CLINICAL NUTRITION HIGHLIGHTS

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2021

How and why thickened liquids improve swallowing safety and swallowing efficiency

DYSPHAGIA

Nestlé Nutrition Institute

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How and why thickened liquids improve swallowing safety and swallowing efficiency

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Julie Cichero, PhD is a speech-language pathologist who has worked for 29 years in the clinical field and conducted research into feeding and swallowing disorders from infancy to old age. She has contributed to the evidence base for diagnostic use of swallow-respiratory sounds, characterisation of thick fluids and complexities associated with pill swallowing difficulties. Julie is Co-Chair for the Board of the International Dysphagia Diet Standardisation Initiative (IDDSI) assisting with global implementation of the IDDSI texture modified food and liquid framework. Julie is a reviewer for medical, nursing, nutrition, speech pathology, chemical engineering and food texture Journals. She has more than 65 publications in peer-reviewed international Journals and is co-author of four books. Research Compliance Manager at Mater Research, Honorary Senior Fellow with the University of Queensland and Adjunct Professor with the Queensland University of Technology, Julie is based in Brisbane, Australia.

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0. Abbreviations & Glossary

Abbreviations

Aliquot	A portion of a larger whole sample
cP	Centipoise
CAD	Canadian Dollar
Cl	Confidence interval
CSE	Clinical swallowing evaluation
EDS	Eating drinking or swallowing
Efficacy	Ability to produce the intended result of the intervention
Swallowing Efficiency	Swallowing action resulting in complete clearance of the bolus from the oral cavity or pharynx. An efficient swallowing mechanism does not leave residue
ENT	Ear nose and throat
ESPEN	European Society for Clinical Nutrition and Metabolism
FAO	Food and Agriculture Organization of the United Nations
FEES	Fiberoptic endoscopic evaluation of swallowing
FSMP	Food for Special Medical Purposes
ID	Intellectual disability
i.v.	Intravenous
LOS	Length of stay
mPa.s	Milli-pascal-seconds
ms	Millisecond
MBSS	Modified barium swallow study
MJ	Mega Joule
Newtonian Fluids	Fluids where the force required to make the fluid flow is proportional to the resulting amount of flow
NICE	National Institute for Health and Care Excellence
NMES	Neuromuscular electrical stimulation
OD	Oropharyngeal dysphagia
ONS	Oral nutritional supplement
PAS	Penetration-Aspiration Scale
PEG	Percutaneous endoscopic gastrostomy
RDI	Reference dietary intakes
Residue	Liquid or solid that remains in the mouth or throat after the swallow
Rheology	The study of the deformation and flow of matter
Swallowing safety	Risk for material entering the airway or the entrance to the airway, measured on the PAS
SLP	Speech and language pathologist
SLT	Speech and language therapy
TMF	Texture-modified food
UES	Upper oesophageal sphincter
UL	Upper Intake Level
US	United States of America
USD	US Dollar
VFS	Videofluoroscopy
VFSS	Videofluoroscopic swallowing studies
V-VST	Volume-viscosity swallow test
WGO	World Gastroenterology Organization

Glossary

Bolus	A discrete rounded mass of a substance, especially of chewed food or a mouthful of liquid at the moment of swallowing
Aspiration	The invasion of a bolus below the level of the true vocal folds
Penetration	Entry of material into the larynx, at or above the level of the true vocal folds
ONS	ONS are typically used in addition to the normal diet, when diet alone is insufficient to meet daily nutritional requirements
PAS	The PAS is an 8-point scale used to categorise swallowing ability and issues related to swallowing safety.
Xerostomia	The symptom of dry mouth resulting from reduced or absent saliva flow as a result of a medical condition, a side effect of radiation to the head and neck, or a side effect of a large number of medications

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1. Summary

Swallowing is a complex process. When the ability to safely swallow regular liquids is impaired, liquids are thickened to slow flow, in an effort to maintain oral hydration. A combination of bolus properties such as viscosity, yield stress, bolus cohesion and slipperiness facilitate safe passage of the bolus. Studies have demonstrated that these features, examined at various levels of thickness, promote safe swallowing. The literature demonstrates that xanthan gum has features that are most appropriate to facilitate swallowing safety when objectively compared with other thickeners. It is imperative that dysphagia clinicians evaluate individuals with dysphagia to determine the 'thickness dose' that is most appropriate to treat each patient's individual needs. A range of thickness levels are required to meet the variability in dysphagia presentations.

2. Introduction

Dysphagia is the medical term for **'difficulty in swallowing'**. In its broadest sense it covers difficulty with managing a bolus from the oral cavity, through the throat (oropharyngeal dysphagia), progressing through to the oesophagus (oesophageal dysphagia). Individuals swallow more than 600 times per day.[1-3] Types of boluses include solids (food), liquids, saliva/secretions and medication.

3. The mechanism of deglutition

There are three generally accepted phases of swallowing; the oral phase, pharyngeal phase and oesophageal phase. Figure 1. There are subtle differences between the way the body manages the ingestion of solids and liquids; these are described under each of the phases of swallowing. The differentiations are 'philosophical' rather than absolute.

3.1. Swallowing solids

The following considers the scenario of 'a bite of an apple'. Figure 1.

A1) As the apple reaches the mouth, the aroma excites the nasal olfactory receptors and there is reflexive secretion of saliva into the oral cavity.

A2) **Mechanoreceptors** in the teeth provide biofeedback as to the bite force necessary to **break the food** (bolus) **into smaller particles**. The purpose of this particle breakdown is to allow the release of flavour compounds, reduce choking risk and to increase the surface area of the bolus, allowing for easier digestion in the gastrointestinal system.

The bolus is moved from the front of the oral cavity towards the molar teeth closest to the cheeks. The molars provide the surface for **grinding and deforming the bolus.**

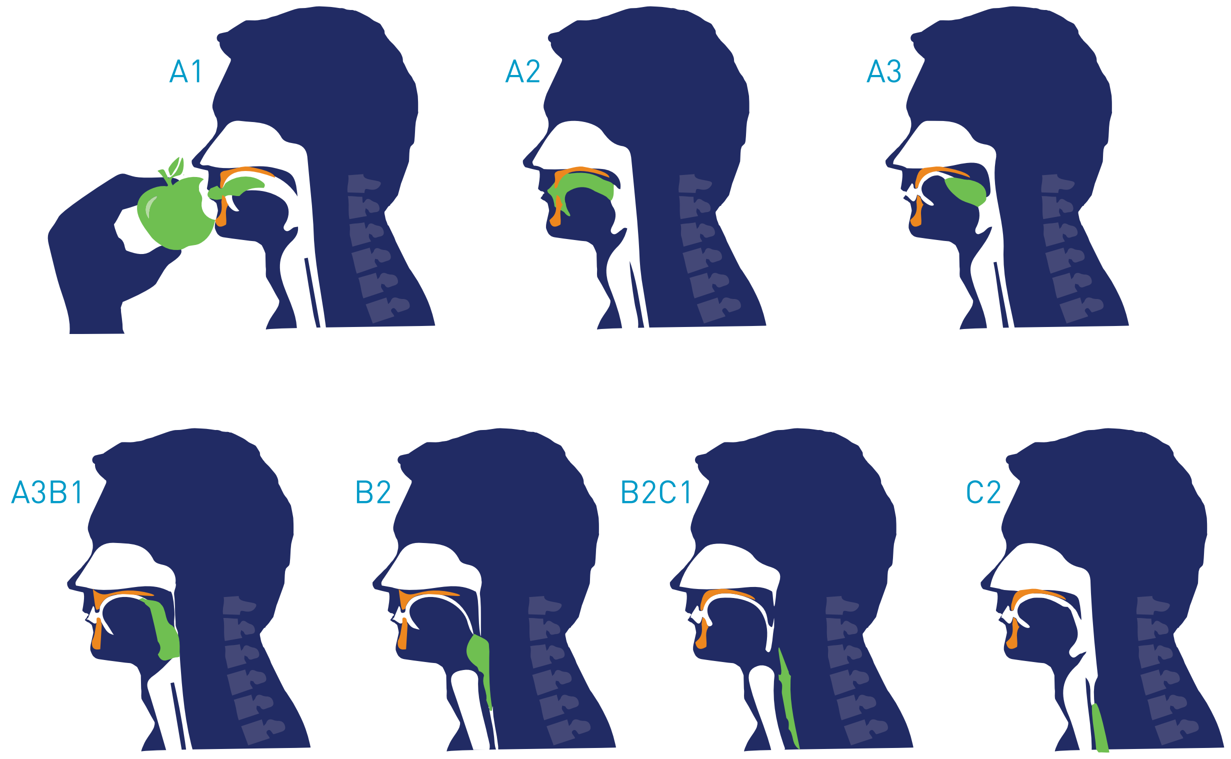

Figure 1. Phases of swallowing

As the food is deformed into smaller particles, it is mixed with saliva and progressively returned to the centre of the tongue where it is collected into a moist "ball" (or bolus).

Saliva aids in adding moisture to soften hard food, and provides a solution for taste molecules to enable the appreciation of sensory qualities, and promote retronasal **appreciation of smell and taste.** This in turn releases more saliva.

A combination of watery and viscous saliva helps to ensure that the **bolus is moist and also slippery.** [4]

Further, **saliva alters the temperature of the bolus**, warming a cold bolus and cooling a hot bolus prior to transporting the bolus to the sensitive mucosa in the pharynx and oesophagus.

During **oral preparation**, the back of the **tongue is raised to provide a barrier to the bolus passing undeformed into the pharynx creating a choking risk.** However, aliquots of chewed food may be passed over the back of the tongue and wait for up to a few seconds at the base of the tongue (valleculae) prior to swallow reflex initiation. As these aliquots are passed to the base of the tongue, **breathing is reflexively paused**, presumably to reduce the likelihood of accidentally inhaling the food particles.[5-6]

A3) With each closing action of the jaw, the **soft palate swings forward** allowing the aerosols from the partially deformed food fragments as they mix with saliva during chewing to **pass directly to the cribriform plate facilitating flavour** appreciation directly to the brain.

The delicate backward and forward relay between the sensory and motor systems allows the bolus to be expertly deformed into particles of roughly 2-4mm (hard foods) held together by saliva in readiness for swallowing.[7]

The number of chewing strokes required to deform the bolus varies from food type to food type. Hard foods, such as the piece of apple, requires approximately 20 chewing strokes.[4]

A3B1) The **oral phase** lasts for as long as food deformation is needed. Once the bolus particles have been deformed so that **they are sufficiently soft enough to reduce potential damage to the sensitive oral, pharyngeal and oesophageal mucosa** and moist enough to be held together cohesively, the swallow reflex is generated.[8]

During swallow initiation the **lips are closed**, preventing anterior spillage and the jaw is closed bringing **the tongue as close as possible to the hard palate**, providing a **mechanical surface to slide and direct the bolus along.** This process transitions the bolus from the oral phase to the pharyngeal phase. The oral to pharyngeal phase transition also transitions the bolus from voluntary control in the oral cavity to reflexive, involuntary control from the moment the swallow reflex is triggered in the pharynx.

B2) As the swallow reflex is generated it triggers a **series of actions within the pharynx that are designed to protect the airway**.[9]

Constriction of the superior pharyngeal constrictor triggers the middle, then inferior pharyngeal constrictors where the wave is then passed to the oesophagus to create the primary oesophageal wave. Moments before the bolus passes over the base of the tongue, the arytenoid cartilages lurch toward the base of the epiglottis.

The **epiglottis** is a tennis racket shaped cartilage with its base (stalk) nestled in the midline of the thyroid cartilage, one of the key structures of the larynx.

The **base of the tongue** connects via muscular attachments with the hyoid bone. The hyoid bone sits in the neck, under the floor of the mouth.

The **hyoid bone** is in turn connected to cartilages of the larynx and also the muscles of the pharynx, creating a unique pulley system. The "anatomical pulley system" allows the entrance to the airway (larynx) to be physically moved upwards and forwards under the protection of the base of the tongue; away from the passing bolus.

The **pharynx** is physically shortened during this process creating a shorter passage for the bolus.

As the **larynx** is lifted, the movement allows the top-heavy epiglottis to fold over the entrance to the airway.

Beneath the epiglottis, the **vocal folds** come together as a further physical barrier to the opening of the airway and breathing momentarily stops (~ 1 sec). Although the epiglottis forms a physical barrier over the airway entrance it is not a perfect seal; it is not like a cork in a bottle. In fact, its presence is much like rock in a stream, creating a mechanism to alter the direction of flow so that the bolus travels through pockets (pyriform sinuses) around either side of the larynx.

B2C1) During **hyolaryngeal movement**, the unique muscular connections between the larynx and the opening to the oesophagus trigger relaxation of the valve that separates the pharynx from the oesophagus, allowing the upper oesophageal sphincter (UES) to open and for the bolus to pass through the pharynx and into the **oesophagus**.

A **series of peristaltic** waves are generated within the oesophagus to progress the bolus in a rhythmic fashion towards the lower oesophageal sphincter; the gateway to the stomach. The triggering of the primary peristaltic wave also triggers relaxation of the lower oesophageal sphincter, the valve between the oesophagus and the stomach, easing passage of the bolus into the stomach for further processing. For solid foods, secondary peristaltic actions are triggered by the presence of the bolus within the oesophagus helping to propel it towards the stomach.

C2) The oesophageal phase typically lasts 4-8 secs for solids.[10]

Efficient bolus passage

For the passage of the bolus to be efficient there are a series of actions that need to occur almost simultaneously. The swallowing system can be likened to a mechanical system. High resolution manometry (HRM) demonstrates that that the bolus is subjected to variable pressures as it moves through the mouth, pharynx and oesophagus.

Closure of the lips during swallowing creates a sealed chamber anteriorly.

The **tongue provides the propulsion** for the bolus head to pass deep into the pharynx. Tongue base pressures acting on the bolus are in the order of 214 mmHg for healthy people.[11] The tongue base meets the pharyngeal constrictors that, as their name suggests, squeeze in a circular fashion to ensure the tail of the bolus is cleared away from the airway.

The **soft palate closes as the swallow reflex is generated**, ensuring that neither the bolus, nor the pressure generated by the tongue can be lost through that valve. In fact, the maximum pressure generated at the soft palate (velopharynx) is approximately 221 mmHg in healthy people.[12]

The **airway closes with a pause to breathing** reducing the likelihood of drawing the bolus towards its entrance.

The **upper oesophageal sphincter relaxes** below the resting pressure of 96 mmHg and opens for about 0.68 secs to accept both the bolus and the pressure driving it.

Bolus propulsion is aligned to UES opening and relaxation.

The triggering of the **primary peristaltic waves** and **vacuum** created with a closed system allows the bolus to be carried away from the pharynx and pulled towards the stomach.

Once the UES has closed, the 'danger' of the bolus has passed.

The airway re-opens, the tongue, jaw and pharynx return to resting position while the soft palate relaxes, facilitating nasal breathing.

3.2. Swallowing liquids

The following considers the scenario of a mouthful of water as it is taken from a glass. The volume taken depends on the stature of the person, with taller individuals taking a larger mouthful than smaller statured people (average 20-25 mL). Figure 1.

A1 A2) The **lips provide a seal** to ensure that liquid passes into the oral cavity. In the case of liquids, the tongue controls and directs the liquid bolus.

A3) The **back of the tongue** is raised to protect the airway, as for the example of solid foods above. The body of the tongue cups to accommodate the bolus.

A3B1) **Sensory receptors** detect the presence of the bolus and, working in tandem with motor receptors, the same sequence of events listed above is set into motion. Again, a small amount of the bolus may transiently move to the spaces at the base of the tongue just prior to swallow reflex initiation.

B2) The **lowering of the epiglottis** causes the bolus to split and travel on either side of the larynx through the pyriform sinuses to the opening of the oesophagus. In contrast to solids, the oral phase for liquids is very fast at approximately 1 second.

B2C1) The **pharyngeal phase** is the same for solids and liquids with a duration of 1 second allowing passage of the bolus while respiration is momentarily ceased.

C2) Travel time through the **oesophagus** is 1-2 secs for liquids.[10] Unlike solid food, the primary peristaltic wave is sufficient to facilitate passage of the liquid bolus into the stomach without further peristaltic waves being generated.

Healthy individuals sometimes segment a single mouthful into smaller aliquots for swallowing. They do this by holding a portion of the bolus towards the front of the mouth while swallowing the remainder of the bolus. This, often unconscious strategy, may be used as a safety mechanism when the initial mouthful is too large, too hot or too cold to be swallowed as a single unit. It may also be used to prolong oral exposure if the taste of the liquid is pleasant (e.g. wine).

4. Dysphagia to solids and liquids

The mechanisms and repercussions of dysphagia for solids and liquids are quite different.

Dysphagia for liquids occurs when the liquid is lost from the front of the mouth, and more importantly from the back of the oral cavity where there is a **high risk for the liquid to enter the larynx; the gateway to the lungs.** Difficulty controlling the flow of liquids can result in a fear of swallowing. Frequent coughing or choking episodes can cause the person to avoid drinking, therefore taking insufficient liquids to maintain adequate hydration. It is just as dangerous when the person has no awareness that aspiration is occurring, where the liquid enters the airway and lungs.

> ***Dysphagia for liquids***
> *can result in **aspiration** where the liquid enters the airway and lungs*
>
> ***Dysphagia for solids** can result in **asphyxiation** with food pieces*

Dysphagia for solids can result in **asphyxiation with food pieces** physically blocking the airway and the preventing the ability to breathe.

Both types of dysphagia can cause **serious illness** such as **malnutrition**, **dehydration** and also complications such as life-threatening aspiration pneumonia, and/or choking, resulting in **death.**

Where there is a significant **loss of muscle mass and function**, it is known as **sarcopenia**; this is a hallmark feature of frailty.[12] Frailty results in an age-associated decline in reserve and function and is characterised by low grip strength, low energy, slow walking speed, low physical activity and unintentional weight loss. Whilst sarcopenia is more commonly associated with skeletal muscles for walking and hand grip, muscle wasting is also seen in the muscles associated with eating and swallowing. A study of **frail elderly** patients showed that more than **two thirds presented with oropharyngeal residue, more than half presented with penetration** of the bolus above the opening of the airway and **17% demonstrated tracheobronchial aspiration or airway invasion**. Impaired tongue propulsion and delayed movement of the hyolaryngeal muscle pully system complex was linked to oropharyngeal residue across liquid thickness levels. These features were not evident in healthy participants.[13] Changes in muscle integrity associated with sarcopenia could contribute to reduced tongue propulsion and delayed hyolaryngeal excursion noted in these elders. At one-year follow up, mortality rates were significantly higher in frail elderly patients (56% vs. 15%) with impaired swallowing safety or swallowing efficiency.

> ***FRAIL ELDERLY PATIENTS:***
> ***66%** oropharyngeal residue*
> ***>50%** penetration*
> ***17%** tracheobronchial aspiration or airway invasion*
> ***56%** on-year mortality*

For both solids and liquids, **safe swallowing relies:**

- On the integrity of sensory and motor systems within the oral cavity, pharynx and larynx
- On the lubrication and integrity of the mucosa and oropharyngeal structures

4.1. Swallowing problems arising from reduced integrity of the sensory and motor systems

4.1.1. Problems with the sensory system

Problems with the sensory system, such as that which might occur **following stroke, head and neck cancer**, or in the **later stages of dementia** can cause the food or liquid to be poorly sensed or perceived. Reduced ability to sense the bolus means that its movement within the oral cavity cannot be tracked and therefore cannot be well controlled. Clinical studies evaluating tongue pressure show significantly reduced tongue-to-palate pressure and different tongue pressure patterns in individuals with dysphagia as a result of stroke.[14] Poor sensation of the bolus can result in misperceptions of bolus size, or readiness for swallowing. It can also cause poor timing for swallow reflex initiation if sensory loss is uneven within the oral cavity. This may result in the bolus falling into the pharynx and larynx before the safety mechanisms that normally protect it are in place. As noted in **Section 3**, these safety mechanisms include:

- Physical barriers, such as closure of the vocal folds and deflection of the epiglottis over the opening of the larynx
- System optimisation for bolus propulsion including tongue driving force to generate bolus velocity through the pharynx and closure of anatomical valves to improve the effectiveness of bolus propulsion
- Cessation of respiration to avoid pulling the bolus towards the airway while it is moving; and
- Opening and timely closure of the upper oesophageal sphincter (UES) to allow bolus entry, and then containment in the oesophagus for further propulsion to the stomach.

As noted above, the bolus is subject to a variety of pressures as it travels through the oral cavity, pharynx and oesophagus. The pressures, and also the velocity of the bolus, provide proxy measures of the strength and efficiency of bolus movement during swallowing. Lower pressure scores are associated with abnormal swallowing function. Specifically, HR manometry studies have shown that individuals with dysphagia of mixed aetiology demonstrated significantly lower pressures generated at key 'anatomical valves' of the soft palate and tongue base, with significantly lower UES resting pressure and ability to sustain the resting pressure (0.49 secs) compared with the values for healthy individuals (0.68 sec). Pressures are shown in Figure 2.[11]

The bolus tail is cleared by action of the squeezing pharyngeal constrictors. Deficiencies in this area are associated with residue remaining in the pharynx after the swallow. In a group of individuals with dysphagia, lower mean pharyngeal contractile interval scores have been significantly associated with greater swallowing impairment as per Figure 3.[15]

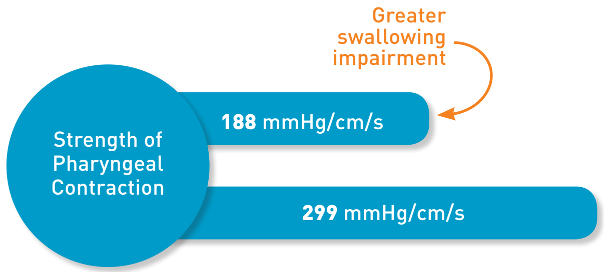

Figure 3. Mean pharyngeal contractile interval scores associated with swallowing impairment[15]

4.1.2. Problems with the motor system

Problems with the motor system, again as a result of **neurological damage to nerves and/or muscles**, or **structural changes associated with surgery** (e.g. head and neck cancer) **significantly impact the ability to move the food or liquid for chewing and swallowing**. This may result in:

- Difficulty moving the food pieces to the molar region for chewing,
- Insufficient bite force, leaving the bolus poorly deformed; and/or
- Poor control of the direction and speed of movement of the bolus as it nears the pharynx.

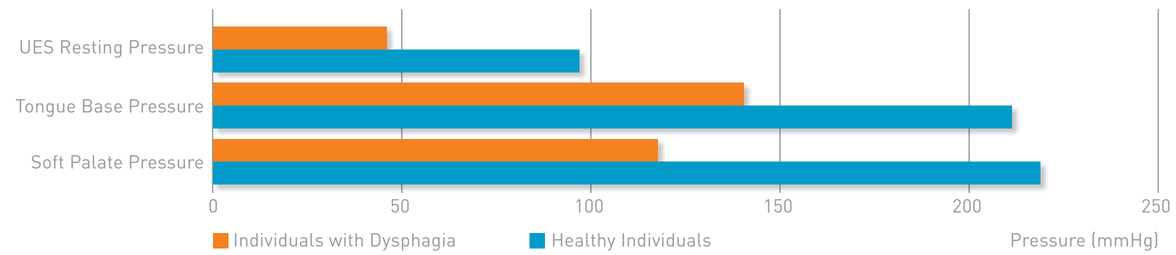

Figure 2. Pressures generated during swallowing: Comparison between healthy individuals and individuals with dysphagia[11]

Poorly deformed food may result in the person swallowing chunks that are too large and could cause a **choking risk**. Where the sensory system remains intact, but the motor system is faulty, individuals can sense that a bolus has been incompletely prepared but are unable to action that feedback. This can result in insufficient food being consumed. An example of this type of problem is Motor Neurone Disease, where fatigue is associated with attempts to prepare the bolus in line with feedback from the sensory system but there is a lack of motor action to respond to the sensory feedback. The food may fracture with a loss of momentum if it is not propelled swiftly. The fractured pieces may then collect at the base of the tongue (valleculae) or in the pockets on either side of the larynx (pyriform sinus).[16] In a **worst-case scenario, choking and asphyxiation can occur with solid food.**

With liquids, **poor motor ability** may result in the **liquid escaping from the lips and/or falling over the back of the tongue into the open airway.** Healthy people with an intact sensory system will cough to expel liquid that has entered or attempted to enter the upper airway. However, sensory loss is common post-stroke, and although liquid enters the airway, a protective cough is not triggered during the airway invasion (aspiration). If liquid is aspirated often enough, or in sufficient quantities, together with other predisposing factors related to oral hygiene and integrity of the immune system, conditions may arise for life threatening **aspiration pneumonia (AP)** to develop. The bolus might also be propelled with a low velocity such that remnants are not adequately cleared from the pharynx and remain in the valleculae or pyriform sinus waiting to be cleared with a further clearing swallow.[17]

Although sensory and motor deficits have been described in isolation above, there are conditions where both sensory and motor deficits combine to increase the severity of dysphagia.

4.2.Changes to salivary lubrication of the oral cavity

The final element that must be considered that impacts dysphagia is the **lubrication of the oral cavity**. The oral, pharyngeal and oesophageal mucosa is typically bathed in saliva that protects and keeps the mucosa moist and slippery.

Saliva is made up of both a watery and viscous, but slippery component (mucin). Particularly for food, the coating of the bolus in the slippery mucins of saliva allows it to slide along the surface of the moist and slippery mucosal structures. **Conditions that reduce saliva flow or change the saliva composition** change the boundary conditions for the bolus, and provide friction, **making it difficult to slide the bolus through the oral cavity and through the pharynx.**[18] Think of trying to roll a sticky ball along a sticky surface rather than a slippery ball gliding along a slippery surface.

The tongue must work harder to propel the bolus out of the mouth and into the pharynx. The pharyngeal constrictors must work harder and for longer to squeeze the tail of the bolus through the pharynx. Due to the sticky nature of the mucosa, the bolus may fracture and stick at the base of the tongue (valleculae) or in the pockets on either side of the larynx (pyriform sinus) requiring additional swallows to clear the residue. Mucosal stickiness may also extend into the oesophagus, making it difficult for the bolus to pass through the oesophagus to the stomach.

Dry mouth (xerostomia) is a feature of the immune disease Sjogren's Syndrome and is a common side effect of radiation to the head and neck. Xerostomia is also a common side effect of many medications. Given that the average elderly person consumes 6-8 medications daily, their risk for dry mouth is increased.[19]

5. Main physical and rheological properties of bolus that facilitate swallowing function

The bolus can be solid, liquid or secretory in nature. The ideal bolus is soft, smooth or homogenous in texture.[20-22] It holds together **to allow efficient** transport through the mouth thereby **avoiding particle loss during transfer from the front of the mouth to the back** of the mouth **where the swallowing reflex is triggered**.

The bolus is also slippery, allowing it to glide along the oral, pharyngeal and oesophageal mucosal surfaces. Factors that increase softness allowing malleability, smoothness and homogeneity of texture include chewing and the addition of saliva.

Some foods have a high-water content, while others increase their water content by supplementation with saliva released during chewing and oral preparation. The moisture content of the 'ready-to-swallow bolus' is relatively constant. This is regardless of the

initial state or texture of the food, demonstrating the importance of the sensory system to perceive this feature as well as the importance of the motor system for bolus preparation.[20-26] The **bolus must also have sufficient weight, or density, and cohesion** for it to be sensed by the oral cavity and interpreted by the brain as a substance that is suitable for swallowing.

For a person with swallowing difficulties,

- **What features of the bolus can be manipulated to improve swallowing safety and swallowing efficiency where the anatomical or physiological system has become impaired?**

The **liquid bolus is fragile when being transported**. When propelled with sufficient force, a liquid bolus is able to travel as a unit. In part this may be aided by hydrogen bonds creating cohesive forces within the liquid. Alternatively, drawing on fluid mechanics, when there is sufficient pressure behind the flow, and it becomes fully developed, the pressure allows it to keep its form, like the spray from a high pressure 'jet-like' garden hose. Where there is **insufficient bolus propulsion and pressure** however, **the bolus will spread in many directions within the oral cavity**. A subtle movement of the tongue, or an incomplete lip closure will see the bolus escaping from the lips, pooling in the cheeks (buccal sulci) or disappearing over the base of the tongue and into the pharynx at a speed dictated by gravity.

- How does one slow the bolus to allow weak or poorly timed muscles to control a fast-moving liquid?
- How does one provide sensation to alert the body that a bolus is present within the oral cavity where oral sensation is diminished?
- How does one provide a smooth, homogenous bolus where the oral system is unable to create one by chewing and/or bolus manipulation?
- How does one provide a wet and slippery bolus where the body is unable to generate this by producing enough saliva to make the bolus and the mucosa slippery to aid bolus transport?

Thickening of a liquid address many of the questions raised. It will **reduce the speed of movement**, and at that same time the **thick nature of the liquid can be more easily 'sensed' within the oral cavity than a thin liquid.** Liquids such as water, milk, juice, tea, coffee, and wine for example, are classified as 'thin' liquids. They flow freely, quickly and unpredictably.

Thickened liquids **allow the body more time to respond, creating a compensatory mechanism to assist airway protection**. The concept of thickness is known as 'viscosity'.

The **addition of thickening agents to regular liquids** to **increase their viscosity provides a reasonable hypothesis to address the challenges raised by dysphagia for liquids**. The ideal attributes of the bolus and their impact on the oral and pharyngeal phases of swallowing are shown in Figure 4.

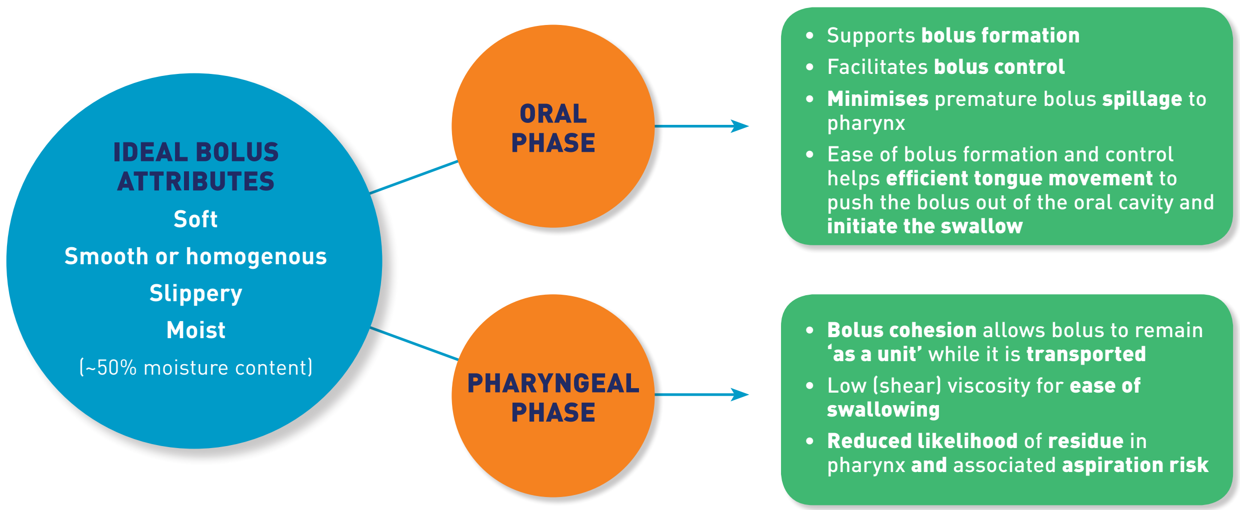

Figure 4. Ideal attributes of the bolus and their impact on the oral and pharyngeal phases of swallowing

6. Properties of thickeners and their mechanism of action

Liquids can subjectively be described as 'thin', like water, or 'thick', like a thick-shake. Rheology is the study of the deformation and flow of matter. Rheologically, all fluids are described in terms of (a) viscosity, (b) density, and (c) yield stress. Although these features of a bolus are most commonly described, there may be other features that are relevant to products designed to aid swallowing for people with dysphagia.

6.1.Viscosity

When objectively describing the 'thickness' of liquids this is a discussion of 'viscosity'. **Viscosity is the resistance of a substance to flow under an applied force.**

Liquids like water do not have much resistance to flow and are, therefore, classified as 'low viscosity'. It takes little effort to stir water with a spoon.

Liquids like molasses or tomato sauce (ketchup) have very slow flow rates and consequently a 'high viscosity'. This time the effort to stir is much greater due to the internal structure of the liquid.

The **unit of measurement for viscosity** in the International System of Units (SI) is pascal-seconds, although it is more commonly reported in the dysphagia literature as **millipascal-seconds** (mPa.s). Viscosity may also be reported in the unit **Centipoise (cP)**, where 1cP=1 mPa.s.

Viscosity can be measured by apparatus that vary in design and are chosen as 'fit for purpose' depending on the nature of the sample to be tested. **Viscometers** or **rheometers** are generally rotational or capillary style instruments and are used for time-dependent measurements.[27] Figure 5. Parallel plate and cone and plate geometries are often reported for measurement of viscosity in the Literature. These devices are most often found in laboratories or in universities and are rarely found in health settings.

When measured using a rheometer, **water** at 20°C, measured at a shear rate of $50 s^{-1}$, has a viscosity of 1.0 mPa.s.[28] In contrast, **honey** has a viscosity of 10,000 mPa.s, and the **tomato sauce (ketchup)** mentioned earlier has a viscosity of 50,000 mPa.s. The larger the number, the thicker the substance. Although water and honey have very different thicknesses, they are both Newtonian fluids.

Newtonian fluids can be described as fluids where the force required to make the fluid flow is directly proportional to the resulting amount of flow.[28] The internal structure of the hydrogen and oxygen molecules within the liquid makes it easy for them to slide over one another. Not all liquids, however, are Newtonian in nature.

For non-Newtonian fluids the viscosity varies with the force being applied to the fluid (or rate of strain). In practical terms, if one stirs thickened liquids slowly, they appear thick. However, the more vigorously one stirs thickened fluids, the thinner they become. In measurement then, we need to know how much strain is being applied to the fluid, or 'how vigorous the stirring is', to be able to anchor and describe the viscosity in a meaningful way. Non-Newtonian fluids can be further sub-categorized. Thickened liquids used in dysphagia management can be 'shear thinning', meaning that the fluid's resistance to flow decreases with increasing rate of shear. That is, they become thinner when sheared ('stirred' or moved) quickly.

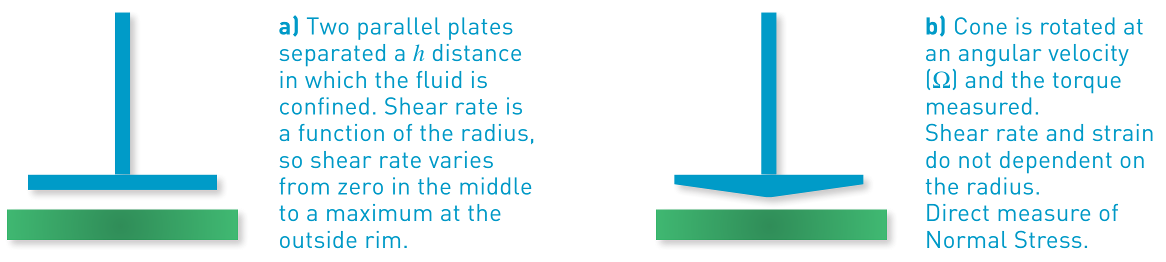

Figure 5. 5a. Schematic of parallel plate geometry and 5b. Schematic of cone and plate geometry for measuring viscosity

Water and honey are both ***Newtonian fluids***

Food items tomato sauce (ketchup) and mayonnaise; and thickened liquids used in dysphagia management, are ***non-Newtonian fluids***

To accurately appreciate the viscosity of thickened liquids, it is critical that the shear rate being applied to the liquid is known. This is particularly important for understanding the viscosity of non-Newtonian liquids. As noted above, apply a vigorous or fast rate of strain, and the liquid becomes thinner; apply a slower rate of strain and the liquid maintains its thickness level.

In the oral cavity as we savour a spoonful of chocolate pudding there is little tongue movement, however, a pudding that has an unpleasant flavour may be moved very quickly through the oral cavity and into the pharynx. Thus, the tongue plays a critical role in changing the shear rate, or how vigorously the bolus moves in the mouth, and ejection from the oral cavity into the pharynx. The pharyngeal constrictors also play a role in sweeping the tail of the bolus through the pharynx, applying a further shear rate.

Dating back to the early 1990's shear rates were reported for swallowing in the range of $1\text{-}100 s^{-1}$ with an average value of $50 s^{-1}$ [29-30] By way of example $50 s^{-1}$ refers to a change in velocity from 0 to 50mm/sec over a distance of 1mm.[31] While a Newtonian fluid such as water has a constant viscosity of 1 mPa.s regardless of whether it is sheared at $50 s^{-1}$ or $100 s^{-1}$, for non-Newtonian liquids the viscosity values measured at $50 s^{-1}$ vs. $100 s^{-1}$ are very different. As shown in Figure 6 below, the samples measured at a shear rate of 50 s-1 are thicker than when they are measured at a faster shear rate of $100 s^{-1}$.

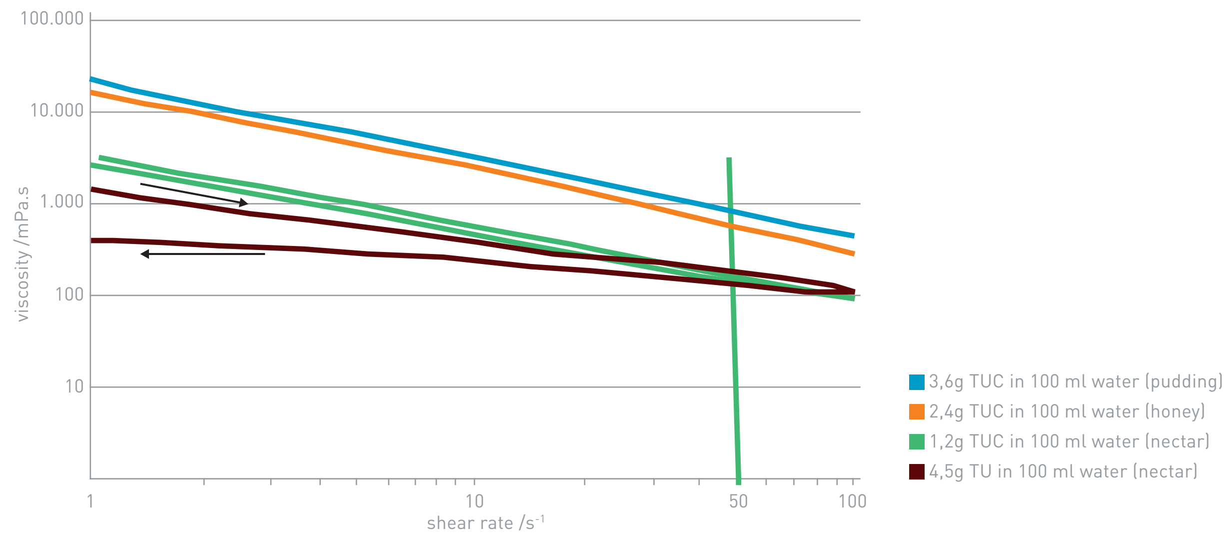

Figure 6. Viscosity of samples of thickened liquids at various shear rates, with a focus on viscosity (thickness) at $50 s^{-1}$. Abbreviations: **TUC**, Resource® ThickenUp Clear; **TU**, Resource® ThickenUp. *Source: Popa Nita el al, 201331*

Stokes *et al.*[32] challenge that although it may be possible to create thickened liquids that have a similar viscosity at $50 s^{-1}$ the viscosity above and below this shear rate is far more difficult to control due to properties such as elasticity. In fact, Popa Nita *et al.*[31] clearly demonstrate this point showing that for shear rates at and above $50 s^{-1}$ that there is little difference in the apparent viscosity of Varibar®Honey and Pudding liquids. Although for healthy people an oral shear rate of $50\text{-}100 s^{-1}$ has been put forward for industry standard testing, the oral shear rates of individuals with dysphagia are unknown. With poor tongue strength and coordination, that is a common feature of oral dysphagia, it would be reasonable to suggest that the oral shear rate for individuals with dysphagia would be far less than $50 s^{-1}$.

Why is shear rate important?

The variability in bolus speed and pressure during the swallowing process means that the bolus is subjected to a range of stresses that differ between the oral cavity, the pharynx and the oesophagus. If we accept that the oral shear rate may be 50 s^{-1}, the pharyngeal shear rate has been proposed to vary from 120 s^{-1} within the pharynx *above* the larynx and approximately 990 s^{-1} within the pharynx *below* the larynx.[33] The results reported were based on a very small sample size of three individuals. This means that a thick liquid may start as one thickness in the oral cavity, but as it is swallowed, it may become thinner and more stretched due to muscular forces acting upon it, like a 'mechanical insult'. Pressure changes from ~ 200 mmHg at the tongue base increasing to 300 mmHg in the pharynx means that the bolus will be stretched and become thinner as it passes through the pharynx. Warming of the bolus to equilibrate it towards body temperature as it passes through the oral cavity and pharynx may also improve bolus malleability and swallowing ease.

The anatomical design of the pharynx and physiological process of swallowing promotes bolus flow safely around the larynx helping to compensate for thinning of the bolus that occurs in the pharyngeal phase during swallowing.[34] For individuals with dysphagia, the degree of tongue propulsion and pharyngeal action to squeeze the tail of the bolus past the larynx will thin the bolus as compared to its original thickness in the mouth, however it will not be the same as the deformation produced by the pharyngeal pressures of a healthy individual. Further if there is **no propulsion** and the bolus falls over the base of the tongue at a speed dictated by gravity, this is faster than if the bolus is controlled during swallowing.[34]

***Thin liquids move rapidly** and can spill out of the mouth and into the throat.*

The **thickness of the bolus** has an impact on its velocity as it travels through the pharynx. In a study of healthy individuals of different ages, swallowing liquids of different thickness levels, differences in bolus velocity were identified.[35] Of interest gender and age differences were noted. Age-related changes were noted for males such that the bolus tail velocity decreased as males became older. However, for females there was a constant average swallowing velocity regardless of age. When the fluid thickness reached 496 mPa.s or greater, the effect of velocity was reduced regardless of gender and averaged at 85-100 mm/s as per Figure 7.

Thickness of the bolus (viscosity)** has an impact on its velocity, it moves more slowly through the oral cavity and pharynx than thin liquids **resulting in safer swallowing due to a lower incidence of aspiration and infiltration into the larynx.

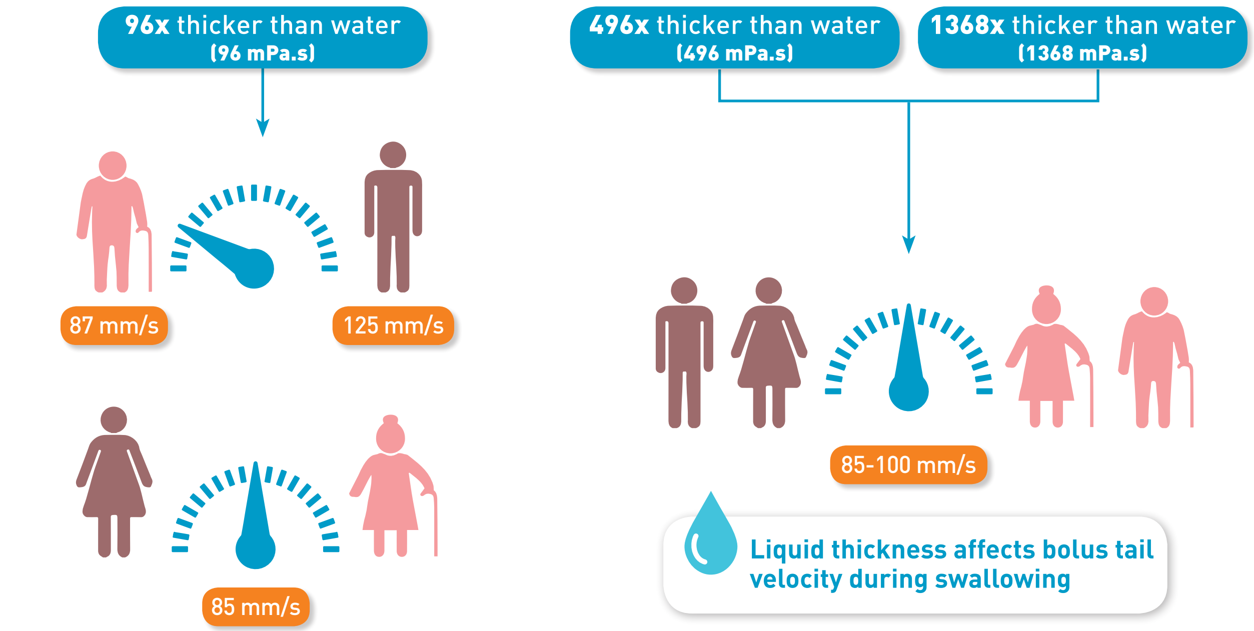

Figure 7. Liquid thickness affects bolus tail velocity during swallowing

Fluid thickness also affects **pharyngeal pressures** such that higher pharyngeal contractile integral pressures have been recorded for pudding thick liquids (>1750 mPa.s) compared with thin liquids for healthy individuals (300 mmHg.cm.s vs. 223 mmHg.cm.s).[15] Pharyngeal pressures of 188 mmHg.cm.s, however, are associated with swallowing impairment, suggesting that the pharyngeal shear rate for people with dysphagia is less than that for people with intact pharyngeal function.

Whilst the viscosity of a liquid provides us with useful information, it does not provide us with a complete understanding of the structure of the fluid.

As an analogy, imagine that we know the weight of an individual. For argument's sake the adult person weighs 55 kg. However, we need much more information before we can determine whether this person's weight should be cause for concern. If the person were male, 55 kg and 190 cm in height, then we would have grave concerns for his physical health, compared to the same weight of a female of 159 cm height. A similar situation occurs with thickened fluids. To have just the viscosity information alone is insufficient. To truly understand the behaviour of thickened fluids we need to consider the material properties of density and yield stress to increase our understanding.

6.2. Density

Density of a fluid is mass per unit volume and most closely equates with the weight of the fluid.

One tends not to think of fluids as having characteristics that make them 'heavy' or 'light', however, this aspect of a fluid's characteristics becomes important when considering the addition of barium to fluids, as is the requirement for radiographic assessment of swallowing (modified barium swallow or videofluoroscopy).

Barium has previously been reported to have high- or low-density preparations.[36] High-density barium changes the physiological parameters of swallowing such that oral transit time and pharyngeal clearance time is longer than for low-density barium preparations. Increased density of barium-enriched thickened fluids when compared with unenriched thickened fluids has also been reported in the literature.[37] Further, two liquids may have the same viscosity but have different densities. For example, thickened infant formula has a density of 0.91 g/cm^3 while liquid barium has a density of 1.62 g/cm^3, despite both liquids being of comparable viscosity.[36]

A fluid that has a **higher density will require more force to generate movement**. Nicosia & Robbins[38] reported that density is a major determinant of fluid ejection from the oral cavity for low viscosity (*i.e.* thinner) liquids, while for thick fluids (1000 mPa.s and greater), viscosity is more important. Between the values of 100-1,000 mPa.s, both viscosity and density have been found to affect ejection time in a mathematical model based on Newtonian fluids.[38] Density of a fluid is usually measured by accurately weighing the fluid of interest in a graduated cylinder of known volume and is reported in g/cm^3.

6.3. Yield Stress

Yield stress relates to the **composition of the fluid**. A fluid that has a 'yield stress' is one where an inherent structure of the fluid must be broken down to allow the fluid to flow. **Yield stress is defined as the stress above which flow occurs.**

Fluids that have a yield stress are usually a particle-filled fluid or a gel.

Consider a single billiard ball and then a group of billiard balls packed close together. There is minimal effort required to push the single ball, however, the more balls that are added to the group, there is an increase in effort required to move the balls as a group. This is because you first need to overcome the packing arrangement (yield stress) before flow (or in this case movement) will occur. [39]

Steele and Van Lieshout[40] reported the yield stress of honey-thick apple juice at 1.42 Pa, whilst its barium counterpart showed a yield stress of 2.1 Pa; not quite double the magnitude. In this instance, more tongue force could be anticipated in order to make the bolus flow. The thicker the fluid, the greater will be its resistance to shear stress. Yield stress is determined from plots of viscosity versus shear stress as measured using a viscometer or rheometer. If viscosity is seen to approach infinity as shear stress approaches zero, then a yield stress is said to be present. Yield stress is measured in Pascals (Pa).

Whilst all three elements of viscosity, density and yield stress most accurately describe any given liquid, as fluids become thicker, the importance shifts to viscosity, with density reportedly playing a limited role.

There are other emerging bolus parameters that also influence swallowing safety. These include cohesion, adhesion, surface tension and perhaps others. These parameters relate to textural and sensory features such as stickiness, slipperiness and fracturability. Evaluation of cohesion or bolus elasticity is emerging as a critical feature of the swallow-safe bolus. [41-42]

7. Effect of bolus viscosity on swallowing safety and swallowing efficiency in oropharyngeal dysphagia (OD) patients

7.1. Effect of viscosity on the oral and pharyngeal stages of swallowing

To determine the effectiveness of thickened liquids as an aid to swallowing safety and swallowing efficiency there are a number of parameters that clinicians review. These are summarised in Table 1.

7.2. Effect of viscosity on swallowing safety and swallowing efficiency

Thick fluids show a number of **physiological changes** to swallowing biomechanics **that assist with safer swallowing.**

For individuals with dysphagia, swallowing thick fluids results in smaller sip sizes,[40] demonstrating an improved ability to sense the bolus with a smaller volume delivered to the airway if aspiration were to occur.

Physiologically, swallowing thick fluids have been found to result in longer periods of breath-holding during the swallow (apnoea), and an exhalation breath after the swallow, which are both part of the natural airway protection mechanism.[43] Chi-Fishman & Sonies,[44] also found that swallowing of thickened fluids shows longer periods of pre-swallow hyoid gestures than thin fluids. This action assists in opening the upper oesophageal sphincter via the hyolaryngeal pulley-like excursion, facilitating passage of the bolus away from the pharynx and into

Parameter of the bolus or physiology measured during radiographic swallowing assessment	Impact on swallowing safety
The size of the bolus naturally selected	Natural selection of a small to moderate bolus as opposed to a large bolus demonstrates an ability to 'sense' the presence and size of the bolus
Segmentation of the bolus within the oral cavity	The decision to segment a single bolus into smaller boluses for swallowing indicates the ability to 'sense of the size of the bolus' and choose to hold some of the bolus in the mouth and progressively swallow small portions until the entire mouthful has been cleared
Efficiency of oral transit time	A bolus that moves efficiently through the oral cavity is less likely to pool in the mouth and mix with saliva, thinning the solution and making it more difficult to control
Efficacy of oral transit	Well-executed oral transport leaves minimal residue requiring fewer clearing swallows
Hyoid movement	Good hyoid movement is associated with well-functioning pulley like connections to enable opening of the upper oesophageal sphincter, allowing the bolus to pass out of the pharynx and into the oesophagus
Efficiency of pharyngeal transit time	A bolus that moves efficiently through the pharynx reduces the amount of time the person needs to hold their breath (apnoea) to protect the airway. Well executed pharyngeal transport leaves minimal residue in the pharynx that will require clearing swallows to allow breathing to resume without risk of drawing residue into the airway
Accuracy of pharyngeal transit (presence or absence of aspiration)	Accurate pharyngeal transit results in the bolus being delivered to the oesophagus, rather than the airway
Breath-holding duration while the bolus is passing through the pharynx (apnoea)	Ability to breath-hold for the entirety of the time the bolus is in the pharynx and in proximity to the airway entrance is a protective feature
Total swallow duration	Short swallow duration and long swallow duration can both be positive features. Their categorisation needs to be viewed in conjunction with whether the speed of the swallowing event resulted in aspiration or avoided aspiration

Table 1. Bolus parameters observed during radiographic assessment of swallowing and its impact on swallowing safety and swallowing efficiency?

the oesophagus; a protective gesture. Maximum oral muscular activity has been found to increase as liquids and pastes become progressively thicker.[45] Total swallow duration increases from liquids to thin pastes (e.g. apple sauce) to thick pastes (e.g. cheese spread or peanut butter). The evidence related to **the number of different levels of thickened fluids demonstrates benefits related to thin fluids vs. paste thickness.**[45-46]

Two recent systematic reviews of the literature **both confirm the benefit of thick fluids in reducing aspiration.**[47-48] Specifically, the reviews found that **thickened liquids increase swallowing safety by reducing the likelihood of penetration and aspiration.** Figure 8. This is in agreement with the work of Zhu *et al.*[34] who described using fluid mechanics and videofluoroscopy that **increasing liquid viscosity changes flow through the pharynx from fast gravity driven flow to slow, displacement flow, and a consequent reduction in bolus velocity.**

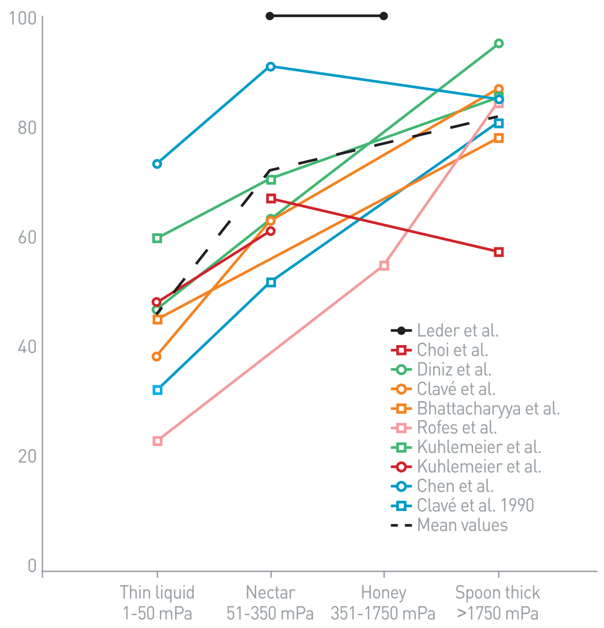

Figure 8. Benefit of thick fluids in reducing aspiration[48]

However, both systematic reviews also found that thicker consistencies, (especially pudding thick) regardless of thickening agent were associated with an increase in residue in the pharynx after the swallow, potentially resulting in post-swallow airway invasion.[48] Moreover, Bolivar-Prados *et al.*[49] and Vilardell *et al.*[50] in recent studies have shown, the use of xanthan gum-based thickening agents improve safety of swallowing without increasing pharyngeal residue.

Robbins *et al.*[51] demonstrated that for individuals with dementia in long-term care settings, there is a two-fold increase in the incidence of pneumonia for individuals provided with liquids thickened to 3000 mPa.s as opposed to liquids thickened to 300 mPa.s

Bisch *et al.*[46] examined differences in swallowing physiology as a function of viscosity for small samples of healthy individuals and those following stroke or neurological impairment. **The increase in viscosity from a thin liquid to a pudding consistency resulted in safer swallowing for the stroke population due to improved timeliness of swallow reflex initiation.** For the neurologically impaired group, benefits to safer swallowing were also demonstrated with a pudding consistency. For example: slowed bolus transport, improved timeliness of swallow reflex initiation, earlier airway protection, faster pharyngeal processing and longer opening of the UES, allowing a better chance of clearing the bolus through the pharynx and into the oesophagus.

Raut *et al.*[52] found that with increased viscosity, the hypopharynx contracts harder and for longer to protect the pharynx. **This pattern fits with the recommendation of speech pathologists to recommend the use of thickened fluids to protect the airway.** However, they caution that for 'weak' and sarcopaenic patients or those with pharyngeal phase dysfunction, the ability to swallow thick and viscous substances is impaired due to an inability to produce the pressures at the tongue and pharynx required to move the bolus. Moreover Newman *et al.* found that thickened liquids induced increased tongue pressure patterns during swallowing and a reduced compliance with consumption as thickness increased.

Increased viscosity does not solely explain improved swallowing safety. A 2014 prospective, double-blind study investigating the **effects of viscosity on aspiration in patients with dysphagia, found that while both starch and gum-based thickeners reduced aspiration events, the gum-thickened liquids appeared to be more effective compared to water, despite being a lower viscosity than the starch-based thickened liquid.**[53] Properties other than viscosity provide textural and sensory cues that may be protective for swallowing function. The impact of being able to provide improved swallowing safety at a lower viscosity level is that compliance with consuming thickened liquids, and therefore hydration, is better with thinner liquids.

Clinical practice guidelines for the management of dysphagia issued by several associations, including the European Society for Swallowing Disorders (ESSD)[54], the European Union Geriatric Medicine Society (EUGMS)[55], the European Society for Clinical Nutrition and Metabolism(ESPEN)[56-57], World Gastroenterology Organization global guidelines[58], the National Institute for Health and Care Excellence (NICE)[59] , the British Dietetic Association[60], and the Scottish Intercollegiate Guidelines Network[61], recommend an intervention with dietary modifications including liquids of appropriate viscosity/consistency such as thickened fluids with the aim of reducing the risk of aspiration pneumonia. Table 2.

Clinical practice guideline	Key recommendations
European Society for Swallowing Disorders Position Statements, 2012 [54]	• Evidence-based individualized treatments include bolus texture modifications and postural adjustments alongside stimulation-based therapies - all of which require further cost-benefit analysis. • A variety of texture modified foods/modified fluid consistencies should be offered/provided to promote enjoyment and encourage intake.
European Society for Swallowing Disorders – European Union Geriatric Medicine Society white paper: oropharyngeal dysphagia as a geriatric syndrome, 2016 [55]	• Suggest guidelines published by the British Dietetic Association and the Royal College of Speech and Language Therapists to provide detail on the kinds and textures of alimentary products needed by patients with oropharyngeal dysphagia. • Patients following modified texture diets should have their swallowing and nutritional status regularly assessed, after the first week and then every 2-3 months for the first year and then every 6 months.
European Society for Clinical Nutrition and Metabolism guideline clinical nutrition in neurology, 2018 [56]	• Liquid thickening should be applied in patients with oropharyngeal dysphagia aspirating on liquids. Liquid intake needs to be closely monitored since there is a high risk of insufficient oral intake – Recommendation A (strong consensus: 100%). • To improve patients' compliance different types of thickening agents should be offered for choice – GPP recommendation (strong consensus: 95%). • Thickened liquids should be used in persons with chronic dysphagia to enhance nutritional status – Recommendation B (strong consensus: 100%).
ESPEN guideline in geriatrics, 2019 [57]	• Texture of food and drinks that can be swallowed safely should be determined by a dysphagia specialist at an individual level.
World Gastroenterology Organization global guidelines, 2014 [58]	• Oral feeding is best whenever possible. Modifying the food consistency to thicken fluid, and diet change with softer foods, can make an important difference.
National Institute for Health and Care Excellence CG - Stroke rehabilitation [59]	• Offer swallowing therapy at least 3 times a week to people with dysphagia after stroke who are able to participate, for as long as they continue to make functional gain. • Swallowing therapy could include compensatory strategies, exercises and postural advice.
British Dietetic Association, 2006 [60]	• Patients who have chewing or swallowing difficulties need fluids and foods of a particular texture and consistency in order to eat without risk of choking or aspiration.
Scottish Intercollegiate Guidelines Network, 2010 [61]	• Advice on diet modification and compensatory techniques should be given following full swallowing assessment.

Table 2. Clinical practice guideline recommendations on compensatory management based of dysphagia

8. The benefits of commercial thickeners to achieve swallowing safety and swallowing efficiency in OD

Increasing the viscosity and/or limiting the volume of liquids is an important method of improving swallowing safety and **swallowing efficiency in OD patients** (reducing penetration into the airway and the likelihood of aspiration). Several clinical and non-clinical studies reported that increasing the bolus viscosity from liquid to nectar and pudding by commercial thickeners significantly reduced the prevalence of laryngeal penetration and aspiration in patients with OD, indicating the beneficial effect of this technique. Table 3.

Study	Design	N	Patient population	Interventions	Comparator(s)	Key outcome measure(s)
Steele CM *et al*, 2019[62]	Prospective, single blinded	332	Stroke or other brain injury aged ≥21 years; Other inpatients or outpatients with dysphagia risk, aged ≥50 years	Xanthan-based thickener (RTUC)	Thin liquid	Swallowing safety Efficiency of swallow as measured by rate of residue
Vilardell *et al*, 2016[50]	Retrospective	122	Adults (≥18 years) with chronic post-stoke OD	Xanthan-based thickener (RTUC)	Thin liquid (mineral water) Starch-based thickener (RTU)	Prevalence of clinical and VFS signs of OD Incidence of aspiration Physiology of swallow response Residues quantity
Leonard *et al*, 2014[53]	Prospective, randomised, double-blind	118	Adults (≥18 years) with dysphagia	Xanthan-gum based thickener (RTUC)	Thin (thin liquid barium) Starch-based thickener (RTU)	Incidence of aspiration PAS score
Rofes *et al*, 2014[63]	Prospective, open label	134	Adults (≥18 years) with dysphagia (n=120) Healthy volunteers (n=14)	Xanthan-gum based thickener (RTUC)	Thin liquid	Prevalence of clinical and VFS signs of OD Physiology of swallow response Residues quantity

Table 3. Clinical and non-clinical studies on effect of viscosity in OD patients

Steele *et al.*[62] carried out a prospective study to assess swallowing impairment in **322 individuals** in the US. The **safety and efficiency of swallowing was measured** using videofluoroscopy during **swallows of liquid barium stimuli in thin, mildly, moderately and extremely thick viscosities.** The results showed that:

- Swallowing safety improved as the thickness of the liquid increased from thin to mildly, moderately and then extremely thick.
- Impairments of swallowing efficiency (as measured by the presence of residue at the end of any swallow) were reduced with increasing thickness of the liquid swallowed.

This study supports the benefits of commercial thickener, based on xanthan gum, to improve the swallowing safety and swallowing efficiency of swallowing in patients with oropharyngeal dysphagia. This is in contrast to starch-based thickeners where residue increases with increasing viscosity.

Leonard *et al.*[53] conducted a prospective, randomised, double-blind study. They compared the **effects of viscosity on swallowing safety in patients with dysphagia (n=118)** when using either a xanthan gum-based thickening agent (Resource® ThickenUp Clear), thin liquid or a starch-based agent (Resource® ThickenUp). The results showed that:

- Thickened liquids were significantly effective in reducing the incidence of aspiration compared with a thin liquid, as measured by videofluoroscopy (VFS) instrumental evaluation (21.5% vs 50.0%; p<0.05).
- The aspiration rate observed for the liquids thickened with xathan gum was lower than that observed with a starch-based thickener, although the difference was not statistically significant (21.5% vs 28.5%; p>0.05).

Vilardell *et al.*[50] compared the **effects of bolus viscosity of two commercial thickeners agents**, a xanthan gum-based thickener (Resource® ThickenUp Clear) and a modified-starch thickener (Resource®

ThickenUp) **on swallow safety and efficacy in post-stroke adult patients with chronic oropharyngeal dysphagia (n=122).** Patients were studied by clinical assessment (V-VST) and VFS methods using three viscosities (liquid 0-50 mPa.s, nectar 51-350 mPa.s and spoon thick >1750 mPa.s). Results from this study showed that:

- Increasing bolus viscosity with both thickeners improved safety of swallow in post-stroke patients with chronic oropharyngeal dysphagia, compared with thin liquids:
  - With both thickeners, the prevalence of clinical signs of safe swallowing significantly increased with enhanced viscosity compared with thin liquid (p<0.001 vs liquid), as shown by significant reductions in voice changes (p<0.001 vs thin) and cough after deglutition (p<0.01 vs thin).
- The prevalence of penetrations and aspirations at nectar-like viscosity, as evaluated by VFS and measured by PAS, was significantly lower with Resource® ThickenUp Clear than with the modified-starch thickener (19.5% vs 44.0%, p<0.01).
- In contrast to liquids thickened with the modified-starch thickener, liquids thickened with the xanthan-gum thickener had a lower prevalence of pharyngeal residue across all of the viscosities tested (9.0% vs 25.0%, 33.8% and 51.8% for thin liquid, nectar- and spoon-thick, respectively), as measured by VFS evaluation.

Rofes *et al.*[63], conducted another prospective, open label study to **assess the effects of bolus viscosity using a commercial xanthan gum-based thickener** (Resource® ThickenUp Clear) **on the clinical signs of oropharyngeal dysphagia and on swallow function in dysphagic patients (n=120), compared with thin liquids.** Results from this study showed again that increasing bolus viscosity (from thin liquid to nectar-thick and spoon-thick) **improved the safety of swallow compared with thin liquid without increasing residue,** as demonstrated by:

- A significant reduction in the prevalence of cough (p<0.05 vs thin-liquid) and voice changes (p<0.001 vs thin liquid) as indicators of aspiration and penetration respectively. This was observed by a validated method of clinical assessment, the volume-viscosity swallow test (V-VST).
- Significant reductions in the prevalence of aspiration as measured by VFS instrumental evaluation: 12.7% with thin-liquid, 7.7% with nectar-like (p<0.01) and 3.4% with spoon thick (p<0.01) viscosity.
- Significant reductions in prevalence of penetration and aspiration, as measured by PAS scores with use of VFS: 3.24±0.18 with thin liquid, 2.20±0.18 with nectar-like (p<0.001), 1.53±0.13 with spoon-thick (p<0.001) viscosity.
- No significant increase in prevalence of oral or pharyngeal residue was observed at nectar-like viscosity, compared with thin-liquid.

In a large clinical trial, increasing bolus viscosity (from thin liquid to nectar-thick and spoon-thick) improved the safety of swallow compared with thin liquid, without increasing residue in dysphagia patients for xanthan-based thickeners.

9. Consistent Terminology to avoid variations of the Viscosity of Thickened Liquids

Prior to 2017, **countries around the world had their own methods for naming and differentiating various levels of liquid thickness**. The earliest recognised system for categorising foods and liquids used in dysphagia management was the **National Dysphagia Diet** (NDD) guidelines on thickened dietary supplements, developed by the American Dietetic Association and the National Dysphagia Diet Task Force in 2002.[64]

The NDD guidelines categorised viscosity into thin, nectar-thick, honey-thick and spoon thick/pudding-like thickness levels (Table 4). Further the NDD provided guidance on the recommended thickness range for each of the thickness levels measured using a rheometer with liquids at a temperature of 20 °C measured at 50 s^{-1}. Over the years several studies demonstrated that the apparent viscosity of thickeners, when prepared according to manufacturer recommended methods, did not correspond to the expected thickness level according to the NDD.[65] Variability of this sort poses risks to patients. It is also important to note that the NDD scale was developed when **starch-based** thickeners were the norm. The subsequent development of shear-thinning xanthan gum-based thickeners further exacerbated the issue.

Thickened fluid classification	Range of fluid viscosity
Nectar-like thickened liquids	51–350 cP
Honey-like thickened liquids	351–1750 cP
Spoon thick/Pudding-like thickened liquids	>1750 cP

Abbreviations: cP, centipoise. Measured at 20 °C, and shear rate of 50 s^{-1}

Table 4. National Dysphagia Diet fluid viscosity scale

However, by 2013 it was apparent that different scales, labels and measuring methods had been developed for national use in Australia, Ireland, Japan, New Zealand, Sweden, the UK and Denmark. When reviewed, there were similarities and differences between the various scales.[66] **The variations posed risks to patient safety and limited the ability of clinicians or researchers to compare results of research and generalise their findings when thick liquids or texture modified foods were used therapeutically.**

In 2017, an **international multidisciplinary group** led the development of an international framework (IDDSI) to label, describe and measure liquids of different thickness and foods of different textures. In a survey of current practice from **2050 respondents from 33 countries**, there was considerable variation in terminology used both within and between countries. However, most drink options recorded thin liquids plus three or more levels of progressively increasing thickness.[67]

The **IDDSI Framework** provides a **common terminology to describe food textures and drink thickness.** IDDSI tests are intended to confirm the flow or textural characteristics of a particular product at the time of testing. Testing should be done on foods and drinks under the intended serving conditions (especially temperature) given that this is the condition the patient will consume the liquid. The clinician has the responsibility to make recommendations for foods or drinks for a particular patient based on their comprehensive clinical assessment. The framework was developed by evidence-based methods, including systematic review and stakeholder engagement from 33 countries.

The Framework consists of **8 levels** (0-7) where **drinks are measured from levels 0-4 and foods are measured from Levels 3-7** (See Figure 9). The Framework is identified by numbers, text labels, colour codes, definitions and measurement methods. It is designed to be used for all people, of all cultures, and in all care settings.

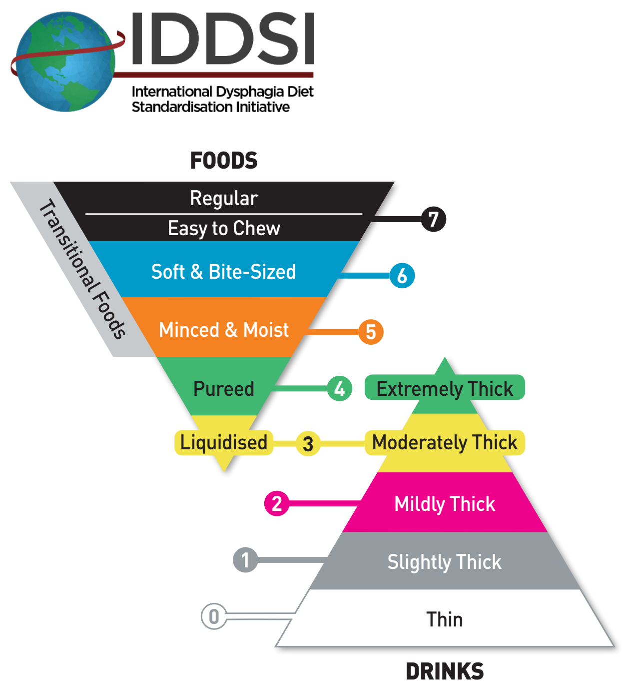

Figure 9. The IDDSI Framework: International Dysphagia Diet Standardisation Initiative 2019 @ https://iddsi.org/

The **published literature prior to 2017 supporting the use of thickened liquids** for the management of dysphagia uses nomenclature from **before IDDSI Standardised terminology** was in use. Table 5 provides an approximate conversion chart for reference. The national and international terminologies provide a method of describing thickened liquids. Some have accompanying methods of measuring liquid thickness. Although thickness is scaled from thinner to thicker, the scale itself does not imply safety. It is the clinician who determines the safety for any particular thickness level for the individual needs of the person.

For example, while individuals post stroke may benefit from a moderately thick or extremely thick liquid to reduce the likelihood of aspiration, a person recovering from head and neck cancer may be at risk on moderately or extremely thick liquids as they lack the tongue propulsion to drive the bolus far enough into the pharynx, potentially resulting in residue post swallow. Individuals recovering from surgery or chemo/radiotherapy may benefit more from mildly thick liquids.[10]

IDDSI	NDD	Australia	UK	Japan
0 Thin	Thin (1-50 cP)	Regular	Thin	Less Mildly thick (< 50 mPa.s)
1 Slightly Thick	No equivalent	No equivalent	Naturally thick	Mildly Thick (50-150 mPa.s)
2 Mildly Thick	Nectar-like (51-350 cP)	Level 150 Mildly Thick	Thickened Stage 1	Moderately Thick (150-300 mPa.s)
3 Moderately Thick	Honey-like (351-1750 cP)	Level 400 Moderately Thick	Thickened Stage 2	Extremely thick (300-500 mPa.s)
4 Extremely Thick	Spoon-Thick (>1750 cP) *Pudding-Thick	Level 900 Extremely Thick	Thickened Stage 3	Over Extremely Thick (>500mPa.s)

IDDSI – International Dysphagia Diet Standardisation Initiative; NDD – National Dysphagia Diet (USA)
*Spoon-Thick is also referred to as 'Pudding-Thick' in some dysphagia literature

10. Thickeners and thickened liquids for special medical purposes

Thickened liquids are rarely a liquid of choice, but one of necessity for safety. They are prescribed to improve swallowing safety and efficacy following a thorough evaluation by a qualified healthcare professional. Speaking very generally, the least viscous liquids are used to treat mild dysphagia whilst increasingly thicker liquids are used to manage more severe forms of dysphagia. However, prescription of fluid thickness is patient-specific and dependent on many variables that require careful evaluation by a qualified Healthcare Professional.

The prevalence of the use of thickened fluids has only been studied comprehensively for the aged care demographic. Of 25,470 residents in a skilled nursing facility, a mean of 8.3% and range of 0-28% of residents received thickened fluids for the treatment of dysphagia.[68] Most patients who required thickened liquids received nectar-thick fluids (30-60%), a smaller percentage received honey-thick fluids (18-33%), whilst only a small proportion received spoon-thick fluids (6-12%).[69] This finding is supported by recent studies demonstrating the therapeutic benefits of liquids tested in the range 150- 450 mPa.s, with no improvement on safety beyond 450 mPa.s for liquids of thickness 800, 1400 and 2000 mPa.s [49] for the cohort examined.

In a survey conducted with more than 2000 respondents over 33 countries, while considerable variation in terminology was noted, clinicians used thin liquids in addition to three or more levels of thickened drink for therapeutic purposes.[67] Of note, survey responses confirmed that paediatric and palliative care clients routinely used slightly thickened drinks for therapeutic purposes. These liquids have been measured at 80 mPa.s at 50 sec^{-1} at room temperature.[70] Although the Bolivar-Prados survey noted benefit in liquids at 150 mPa.s, they did not test liquids thinner than that consistency.[49]

Thickeners and thickened liquids "for the dietary management of dysphagia" are **regulated in the EU as "Food for Special Medical Purposes"** (FSMPs).

FSMPs are recognized as a specialized category of foods intended to be used by vulnerable patient populations, where specific legislation is critical to ensure FSMPs are appropriately labelled and marketed for their intended use. Without this specific categorization of food, it is difficult to ensure appropriate information is provided to the patient and health care professional.

FSMPs are defined in article 2(2)(g) of framework Regulation (EU) 609/2013. "FSMP means food specially processed or formulated and intended for the dietary management of patients, including infants, to be used under medical supervision; it is intended for the exclusive or partial feeding of patients with a limited, impaired or disturbed capacity to take, digest, absorb, metabolise or excrete ordinary food or certain nutrients contained therein, or metabolites, or with other medically-determined nutrient requirements, whose dietary management cannot be achieved by modification of the normal diet alone". [71]

The regulatory environment of FSMPs in the EU has been previously well described by Bushell & Ruthsatz.[72] The authors show that the definition of FSMPS is broad enough to encompass a wide variety of FSMPs necessary to meet the specific nutritional needs of many diseases, including dysphagia. All elements of the FSMP definition must be taken into consideration, and not one element should be considered in isolation to include or exclude a product from this category. The levels set out in FSMP must be considered together with the clinical case that supports their use to determine their suitability for categorisation.

Taken together with the information above, **thickeners and thickened liquids for the dietary management of oropharyngeal dysphagia meet the definition of Food for Special Medical Purposes.**

- **Different from other food agents with thickening properties** such as flour, corn-starch and tapioca, thickeners based on starch or gums are specifically processed in order to achieve a stable and appropriate texture free of lumps that are safe to be swallowed by patients suffering from dysphagia.
- The **use of thickeners under medical supervision is of paramount importance for the safety of the patient.** Thickeners are the main therapeutic pillar for dysphagia management regardless of healthcare or community setting, and regardless of age. Appropriate treatment and management by a qualified Healthcare Professional is essential for the prescription of the appropriate thickener and thickness level to best meet the person's needs from their thickened liquid for hydration and medication transfer purposes.
- The **intended use of thickeners is to enable safe feeding of patients with dysphagia, who cannot eat ordinary food or drinks without the risk of aspiration.** The prescription of thickened liquids helps to prevent common complications such as dehydration, pneumonia, reduced quality of life and economic burden.
- The measure of whether it is possible to achieve the required nutritional intake by modification of the normal diet must be considered in the context of the patient and the challenges of their disease or medical condition. The Commission Notice on the Classification of Food for Special Medical Purposes [48] explains that FSMPs **may offer nutritional and clinical advantages to patients over and above a modification of the normal diet alone.** This must be taken into account, even if to some extent a modification of the normal diet may address the nutritional requirements of dysphagia patients.

The field of dysphagia is relatively young with concerted research occurring over the last 30 years. The development of thickener types to manage dysphagia is progressing rapidly. The learnings about different thickening agents underscore the importance of understanding their conditions of use for patient safety. **To date thickener companies have provided dose rates on packaging to assist clinicians and patients to achieve particular thickness levels.** Recent research consistently demonstrates that doses for the different thickness levels need to be tailored to the product being thickened. For example, to achieve the same thickness level, the amount of thickener added to water is different to the amount of thickener added to milk.[73] **Manufacturer labelling should clearly state the liquid used to develop the thickener dose to achieve a range of thickness levels.** However, clinicians need to work with their patients to **determine individual dosages to suit each patient's individual needs, assessing the thickness level prior to serving to ensure safety.**[74] Education is required to ensure that clinicians understand that a single dose recipe per thickness level, regardless of liquid type, is an unrealistic and unsafe expectation. In much the same way that medical professionals will adjust medication dose to manage symptoms at an individual level, the same is true of thickener prescription for the management of dysphagia.

11. Ingredients of thickening agents used in clinical practice for the dietary management of individuals who suffer oropharyngeal dysphagia

The development of thickening agents specifically for the treatment of dysphagia has advanced over the years. Although food agents such as flour, cornstarch and tapioca have for centuries been used to thicken culinary items such as sauces and gravies, these items are unsuitable for use as thickening agents for people with dysphagia. Flour and corn starch clump. They are difficult to prepare, requiring heat to help them swell and absorb water. They are unstable, losing their thickness with prolonged stirring, heating or when mixed with acids (e.g. lemon juice). Early thickening agents used for dysphagia in the 1990's used modified starch that overcame the heating process to allow powdered starch to be added to cold beverages for thickening purposes. However, research published circa 2005 demonstrated problems with stability of starch-based thickening agents. Garcia *et al.*[75] found that 80% of samples thickened with starch-based thickeners became thicker 10 minutes following the standard wait time and one third thicker again 30 minutes post the standard wait time. In contrast, the gum-based thickeners maintained their thickness level at the end of standard waiting time, and 10- and 30-minutes post standard waiting time. Similar results were reported by Matta *et al.*[76] confirming good stability of gum-based thickeners. Older generation starch-based thickeners were cloudy in appearance, whereas new generation gum-based thickeners have a 'clear' appearance.

11.1. Starch-based thickening agents

Starch-based thickening agents are composed of modified starch, carbohydrate granules that have the capacity to absorb water and swell, causing an increase in liquid viscosity.[76]

Starch-based thickeners are associated with limitations such as a starchy taste and grainy texture.[76] Accurate viscosity is difficult to achieve when using starch-based thickeners due to starch settling in the solution resulting in a loss of viscosity[77], clumping and production of lumps from poor incorporation of the starch powder with the liquid or the starch solution continuing to absorb liquid and thickening over time.[78] Starch granules can be also hydrolysed by amylase, an enzyme present in saliva which breaks down starch. If the bolus stays in the oral phase for a long period of time (e.g. 10 sec +), the starch-based bolus may be broken down before it is swallowed, increasing risk of airway invasion.[79] Anecdotally, clinicians have also reported that a spoon coated in saliva that is repeatedly dipped into a container of starch thickened liquids, results in a thinning of the liquid over time.

Liquids thickened with starch require a greater number of tongue actions to successfully swallow pudding thick liquids. More recently an *in vitro* swallowing model showed that there is more post-swallow residue left in the pharynx when thicker boluses are swallowed compared with thinner boluses.[80]

11.2. Gum-based thickening agents

The new generation of thickening agents are composed of hydrocolloids, such as xanthan gum. Xanthan gum causes meshes of entanglements that water molecules become lodged in, creating stable networks that maintain viscosity levels over time. Xanthan gum thickeners offer improved palatability and are not degraded by amylase. Xanthan gum is stable in both hot and cold temperatures offering an ability to thicken hot and cold beverages.[75] This feature is important to patient compliance taking thickened liquids and therefore the ability to meet hydration targets. Due to the ability to maintain viscosity over time, improved palatability over starch-based powders and lack of sensitivity to amylase, xanthan gum-based thickeners are currently the established choice in clinical practice.

The performance characteristics of starch and gum based thickened agents are compared in Figure 10, with reference to ideal bolus attributes.

As noted previously, lower oral and pharyngeal residues are noted for xanthan gum thickened liquids as compared to starch thickened liquids.[80] The benefits associated with xanthan gum have been proposed to be related to its elastic nature and higher extensional viscosity when compared with starch thickened liquids. Mackley *et al.*[81] assessed the shear and extensional rheology of starch thickened liquids, combination (starch + gum) thickened liquid and xanthan gum thickened liquid. Starch thickened liquids were found to have fast filament decay, breaking quickly and easily. The combination thickened liquid showed cohesion with thinning of the filament before breaking while the xanthan gum thickened liquid showed extended filament holding abilities. Mackley noted that the results for xanthan gum were showed a shorter filament break up time compared with Newtonian liquids at a similar low shear viscosity. Of interest, all three sets of thickened liquids had very similar shear rheology profiles compared with the marked differences noted for the extensional rheology profiles.[81] Factors associated with cohesion, adhesion and surface tension clearly warrant further investigation.

Some studies have suggested that xanthan gum thickeners may affect the bioavailability of water in the body and contribute to dehydration due to the reduced extraction of water from xanthan gum-thickened liquids.[75] However, well-designed studies have demonstrated that water was rapidly absorbed and equilibrated within 60 minutes with water

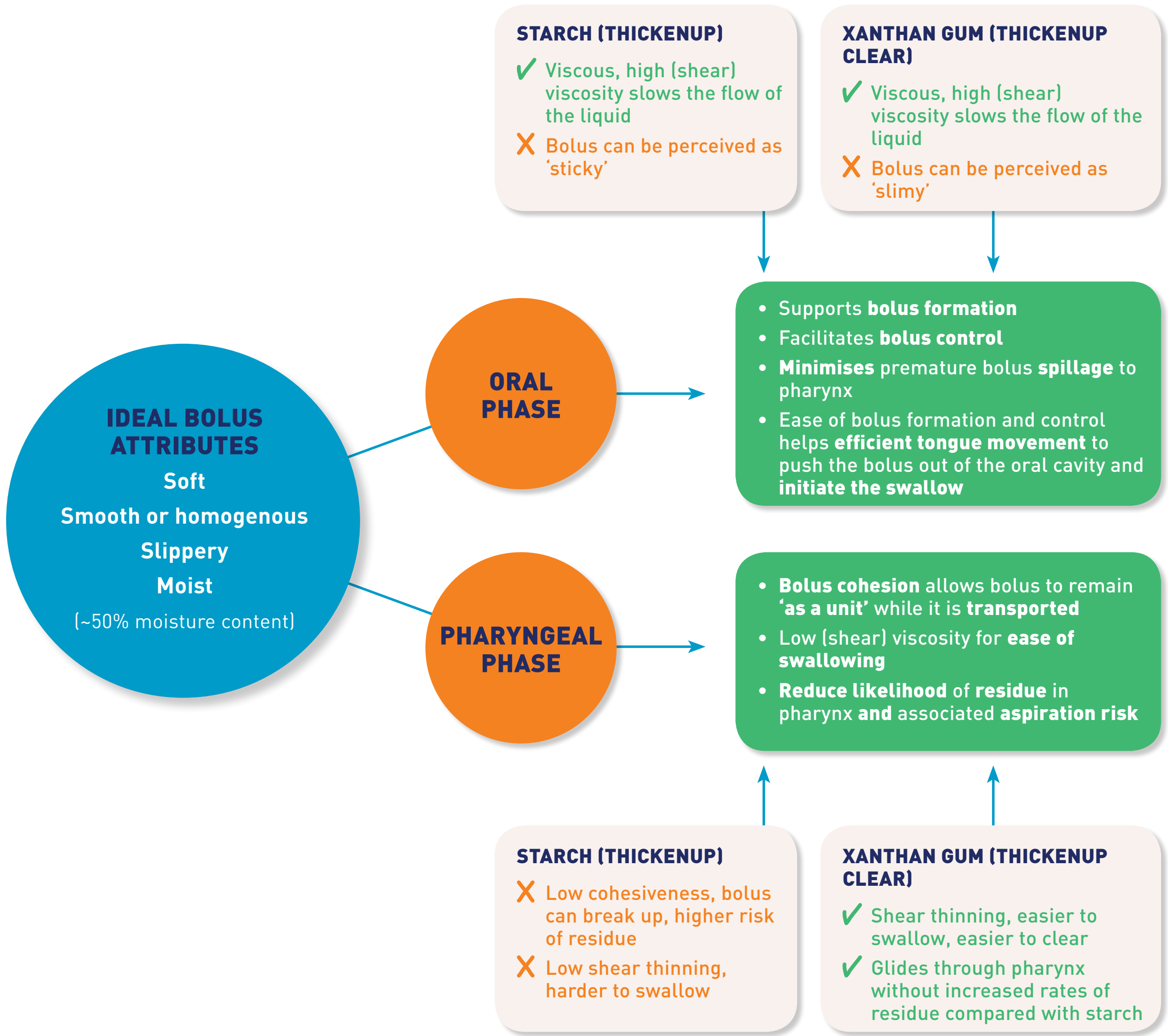

Figure 10. Performance characteristics of starch and gum based thickening agents referenced against ideal bolus attributes

absorption exceeding 95% of the administered dose of Extremely Thick liquids, suggesting that the bioavailability of water is not compromised when using thickening agents.[82]

If there is sufficient availability of water from thickened liquids, then other factors must influence dehydration commonly associated with dysphagia. Hospitalised individuals, regardless of dysphagia status, have been found to have insufficient access to containers of liquids, difficulty opening drink containers, and difficulty accessing staff to assist them with drinking.[83] Increasing levels of thirst have been statistically associated with increased levels of disability in a study of patients on oncology, orthopaedic and general medical wards. Steps can be put in place to improve access to thickened liquids, however a more challenging variable needs to be addressed. Specifically, thickened liquids do not have the same thirst-quenching characteristics that regular unthickened liquids possess. When the mouth is wet, as occurs with an influx of saliva and wetness provided by liquids, oral signals are conveyed to the brain to signal that thirst has been quenched and drinking behaviour can cease. However, thirst will persist if the oral phase is bypassed, even if the person is physiologically hydrated by direct infusion of water to the stomach.[84] Anecdotally, individuals with dysphagia complain of thirst and that thickened liquids leave a coating feeling inside the mouth. This feature is not specific to individuals with dysphagia, with a study showing that healthy individuals reported that thirst sensation progressively worsened with increasing viscosity.[85]

In addition to challenges associated with thirst quenching ability, thick liquids also result in poor flavour release. A number of studies have demonstrated that once polymers reach the critical point of random coil overlap (c*) and form entangled networks, flavour perception decreases with increasing viscosity.[86] Flavour suppression and 'off flavours' of thickened liquids have been reported by Matta *et al.* Starch based thickeners were found to impart a starch flavour and a grainy texture for nectar- and honey-thick consistencies. Gum based thickeners did not produce grainy textures but do produce a higher 'slickness' than starch-based thickeners. Flavour suppression was demonstrated for all thickening agents. A combination of poor flavour plus poor thirst-quenching ability may help to explain why patients consume less thickened liquids than unthickened liquids. The ability to target the thickness level that is just sufficient to manage the swallowing problem is a clinical skill that is necessary for swallowing safety and patient compliance. Although thickener recipes can be provided, ultimately it is the clinician's responsibility to determine what is safest for each patient.

11.3. Gellan Gum thickening agents

Gellan gum is a viscous soluble fibre that has stability over a range of pH and temperatures. It is a widely used gelling agent used in pharmaceutical formulations. Gellan gum has been developed as a thick oral gel vehicle to administer the drug carbamazepine as an alternative to solid oral dosage forms (e.g. tablets/pills).[87] Gellan gum provides a stable and consistent viscosity in solutions that are mixed with saliva containing ions, mucin and alpha amylase. These properties of saliva have been shown to thin out liquids that have been thickened with modified starch and to a lesser extent starch-gel combination thickener. [88]

11.4. Acacia Gum thickening agents

Acacia gum, also known as gum Arabic, is one of the oldest natural gums and can be described as a gummy exudate from Acacia Senegal and Acacia Seyal trees. It is a complex polysaccharide with soluble fibres and in its natural state is of low viscosity. Acacia gum is highly soluble in cold temperature and water up to concentrations of 50-55% and has been widely used as a stabiliser, thickener, and flavouring agent.[89] However, acacia gum is poorly soluble in liquids other than water. There is an exponential increase in viscosity with increasing concentration of Acacia Gum. Of interest, acacia gum displays low viscosity even at high concentrations and does not gel. Unlike the other thickening agents, the flow of acacia gum solutions at certain concentrations results in Newtonian flow behaviour at concentrations below 20% weight, meaning that there is a linear relationship between shear rate and shear stress. This is particularly the case when the shear rate is 100 s^{-1} or above. In practical terms this is important for swallowing, particularly for people with poor tongue propulsion. There are benefits when flow is able to occur in proportion to the stress applied to the liquid as opposed to needing to use energy to generate a force to overcome the resistance to make the liquid flow. Imagine the ease of pushing a box along a layer of rollers, compared with the effort associated with pushing a box along a static bench. Due to its inherent nature, acacia gum is hypothesised to provide the liquid equivalent of rollers allowing the bolus to glide easily with the movement of the tongue. This effect is evident at certain concentrations with shear thinning behaviour (*i.e.* the solution becomes thinner as the shear rate increases) occurring at low (1-4%) and high concentrations of acacia gum (20% and higher). The surface properties of acacia gum are quite unique. It is this feature that provides its ability to form a layer over the surface on which it is travelling to allow the liquid to glide easily and is demonstrated in its Newtonian nature. Furthermore, it is able to do this while remaining thick, but elastic gel-like and highly cohesive.

11.5. Carageenan thickening agents

Carageenan is a naturally occurring polysaccharide extracted from red seaweed. It is widely used in the food industry because of its physical properties such as gelling, thickening and dehydrating and is safe for human consumption. This product works by swelling and producing layers of gel. The viscosity of carrageen increases exponentially with concentration.[90] Carageenan solutions are highly affected by temperature and show a significant increase in yield stress at low temperature when compared with xanthan gum and starch-based solutions (Marcotte, 2001). Many products, including soymilk, chocolate milk in particular and other flavoured milk, dairy products and nutritional supplements rely on carrageenan for their uniform consistencies and stability for packaging and storage.[90]

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