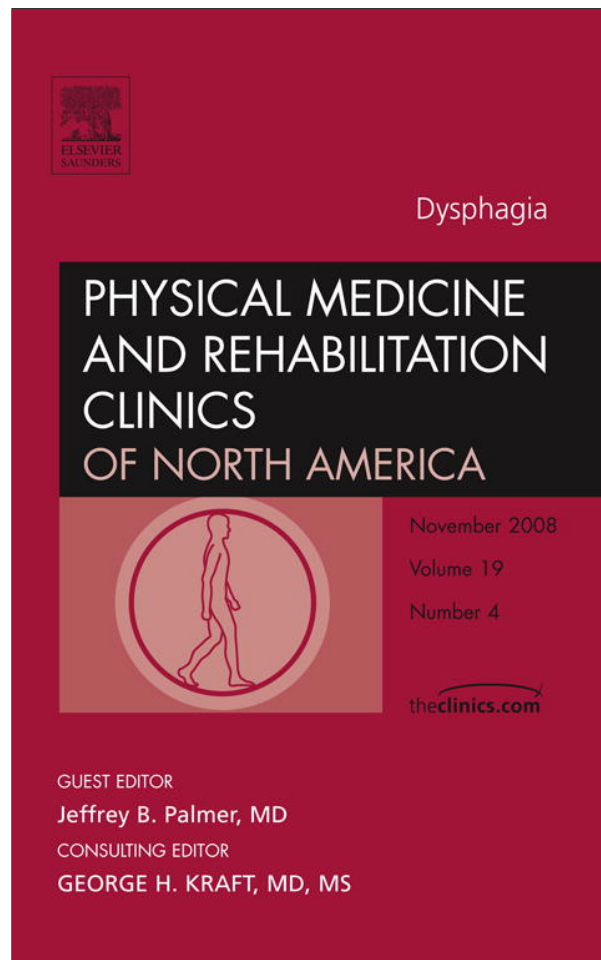


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The Videofluorographic Swallowing Study

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The literature is dense with measurement methods used to estimate the presence and degree of oropharyngeal and esophageal swallowing dysfunction. These methods are directed toward gaining objective indexes of the timing [1–8], pressure [5,9–15], range [16–18], and strength [19–21] of structural movements, bolus flow patterns [22–26], bolus clearance and efficiency [11], airway protection [27,28], and sensation [29–32]. These studies have established a strong theoretic framework toward understanding the nature of swallowing abnormalities. Multiple assessment methods are in existence and development. Although the current health care climate demands fiscal responsibility, clinicians must choose the test that is appropriate for each patient and delivers the highest diagnostic and prognostic clinical yield. Furthermore, the test and the measurement methods used to capture oropharyngeal swallowing impairment must be practical for routine clinical application.

The videofluorographic swallowing study (VFSS), also known as a *modified barium swallowing* (MBS) examination, is often considered the

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preferred instrument by most practicing swallowing clinicians because it allows visualization of bolus flow in relation to structural movement throughout the upper aerodigestive tract in real time. The VFSS also permits detection of the presence and timing of aspiration (ie, entry of ingested material through the level of the true vocal folds into the trachea) [33,34] and helps identify the physiologic and often treatable causes of the aspiration [35–39]. Furthermore, clinicians are able to observe the effects of various bolus volumes, bolus textures, and compensatory strategies on swallowing physiology [37].

Clinicians evaluating and treating swallowing disorders use a videofluoroscopic radiology procedure to assess swallowing physiology in patients who have symptoms of swallowing disorders (ie, dysphagia) and to estimate the degree of swallowing impairment from observations made during the examination. The examination usually includes the collaborative expertise of a physician, most commonly a radiologist or physiatrist, and speech–language pathologist.

This MBS examination captures sequential videoradiographic images of barium contrast-impregnated food and liquid as they are transported through the oral cavity, pharyngeal cavity, and esophagus in real time. Various volumes and textures of food and liquid are administered and clinical impressions of the presence and degree of swallowing impairment are obtained from the radiographic images [35,38–43]. Judgments are also made regarding the coordination and timing of swallowing events [1,28,36,44–48]. Based on these qualitative observations, critical and sometimes life-sustaining recommendations are made regarding oral versus nonoral intake, diet type, referrals to other medical specialties, and treatment strategies that improve function or minimize the risk for aspiration [38].

Despite the clinical efficacy of the examination, clinicians must acknowledge that the patient's performance during the examination may not be entirely representative of the patient's typical eating and drinking function. Variables such as fatigue, medications, and anxiety may impact the testing results. Clinicians must observe patients during their usual eating and drinking environment to determine the external validity of the examination results and assess the patient's ability to carry-over any learned swallowing strategies. Furthermore, the VFSS is also used to monitor any changes in swallowing function over time during the course of swallowing treatment and the progression of a disease or condition.

Videofluorographic swallowing study: an indirect sensory and motor examination

Swallowing is an array of synergistic interdependent movements, initiated by a complex set of sensory inputs that generate motor responses. These motor responses create pressures and forces to propel ingested materials

through the upper aerodigestive tract and simultaneously protect the upper airway. Although the VFSS does not use direct measures of sensation and muscle strength, the following evidence suggests that trained examiners can make accurate and reliable clinical judgments about the presence of sensory and motor impairment.

The following description of VFSS observations are characterized as physiologic components. Most observed components contribute to judgments of sensory and motor impairment because the initiation and integrity of the motor response partly depends on sensory input.

A prime example of this combined sensorimotor assessment is observation of the motor events that occur early in the pharyngeal swallow. If these events are delayed for several seconds, the sensory input to the pharyngeal motor response is probably decreased below the normal level required to initiate the cascade of pharyngeal motor events. Clinicians evaluate the sensorimotor relationships during the VFSS and administer various bolus consistencies, textures, and sometimes taste to assess their effect on swallowing function.

Swallowing physiology: foundation for videofluorographic swallowing study

Swallowing is a complex physiologic event comprised of simultaneous and sequential contractions of muscles of the oral–facial region, pharynx, larynx, and esophagus. Descriptions of swallowing physiology were attempted well before the development of a sophisticated modality for viewing the rapid contractions and movements of the muscles and structures associated with swallowing. In 1813, Magendie [49] was the first to separate swallowing into phases or stages representing the anatomic regions traversed by the *bolus*, or ball of material, to be swallowed. The rapid sequential and overlapping motions characterizing adult human swallowing behavior were better appreciated after radiography was introduced, especially videoradiography.

Although phase descriptions remain in current literature, evidence suggests that the physiologic components of the process overlap and are interdependent as the bolus traverses the regional phases (oral, pharyngeal, esophageal), which has led clinicians to attempt to assess the physiology of the swallowing rather than report abnormality of a given phase. Furthermore, the physiology is the target of swallowing rehabilitation, and therefore these targets must be identified before the treatment plan is developed. Swallowing clinicians attempt to evaluate components of swallowing behavior on VFSS examinations in patients presenting with clinical signs or symptoms of dysphagia (Box 1).

Clinicians also use the 15 literature-based components to estimate the severity of the impairments and make critical intake and diet texture recommendations, swallowing therapy recommendations, and predictions about functional outcomes [38,40,41].

Box 1. List of 15 physiologic components assessed during VFSS

1. Lip closure
2. Lingual elevation
3. Tongue-to-palatal seal
4. Bolus preparation/mastication
5. Bolus transport/lingual motion
6. Initiation of pharyngeal swallow
7. Soft palate elevation and retraction
8. Laryngeal elevation
9. Anterior hyoid excursion
10. Laryngeal closure
11. Pharyngeal contraction
12. Pharyngoesophageal segment opening
13. Tongue base retraction
14. Epiglottic inversion
15. Esophageal clearance

Although the late oral and early pharyngeal components of swallowing are the most critical from a safety viewpoint, the oral preparatory and early oral transport aspects of swallow are the most aesthetically and psychologically important. During the oral preparatory stage of swallow, the bolus is manipulated by lingual motion and masticated (if necessary). Although not a characteristic of natural drinking or eating behavior in most healthy individuals [50], the ability to contain a liquid bolus (component 1, Fig. 1A) in the oral cavity through an anterior lip seal and lateral and posterior tongue-to-palatal contact (Fig. 1B) is assessed. The proficiency of this task provides clinical information about a patient's ability to follow simple commands during swallowing, which is an important prognostic indicator for successful learning of compensatory swallowing strategies.

Furthermore, the ability to contain a bolus within the oral cavity provides information on oral motor control. The tongue is the major mobile element of the oral swallow and plays a complementary role in bolus preparation and mastication. The tongue also plays a major role in bolus containment and airway maintenance [51,52]. The back of the tongue assumes a slightly elevated position from contraction of various muscle groups, and opposes an actively contracted soft palate that is drawn downward and forward (component 2, see Fig. 1B). This glossopalatine mechanism (component 3, see Fig. 1B) ensures that portions of a liquid bolus do not fall prematurely over the base of the tongue [35,43]. The ingested material is mixed with saliva and tasted during rotary mandibular chewing (component 4), a motion that is integrated into the oral swallowing process and propelled through the oral cavity by way of lingual motility (component 5, Fig. 1C, D) [51–54].

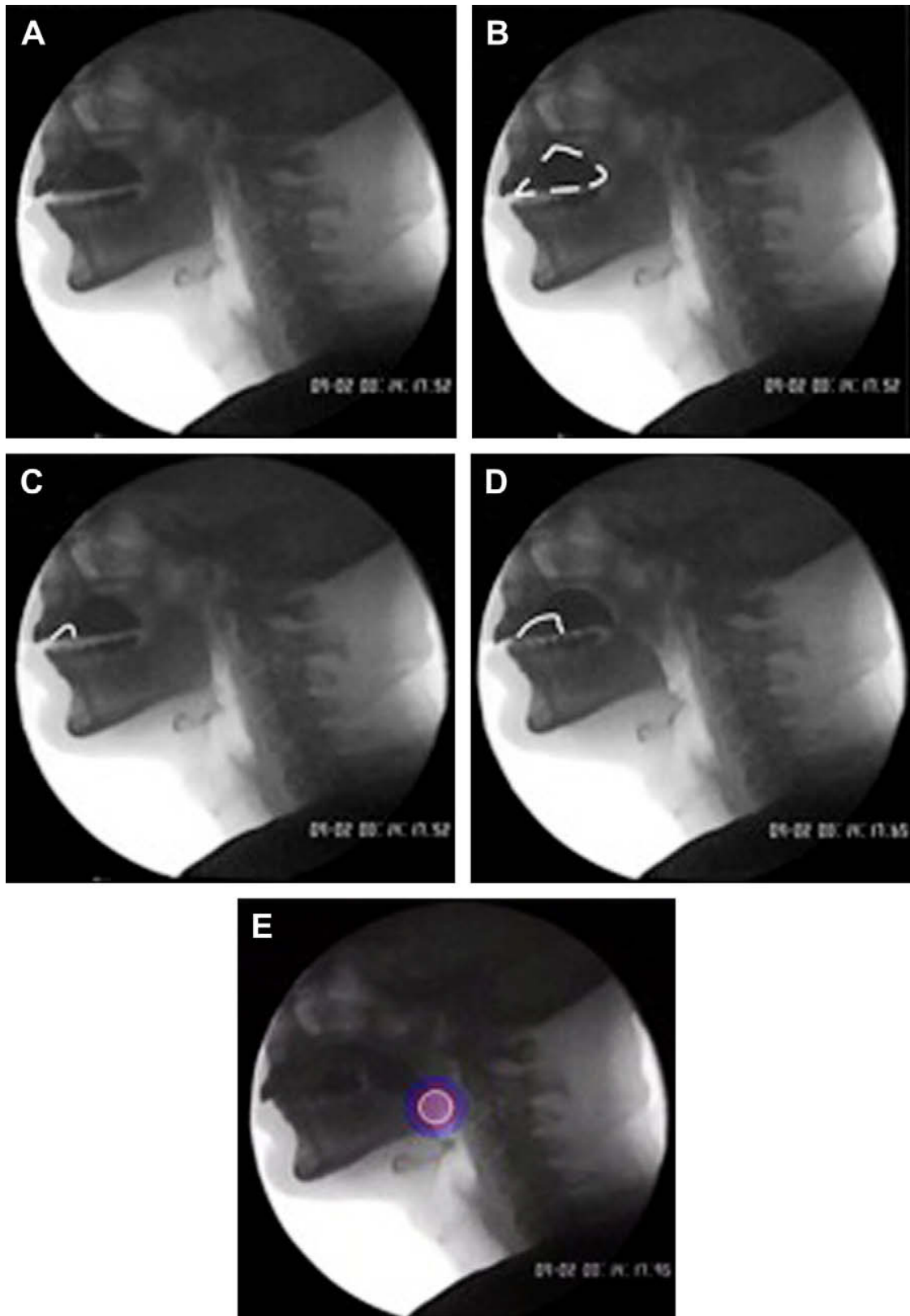


Fig. 1. Oral components of swallowing as depicted on lateral views from VFSS recordings. Oral containment through (A) anterior lip seal and (B) tongue-to-palatal contact. (C) Early and (D) mid-lingual motility during oral bolus transport. (E) Initiation of the pharyngeal swallow.

When adult humans eat natural bite sizes of solid foods, portions of the food may be propelled to and accumulate in the pharynx during mastication [54]. If the system has inefficiencies, such as muscle weakness or sensory loss, residual material may remain in the oral or pharyngeal cavity, placing the patient at risk for inadequate nutrition/hydration or airway compromise.

As the bolus is propelled through the oral cavity through upward and forward motion of the tongue, the head of the bolus reaches the region of the posterior oral cavity or oropharynx. When the sensory receptive fields in these areas are stimulated, the pharyngeal swallow is initiated (component 6, Fig. 1E) and the respiratory pause to accommodate swallowing becomes obligatory [51,52,55].

Although onset of the pharyngeal swallow varies relative to the position of the bolus [56], when initiated it is characterized by five mechanical events that have been shown to overlap during synchronized videorecordings of structural movements during swallow. These events protect the airway and clear the pharynx of ingested material, and include (1) elevation and retraction of the soft palate (component 7, Fig. 2A); (2) elevation and anterior displacement of the larynx (component 8, Fig. 2B) and hyoid bone (Fig. 2C); (3) laryngeal closure (component 10, Fig. 2D); (4) pharyngeal contraction (component 11); and (5) opening of the pharyngoesophageal region (component 12, Fig. 2E) [1,28,35,36,40,41,43–48]. Contraction of the pharyngeal constrictors (Fig. 2F) coincides with the forceful retraction of the tongue (component 13, Fig. 2G), which applies strong positive pressure on the bolus tail, assisting in pharyngeal clearance and prevention of pharyngeal residue [5,44,47]. The hyoid bone and larynx move as a functional unit in a superior and anterior trajectory during a normal, nutritive swallow.

These critical motions, observed during VFSS, are physiologically linked to effect vestibular closure (ie, through approximation of the arytenoid cartilages and the epiglottic petiole together with full inversion of the epiglottic tip) (component 14, see Fig. 2F; Fig. 2H) and to opening and distension of the pharyngoesophageal segment (PES) (see Fig. 2E). Opening of the segment permits entry of the ingested material into the cervical esophageal region [5,44,45,47,48,57]. The traction placed on the cricoid cartilage during this brisk motion pulls the cartilage anteriorly and away from the posterior pharyngeal wall, opening the compliant PES region (see Fig. 2E) [5,44,45,47,48,57]. This compliance is related to early relaxation of the cricopharyngeal muscle, the primary muscular component of the segment [55]. As the larynx descends toward its rest position in the latter stages of pharyngeal swallowing, respiration is resumed and characterized by a small expiratory airflow in most adult human swallows [58–60].

The mechanics of the esophageal body and lower esophageal sphincter are less complex and easier to study because of their slow speed relative to oropharyngeal swallow events. The bolus head enters the cervical esophageal region through the distended PES, continues through the esophagus,

and is propelled and cleared (component 15, Fig. 3) through primary and secondary esophageal peristaltic muscle contractions [61,62]. These contractions continue until the bolus head and tail progress through the passively relaxed lower esophageal sphincter (LES) and advance into the stomach.

A few behavioral interventions are available to modify the contractile characteristics of the esophagus and improve esophageal clearance [41]. However, clinical evidence and preliminary research indicate that esophageal clearance in the upright position seems to have some functional impact on pharyngeal clearance and possible airway protection [63]. Therefore, clinicians observe esophageal clearance in the upright eating and drinking position during the MBS examination to gain an impression of the potential impact of incomplete or slowed esophageal clearance on oropharyngeal swallowing function; the potential for aspiration of residual esophageal contents; and the nutritional status of the patient.

The anteroposterior image projection is the optimal view for assessing the efficiency of esophageal clearance in the upright position. This viewing plane is also best suited to determine the overall symmetry of oropharyngeal swallowing function and the immediate effectiveness of compensatory postures.

Move toward standardization

By definition, a *gold standard* is a test against which all other tests are measured. The VFSS has often been described as the gold standard for the evaluation of oropharyngeal swallowing. However, a single test is unlikely to provide the best assessment of swallowing for every patient and condition. Other imaging methods, such as flexible endoscopy, may supplant or complement VFSS examination. Nonetheless, clinical use data indicate that VFSS is the preferred method by most practicing clinicians, and efforts should be taken to standardize the examination protocol, terminology used to describe swallowing behavior, and method for quantifying swallowing impairment.

Clinicians have not adopted a universally accepted terminology or tool that has been empirically based, reliable, and valid for converting clinical information into a quantifiable metric to diagnose swallowing impairment. Empiric evidence and standardization have been lacking for selecting the measured physiologic components and types of measures used, and categorizing functional swallowing components into regional domains (ie, phases). This lack of standardization in measurement methods across clinics and laboratories impedes understanding of true functional results in studies documenting rehabilitative (swallowing therapy) and restorative (surgery and medications) effects of treatment; produces ambiguous reporting of outcomes; and hinders understanding of what restorative and rehabilitative targets should be to impact the overall health and well-being of patients who have dysphagia.

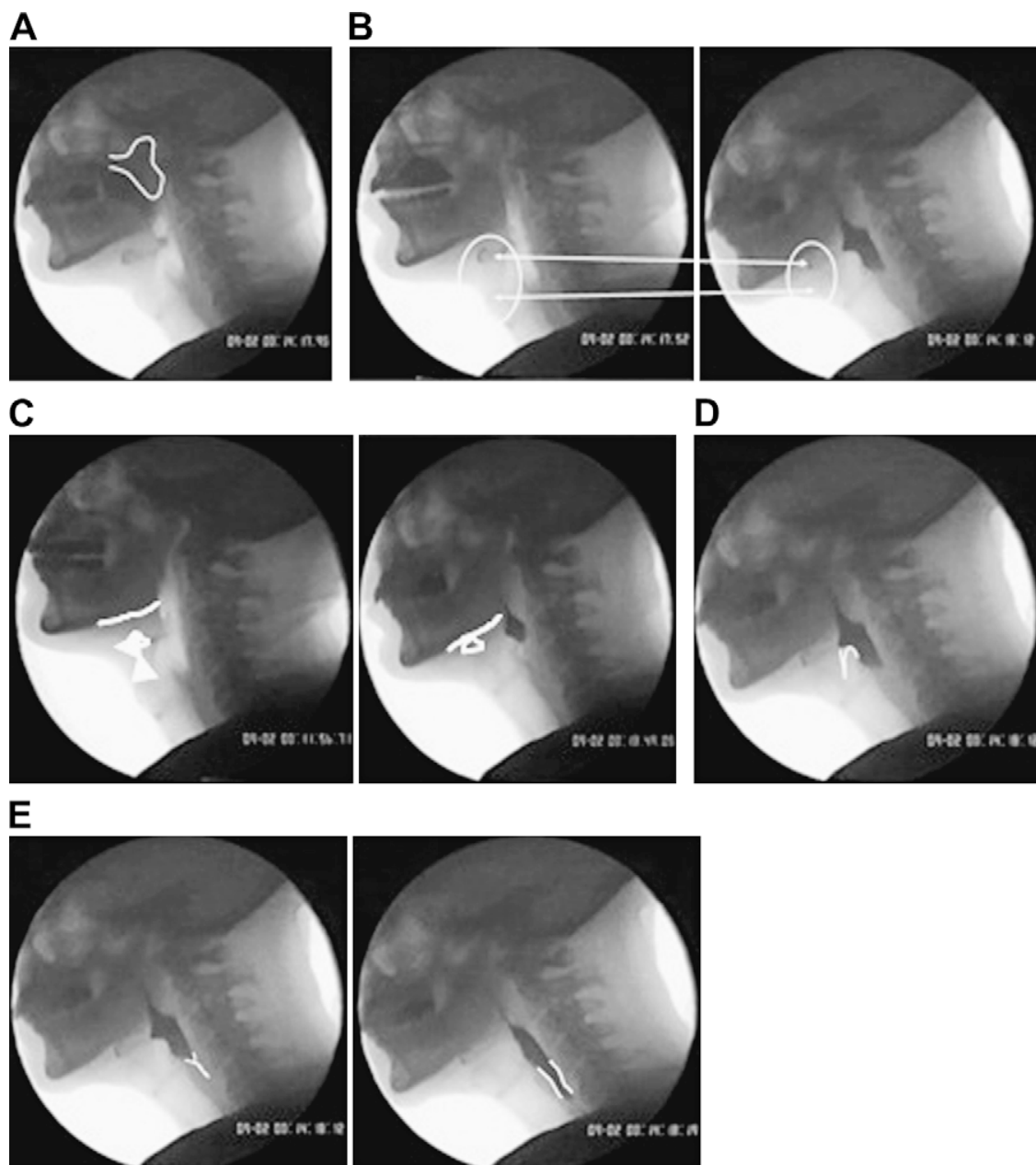


Fig. 2. Pharyngeal components of swallowing as depicted on lateral views from VFSS recordings. (A) Elevation and retraction of the soft palate. Elevation and anterior displacement of the (B) larynx and (C) hyoid bone. (D) Laryngeal closure through apposition of arytenoid cartilages to epiglottic base. (E) Opening and distension of pharyngo-esophageal segment. (F) Pharyngeal contraction and stripping wave. (G) Tongue base retraction and apposition with posterior pharyngeal wall. (H) Epiglottic inversion.

The Agency for Health Care Research and Quality (AHRQ) reports [64]:

- Standardization is critical to supporting valid comparisons and benchmarking across health care settings
- Comparability makes the information useful for quality improvement and public reporting
- Standardization assures users of the results that the validity and reliability built into the instrument by the developers are maintained

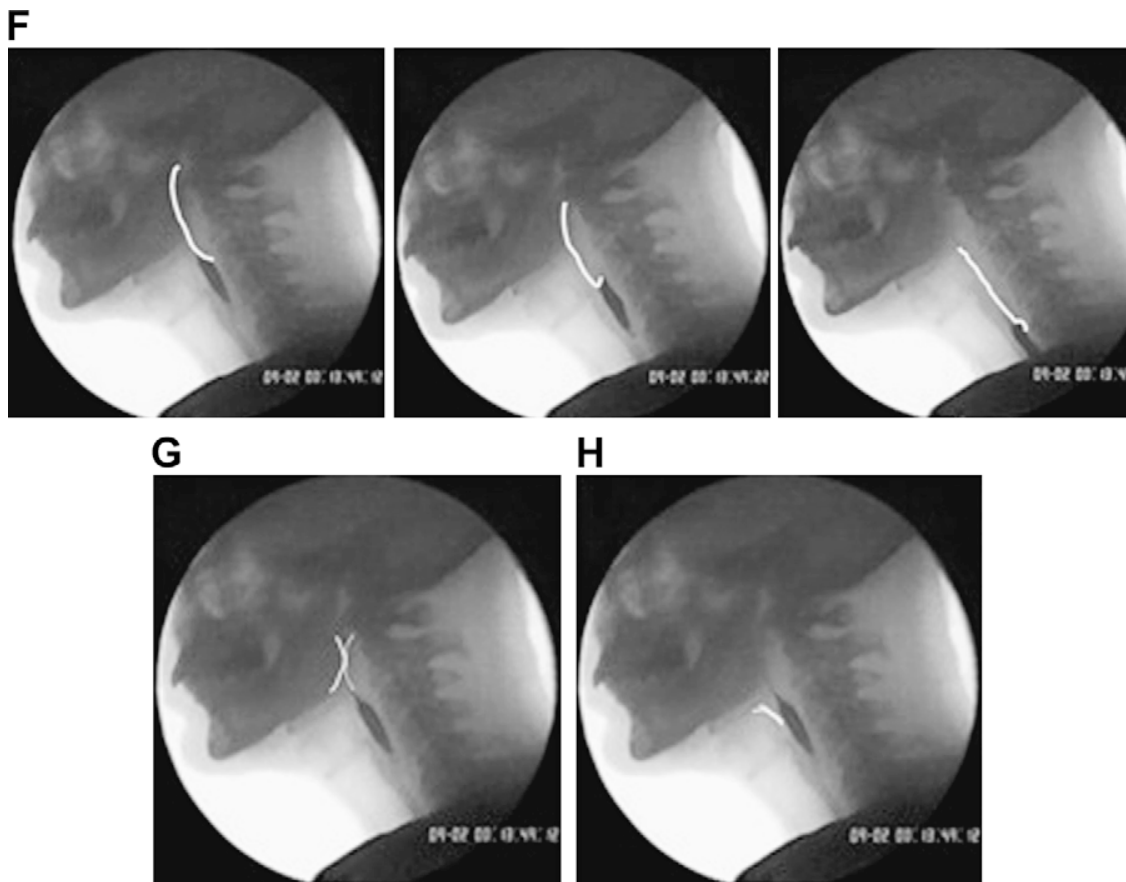


Fig. 2 (continued)

- Adaptation of a voluntary standards system will lead to optimization of patient care quality, safety, efficacy, and cost

AHRQ further reports that voluntary standards should be applied to the content and format of the test instrument, the data collection protocol, the analyses and interpretations, and reporting. Translating Research into Practice-II initiative focused on implementation of techniques and factors, such as those associated with successfully translating research findings into diverse applied setting. This initiative brought clinician accountability to the forefront in clinical practice. The report stated that the increased demands for accountability in health care, including reporting of clinical performance using standardized quality measures, have created a sense of urgency about improving these areas within health care organizations and clinical practices.

Standardization: videofluorographic swallowing study procedure and protocol

The descriptions of the VFSS as originally described by Logemann [40] continue to be followed in most clinical practices [42,65]. Patients are initially positioned in the lateral view, and regions of visualization include



Fig. 3. Esophageal clearance in the upright position as depicted on the anteroposterior view from VFSS recording.

the oral cavity, pharyngeal cavity, larynx, and cervical esophagus. The visualization field includes the lips anteriorly, nasal cavity superiorly, cervical spinal column posteriorly, and the entire PES inferiorly [35,38,40,41,43]. The larynx should be in full view within this visualization field. The VFSS occurs in a standard radiology fluoroscopy suite. The fluoroscope is activated by the radiologist for a few seconds before and then after administration of the barium substances. The fluoroscope is deactivated shortly after the bolus tail exits the cervical esophageal region.

The lateral view is ideal for judging movements that generate pressures and open and close critical valves during swallow. Patients are then positioned in the anteroposterior (ie, frontal) viewing plane so that judgments can be made about symmetry of bolus flow, pharyngeal wall contraction, and symmetry of structure and function during bolus flow. All patients should ideally be examined in the lateral and frontal positions. An examination performed in only the lateral position can miss vital abnormalities that can be appreciated only in the frontal position. For example, examination in the frontal position is essential to detect unilateral abnormalities, such as unilateral pharyngeal paresis or paralysis and unilateral vocal fold paralysis. Total radiation exposure averages 3 to 5 minutes, an amount typically encountered in an upper gastrointestinal series. The examination may be extended depending on the nature and severity of the swallowing problem and patient condition; however, the goal of minimizing radiation exposure while maximizing clinical yield is consistently maintained.

Accurate analysis requires video freeze-frame and slow motion capability. Dynamic recording at a minimum of 30 video frames per second is essential for detecting the rapid movements and bolus flow events associated with oropharyngeal swallowing and is easily accomplished through linking a recording device to the fluoroscopic unit. A 100- or 105-mm spot-film

camera with maximum frame rates of 6 to 8 frames per second is inadequate to evaluate swallowing (eg, subtle but critical laryngeal penetration or aspiration may be visible on only 1 or 2 frames of a sequence of 30 frames per second) [42,65].

The VFSS typically includes administration of various bolus volumes and textures because data have shown the potential physiologic benefits of manipulating these sensory variables. However, the consistencies of the contrast material and volumes administered have not been standardized across most clinics; one reason is that clinicians often introduce certain consistencies based on their clinical intuitions of likely patient performance. However, implementation of these practices has not been validated.

A recent study [66] has shown the need and feasibility of standardizing contrast materials. Martin and colleagues [66] determined the contribution of bolus volumes, consistencies, and textures to the overall impressions of swallowing component scores. Although the investigators identified a role for most commonly tested standardized volumes of thin liquid, nectar-thick liquid, honey-thick liquid, pudding, and cookie to one or several of the component impairment scores, 5 mL of thin and nectar-thick liquid provided sufficient information that allowed trained clinicians to make reliable assessments of the 15 physiologic swallowing components. If 5 mL of liquid (thin and nectar-thick) continues to allow judgments of impairment in subsequent studies, these two swallow trials may serve as “screening swallows” that signal the need to progress, or perhaps conclude the MBS examination. This finding certainly attests to the potentially misguided practice of foregoing the thin-liquid swallow because of the perception that patients will perform better (ie, less aspiration) with a more viscous bolus.

Standardization: videofluorographic swallowing study terminology, interpretation, and reporting

In addition to testing the role for standardizing the VFSS protocol, the study by Martin and colleagues [66] also intended to rigorously test the reliability, content, construct, and external validity of a new MBS tool (MBSImp) to quantify swallowing impairment. The tool includes an ordinal scaling methodology of each of the previously described set of physiologic components, whereby each score represents a unique observation from the VFSS. The tool shows content and construct validity and good concordance between and within clinician scoring.

Furthermore, because the VFSS represents a clinical simulation of a feeding/eating experience, any measures of impairment gained from the test should demonstrate relevance to the functional outcome of the patient. The tool was examined for this relationship, and the measures of swallowing impairment showed good external validation through statistically significant correlations with blinded outcome assessments of diet, health status, nutrition, and quality of life.

Adaptation of this voluntary standards system will lead to optimization of patient care quality, safety, efficacy, and cost. Standardized practices facilitate interinstitutional exchange of patient data using electronic data collection, aggregation, and reporting systems [64,67]. The results of this study show the achievement of a critical strategic step toward standardizing swallowing assessment. Implementation of standardized training, protocol, contrast materials, and measurements should improve the ability to compare the swallowing impairment exhibited by patients who have dysphagia during recovery or physiologic decline associated with natural histories of progressive neurologic diseases across clinics and clinical laboratories.

Videofluorographic swallowing study: a rehabilitation examination

A primary purpose of a VFSS is to determine the effect of various behavioral and sensory interventions on the physiologic function of the swallowing mechanism. Several studies have shown the ability to detect immediate effects of compensatory strategies (bolus volume, consistency and taste, postural alterations, swallowing, and respiratory maneuvers) on swallowing physiology [9,14,68–82]. The systematic application of these evidence-based strategies, if applied directly to the observed physiologic impairment, often leads to the development of eating and drinking strategies that may be immediately implemented by the patient, caregiver, and clinician. Swallowing rehabilitation strategies are described elsewhere in this edition and will not be repeated here. Although patients may not be deemed safe for immediate oral intake after examination, the importance of the VFSS for optimizing oral intake within the limits of the patient's physiologic potential cannot be understated. Proper administration and interpretation of the examination has the potential to upgrade oral intake status and diet textures and determine oral intake restrictions [38,83]. Recommendations are based not only on the patient's physiologic status but also on their cognitive status, the caregiver situation, and the nature of the underlying disease or condition.

Summary

Strong evidence has shown VFSS to be the ideally suited method for identifying and quantifying the presence and nature of oropharyngeal and cervical esophageal swallowing disorders. The ability to assess overlapping and interdependent structural movements as they relate to bolus flow in real time throughout the swallowing process has had high clinical yield. When the VFSS protocol is standardized, interpreted, and reported by trained clinicians using standardized and validated measures, treatment can be systematically applied during and after the examination according to the physiologic swallowing problem. Furthermore, change in the patient's

swallowing performance and responsiveness to swallowing interventions can be consistently applied and communicated across clinics and hospitals. These standardized practices will result in seamless patient care and optimize swallowing treatment throughout the continuum of care.

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References

- [1] Cook IJ, Dodds WJ, Dantas RO, et al. Timing of videofluoroscopic, manometric events, and bolus transit during the oral and pharyngeal phases of swallowing. *Dysphagia* 1989;4(1):8–15.
- [2] Kendall K, McKenzie SW, Leonard R, et al. Timing of events in normal swallowing: a videofluoroscopic study. *Dysphagia* 2000;15(2):74–83.
- [3] Martin-Harris B, Brodsky MB, Michel Y, et al. Breathing and swallowing dynamics across the adult lifespan. *Arch Otolaryngol Head Neck Surg* 2005;131(9):762–70.
- [4] Martin-Harris B, Brodsky MB, Price CC, et al. Temporal coordination of pharyngeal and laryngeal dynamics with breathing during swallowing: single liquid swallows. *J Appl Phys* 2003;94(5):1735–43.
- [5] McConnel FM, Cerenko D, Mendelsohn MS. Manofluorographic analysis of swallowing. *Otolaryngol Clin North Am* 1988;21(4):625–35.
- [6] Perlman AL, Palmer PM, McCulloch TM, et al. Electromyographic activity from human laryngeal, pharyngeal, and submental muscles during swallowing. *J Appl Phys* 1999;86(5):1663–9.
- [7] Tracy JF, Logemann JA, Kahrilas PJ, et al. Preliminary observations on the effects of age on oropharyngeal deglutition. *Dysphagia* 1989;4(2):90–4.
- [8] Van Daele DJ, McCulloch TM, Palmer PM, et al. Timing of glottic closure during swallowing: a combined electromyographic and endoscopic analysis. *Ann Otol Rhinol Laryngol* 2005;114(6):478–87.
- [9] Castell JA, Castell DO, Schultz AR, et al. Effect of head position on the dynamics of the upper esophageal sphincter and pharynx. *Dysphagia* 1993;8(1):1–6.
- [10] Castell JA, Dalton CB, Castell DO. Pharyngeal and esophageal sphincter manometry in humans. *Am J Physiol Gastrointest Liver Physiol* 1990;258(2):G173–8.
- [11] Kahrilas PJ, Logemann JA, Lin S, et al. Pharyngeal clearance during swallowing: a combined manometric and videofluoroscopic study. *Gastroenterology* 1992;103(1):128–36.
- [12] Robbins J, Hamilton JW, Lof GL, et al. Oropharyngeal swallowing in normal adults of different ages. *Gastroenterology* 1992;103(3):823–9.

- [13] Perlman AL, Schultz JG, VanDaele DJ. Effects of age, gender, bolus volume, and bolus viscosity on oropharyngeal pressure during swallowing. *J Appl Phys* 1993;75(1):33–7.
- [14] Shaker R, Ren J, Podvrsan B, et al. Effect of aging and bolus variables on pharyngeal and upper esophageal sphincter motor function. *Am J Physiol* 1993;264(3 Pt 1):G427–32.
- [15] Steele CM, Huckabee ML. The influence of orolingual pressure on the timing of pharyngeal pressure events. *Dysphagia* 2007;22(1):30–6.
- [16] Greene JR, Wang YT. Tongue-surface movement patterns during speech and swallowing. *J Acoust Soc Am* 2003;113(5):2820–33.
- [17] Logemann JA, Pauloski BR, Rademaker AW, et al. Temporal and biomechanical characteristics of oropharyngeal swallow in younger and older men. *J Speech Lang Hear Res* 2000;43(5):1264–74.
- [18] Logemann JA, Pauloski BR, Rademaker AW, et al. Oropharyngeal swallow in younger and older women: videofluoroscopic analysis. *Journal of Speech Language & Hearing Research* 2002;45(3):434–45.
- [19] Burkhead LM, Sapienza CM, Rosenbek JC. Strength-training exercise in dysphagia rehabilitation: principles, procedures, and directions for future research. *Dysphagia* 2007;22(3):251–65.
- [20] Lazarus C, Logemann JA, Pauloski BR, et al. Effects of radiotherapy with or without chemotherapy on tongue strength and swallowing in patients with oral cancer. *Head Neck* 2007;29(7):632–7.
- [21] Leonard RJ, Belafsky PC, Rees CJ. Relationship between fluoroscopic and manometric measures of pharyngeal constriction: the pharyngeal constriction ratio. *Ann Otol Rhinol Laryngol* 2006;115(12):897–901.
- [22] Cerenko D, McConnel FM, Jackson RT. Quantitative assessment of pharyngeal bolus driving foci. *Otolaryngol Head Neck Surg* 1989;100(1):57–63.
- [23] Daniels SK, Schroeder MF, DeGeorge PC, et al. Effects of verbal cue on bolus flow during swallowing. *Am J Speech Lang Pathol* 2007;16(2):140–7.
- [24] Johnsson F, Shaw D, Gabb M, et al. Influence of gravity and body position on normal oropharyngeal swallowing. *Am J Physiol* 1995;269(5 Pt. 1):G653–8.
- [25] McConnel FM, Guffin TNJ, Cerenko D, et al. The effects of bolus flow on vertical pharyngeal pressure measurement in the pharyngo-esophageal segment: clinical significance. *Otolaryngol Head Neck Surg* 1992;106(2):169–74.
- [26] Olsson R, Nilsson H, Ekberg O. Pharyngeal solid-state manometry catheter movement during swallowing in dysphagic and nondysphagic participants. *Acad Radiol* 1994;1(4):339–44.
- [27] Kahrilas PJ, Lin S, Rademaker AW, et al. Impaired deglutitive airway protection: a video-fluoroscopic analysis of severity and mechanism. *Gastroenterology* 1997;113(5):1457–64.
- [28] Logemann JA, Kahrilas PJ, Cheng J, et al. Closure mechanisms of laryngeal vestibule during swallow. *Am J Physiol* 1992;262(2 Pt 1):G338–44.
- [29] Aviv JE, Martin JH, Keen MS, et al. Air pulse quantification of supraglottic and pharyngeal sensation: a new technique. *Annals of Otolaryngology, Rhinology & Laryngology* 1993;102(10):777–80.
- [30] Leow LP, Huckabee ML, Sharma S, et al. The influence of taste on swallowing apnea, oral preparation time, and duration and amplitude of submental muscle contraction. *Chem Senses* 2007;32(2):119–28.
- [31] Logemann JA, Pauloski BR, Colangelo L, et al. Effects of a sour bolus on oropharyngeal swallowing measures in patients with neurogenic dysphagia. *J Speech Hear Res* 1995;38(3):556–63.
- [32] Pelletier CA, Dhanaraj GE. The effect of taste and palatability on lingual swallowing pressure. *Dysphagia* 2006;21(2):121–8.
- [33] Robbins J, Coyle J, Rosenbek J, et al. Differentiation of normal and abnormal airway protection during swallowing using the penetration-aspiration scale [see comment]. *Dysphagia* 1999;14(4):228–32.

- [34] Rosenbek JC, Robbins JA, Roecker EB, et al. A penetration-aspiration scale. *Dysphagia* 1996;11(2):93–8.
- [35] Dodds WJ, Logemann JA, Stewart ET. Radiologic assessment of abnormal oral and pharyngeal phases of swallowing. *Am J Roentgenol* 1990;154(5):965–74.
- [36] Ekberg O, Sigurjonsson SV. Movement of the epiglottis during deglutition. A cineradiographic study. *Gastrointest Radiol* 1982;7(2):101–7.
- [37] Logemann JA. Behavioral management for oropharyngeal dysphagia. *Folia Phoniatri Logop* 1999;51(4–5):199–212.
- [38] Martin-Harris B, Logemann JA, McMahon S, et al. Clinical utility of the modified barium swallow. *Dysphagia* 2000;15(3):136–41.
- [39] Ramsey GH, Watson JS, Gramiak R, et al. Cinefluorographic analysis of the mechanism of swallowing. *Radiology* 1955;64(4):498–518.
- [40] Logemann JA. Manual for the videofluorographic study of swallowing. 2nd edition. Austin (TX): ProEd; 1993.
- [41] Logemann JA. Evaluation and treatment of swallowing disorders. Austin (TX): ProEd; 1998.
- [42] Jones B, Donner MW. Normal and abnormal swallowing: Imaging in diagnosis and therapy. New York: Springer Verlag; 1991.
- [43] Dodds WJ, Stewart ET, Logemann JA. Physiology and radiology of the normal oral and pharyngeal phases of swallowing. *Am J Roentgenol* 1990;154(5):953–63.
- [44] Atkinson M, Kramer P, Wyman S, et al. The dynamics of swallow. I. Normal pharyngeal mechanisms. *J Clin Invest* 1957;36:581–98.
- [45] Kahrilas PJ, Dodds WJ, Dent J, et al. Upper esophageal sphincter function during deglutition. *Gastroenterology* 1988;95(1):52–62.
- [46] McConnel FM, Hester TR, Mendelsohn MS, et al. Manofluorography of deglutition after total laryngopharyngectomy. *Plast Reconstr Surg* 1988;81(3):346–51.
- [47] Sokol EM, Heitmann P, Wolf BS, et al. Simultaneous cineradiographic and manometric study of the pharynx, hypopharynx, and cervical esophagus. *Gastroenterology* 1966;51(6):960–74.
- [48] Jacob P, Kahrilas PJ, Logemann JA, et al. Upper esophageal sphincter opening and modulation during swallowing. *Gastroenterology* 1989;97(6):1469–78.
- [49] Magendie F. Memoire sur l'usage de l'epiglote dans la deglutition. Paris: Meguigon-Marvis; 1813.
- [50] Daniels SK, Corey DM, Hadskey LD, et al. Mechanism of sequential swallowing during straw drinking in healthy young and older adults. *Journal of Speech Language & Hearing Research* 2004;47(1):33–45.
- [51] Storey AT. Interactions of alimentary and upper respiratory tract reflexes. In: Sessle BJ, Hannam A, editors. *Mastication and swallowing: biological and clinical correlates*. Toronto: University of Toronto; 1976. p. 22–36.
- [52] Palmer JB, Rudin NJ, Lara G, et al. Coordination of mastication and swallowing. *Dysphagia* 1992;7(4):187–200.
- [53] Hiimeae KM, Palmer JB. Food transport and bolus formation during complete feeding sequences on foods of different initial consistency. *Dysphagia* 1999;14:31–42.
- [54] Hiimeae KM, Palmer JB. Cyclic motion of the soft palate in feeding. *J Dent Res* 2005;84:39–42.
- [55] Yoshida T. Electromyographic and x-ray investigations of normal deglutition. *Otologia (Fukuoka)* 1979;25:824–72.
- [56] Martin-Harris B, Brodsky MB, Michel Y, et al. Delayed initiation of the pharyngeal swallow: normal variability in adult swallows. *Journal of Speech Language & Hearing Research* 2007;50(3):585–94.
- [57] Cook IJ, Dodds WJ, Dantas RO, et al. Opening mechanisms of the human upper esophageal sphincter. *Am J Physiol* 1989;257(5 Pt 1):G748–59.

- [58] Martin BJW. The influence of deglutition on respiration [doctoral dissertation]. Evanston (IL): Northwestern University; 1991.
- [59] Martin-Harris B. Coordination of laryngeal dynamics and peripheral respiratory patterns: Isolated and sequential swallows. Presented at the Tenth Annual Meeting of the Dysphagia Research Society. Albuquerque, NM; October 11–13, 2001.
- [60] Klahn MS, Perlman AL. Temporal and durational patterns associating respiration and swallowing. *Dysphagia* 1999;14(3):131–8.
- [61] Castell DA, Diederrich LL, Castell JA. Esophageal motility and pH testing. 3rd edition. Highlands Ranch (CO): Sandhill Scientific, Inc.; 2000.
- [62] Levine MS. Radiology of the esophagus. Philadelphia: Saunders Company; 1989.
- [63] Mendell DA, Logemann JA. A retrospective analysis of the pharyngeal swallow in patients with a clinical diagnosis of GERD compared with normal controls: a pilot study. *Dysphagia* 2002;17(3):220–6.
- [64] Agency for Healthcare Research and Quality. Translating research into practice (TRIP)-II. Fact Sheet. AHRQ Publication No. 01-P017, March 2001. Available at: <http://www.ahrq.gov/research/trip2fac.htm>. Accessed November 1, 2007.
- [65] Jones B. Radiographic evaluation of motility of mouth and pharynx. *GI Motility* online. 2006. Available at: <http://www.nature.com/gimo/index.html>. Accessed December 7, 2007.
- [66] Martin-Harris B, Michel Y, Brodsky MB, et al. MBS measurement tool of swallow impairment—MBSImp: establishing a standard. Presented at the 15th Annual Meeting of the Dysphagia Research Society. Vancouver, BC, Canada; March 7–10, 2007.
- [67] Waters TM, Logemann JA, Pauloski BR, et al. Beyond efficacy and effectiveness: conducting economic analyses during clinical trials. *Dysphagia* 2004;19(2):109–19.
- [68] Dodds WJ, Man KM, Cook IJ, et al. Influence of bolus volume on swallow-induced hyoid movement in normal subjects. *AJR Am J Roentgenol* 1988;150(6):1307–9.
- [69] Ren J, Shaker R, Zamir Z, et al. Effect of age and bolus variables on the coordination of the glottis and upper esophageal sphincter during swallowing. *Am J Gastroenterol* 1993;88(5):665–9.
- [70] Lazarus CL, Logemann JA, Rademaker AW, et al. Effects of bolus volume, viscosity, and repeated swallows in nonstroke subjects and stroke patients. *Arch Phys Med Rehabil* 1993;74(10):1066–70.
- [71] Poudroux P, Kahrilas PJ. Deglutitive tongue force modulation by volition, volume, and viscosity in humans. *Gastroenterology* 1995;108(5):1418–26.
- [72] Bisch EM, Logemann JA, Rademaker AW, et al. Pharyngeal effects of bolus volume, viscosity, and temperature in patients with dysphagia resulting from neurologic impairment and in normal subjects. *J Speech Hear Res* 1994;37(5):1041–59.
- [73] Rademaker AW, Pauloski BR, Colangelo LA, et al. Age and volume effects on liquid swallowing function in normal women. *Journal of Speech Language & Hearing Research* 1998;41(2):275–84.
- [74] Hiss SG, Strauss M, Treole K, et al. Effects of age, gender, bolus volume, bolus viscosity, and gustation on swallowing apnea onset relative to lingual bolus propulsion onset in normal adults. *J Speech Lang Hear Res* 2004;47(3):572–83.
- [75] Logemann JA. Noninvasive approaches to deglutitive aspiration. *Dysphagia* 1993;8(4):331–3.
- [76] Logemann JA. Rehabilitation of oropharyngeal swallowing disorders. *Acta Otorhinolaryngol Belg* 1994;48(2):207–15.
- [77] Robbins J. Can thickened liquids or chin down posture prevent aspiration? *Ann Intern Med* 2008;148(7):1–39.
- [78] Welch MV, Logemann JA, Rademaker AW, et al. Changes in pharyngeal dimensions effected by chin tuck. *Archives of Physical Medicine & Rehabilitation* 1993;74(2):178–81.
- [79] Shanahan TK, Logemann JA, Rademaker AW, et al. Chin-down posture effect on aspiration in dysphagic patients. *Arch Phys Med Rehabil* 1993;74(7):736–9.

- [80] Shaker R, Ren J, Zamir Z, et al. Effect of aging, position, and temperature on the threshold volume triggering pharyngeal swallows. *Gastroenterology* 1994;107(2):396–402.
- [81] Ayuse T, Ayuse T, Ishitobi S, et al. Effect of reclining and chin-tuck position on the coordination between respiration and swallowing. *J Oral Rehabil* 2006;33(6):402–8.
- [82] Logemann JA, Rademaker AW, Pauloski BR, et al. Effects of postural change on aspiration in head and neck surgical patients. *Otolaryngol Head Neck Surg* 1994;110(2):222–7.
- [83] Jones B. The tailored examination of the dysphagic patient. *Appl Radiol* 1995;24:84–9.