gum-based (GB1TS) thickened fluids (nectar stage).

4.4 RTU ONS for Dysphagia Management

Texture or consistency modification of liquids or solids is commonly done by using food thickeners in powder form. One drawback of using thickening powders based on starch and/or gums is the control of consistency or flow properties in the final product. Thus, flow properties are highly dependent on the amount, preparation mode, elapsed time after preparation, and residence time in the mouth being in contact with saliva (Brito-de la Fuente, Staudinger-Prevost, et al., 2012; Hanson, O'Leary, et al., 2012; O'Leary et al., 2010).

An alternative to this practice is the use of RTU ONS specially designed for the nutritional support at different stages of dysphagia. These ONS have several advantages from a nutritional point of view, as they are designed for complete nutrition. In addition, their controlled consistency and texture provide a standardized management of dysphagia (Brito-de la Fuente, Staudinger-Prevost, et al., 2012).

There are several RTU ONS products available in the market, but in these products the relationship between their consistency and the different phenotypes, age groups, and swallowing impairments of dysphagia patients is far from being considered. In fact, from different data published in the literature on viscous properties of RTU ONS products, it is clear that there are significant differences among products designed for the same level or stage of dysphagia (Germain, Dufresne, & Ramaswamy, 2006; Steele & Cichero, 2008; Strowd, Kyzima, Pillsbury, Valley, & Rubin, 2008).

Aiming to close this gap, Brito-de la Fuente, Staudinger-Prevost, et al. (2012) have reported a new approach for designing RTU ONS products, which should consider the following aspects:

1. Ideally, the most appropriate modification of food consistencies should follow from a clear assessment of the swallowing problem. In this sense, videofluoroscopic swallow studies (VFSS) has become the "golden standard" for the evaluation of swallowing and, thus, dysphagia (Ekberg et al., 2009; Logemann, 2007; Palmer, Kuhlemeier, Tippett, & Lynch, 1993).
2. The design of RTU ONS products should be based on the control of their rheological properties (i.e., viscosity, elasticity, etc.), in particular at industrial scale. If at all, viscosity is by far the only recognized rheological property in the dysphagia community. In spite of this, some authors have already suggested the potential role of elasticity during swallowing (Ekberg et al., 2009; Ishihara, Nakauma, Funami, Odake, & Nishinari, 2011; Ould-Eleya & Gunasekaran, 2007;

Quinchia et al., 2011; Steele & Cichero, 2008) and, thus, the need for more comprehensive rheological information on normal foods offered to dysphagic patients.

3. The design of new products for the dietary management of dysphagia patients, from an industrial point of view, becomes even more challenging if the recommendations or guidelines from health professionals are taken into consideration. Moreover, in the United Kingdom, The British Dietetic Association (2009) recently reissued its "National Descriptors for Texture Modification in Adults," using again subjective descriptors from sensorial analysis.
4. Barium sulfate-based contrast fluids (SBTF), designed for different dysphagia levels (nectar, honey, pudding), can be used to assess safety and efficacy of swallowing among dysphagia patients based on their phenotype, age, gender, and specific swallowing impairment. These fluids could be used as benchmarks for the design and manufacture of RTU ONS products targeting a specific dysphagia patient group. To achieve this goal, a comprehensive characterization of the viscous flow behavior, in a very wide range of shear rates, of both the contrast fluid and the ONS is needed. In other words, this approach is based on the matching of the flow properties of the RTU ONS product with those of the SBTF, by taking into consideration both formulation and process conditions. The results obtained by Brito-de la Fuente, Staudinger-Prevost, et al. (2012), for a pudding-like consistency, clearly suggest that it is possible to obtain an excellent rheological similarity of both SBTF and RTU ONS produced at industrial scale. Thus, the viscous flow curves for both products match in the whole shear rate range studied fairly well, no matter what RTU ONS product aging was.
5. However, the linear viscoelasticity functions for the RTU ONS sample may be different to those of the SBTF. Although, a dramatic shear-induced pudding structural destruction takes place in the nonlinear regime for both products, the shear-induced microstructural breakdown should be likely more important for the RTU ONS product. In summary, both linear viscoelasticity properties and nonlinear relaxation modulus should be optimized to obtain the rheological (viscous flow) similarity to commercial standards for videofluoroscopic studies.

On the other hand, Casanovas, Hernández, Martí-Bonmatí, and Dolz (2011) have proposed an objective classification of a wide range of commercial thickened food widely used in patients with dysphagia. This classification was made taking into account the complete flow curve (for shear rates between approximately 10^{-5} and 100 s^{-1}). In addition, to establish the classification, they also considered the thixotropic and viscoelastic behavior of each product. Up to 11 parameters were evaluated to define each of the following five dysphagia stages: nectar, honey, pudding, puree, and pâté.

4.4.1 Elongational Flow of ONS for Dysphagia Management

Turcanu et al. (2015) have studied the extensional properties of a pudding-like starch-based ONS after addition of either a solution of a commercial human α-amylase lyophilized powder (α-A), mechanically stimulated saliva (MHS), or "in vivo" stimulated whole human saliva (WHS), by using a capillary break-up extensional rheometer (CABER, Thermo-Haake, Germany).

The results obtained demonstrated that the filament lifetime is shorter when alpha-amylase solution (α-A) or MHS are added to the ONS, transforming its filament shape into a more cylindrical one.

For the case of "in vivo" mixing (WHS), the results showed an unexpected increase in filament lifetime leading to the formation of a stable filament with an equilibrium time (t_{ec}) instead of a breakup time (t_b). This increase in filament lifetime and the formation of the beads-on-a-string with WHS could be explained by the presence of human mucin components (glycosylated proteins), naturally occurring in food-stimulated saliva (Johansson, Stading, Diogo-Löfgren, & Christersson, 2011; Sonesson, Wickström, Kinnby, Ericson, & Matsson, 2008). These components play a key role in swallowing, lubrication, and bolus formation, by ensuring food aggregation (Sarkar, Goh, & Singh, 2009). The lack of elasticity in the case of mechanically stimulated saliva may be explained by the small amount of mucins produced while chewing tasteless or unappealing food or other non-food products.

It is apparent that much more work should be done in this field, aiming to establish the real influence of the extensional flow of the bolus on the performance of texture-adapted fluids for dysphagia nutritional management.

5. CONCLUSIONS

Dysphagia or swallowing disorders are a prevalent condition recognized by the WHO in the International Classification of Diseases. There are several origins for dysphagia: (a) pathophysiological events coming from organic or structural diseases and (b) diseases causing impaired physiology.

This chapter reviews the most recent advances in understanding dysphagia caused by diseases that impair oropharyngeal physiology, also known as oropharyngeal dysphagia (OD). Prevalence of OD is extremely high and affects millions of people worldwide (e.g., around 54 million people only in Europe, USA, and Japan together). Despite the severity of OD complications, the standard of care for the majority of these patients is very poor as most are not diagnosed or treated.

In this sense, methods and strategies for the diagnosis of OD, the nutritional consequences (i.e., malnutrition, dehydration), and respiratory complications (i.e., food bolus-related aspiration pneumonia) are reviewed. OD is a high risk factor for malnutrition and dehydration. Thus, the nutritional management of OD patients should be an essential part of any multidisciplinary-based strategy defined to treat it.

Food texture and consistency modification are a common practice in the nutritional management of OD. A clinical evidence base showing the benefits of this practice has been recognized by dysphagia-related professional associations (e.g., ESSD). However, more research is needed to better understand food bolus flow or rheological properties and their precise role in the complex swallowing process (i.e., shear rates during the OD swallowing phase). Furthermore, there is an urgent need for standardization of food bolus consistency descriptors, terminology, and viscosity measurements. A clinical guideline on bolus modification for patients with OD is urgently needed.

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