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¹Critical Factors in the Oral Control Needed for Chewing and Swallowing

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Abstract

Normal oropharyngeal swallowing is a complex set of neuromotor behaviors containing three phases: 1) Oral preparation to break food down to a swallowable consistency; 2) Oral phase which propels food from the mouth; 3) Pharyngeal phase creates pressure to push food into the esophagus, and includes valve functions which prevent food from entering the nose or airway and allow food into the esophagus. Systematic changes in normal oropharyngeal swallow are based on volume, viscosity, and taste of the food swallowed as well as age. Patients with oropharyngeal swallowing difficulties (dysphagia) react differently to these systematic variables in food characteristics. This review manuscript presents the results of a series of studies that examine the role of each of the stages of the nonoral oropharyngeal swallow. The importance of the definition of food viscosity in the care of dysphagic patients and the role of food production companies in this effort are emphasized.

Keywords

Normal swallowing; dysphagia; food; volume; viscosity; taste; age; videofluoroscopy

Tongue function is critical to chewing and swallowing in normal individuals. The tongue is made up almost entirely of muscles, some of which are extrinsic in that they attach from the tongue to external structures, and move the tongue within and outside the oral cavity. Other muscles are intrinsic in that they go from one part of the tongue to another and shape the tongue for various tasks. There is also a small amount of connective tissue and fat in the tongue.

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Practical Applications: The body of research work that we are summarizing and reviewing here is designed to provide a baseline regarding normal oropharyngeal swallow function in adults against which abnormalities in swallow can be compared. Understanding swallow disorders in the oral and pharyngeal stages of deglutition enables food scientists to develop food textures which are most successfully swallowable by specific types of dysphagic patients. All of the studies reviewed here have been approved by Northwestern University Institutional Review Board (IRB).

Oral versus Base of Tongue

Looking at the total tongue neurologically and anatomically, it is actually divided into two regions shown in Figure 1, the oral portion of the tongue and the base of the tongue. The division between the oral portion of the tongue and the base of tongue is just below the circumvallate papillae, as shown by the diagonal line in Figure 1. Above and left of the diagonal line is the oral tongue. To the right and inferior to the diagonal line in Figure 1 is the base of tongue. Most of the sounds of speech in most languages are produced with the oral portion of the tongue [1]. Both the oral portion and the base of tongue function in swallowing in very different ways.

The oral tongue is innervated by the 12th cranial nerve, the hypoglossal nerve. The oral tongue is under cortical voluntary control in the central nervous system. The base of tongue is under control of the 10th cranial nerve, the Vagus, by way of the glossopharyngeal muscle. In some languages there are speech sounds produced by the base of tongue. In English we have no sounds produced by the base of tongue. For swallowing, the base of tongue is under medullary control in the central nervous system. During swallowing, both the oral tongue and the base of tongue are the most important generators of pressure to drive food through the oral cavity and pharynx and into the esophagus [2, 3]. There is sometimes a misconception that gravity is responsible for dropping food through the upper aero digestive tract into the esophagus. This is not true. Active pressure is required for an efficient and safe swallow. We are gaining increasing knowledge about the pressures generated by the oral tongue and their role in assuring a safe and functional oropharyngeal swallow. The work of Dr. JoAnne Robbins who attended the first meeting of this organization is leading the way in increasing our understanding of normal and abnormal oral tongue pressures during swallowing [4, 5].

Normal age effects on oropharyngeal swallows

There are changes in normal oral tongue function with age, [6, 7, 8, 9, 10, 11] one of which is the position the oral tongue takes when liquid consistency foods are placed in the mouth [12].

Most younger individuals and some older normal swallowers put the food on the top of the tongue which elevates to initiate the oral stage of swallow. This is known as the tipper swallow. More frequently normal older individuals (60 plus years of age) keep the tip of the oral tongue retracted somewhat on the floor of mouth. When they initiate the oral stage of swallow, many older individuals slide their tongue forward, to pick up the liquid bolus, placing the bolus on top of the tongue in the same position as in young people and initiate the swallow. This is known as the dipper pattern of swallow initiation. This dipper pattern tends to prolong the time of oral transit, that is the time of food moving through the oral cavity during the oral stage of swallow. The reason for this difference is not clear, but it is not related to the state of dentition. Other changes in swallow with normal aging include a slight but significant increase in time to trigger the pharyngeal stage of the swallow, a slight increase in residual food in the mouth or pharynx after the swallow and an increased frequency of penetration of food into the top of the airway. Penetration is distinct from aspiration [13]. Penetration is defined as food or liquid entering the larynx, but not below the

true vocal folds. As the swallow progresses, penetrated material is squeezed from the larynx. There is no sensory response to penetration [13] in contrast, aspiration indicates the entry of food or liquid below the true vocal folds and into the trachea. The normal sensory response to aspiration is a cough.

As we age, we lose some of our muscular reserve, more so in men than women [14]. With every muscular activity we perform, we must use adequate muscle strength to achieve the desired goal such as standing up from a chair, or swallowing. A young man and an old man can both successfully stand up from the same type of chair. However, the elderly man looks different from the young man in the way he stands. The muscular goal, which is to stand from the chair, is the same for both, but it is accomplished differently because of different muscular strength. Differences are seen in reserve between young and old men in swallowing as shown in.

The graph in Figure 2 shows mean hyoid bone movement during 10ml liquid swallows of normal young men in their 20's and of normal elderly men in their 80's. None of these individuals had any swallowing problem. Time 0 on the graph shows the onset of upper sphincter opening during the large volume (10ml) swallows. Hyoid motion both up and forward yanks the upper esophageal sphincter, also known as the cricopharyngeal sphincter, open. Looking at the young and old men's graphs in Figure 2, shows both of the points of upper esophageal sphincter opening for the young and old men to be virtually identical. However, the hyoid in the young men continues to elevate beyond the point needed to accomplish upper esophageal/cricopharyngeal opening. The difference in the amount of hyoid elevation to achieve the task of opening the upper esophageal sphincter and the actual degree of hyoid lifting represents muscular reserve. Reserve is the difference in hyoid movement required to accomplish the task, in this case the task is cricopharyngeal opening vs. the degree of movement actually used. In the elderly men the hyoid reaches the critical point to achieve upper sphincter opening at the same time point as in young men, but does not go much further. There is almost no reserve in the elderly men. Reserve is critical when an individual becomes ill and muscle strength and range of motion are reduced. When a patient becomes weak from illness, muscular reserve is often reduced. This is also known as sarcopenia. In young men there is ample reserve to lose before they have trouble opening the upper esophageal sphincter during swallowing. In the elderly men there is little muscular reserve to lose. Illness in elderly men results in loss from the necessary movement to open the cricopharyngeal sphincter. This then creates inefficient swallow with food remaining in the pharynx and slipping into the airway potentially resulting in an unsafe swallow. The etiology for loss of muscular reserve can simply be generalized weakness from a urinary tract infection, pneumonia, or flu. It does not need to be a problem in the head and neck. This loss of reserve may explain why elderly individuals can develop pneumonia so easily when hospitalized or bed ridden and weak and why men are silent aspirators more often than women [15].

Role of the Oral Tongue in Providing Sensory Information

The activity of the oral tongue in accepting food into the mouth and manipulating it within the mouth is critical in triggering and programming of the pharyngeal aspect of swallow as

well as providing sensory information on volume, viscosity, and taste to the medulla as well as information on the location of the food in the mouth.

It is important to emphasize here that the oral tongue plays a critical role not only in chewing behavior and in generating pressure on the food to propel it out of the mouth during swallow, but in defining the volume of food to be swallowed, and the viscosity of the food to be swallowed. The sensory information based on the viscosity of the food and the oral tongue manipulation of the food during chewing will define the amount of food swallowed in a single amount and how much food is moved to the cheek pouch for a second swallow later. While thin liquids are swallowed in varying volumes from 1ml for saliva to 15ml – 20ml for coffee, tea, etc., the thicker foods are swallowed in smaller amounts, most frequently 5ml (16). It is the oral tongue which subdivides that food in the mouth to a swallowable bolus size in relation to viscosity. Thus, the sensory input from the oral tongue, its shaping and movement are critical to achieve effective oral control and a safe and efficient pharyngeal swallow. This sensory input goes to the medulla or the lower part of the brainstem. Both, viscosity and volume are critical elements in programming the oropharyngeal swallow. This is true for both, normal and abnormal swallowers.

Volume information comes from the shaping of the tongue around the food or bolus in the mouth. The central portion of the tongue will be depressed further and further as the volume of the liquid or other food enlarges [17]. This change in tongue shape as shown in Figure 3 is believed to send important sensory information about volume to the brainstem. Volume is the most important variable in changing the normal pharyngeal stage of swallow in its timing and coordination [18]. The larger the bolus, the sooner the pharyngeal swallow triggers and the later the tongue base will come into action [1].

Role of the Oral Tongue in Chewing

The role of the oral tongue in chewing is critical. It is the oral tongue that controls food or liquid in the mouth, moving it onto the teeth, mixing it with saliva as the food comes off of the teeth, and replacing the food back on the teeth [19]. Even without any teeth, many individuals are capable of “gumming” their food using tongue control of the food and eating an essentially normal diet. It is always surprising to me the number of times I have had Head and Neck surgeons refer patients for dentures after having removed half or more of the patient's oral tongue because of oral cancer. The surgeon will sometimes tell patients to get a denture so they can chew. In fact, that may not be possible with a denture because of the extent of tongue tissue loss. The surgeon's recommendation is based on the mistaken idea that teeth are required for chewing, but the tongue is not; this is absolutely untrue. Intraoral prosthetics which will facilitate tongue interaction with the hard palate have been developed such that even a small amount of remaining tongue movement enables the patient to control food in their mouth and crush food between the remaining tongue and the prosthesis which covers the hard palate so they can eat a broader diet [20].

This figure shows an example of such a prosthesis known as a hard palate reshaping prosthesis which is normally designed by a specialized dentist, the Maxillofacial Prosthodontist, with input from a Speech Language Pathologist. The Maxillofacial

Prosthodontist has expertise in taking impressions of the hard palate and constructing the hard palate portion of the prosthesis. The speech language pathologist provides information on how far down the hard palate should be reshaped and lowered to meet the remaining tongue movement for both speech and swallowing. In almost all languages there are speech sounds produced with the tongue contacting the hard palate which this prosthesis improves. For swallowing the sides of the tongue seal against the lateral and anterior alveolar ridge. The midline of the tongue sequentially squeezes up and back against the hard palate. Even patients with 90 percent of their tongue removed can benefit from such a prosthesis improving both speech and swallowing. The team work of the two professionals, the Speech Language Pathologist and the Maxillofacial Prosthodontist assures greatest success of this prosthesis.

Role of the Oral and Base of Tongue in Pressure Generation During Swallow

Swallowing is a pressure phenomenon with pressure generated first by the oral tongue followed by the tongue base [21]. The point at which pressure is applied to the bolus is the posterior end or the tail of the bolus. The larger the bolus, the sooner the leading edge of the bolus crosses the back of the oral tongue. The pharyngeal stage is activated by the triggering of the pharyngeal swallow which closes the velopharynx, closes the airway, and opens the sphincter to the esophagus (also known as the cricopharyngeus sphincter). Oral transit is longer if the volume being swallowed is larger. The oral tongue pressure continues until the tail of the bolus reaches the pharynx when the pharyngeal swallow is triggered and the tongue base and pharyngeal walls come together to take over generation of pressure on the tail of the bolus as it moves through the pharynx. If the tongue base were to initiate its pressure too early, part of the bolus could be squirted up into the nose or back into the oral cavity.

The Pharyngeal Stage of Swallow

All of the pharyngeal motor aspects of swallow are triggered in the medulla, a primary swallow center. This pharyngeal trigger not only initiates velopharyngeal closure to prevent food from going into the nose but also initiates tongue base movement to touch the posterior pharyngeal walls and the lateral pharyngeal wall activity moving medially to meet the backward moving base of tongue [17]. The hyoid and larynx lift and move forward on a diagonal trajectory which contributes to helping the airway close as well as the yanking open of the upper esophageal sphincter [21, 22, 23]. All of these muscular activities in normal swallow all occur in only approximately .5 to 1.5 seconds. Together, then, the oral tongue and the base of tongue are the major pressure generators to clear food from the mouth and through the pharynx. Damage to any one of the pharyngeal structures can cause inefficient swallowing with food left behind in the mouth or pharynx, or unsafe swallow with food or liquid or both entering the airway and being aspirated.

Evaluation of Oropharyngeal Swallow

Dysphagia or difficulty moving food safely and efficiently from the mouth to the esophagus and ultimately the stomach can be caused by a very large number of types of structural or neurologic damage, pulmonary problems, and other medical diagnoses. Any of the motor or sensory controls of the structures in the oral preparation, oral or pharyngeal stages of the swallow can affect both efficiency and safety of the swallow.

There are a number of procedures for evaluation and measurement of the oral pharyngeal aspects of swallow.

The most frequently used assessment and research tool to study the function of the tongue and other structures during the oropharyngeal swallow is the radiographic or videofluoroscopic assessment known as the Modified Barium Swallow (MBS or the Videofluoroscopic Swallow Study [VFSS]). This examination enables us to visualize almost all of the various motor and sensory aspects of swallow and to compare these with normal function for the patient's age and gender [24]. A number of other procedures have been used to study the oropharyngeal swallow including Fiberoptic Endoscopic study of swallow (FEES), Manometry, and Ultrasound. None of these latter procedures examines as many of the components of swallow physiology as MBS.

During the Modified Barium Swallow the patient is viewed radiographically in the lateral plane initially, and the patient is given measured amounts of thin liquid barium: 1ml, 3ml, 5ml, 10ml, and cup drinking, nectar thickened liquid as needed if the patient cannot handle the thin liquid, barium pudding as well as a fourth of a small cookie, specifically a Lorna Doone cookie coated with 1-3 ml of barium, with two swallows of each material.

Then the patient is turned to the anterior posterior view to see the symmetry of the swallow on selected volumes and viscosities.

This protocol enables us to compare the patient's swallow on various volumes and viscosities with normal swallowers. It also enables us to identify most safe and efficient types of swallow and to recommend the type of diet that the patient can take orally or not. Thus, at the end of the Modified Barium Swallow, we are able to recommend the type of food viscosity and volume which is safest for the patient as well as to identify the best therapy for the patient based on the physiologic and or anatomic disorders causing the inefficiency or reduced safety of the swallow [25, 26]. From that information we can define a treatment program for the patient's dysphagia.

The Role of Taste in Oropharyngeal Swallow

Taste is a critical food characteristic for patients with dysphagia, particularly the sour taste [27, 28, 29]. Several studies have examined the changes in swallow measures in patients who have suffered a stroke or other neurologic damage or treatment for head and neck cancer when swallowing a sour liquid such as 50% barium liquid and 50 % ReaLemon Lemon Juice. Similarly, carbonation can increase oral awareness for some patients [30]. A great deal more research on this topic is needed.

The Contribution of Food Companies

Several food companies have produced foods of various viscosities for dysphagic patients. Almost all food companies know the viscosity of the all food products they produce. However, they generally believe that the viscosity information is part of their “secret” food formulas. This means patients can look at a food label and identify the calories and most of the contents in the food, but cannot find information on the viscosity of the food. As the millions of dysphagic patients try to fill their dietary needs based on the food viscosity they can swallow safely and efficiently they are unable to find the viscosity levels on the labels of food they are selecting. Dysphagic patients constitute important customers for the food industry. It is important that food companies include viscosities on food labels for the good of dysphagic customers. This would be a major contribution of the food industry to the care of dysphagic patients and the clinicians working to help them return to safe and efficient oral intake.

When considering development of foods for dysphagic patients it is critical to remember that there is no single dysphagia diet [1]. Each patient exhibits different anatomic and or physiologic abnormalities in the oropharyngeal swallow and different severities of disorders resulting in different problems with different food consistencies. During the radiographic assessment of the oropharyngeal swallow, the Modified Barium Swallow, a range of food volumes and viscosities of barium are usually presented in two swallows of each: thin liquids in 1, 3, 5, 10 ml volumes and cup drinking, nectar thick liquid, thin and thick honey consistencies, pureed/pudding consistency and one fourth of a Lorna Doone cookie with 1 ml barium pudding for contrast. Also, if patients exhibit a sensory disorder in their oropharyngeal swallow, measured boluses of a sour liquid or a carbonated liquid are usually tested for their impact on swallow physiology. Therefore, any company interested in producing food for dysphagic patients will need to develop more than one of the food consistencies noted above. With millions of dysphagic patients there is clearly need for such a range of food viscosities, taste and textures.

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Figure 1.
Lateral drawing of the oral cavity and pharynx with the diagonal line separating the oral tongue and the base of tongue.

Figure 2.

Plot of averaged vertical hyoid movement at $1/30^{\text{th}}$ of a second intervals on 10-cc liquid swallows for the 8 younger men and 8 older men. Time 0 represents the first frame showing cricopharyngeal (upper esophageal) opening.

Figure 3.
Lateral drawing of the head and neck with an arrow indicating the point where the pressure is being applied to the bolus tail.

Figure 4.

Diagrams of palate lowering/palate augmentation prostheses for a surgically treated oral cancer patient.