Title

A review of diet standardisation and bolus rheology in the management of dysphagia

Author

Dr. Ben Hanson

Affiliation and Contact Details

UCL Mechanical Engineering
University College London
London WC1E 7JE, UK
Tel: +44 207 679 3894
Email: b.hanson@ucl.ac.uk

Abstract

Purpose: Texture modification is a widespread practice as a strategy for the management of dysphagia and can be very effective in individual cases. However, it is often performed in a qualitative, subjective manner and practices vary internationally according to multiple sets of national guidelines. This paper aims to identify best practice by reviewing the theory and practice of texture modification, focussing on recent advances.

Recent findings:
Instrumental assessment of texture modification in-vivo is challenging, but studies including rheology and perception have indicated that fluid viscosity is only one of many factors affecting texture modification in practice. Systematic reviews have identified a historical lack of high-quality clinical evidence, but recent controlled studies are beginning to identify positive and negative aspects of thickened fluids. Research and practice to date have been limited by the lack of control and standardisation of foods and drinks. However in 2015 a not-for-profit organisation, the International Dysphagia Diet Standardisation Initiative, has published a framework for texture modification from thin liquids to solid foods based on all the existing documentation and guidance, and the –limited– available clinical evidence.

Summary:
Rheology exists in the lab, however normal practice is often subjective or lacking control and standardisation. In the near future, cohesion of practice and the availability of practical standardisation tools may increase awareness and use of rheology.

Keywords
Dysphagia, Swallowing, Rheology, Viscosity, Texture modification

Key points

- The relationships between rheology and swallowing are beginning to be characterised using oral pressure sensing and videofluoroscopy, together with careful control of bolus rheology.

- It is becoming clearer that viscosity alone is not sufficient to categorise texture modification.

- Literature to date shows a trend for reduced aspiration with increased thickness of liquids, and increased residue with some thicker consistencies, however evidence is scarce.

- An inconsistent approach to definition of texture modification techniques has been limiting the collation of a coherent evidence base.

- A new international standard (IDDSI) has been created, drawing on available evidence and including practical objective measures.

1. Introduction

This paper reviews advances in the multidisciplinary challenge of managing oropharyngeal dysphagia (OD) through texture modification (TM) of the diet, e.g. thickened drinks and pureed foods. The review complements a recent review in this journal [1] on diagnosis and treatment techniques and covers the previous 18 months, including earlier work which still represents state-of-the-art. Texture modification has lacked a comprehensive base of clinical evidence, however that evidence is now emerging through recent systematic reviews and new research. Lab-based rheology studies have continued to better-characterise fluids for diagnosis and management, and tools are being developed to apply this science in practical settings. Standardisation has been inconsistent to date but during 2015 the International Dysphagia Diet Standardisation Initiative launched a new framework, based on systematic reviews of practice and of the available multidisciplinary research. This framework proposes objective measures of consistency and has the potential to unify practice in the coming years.

2. Research in Swallowing and Rheology

The formation of a bolus and its subsequent manipulation and deglutition are interactive processes: the bolus deforms and moves in response to the forces acting on it provided by gravity and muscular contractions [2]. Texture modification aims to control this relationship, often aiming to make liquids flow more slowly, foods flow more easily, or heighten the perception of the bolus. Recent work has helped characterise some of the basic psychophysics: Instrumental investigations of swallows using xanthan gum showed that tongue-palate propulsion pressure increased to adapt to thicker liquids, but the increases were relatively small in magnitude [3*]. Videofluoroscopic measures (scaled to account for variations in the individuals' anatomy) showed an increase in the magnitude and velocity of the hyoid motion with increased thickness [4] and EMG measures of hyolaryngeal muscle activity [5] showed increased peak amplitude of sEMG measures. Bolus viscosity was also found to have a measurable effect on EEG measures of brain activity [6]. These results demonstrate that increased thickness of a bolus requires larger effort from swallowing muscles but that for healthy individuals, for mid-thickness gum-thickened liquids, the effort is well below physiological limits. These results may be attributable to the non-Newtonian shear-thinning response of most TM fluids: under gentle pressure (e.g. gravity) they will flow slowly however under increased pressure (e.g. tongue-palate peristalsis) the flow speed increases disproportionately, achieving fast flow rates without excessive pressure. These attributes are thought to make shear-thinning products well-suited to dysphagia management: Rosenthal & Chen's new book [7**] describes this applied rheology and important practical considerations.

Although apparent viscosity has been used as a quantifier in research and in standardisation (in USA [8] and Australia [9]), it is becoming clearer that viscosity alone is not sufficient to categorise the flow and perception of TM products. Vickers et al. [10*] showed that materials having equal apparent viscosity (measured at 30 /s) had significantly different perceived thickness. Materials with more-pronounced shear-thinning were perceived as being less thick, more slippery, less sticky, requiring fewer repeat swallows to clear and leaving less mouth-coating (R^2 =0.97 with objective measure of mouth-coat). Different beverage-thickener combinations can exhibit large differences in shear-thinning behaviour resulting from the interaction of starch, gums and juice particulates; this could confuse patients [11*]. It is interesting that materials may be perceived differently despite absence of significant differences in in-mouth pressure-bulb measurements [10*],[12]: this may reflect the tongue being more sensitive than the pressure-bulb, or, that the pressures required to propel these (relatively low-viscosity and low-mass) liquid boluses are quite small compared to the baseline pressure involved in accelerating the tongue itself and creating a lingual-palatal seal.

Measuring bolus motion in-vivo is extremely challenging (reviewed by Steele[13], Figure 1). Zhu et al. [14] attempted to determine characteristic shear rates for a range of fluids and estimated 120 /s and 990 /s in the mesopharynx and hypopharynx respectively. However these estimates are based on 2D videofluoroscopic images which quantify gross motion, not the flow within the bolus so it is not known whether the flow is turbulent (likely for lower viscosities) or "plug flow" - sliding as a coherent whole. Flow can be visualised in a lab using Doppler ultrasound [15]. Cohesiveness and surface tension for some materials can be derived from "capillary breakup elongational rheometry (CaBER)" – stretching a sample between two plates [16], [17]. Tribology (the interaction between surfaces with a lubricating layer) is very important to oral processing and swallowing [18*] and is particularly linked to perception of slipperiness or creaminess [18*]. However even detailed rheology and tribology measures were found insufficient to describe mouth-feel [19] (of liquid medicines) highlighting the complexity of perception.

Saliva can be a very significant variable in the practical effectiveness of a texture modification strategy [18]. Increased salivary flow rate, correlated to masseter muscle activity (sEMG measured) during bolus formation, helps break down the bolus's structure [20]. After 10 seconds' oral processing, viscosity of expectorated boluses of gum- or starch-thickened water decreased by 70% and 35% respectively [21]. This was attributed to the effect of alpha-amylase, but a general dilution effect may also have contributed [18]. Saliva varies widely in quality and quantity: one "dry-mouth" group - Sjögren's syndrome (SS) – also showed dramatically reduced mucin content and stringiness ("spinnbarkeit") of saliva [22].

Where foods require chewing, Iguchi et al. [20] found that EMG measures of masseter and suprahyoid muscle groups related to the food hardness, adhesiveness and cohesiveness, changing as food was broken down. Upper limits of tongue capability were investigated by Alsanei et al [23]: maximum isometric tongue pressure (MITP) was well-correlated to the maximum hardness of mashed potato or vege-gel which could be crushed by the tongue alone. Decreased MITP resulting from sarcopenia was identified as an independent risk factor for dysphagia [24], [25*] so there is a potential risk of inadequate nutritional intake worsening swallowing function, but the vicious cycle could be halted by nutritional supplements and effective dysphagia management.

3. Clinical evidence relating to texture modification and swallowing

Through 2014-15 IDDSI conducted a systematic review of the influence of food texture and liquid consistency modification on swallowing physiology and function [26**]. Evidence was graded [27] and assessed for risk of bias [28]; unfortunately the small quantity and low quality was disappointing and surprising. From 10147 search results, 488 articles described a measurement of swallowing using more than one consistency of food or liquid but only 36 met quality criteria and relevance. Thicker liquids were reported to increase the duration of swallowing events in accelerometry [29], electromagnetic articulography [30], ultrasound [31] and surface electromyography signals [32], [33], [34], and also on videofluoroscopy for pharyngeal transit time measures [35], [36], although more recently a study found no effect of thickening on bolus velocity [37]. Regarding dysphagia, several videofluoroscopic studies provided evidence of texture modification having a measurable effect on swallowing efficacy [38], [39], [40], [41], e.g. reduced penetration–aspiration with increasing viscosity [36]. A further systematic review of aspiration measures in the head & neck cancer population [42*] identified only 4 papers published 1996 to 2011 reporting a general trend towards less aspiration on pureed consistencies vs thin [43-46]. However "thin" radiopaque liquids sometimes had a viscosity comparable to a thickened liquid [47]. Historically, this lack of standardisation in materials and methods has been a critical factor in the lack of an evidence base for thickening liquids.

Recently, evidence regarding aspiration has been supplemented by quantitative studies of dysphagic patients: in videofluoroscopic assessments of 120 patients the incidence of safe swallows was only 24% with thin liquids but increased to 55% with nectar consistency, and 85% at spoon-thick [48*]. Vilardell et al. [37*] further investigated starch- and gum-based thickener types in a post-stroke population of 122; penetration and aspiration were convincingly reduced with increasing thickness for both types (Fig. 2). However elsewhere, in 100 patients assessed by videofluoroscopy [49*], xanthan gum had a more-pronounced reduction in aspiration compared to starch-thickened fluid, which did not produce a statistically significant decrease despite starch having approximately double the viscosity at

50 /s. Similarly, the penetration-aspiration scores were significantly lowered by gum-thickened liquids vs thin, but not starch-thickened [49*].

There is also evidence of negative outcomes associated with increased thickness: the IDDSI review [26**] identified greater vallecular residue for thicker consistencies [39, 41, 50, 51] and Troche et al [40] observed a greater number of tongue pumps required to swallow a pudding-thick consistency than a thin liquid. This trend was also recently observed for starch- but not gum-based thickeners [37*] (with equal apparent viscosity) with significantly more oral and pharyngeal residue was apparent for starch vs gum at thicker consistencies. Texture modification is sometimes associated with decreased hydration. McGrail & Kelchner [52*] studied a post-stroke population: patients on thin liquids consumed 55% more liquid than those on nectar or honey consistencies (who averaged only 907 ml/day). Notably, thin liquids were offered in greater quantity (mean 2575 ml; 62% more) than thickened liquids; reasons were not recorded but may be due to the inconvenience of preparing thickened liquid or a negative spiral whereby the patient consumes less, so is offered less. Thick drinks are often considered less-preferable but this may apply more to spoon-thick products, since Zargaraan et al. [53] found dysphagic individuals preferred increased thickness of a cocoa drink.

4. Current practice and standardisation approaches internationally

One of the fundamental challenges in using thickeners is that even when carefully controlling quantities of thickener, the final viscosity depends on the type of drink being thickened [11]. For example infant formula needs significantly longer to thicken and results in a higher final viscosity [54*]; concern was a reported of the lack of guidance [55]. Thickening occurs more slowly at refrigerated temperature (5°C) and even more slowly for refrigerated milk, which may require 45-60 minutes [56] and reaches a higher final viscosity, increasing with fat content [57*] and protein content [58]. Serving temperature is important: viscosity of thickened water at 40°C was approximately half that at 8°C [57] which is understandable given the viscosity of pure water would also approximately halve from 8 °C to 40 °C [59]. Different thickeners introduce further variation: Vilardell et al [37*] found starch and gum to have equal apparent viscosity at 50/s, however Leonard et al. [49*] found starch-thickened water twice as thick at 50/s (290-330 vs 150-170 cP). This may reflect differences in manufacturer's instructions internationally (Spain vs USA) however the lack of international consistency has been a critical factor in the lack of a coherent evidence base: the IDDSI systematic review of food modification found there were "effectively no stimuli that were the same in any two or more studies"[26].

Currently, texture modification recommendations vary across the world (Table 1 [60]). Australia, Ireland, Japan, New Zealand, Sweden, the UK, USA and Denmark have published national descriptors/guidance [8, 9, 61, 62-64] however all these acknowledge the lack of clinical evidence; IDDSI [60] concurred with the needed for a systematic review of evidence and for consistent international guidelines; these points were further echoed by the European Society for Swallowing Disorders (ESSD) in a white paper at their 2015 meeting. In 2015 IDDSI created a framework of global standardised terminology and definitions based on current clinical and research evidence for texture modified foods and thickened drinks, Figure 3 [65**]. One prominent feature is an overlap between thick drinks and pureed foods which could have identical textural / flow properties [7], thus removing the subjective categorisation of "food" or "drink".

Objective measurement is desirable, however categorisation of fluids lacks an agreed convention on viscosity measurement [26] with thresholds representing clinical consensus or an educated guess [60]. Viscosity at 50 /s is impractical in-situ and, more importantly, may not represent the appearance or perception of fluids.

Some practical measurement tools have recently been investigated; observation of flow through a fork is currently recommended in Australia [9] and was recently evaluated [66]: although lay-persons and clinicians were able to differentiate thinnest and thickest categories, there was very large variability in “middle-consistency” fluids. A line-spread test gives a measure of fluid spread on a plate and can indicate whether a material is likely to be in a nectar-thick or honey-thick category [67*]. The measure can be related to viscosity if restricted to one type of thickener [68], but line-spread measurements of different types of thickeners cannot be compared with their viscosity measurements [69*] and may not match the perception during swallowing which “calls into question the use of line-spread or consistometer measurements” [11]. Semi-fluid products often exhibit a yield stress – a material will not flow until the yield stress has been exceeded – explaining how the material is able to retain its shape on a fork [66] or inclined plane [70]. Yield stress is likely the key property assessed by line-spread or fork test observations, and may be relevant for “controllability” of a bolus on a spoon or on the tongue. However, it generally has a very low magnitude of the order of 1/1000 of tongue pressures recorded during swallowing [3*], such that it’s often difficult or unreliable to measure [10], therefore during a swallow it may be negligible compared to viscous stresses. IDDSI [65**] have recommended classifying liquids using a measurement of fluid while it is flowing, using a syringe as a practical measure of extensional viscosity. Extensional viscosity is well-related to the types of deformations involved in swallowing [7] and the rheological theory involved is summarised by Moberg et al. [71]. Since food categorisation involves measures of particle size and consistency/ hardness, a similar practical tool for foods has not been feasible. Instead, IDDSI recommended applying a crushing pressure with thumbnail blanching used as a non-instrumental pressure indicator of approximately 16 kPa (representing a weakened tongue pressure).

5. Future directions

Conventional lab equipment (e.g. rheometers) may over-simplify the in-vivo environment, so research groups are aiming to create more-physiological mechanical simulators. For example Hayoun et al. [72] simulate oropharyngeal propulsion using a roller driven by a falling weight and have revealed potential mechanisms by which increased viscosity could lead to increased residue through reducing the completeness of tongue-palate closure. Dirven et al 2015 [73] aim to study oesophageal swallowing using peristalsis applied through a series of pneumatic actuators. Computer simulation of swallowing has had relatively minimal progress due to the complex psychophysics. The geometry of the pharynx can be visualised in 3D [74], but only as a solid, stationary model; a deformable tongue model has been created [75], but approximating it as a passive viscoelastic material is extremely simplified. A simulation of the motion of different fluid consistencies has been included in an app available in the UK [76]; although very simple, this provides a visual indication of consistency.

Many thickeners and stabilisers are used in conventional foods; increasingly these are now being investigated specifically for dysphagia management, e.g. mamaku gum (used by Maori people of New Zealand) [17], or gelatinous fat which thickens while increasing calorific content [77]. New techniques employ enzymes to soften root vegetables while retaining nutritional content [78*] or a beef steak, enabling it to be easily crushed with a teaspoon (less than 1/15 the firmness of normally-cooked steak) [79*]. These techniques are currently labour-intensive but are an inspiring approach to improve the quality of texture modified diets.

6. Conclusions

Investigations of oral processing and perception are improving our understanding of the interactions involved in swallowing a bolus. The mechanical properties of texture modified products can be characterised, however their perception and behaviour during swallowing depend on more than the apparent viscosity of the bolus. A clinical evidence base is starting to emerge, however texture modification needs to be standardised in order that research studies can be compared, collated and reproduced. An international dysphagia diet standardisation initiative (IDDSI) launched a framework with that aim. Standardisation will likely be an iterative process as more-precise definition of texture modification allows higher-quality, more-reliable clinical evidence to be produced, which in turn will more clearly identify important features of texture modification for clinical safety, efficiency and palatability.

Acknowledgements
None.

Financial support and sponsorship:
None.

Conflicts of interest:
Dr Ben Hanson has received financial support for research at UCL from Fresenius-Kabi Ltd and support-in-kind and product samples from Nestle Nutrition Institute. He has received honoraria for participation in conferences from Fresenius-Kabi Ltd and Nestle. He sits on the board of IDDSI but receives no payment.

References

1. Miles, A. and J.E. Allen, Management of oropharyngeal neurogenic dysphagia in adults. Curr Opin Otolaryngol Head Neck Surg, 2015. **23**(6): p. 433-9.
2. Logemann, J.A., Critical Factors in the Oral Control Needed for Chewing and Swallowing. J Texture Stud, 2014. **45**(3): p. 173-179.

* 3. Steele, C.M., et al., Variations in tongue-palate swallowing pressures when swallowing xanthan gum-thickened liquids. Dysphagia, 2014. **29**(6): p. 678-84.
Using instrumental assessment - oral pressure sensing – to study xanthan-gum-thickened products finding large changes in apparent viscosity corresponding to smaller changes in oral pressure required to swallow.

4. Nagy, A., et al., The Effect of Bolus Consistency on Hyoid Velocity in Healthy Swallowing. Dysphagia, 2015. **30**(4): p. 445-51.
5. Watts, C.R. and B. Kelly, The Effect of Bolus Consistency and Sex on Electrophysiological Measures of Hyolaryngeal Muscle Activity During Swallowing. Dysphagia, 2015. **30**(5): p. 551-7.
6. Jestrovic, I., J.L. Coyle, and E. Sejdic, The effects of increased fluid viscosity on stationary characteristics of EEG signal in healthy adults. Brain Res, 2014. **1589**: p. 45-53.

** 7. Rosenthal, A. and J. Chen, Modifying Food Texture. 2015: Woodhead Publishing.
A recent review book very thoroughly covering aspects of oral processing and swallowing, including specific reference to dysphagia. Very relevant for texture modification, explaining some of the reasons for success & failure of this strategy.

8. National Dysphagia Diet Task Force, National Dysphagia Diet: Standardization for Optimal Care. 2002: Chicago, IL.
9. Cichero, J. and Dietitians Association of Australia and The Speech Pathology Association of Australia Limited, Texture-modified foods and thickened fluids as used for individuals with dysphagia: Australian standardised labels and definitions. Nutrition & Dietetics, 2007. **64**(Supplement 2): p. 24.

* 10. Vickers, Z., et al., Relationships Among Rheological, Sensory Texture, and Swallowing Pressure Measurements of Hydrocolloid-Thickened Fluids. Dysphagia, 2015. **30**(6): p. 702-13.
Very comprehensive study of perceptions of healthy volunteers (no dysphagia) perceptions of a wide range of texture-modified products.

* 11. Moret-Tatay, A., et al., Commercial thickeners used by patients with dysphagia: Rheological and structural behaviour in different food matrices. Food Hydrocolloids, 2015. **51**: p. 318-326.
Notable investigation of microstructure in efforts to explain thickening achieved by gum and starch.

12. Steele, C.M., et al., Oral perceptual discrimination of viscosity differences for non-newtonian liquids in the nectar- and honey-thick ranges. Dysphagia, 2014. **29**(3): p. 355-64.
13. Steele, C.M., The Blind Scientists and the Elephant of Swallowing: A Review of Instrumental Perspectives on Swallowing Physiology. Journal of Texture Studies, 2015: p. n/a-n/a.
14. Zhu, J.F., H. Mizunuma, and Y. Michiwaki, Determination of Characteristic Shear Rate of a Liquid Bolus through the Pharynx during Swallowing. Journal of Texture Studies, 2014. **45**(6): p. 430-439.
15. Berta, M., et al., Correlation between in-line measurements of tomato ketchup shear viscosity and extensional viscosity. Journal of Food Engineering, 2016. **173**: p. 8-14.
16. Szopinski, D., et al., Extensional flow behavior of aqueous guar gum derivative solutions by capillary breakup elongational rheometry (CaBER). Carbohydr Polym, 2016. **136**: p. 834-40.
17. Jaishankar, A., et al., Probing hydrogen bond interactions in a shear thickening polysaccharide using nonlinear shear and extensional rheology. Carbohydr Polym, 2015. **123**: p. 136-45.

* 18. Chen, J., Food oral processing: Some important underpinning principles of eating and sensory perception. Food Structure, 2014. **1**(2): p. 91-105.
Related to [Rosenthal & Chen, 2015], this provides a broad review of the important mechanical considerations for swallowing – demonstrating that there is far more involved than simply viscosity.

19. Batchelor, H., et al., The application of tribology in assessing texture perception of oral liquid medicines. 2015. **479**(2): p. 277–281.
20. Iguchi, H., et al., Changes in jaw muscle activity and the physical properties of foods with different textures during chewing behaviors. Physiol Behav, 2015. **152**(Pt A): p. 217-24.
21. Vallons, K.J., et al., The Effect of Oral Processing on the Viscosity of Thickened Drinks for Patients With Dysphagia. Ann Rehabil Med, 2015. **39**(5): p. 772-7.
22. Chaudhury, N.M., et al., Changes in Saliva Rheological Properties and Mucin Glycosylation in Dry Mouth. J Dent Res, 2015. **94**(12): p. 1660-7.
23. Alsanei, W.A., J. Chen, and R. Ding, Food oral breaking and the determining role of tongue muscle strength. Food Research International, 2015. **67**: p. 331-337.
24. Maeda, K. and J. Akagi, Sarcopenia is an independent risk factor of dysphagia in hospitalized older people. Geriatr Gerontol Int, 2015.

* 25. Maeda, K. and J. Akagi, Decreased tongue pressure is associated with sarcopenia and sarcopenic dysphagia in the elderly. Dysphagia, 2015. **30**(1): p. 80-7.
Highlighting an important clinical relationship –dysphagia is rarely seen in isolation- and also relating nutrition to the biomechanics and texture modification.

** 26. Steele, C.M., et al., The influence of food texture and liquid consistency modification on swallowing physiology and function: a systematic review. Dysphagia, 2015. **30**(1): p. 2-26.

The systematic review of evidence. Inclusion criteria were strict, but necessarily so for clinical evidence. The previous body of work was surprisingly lacking in quality and quantity.
27. Council, N.H.a.M.R., How to use the evidence: assessment and application of scientific evidence. 2000.
28. Lundh, A. and P.C. Gotzsche, Recommendations by Cochrane Review Groups for assessment of the risk of bias in studies. BMC Med Res Methodol, 2008. **8**: p. 22.
29. Lee, J., et al., Effects of liquid stimuli on dual-axis swallowing accelerometry signals in a healthy population. BioMedical Engineering OnLine, 2010. **9**(1): p. 7.
30. Lieshout, C.M.S. and H.H.M.v. Pascal, Does Barium Influence Tongue Behaviors During Swallowing? American Journal of Speech-Language Pathology, 2016. **14**(1): p. 27-39.
31. Chi-Fishman, G. and B.C. Sonies, Effects of systematic bolus viscosity and volume changes on hyoid movement kinematics. Dysphagia, 2002. **17**(4): p. 278-87.
32. Ruark, J.L., et al., Bolus consistency and swallowing in children and adults. Dysphagia, 2002. **17**(1): p. 24-33.
33. Reimers-Neils, L., J. Logemann, and C. Larson, Viscosity effects on EMG activity in normal swallow. Dysphagia, 1994. **9**(2): p. 101-6.
34. Igarashi, A., et al., Sensory and motor responses of normal young adults during swallowing of foods with different properties and volumes. Dysphagia, 2010. **25**(3): p. 198-206.
35. Goldfield, E.C., et al., Preterm infant swallowing of thin and nectar-thick liquids: changes in lingual-palatal coordination and relation to bolus transit. Dysphagia, 2013. **28**(2): p. 234-44.
36. Bingjie, L., et al., Quantitative videofluoroscopic analysis of penetration-aspiration in post-stroke patients. Neurol India, 2010. **58**(1): p. 42-7.
* 37. Vilardell, N., et al., A Comparative Study Between Modified Starch and Xanthan Gum Thickeners in Post-Stroke Oropharyngeal Dysphagia. Dysphagia, 2015.
Recent evidence of clinical efficacy of texture modificaiton, identifying differences in residue between different thickener types.
38. Chen, M.Y., et al., Clinical and videofluoroscopic evaluation of swallowing in 41 patients with neurologic disease. Gastrointest Radiol, 1992. **17**(2): p. 95-8.
39. Barata, L.F., et al., Swallowing, speech and quality of life in patients undergoing resection of soft palate. Eur Arch Otorhinolaryngol, 2013. **270**(1): p. 305-12.
40. Troche, M.S., C.M. Sapienza, and J.C. Rosenbek, Effects of bolus consistency on timing and safety of swallow in patients with Parkinson's disease. Dysphagia, 2008. **23**(1): p. 26-32.
41. Lee, K.L., et al., Is swallowing of all mixed consistencies dangerous for penetration-aspiration? Am J Phys Med Rehabil, 2012. **91**(3): p. 187-92.
* 42. Barbon, C.E. and C.M. Steele, Efficacy of Thickened Liquids for Eliminating Aspiration in Head and Neck Cancer: A Systematic Review. Otolaryngol Head Neck Surg, 2015. **152**(2): p. 211-218.
Notable but very little relevant research was available for review.
43. Graner, D.E., et al., Swallow function in patients before and after intra-arterial chemoradiation. Laryngoscope, 2003. **113**(3): p. 573-9.
44. Newman, L.A., et al., Swallowing and speech ability after treatment for head and neck cancer with targeted intraarterial versus intravenous chemoradiation. Head Neck, 2002. **24**(1): p. 68-77.
45. Lazarus, C.L., et al., Swallowing disorders in head and neck cancer patients treated with radiotherapy and adjuvant chemotherapy. Laryngoscope, 1996. **106**(9 Pt 1): p. 1157-66.
46. Pauloski, B.R., et al., Swallow function and perception of dysphagia in patients with head and neck cancer. Head Neck, 2002. **24**(6): p. 555-65.
47. Logemann, J.A., et al., Effects of xerostomia on perception and performance of swallow function. Head Neck, 2001. **23**(4): p. 317-21.
* 48. Rofes, L., et al., The effects of a xanthan gum-based thickener on the swallowing function of patients with dysphagia. Aliment Pharmacol Ther, 2014. **39**(10): p. 1169-79.
Recent evidence of clinical efficacy of texture modification.
* 49. Leonard, R.J., et al., Effects of bolus rheology on aspiration in patients with Dysphagia. J Acad Nutr Diet, 2014. **114**(4): p. 590-4.
Recent evidence of clinical efficacy of texture modification.
50. Lin, P.H., et al., Effects of functional electrical stimulation on dysphagia caused by radiation therapy in patients with nasopharyngeal carcinoma. Support Care Cancer, 2011. **19**(1): p. 91-9.
51. Hind, J., et al., Comparison of standardized bariums with varying rheological parameters on swallowing kinematics in males. The Journal of Rehabilitation Research and Development, 2012. **49**(9): p. 1399.
* 52. McGrail, A. and L. Kelchner, Barriers to Oral Fluid Intake: Beyond Thickened Liquids. Journal of Neuroscience Nursing, 2015. **47**(1): p. 58-63.
Important wider implications of texture modification, regarding hydration.
53. Zargaraan, A., et al., Effect of Rheological Properties on Sensory Acceptance of Two-Model Dysphagia-Oriented Food Products. Journal of Texture Studies, 2015. **46**(3): p. 219-226.
* 54. September, C., T.M. Nicholson, and J.A. Cichero, Implications of changing the amount of thickener in thickened infant formula for infants with dysphagia. Dysphagia, 2014. **29**(4): p. 432-7.
Important evidence of interactions with infant formula highliting the extreme care that must be taken if attempting to thicken infant formula.
55. Dion, S., et al., Use of Thickened Liquids to Manage Feeding Difficulties in Infants: A Pilot Survey of Practice Patterns in Canadian Pediatric Centers. Dysphagia, 2015. **30**(4): p. 457-72.

56. Kim, S.G. and B. Yoo, Viscosity of dysphagia-oriented cold-thickened beverages: effect of setting time at refrigeration temperature. Int J Lang Commun Disord, 2014.
* 57. Hadde, E.K., T.M. Nicholson, and J.A.Y. Cichero, Rheological characterisation of thickened fluids under different temperature, pH and fat contents. Nutrition & Food Science, 2015. **45**(2): p. 270-285.
Detailed study higlighting practical considerations and documenting sources of variability in using thickeners on a variety of beverages.
58. Hadde, E.K., et al., Rheological characterisation of thickened milk components (protein, lactose and minerals). Journal of Food Engineering, 2015. **166**: p. 263-267.
59. Kestin, J., M. Sokolov, and W.A. Wakeham, Viscosity of Liquid Water in the Range -8C to 150C. J. Phys. Chem. Ref. Data, 1978. **7**(3): p. 941-948.
60. Cichero, J.Y., et al., The Need for International Terminology and Definitions for Texture-Modified Foods and Thickened Liquids Used in Dysphagia Management: Foundations of a Global Initiative. Current Physical Medicine and Rehabilitation Reports, 2013. **1**(4): p. 280-291.
61. New Zealand Speech Therapy Association and New Zealand Dietetic Association, Standards and definitions for texture modified foods and fluids. 2007: New Zealand.
62. Wendin, K., et al., Objective and quantitative definitions of modified food textures based on sensory and rheological methodology. Food Nutr Res, 2010. **54**.
63. National Patient Safety Agency, et al., Dysphagia diet food texture descriptions. 2011.
64. Andersen, U.T., et al., Systematic review and evidence based recommendations on texture modified foods and thickened fluids for adults (>18 years) with oropharyngeal dysphagia. e-SPEN Journal. **8**(4): p. e127-e134.
** 65. International Dysphagia Diet Standardisation Initiative, Global standardised terminology and definitions for texture modified foods and thickened drinks. 2015. http://iddsi.org/resources/framework/
Recent publication of an international framework for standardisation, based on available evidence and including practical objective measures.
66. Karsten Hadde, E., J. Ann Yvette Cichero, and T. Michael Nicholson, Viscosity of thickened fluids that relate to the Australian National Standards. International Journal of Speech-Language Pathology, 2015: p. 1-9.
* 67. Lund, A.M., J.M. Garcia, and I.V.E. Chambers, Line Spread as a Visual Clinical Tool for Thickened Liquids. American Journal of Speech-Language Pathology, 2013. **22**(3): p. 566-571.
Investigation of the line-spread as a practical objective measure of consistency.
68. Kim, S.G., W. Yoo, and B. Yoo, Relationship between Apparent Viscosity and Line-Spread Test Measurement of Thickened Fruit Juices Prepared with a Xanthan Gum-based Thickener. Prev Nutr Food Sci, 2014. **19**(3): p. 242-5.
* 69. Park, J.H., et al., Comparison of different gum-based thickeners using a viscometer and line spread test: a preliminary study. Ann Rehabil Med, 2014. **38**(1): p. 94-100.
Relating to (Lund et al, 2013), demonstrating the limitations of the line-spread test when applied to different material types.
70. Coussot, P. and S. Boyer, Determination of Yield Stress fluid behaviour from Inclined Plane Test. Rheol Acta, 1995. **34**: p. 10.
71. Moberg, T., et al., Extensional viscosity of microfibrillated cellulose suspensions. Carbohydr Polym, 2014. **102**: p. 409-12.
72. Hayoun, P., et al., A model experiment to understand the oral phase of swallowing of Newtonian liquids. J Biomech, 2015.
73. Dirven, S., et al., Biomimetic Investigation of Intrabolus Pressure Signatures by a Peristaltic Swallowing Robot. IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT, 2015. **64**(4): p. 8.
74. Gastelum, A., et al., Building a three-dimensional model of the upper gastrointestinal tract for computer simulations of swallowing. Med Biol Eng Comput, 2015.
75. Kato, T., et al., Development of Tongue Deformation Model Based on Tissue Incompressibility. TRANSACTIONS OF JAPANESE SOCIETY FOR MEDICAL AND BIOLOGICAL ENGINEERING 2014. **52**(6): p. 7.
76. Fresenius Kabi Ltd. MyDysphagia. 2015; Free iOS app for iPhone, iPad. Available from: https://itunes.apple.com/gb/app/mydysphagia/id1038008854?mt=8
77. Sano, J., et al., Basic Evaluation of Gelatinous Fat to Improve Properties of Nursing Care Food. J Oleo Sci, 2015. **64**(6): p. 653-62.
* 78. Umene, S., et al., Physical properties of root crops treated with novel softening technology capable of retaining the shape, color, and nutritional value of foods. Dysphagia, 2015. **30**(2): p. 105-13.
Interesting technique to modify texture without mechanical pureeing or adding water, although currently relatively expensive.
* 79. Takei, R., et al., Changes in Physical Properties of Enzyme-Treated Beef Before and After Mastication. Journal of Texture Studies, 2015. **46**(1): p. 3-11.
As with (Umene et al, 2015), an interesting technique and here the study investigated the oral processing relating to the mechanical properties.