Measurement and Assessment of Swallowing: A Review

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> "Swallowing is a complex, highly organised sequence of events that originates in the swallowing centre of the brain. …There has been a recent surge in the development of novel investigations exploring the swallow cycle."

Abstract

Several different methods are available for examining the swallowing cycle and assessing dysfunction. The current gold standard and most widely used method is the modified barium swallow study, which uses videofluoroscopy to assess bolus transit through mouth, pharynx and upper oesophagus. Other methods include fibre-optic endoscopic evaluation, which uses a flexible endoscopy to observe the swallowing process. This method allows for precise visualisation of the anatomy. Surface electromyography and cervical auscultation, although not very specific, can be used as rapid screening tools for dysphagia. Manometry uses pressure sensors to record peristaltic activity in the pharynx and upper oesophagus and can be used in conjunction with video fluoroscopy (manufluorography) for more detailed information. The aim of this review article is to look at current methods for evaluating swallowing and to outline the advantages and disadvantages of each of these methods.

Introduction

Swallowing is a complex, highly organised sequence of events that originates in the swallowing centre of the brain. It is entirely under reflex control and is initiated by voluntary movement of a food bolus to the back of the throat. This causes sensory impulses to be generated that are subsequently transmitted to the medulla and lower pons, from which motor impulses then travel to pharyngeal and oesophageal muscles to initiate swallowing. During swallowing, respiration is reflexively inhibited to prevent food from being aspirated[4]. Problems with this complex process can lead to significant health issues including aspiration pneumonia, dehydration, malnutrition and reduction in quality of life. Difficulty in swallowing is termed "dysphagia".

Definition

Dysphagia is defined as an abnormality in the transfer of a bolus from the mouth to the stomach[5]. It is associated with a sensation that solids or liquids are not being swallowed correctly.

Aetiology and Classification

Dysphagia is not a single disease entity, but a clinical manifestation of any problem involving the complex swallowing mechanism[6]. It is therefore important to determine the underlying causes.

1. Neurogenic dysphagia

Stroke is the most common cause of neurogenic dysphagia, with 30-40% of stroke victims suffering from significant dysphagia. As many as 20% will die in the first year from aspiration pneumonia secondary to the dysphagia[7]. Parkinson's disease causes degeneration of subcortical neurons (especially in the substantia nigra), leading to progressive motor deficits. In later stages it can lead to dysphagia due to dysfunction of oral, pharyngeal and oesophageal muscles[8]. Lower motor neuron deficits such as myasthenia gravis, Eaton-Lambert syndrome, amyotrophic lateral sclerosis and multiple sclerosis may equally lead to significant dysphagia if they affect neurons supplying oral, pharyngeal or oesophageal musculature; nerves in the swallowing centre may also be implicated. Traumatic brain injury is another major cause of neurogenic dysphagia. Finally, iatrogenic or congenital recurrent laryngeal nerve paralysis may also cause transient or permanent dysphagia. Unilateral paralysis is usually self-limiting and less severe in nature.

2. Structural/Mechanical dysphagia

The most common cause of mechanical swallowing difficulty is surgical resection of head and neck cancers. Tumours of this area include squamous cell carcinoma, thyroid carcinoma, adenocarcinoma and neuroendocrine neoplasia. Removal of parts of the tongue (glossectomy), larynx (laryngectomy) or even the oesophagus (oesophagectomy) may cause problems with swallowing. Other mechanical causes for dysphagia include infection/inflammation such as tonsillitis, epiglottitis, pharyngitis or quinsy (this may cause trismus - an inability to fully open one's mouth).

3. Oesophageal dysphagia

Oesophageal dysphagia refers to any cause of dysphagia that originates in the oesophagus. This may occur when the lumen becomes stenotic after swallowing a bolus that is too large for the oesophageal lumen. Another common cause of this is the formation of rings and webs of abnormally thick mucosal bands, causing narrowing in patients with iron deficiency anaemia. Furthermore, strictures may occur due to irradiation in patients being treated for head and neck cancers, or by acid reflux into the oesophagus, which is known as gastro-oesophageal reflux disease (GORD). Finally, sphincteric problems might occur at the lower end of the oesophagus, which can cause late regurgitation of food. This is called achalasia and is due to a non-relaxing lower oesophageal sphincter. A barium swallow test shows a classic dilated oesophagus with "parrot-beaked" tapering at the junction.

Swallowing Measurement

Several different methods for evaluating swallow and dysphagia have been described. Preceding any investigation is a thorough history and examination by ear, nose and throat specialists, speech and language therapists and nurses. Some studies offer subjective information that requires further evaluation (e.g. modified barium swallow study) and others determine quantitative values (e.g. impedance pharyngography[9] and studies to measure average volume per swallow, speed per swallow and swallowing capacity[10]). Clinical examination is able to identify only 60% of people who aspirate, leaving 40% undiagnosed and vulnerable to significant complications[11]. Thus, the need for effective diagnostic tools is great.

1. Modified Barium Swallow (MBS) Study

This investigation involves the use of video fluoroscopy to examine anatomical or physiological deficits along the oropharynx and monitor improvements in rehabilitation[12]. This procedure is widely available and can be used in patients of all ages. It is considered the gold standard for evaluating not only swallow dysfunction, but the mechanism of swallow itself[6]. The examination is done in the upright position and examined laterally as well as anteroposteriorly. The patient is given a bolus of thin liquid to swallow orally. This liquid contains barium and represents saliva. The patient first takes 1mL and then progresses to 2mL, 5mL and finally 10mL. Should the patient fail at one stage of the test, measures such as postural techniques or sensory enhancement are taken to help them to swallow the bolus[12]. The examination is done by videofluoroscopy, which films the entire swallowing sequence. The average swallowing cycle requires only 1.0-1.5sec (with the oral phase only lasting about 0.5sec). This requires a high frame rate that only filming can provide (30 frames/s). Using this method the cycle can be carefully examined frame-by-frame (refer to Figure 1)[13].

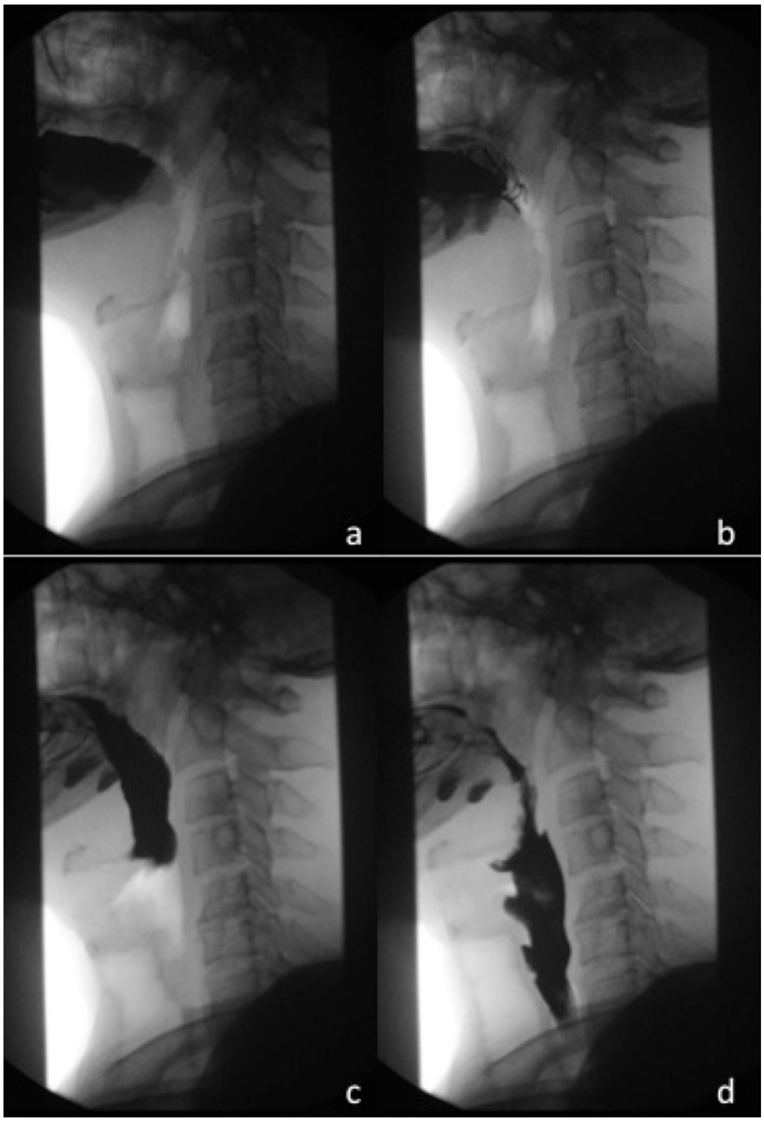

Figure 1. *Lateral radiographic overview of a normal swallowing sequence of a healthy patient with 10mL of barium. (a) Barium bolus is positioned in the mouth and is sealed off from the throat by approximation of the tongue with the soft palate. (b) The soft palate opens, allowing barium into the oropharynx. (c) Pharyngeal phase of swallowing has commenced. The upper oesophageal sphincter is open allowing free passage of fluid. (d) Peristaltic activity in the cervical oesophagus propels bolus into stomach. Adapted from Hellerhoff*[1]

Videofluoroscopy also provides information on transit time, motility problems and amount and aetiology of aspiration. The patient only receives only small amounts of radiation during the procedure[14].

A study of 608 patients by Martin-Harris et al. aimed to examine the clinical utility and yield of the MBS study[15]. They found some degree of abnormality in 90% of patients examined. Aspiration occurred in 32% and abnormal swallowing physiology was identified in 57% of those in which aspiration did not occur. Appropriate referral to other specialties (e.g. gastroenterology or speech and language therapy) after examination occurred in most cases. They concluded that MBS has a low false-positive rate and is a cost-effective investigation when compared to bedside observations or medical diagnosis[15].

2. Fibre-Optic Endoscopic Evaluation of Swallowing (FEES)

This assessment was first described by Langmore, Schatz and Olsen in 1988 and has become increasingly popular for assessing oral cavity and pharyngeal anatomy[16]. It was developed to evaluate the swallow mechanism if the more expensive videofluoroscopy was not available.

This procedure uses a flexible fibre-optic pharyngolaryngoscope (3.7mm diameter) to gain access to the pharyngeal space. No anaesthetic is required. The patient is seated upright (or at

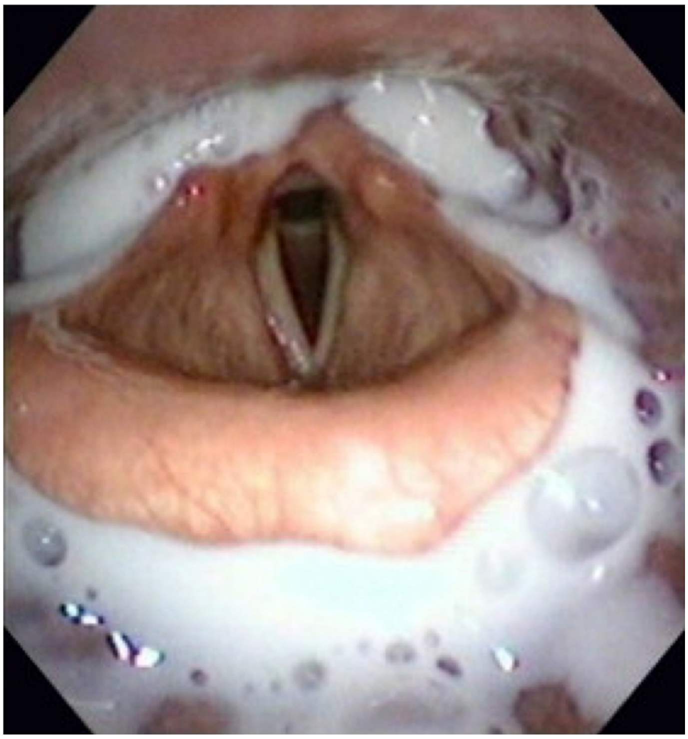

Figure 2. FEES image of the vocal folds. White liquid spillage into vallecula and pyriform fossae. Epiglottis anteriorly (bottom of picture). Adapted from Leder, S.B. and Murray, J. T.[3]

45° if bed-bound) and the scope is introduced into the nares. The scope is advanced below the inferior turbinate into the nasopharynx, where the velopharyngeal competence can be assessed. Moving through the oropharynx, the scope is finally passed to a point posterior to the epiglottis, giving clear view of the vocal cords.

With the scope in this position, the swallow assessment can commence: measured quantities of food/liquid (5-10ml) are given to the patient to swallow. The substances are dyed with green or blue food colouring. The bolus cannot be monitored during pharyngeal swallow as the substance obstructs the view of the scope. However, the phases immediately preceding and following swallow can be observed and provide useful insight into premature spillage and residual food in the pharynx[16,14,17].

FEES is more sensitive than MBS in examining anatomy and can identify subtle anomalies. It provides limited information on the oral phase of swallowing and is unable to examine the pharyngeal phase (Figure 2)[17]. There is no radiation exposure and it can be performed faster and with less preparation than videofluoroscopy, making it ideal when immediate information is required.

A study by Kelly et al. found that, in general, pharyngeal residue was perceived to be greater in FEES than in videofluoroscopic studies[18]. Their study concluded that FEES and videofluoroscopy cannot be used interchangeably, but should be used to complement each other. An advantage of FEES is its use in patients who are bed-bound and cannot sit up for a barium swallow test.

3. Scintigraphy

Scintigraphy is a nuclear medicine test used to track the movements of a bolus and effectively quantify residual volumes in the oropharynx, pharynx, larynx, trachea and/or lungs. During the test, the patient swallows a bolus of radioactive liquid (containing technetium 99m) and this is recorded by a gamma camera. For the swallow phase, data acquisition is continuous (25 frames/s) and usually involves the oral cavity, thoracic cavity and, less frequently, the upper abdominal cavity. Static images at 15-30 min intervals are acquired for several hours after the test. Results are reported on time-activity curves[19]. This yields a quantitative image of transit and metabolic processes, and the amount of aspiration and residue can be measured[17]. This investigation does not provide information on the anatomy and physiology of the underlying mechanism for dysphagia. It is particularly useful for the assessment of GORD. If lungs and airways are clear of material immediately after swallowing, but it is accumulating over time, GORD is the cause of the aspiration[19].

4. Ultrasound

Ultrasound has been used to observe tongue function, motion of the hyoid bone, and to measure oral transit times. It has limited capacity for assessing the pharynx due to the different tissue types that are located in the neck as well as the deep location of the pharynx. Ultrasound remains useful for assessing tongue movement during the preparatory and oral phase of swallowing[20].

5. Electromyography

Surface electromyography (SEMG) can be used to measure electrical surface activity of the muscles involved in swallowing. This investigation relies on the presumption that different diseases and patterns of dysphagia have unique SEMG patterns[21]. Surface electrodes are placed on the skin above the muscle being investigated. Floor-of-mouth or laryngeal elevation muscles have been used most frequently for this test, as they are closest to the surface. They provide good information about the initiation and oral phase of swallowing. SEMG cannot detect activity in pharyngeal musculature as the muscles are situated too deeply.

An alternative electromyographic method uses hooked-wire electrodes to assess superior pharyngeal constrictor muscle activity during swallowing[22]. This method is very invasive and, given that less invasive tests with better results are available, this test is useful only for very specific cases where dysfunction of specific swallow muscles must be assessed. SEMG, although not very useful for diagnosis, can provide a quick and easy screening test with high sensitivity but low specificity for dysphagia or odynophagia[21].

6. Swallowing Sounds (Acoustics)

The goal of cervical auscultation is to establish physical parameters of swallowing sounds that are characteristic of dysphagia. These parameters can then be evaluated objectively via acoustic analysis. The advantages of such a system is that it is non-invasive, inexpensive, objective, can be performed at the bedside and does not expose the patient to radiation[23].

This technique uses microphones placed on the neck to record the swallowing sound. The most widely accepted position with the least amount of noise (generated by the carotid artery and laryngeal elevation) is the lateral border of the trachea, just inferior to the cricoid cartilage[23,24]. The patients are asked to swallow different-sized boluses in one complete action. In a study by Santamato et al., every swallow was recorded and three parameters were established as the acoustic profile: firstly, the duration of the swallowing sound (DSS) measured in miliseconds (ms) and defined as the time between start and the end of the acoustic signal; secondly, the peak intensity (PI) measured in decibels (dB) and defined as the highest displacement of the acoustic signal; and finally, the peak frequency (PF) measured in Hertz (Hz). The DSS in patients with neurogenic dysphagia was significantly increased when compared to healthy patients (1402 msec and 440 msec respectively; $p<0.01$)[24].

Although this test manages to objectively quantify certain parameters, it is still difficult to correlate an acoustic signal to an anatomical event. The efficacy of this test is also affected by inter-patient variation of the previously mentioned parameters, as well as by age[25].

7. Manometry

Oesophageal manometry is routinely used to establish oesophageal function. It uses a pressure sensor and transducer to relay pressure information within the oesophagus. This pressure represents peristaltic function and sphincteric competence[26]. It is a useful tool in the diagnosis of GORD, achalasia and dysphagia which is caused by dysfunction of the upper oesophageal sphincter. It cannot, however, monitor the entire swallowing process.

Pharyngeal manometry records pressure changes in the pharynx during the swallowing cycle. It requires solid-state pressure sensors with a fast frequency response. Unlike oesophageal manometry, where transit time ranges from 8-20s, pharyngeal transit time is significantly shorter at 0.5-1.5s. Three pressure sensors are placed transnasally: one at the base of the tongue, another at the upper oesophageal sphincter and a third at the upper oesophagus. This investigation is often done concurrently with video fluoroscopy to correlate pressure change with anatomical and physiological processes and events.

Until recently, pharyngeal manometry was not widely used as the resolution of the solid-state

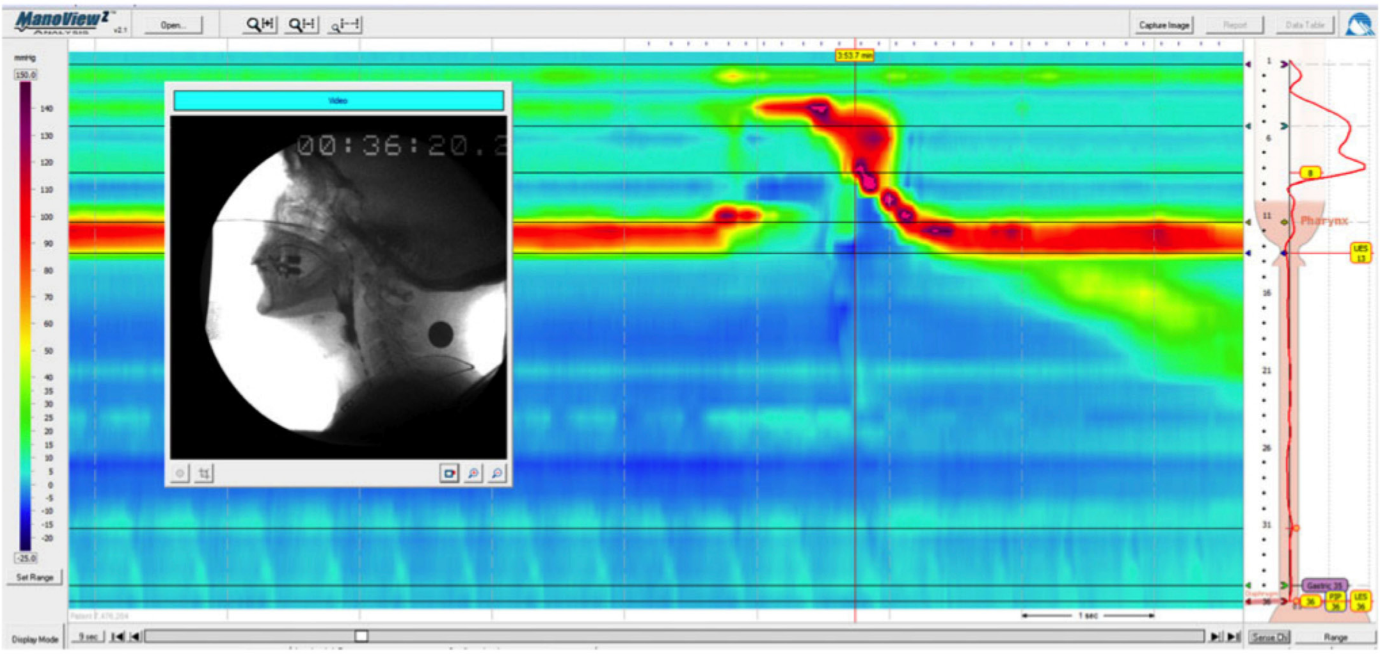

Figure 3. *Screenshot from ManoView™. X-axis: time, Y-axis: sensor position (distance). Moving the red line advances the video-fluorography and the topographical map. The numbers on the right denote the sensor number. Adapted from Nativ-Zeltzer et al.*[2]

pressure sensors was very low. In addition, it was difficult to correlate pressure changes with anatomical events. High-resolution manometry uses more sensors (30-36 compared to 3-5 in older devices) that are smaller and placed much more closely together (<1cm apart) than those of older manometric systems[2]. The upper oesophageal sphincter can move up to 3cm during swallowing[27], causing it to move in relation to the old sensors and possibly even miss them. The new system resolves the issue of having to place sensors in an exact location to yield useful data.

Along with the improvement of manometry, new sensory software has been produced which allows concurrent videofluorographic and manometric observation of the swallowing process (ManoView™).

The two measurement modalities together provide a more in-depth view into the process of swallowing and its dysfunction in dysphagia. Manometry alone cannot observe the oral phase of swallow, cannot determine if there is any residue present, and lacks mechanical accuracy. It does aid videofluoroscopy in objectively quantifying pressure vectors that are affecting the bolus as well as provide subtle cues as to the nature of the dysphagia[2].

Conclusion

There has been a recent surge in the development of novel investigations exploring the swallow cycle. MBS is a relatively expensive procedure, requiring elaborate equipment, several experts from different fields and a precise experimental regime. So, although it is the current gold standard for diagnosing dysphagia, there is a demand for effective alternative methods offering faster and cheaper screening of pharyngeal function. MBS is not available in every hospital/clinic and, in some situations (e.g. bed-bound patient), cannot be used at all. Manometry is the most sophisticated investigation and yields most data for one swallow cycle. It may be used to diagnose more complex disease or pharyngeal dysfunctions.

In summary, no single procedure is perfect for examining swallow. Rather than looking at each procedure as an exclusive diagnostic tool, they should be viewed as adjuvants to each other in the diagnosis of complex swallowing disorders.

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