CHAPTER 2

ANATOMY AND PHYSIOLOGY OF NORMAL DEGLUTITION

Understanding the normal anatomy and physiology of swallowing provides the foundation for evaluation and treatment of swallowing disorders. Diagnosis of dysphagia is designed to identify the abnormal elements of each patient's anatomy and physiology. Treatment is designed to compensate for or improve function in those abnormal elements.

Anatomic Structures

The anatomic areas involved in deglutition include the oral cavity, pharynx, larynx, and esophagus, shown in midsagittal section in Figure 2.1. Structures in the oral cavity are labeled in Figures 2.1 and 2.2, and include the lips anteriorly, the teeth (24 deciduous, 32 permanent), hard palate, soft palate, uvula, mandible or lower jaw, floor of mouth, tongue, and faucial arches. Between the anterior and posterior faucial arches are the palatine tonsils, as seen in Figure 2.2, easily viewed during an oral examination. The pockets or side cavities created by the normal juxtaposition of structures are important in swallowing because in patients with swallowing disorders, these natural cavities or spaces are usually where food or liquid collects and may remain after the swallow. For example, the sulcus is the space formed between the alveolus and cheek or lip musculature both superiorly and inferiorly. There are sulci between the lips and the maxilla

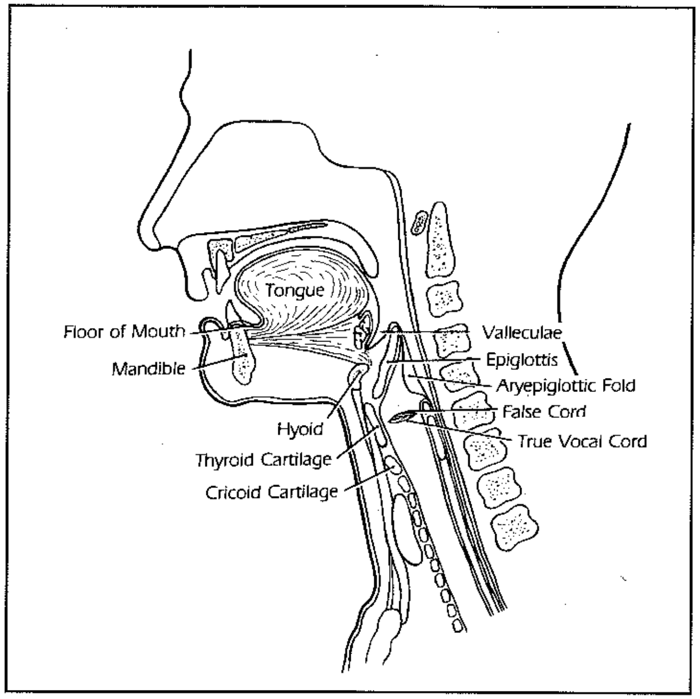


Figure 2.1. Midsagittal section of the head and neck.

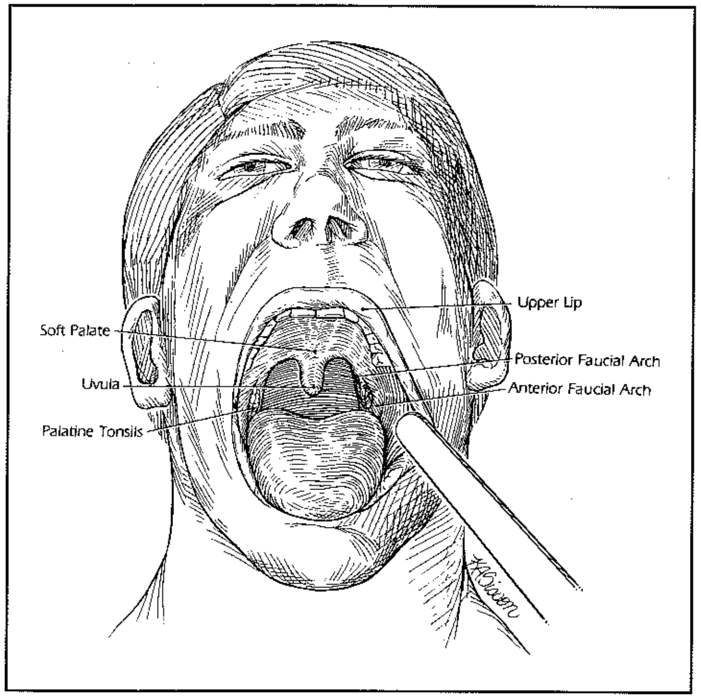


Figure 2.2. Frontal view of the oral cavity, showing anterior and posterior faucial arches.

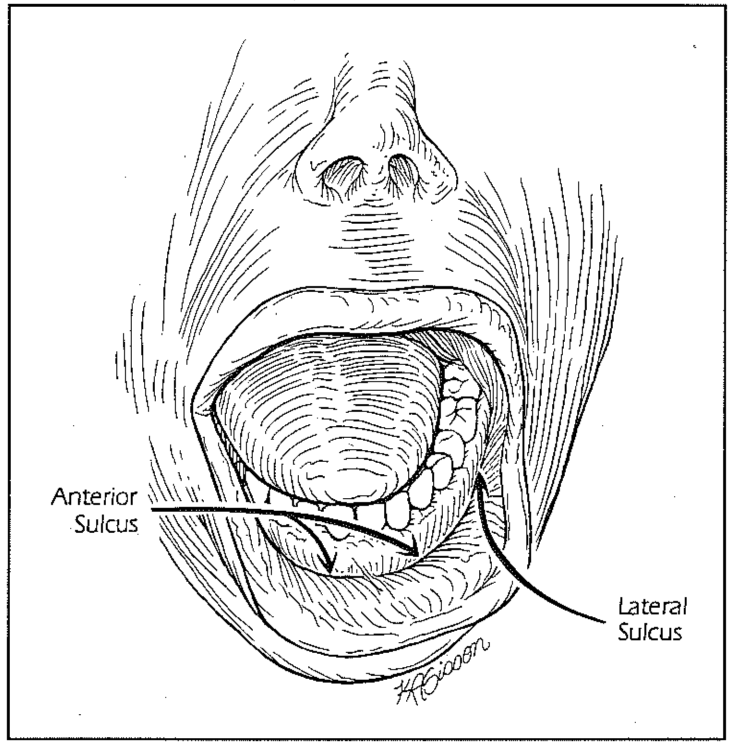


Figure 2.3. Frontal view of the oral cavity with lower lip pulled outward to reveal the anterior and lateral lower sulci.

and mandible and between the cheeks and the maxilla and mandible, both laterally and anteriorly, as shown in Figure 2.3.

Musculature forming the floor of the mouth includes the mylohyoid, geniohyoid, and anterior belly of digastric, all of which attach to the body of the mandible anteriorly and the body of the hyoid bone posteriorly. The hyoid bone forms the foundation for the tongue, the body of which sits on the hyoid. The hyoid bone is embedded in the base of the tongue, articulating with no other bone. The hyoid is suspended in the soft tissue by the floor of mouth muscles and the posterior belly of digastric and the stylohyoid, both attached posterolaterally from the region of the temporal bone, as shown in Figure 2.4. The larynx is suspended from the hyoid bone by the thyrohyoid ligament and thyrohyoid muscle. If the hyoid elevates and moves forward, the larynx will move upward and forward unless it is stabilized by other muscles.

The tongue is composed almost entirely of muscle fibers going in all directions. Functionally, for swallowing, the tongue can be divided into an oral portion and a pharyngeal portion. The oral tongue includes the tip, blade, front center, and back, as indicated in Figure 2.5. Anatomically, the oral tongue end

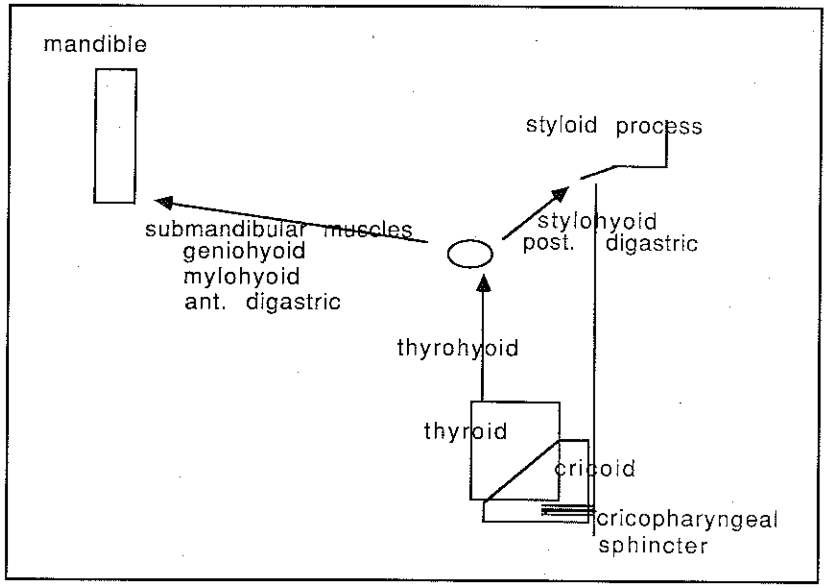


Figure 2.4. Diagram of the suspension of the hyoid bone in the neck from a lateral view. The hyoid (the center oval) is suspended by the submandibular muscles from the mandible anteriorly, and by the stylohyoid and posterior digastric muscle from the styloid process laterally and posteriorly.

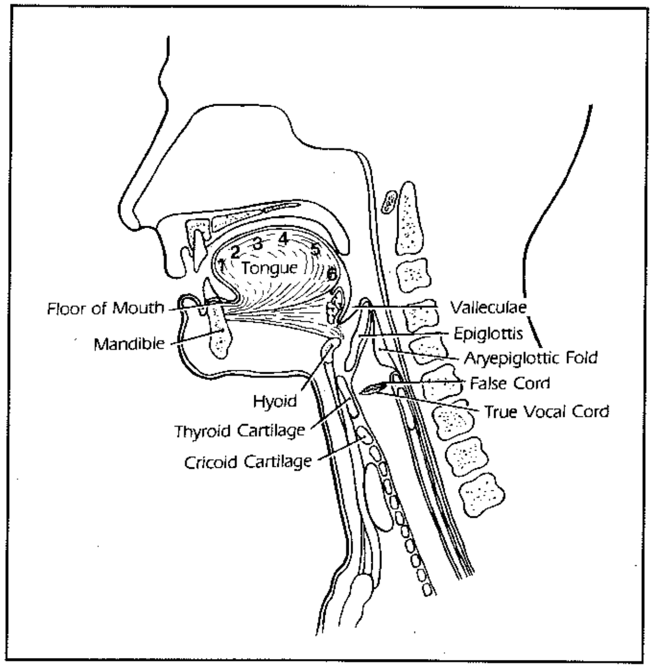


Figure 2.5. Lateral view of the oral cavity with the parts of the oral tongue labeled: tip (1), blade (2), front (3), center (4), and back (5). The tongue base (6) extends from the circumvallate papillae or approximately the tip of the uvula to the hyoid bone.

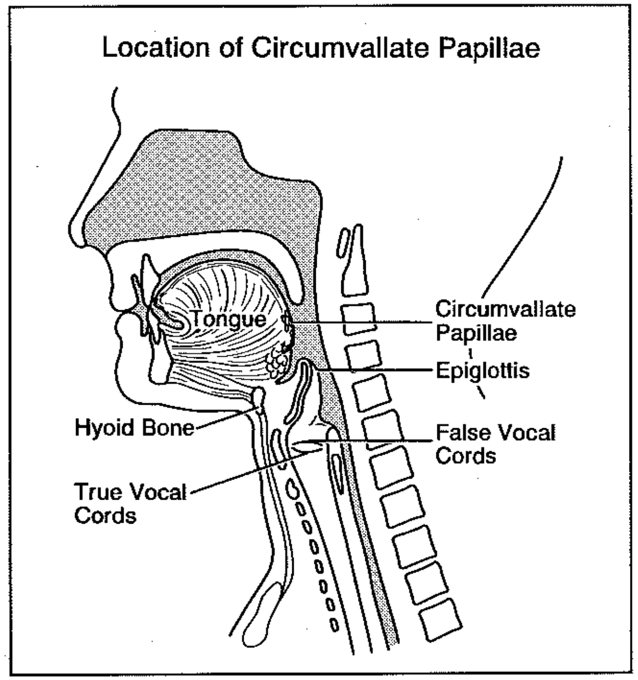


Figure 2.6. The oral cavity from a lateral view indicating the location of the circumvallate papillae.

at the circumvallate papillae, shown in Figure 2.6. The oral tongue is active during speech and during the oral stages of swallow and is under cortical or voluntary neural control. The pharyngeal portion of the tongue, or tongue base, begins at the circumvallate papillae and extends to the hyoid bone. The tongue base is active during the pharyngeal stage of swallow. The tongue base is under involuntary neural control coordinated in the brainstem (medullary swallow center), but can be placed under some degree of voluntary control.

The roof of the mouth is formed by the maxilla or hard palate, the velum or soft palate, and the uvula. The soft palate may be pulled down and forward against the back of the tongue by the palatoglossus muscle in the anterior faucial arch or may be elevated and retracted to contribute to velopharyngeal closure by a combination of muscle pulls, including the palatopharyngeus located in the posterior faucial arch, the levator palatal muscle, and the fibers of the superior pharyngeal constrictor.

Three large salivary glands are on each side: the parotid glands, the submandibular glands, and the sublingual glands. Many small glands are also in the mucous membrane of the tongue, lips, cheeks, and roof of the mouth. The salivary glands produce two kinds of fluid, a viscid, mucuslike fluid which is thicker, and a serous fluid which is thinner and more watery. The parotid gland produces

papillae- little bumps on tongue that help grip food during chew

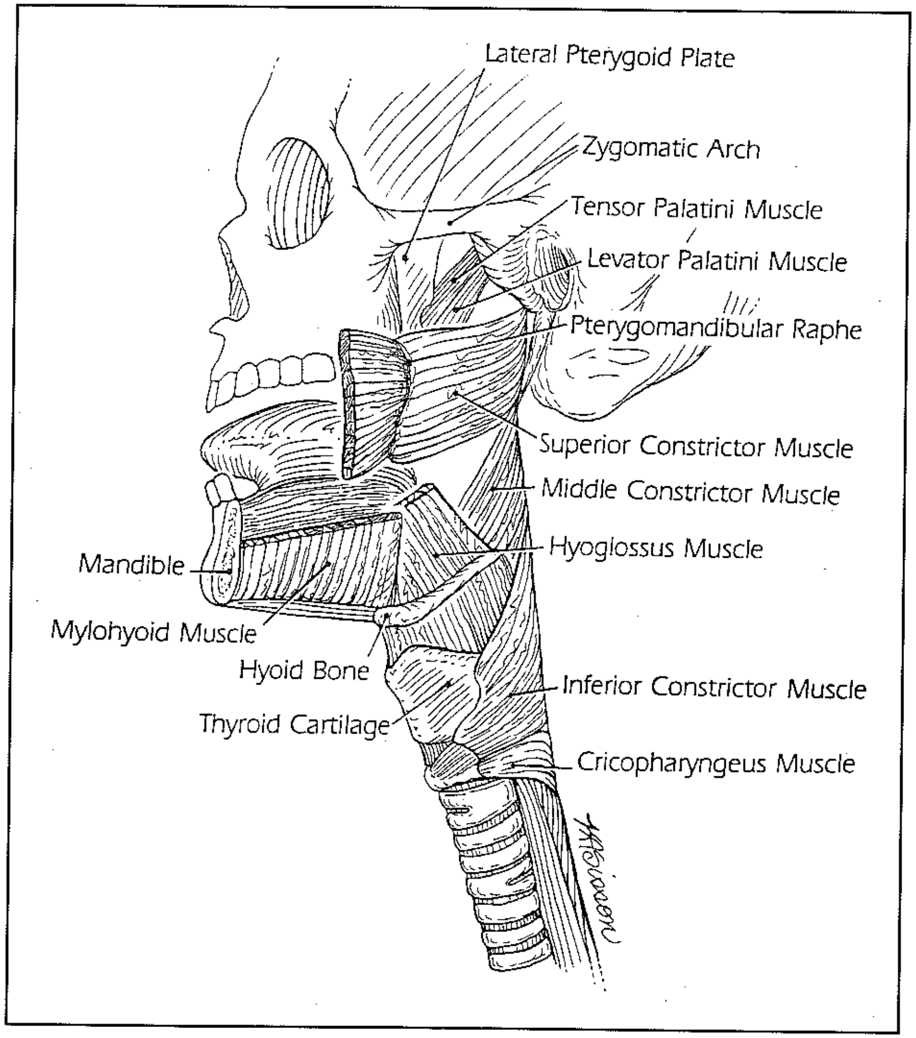


Figure 2.7. Lateral view of the pharyngeal constrictors (superior, medial, and inferior) and their anterior attachments.

the serous fluid, whereas the other glands produce some of both types of fluid, although the submandibular glands tend to produce more serous fluid and the sublingual glands more mucous. Saliva not only serves to maintain oral moisture and reduce tooth decay, but assists in digestion and is a natural neutralizer of stomach acid that may reflux into the esophagus.

Pharyngeal structures involved in deglutition include the three pharyngeal constrictors, superior, medial, and inferior, which form the posterior and lateral

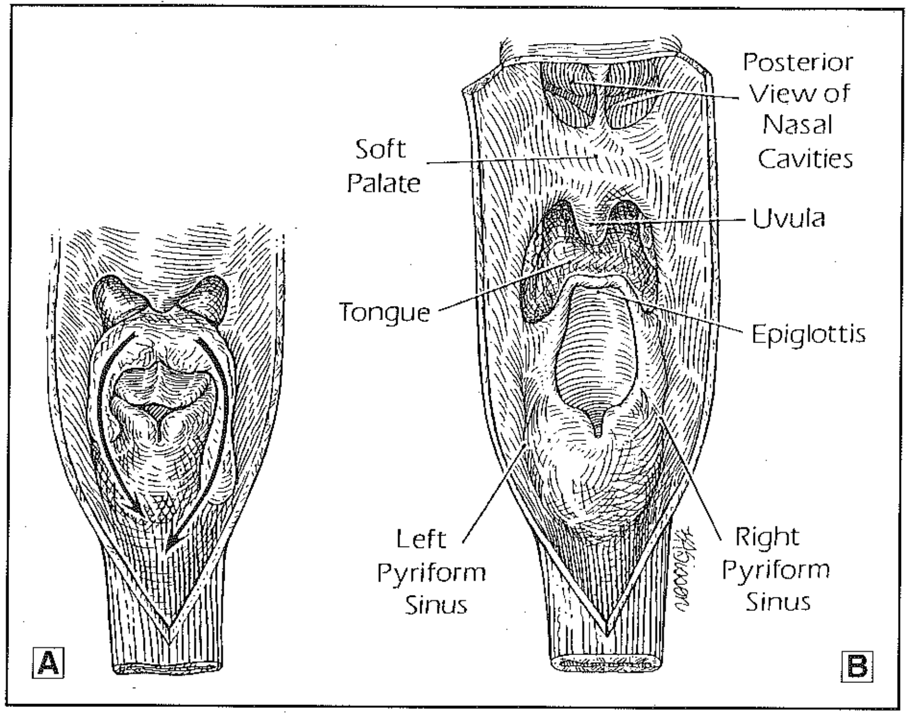


Figure 2.8. Posterior views of the pharynx with the pharyngeal constrictors cut at posterior midline and laid back to reveal the structures anterior to the pharynx. The pyriform sinuses can be seen as spaces created between the sides of the larynx and the pharyngeal constrictors attaching anteriolaterally to the larynx. Arrows on the figure (A) indicate the pathway of food and liquid down the pyriform sinuses on each side during the swallow.

pharyngeal walls. As pictured in Figure 2.7, fibers comprising these muscles arise from the median raphe in the midline of the posterior pharyngeal wall, and run laterally to attach to bony and soft tissue structures located anteriorly. Structures to which these fibers attach anteriorly include the pterygoid plates on the sphenoid bone, the soft palate, the base of the tongue, the mandible, the hyoid bone, and the thyroid and cricoid cartilages. Thus, all of these structures form the anterior wall of the pharynx. Inferior fibers of the superior constrictor that attach to the tongue base are known as the glossopharyngeus muscle. This muscle is probably responsible for tongue base retraction and simultaneous anterior bulging of the posterior pharyngeal wall at the tongue base level.

As the fibers of the inferior constrictor attach to the sides of the thyroid cartilage anteriorly, spaces are formed between these fibers and the thyroid cartilage on each side, as illustrated in Figure 2.8. These spaces are known as the pyriform sinuses. These end inferiorly at the cricopharyngeal muscle, which is the most inferior structure of the pharynx. Cricopharyngeal muscle fibers attach to the posterolateral surface of the cricoid lamina. The cricopharyngeal muscle fibers have been described by some investigators as part of the inferior constrictor. At rest, these fibers are in some degree of tonic contraction in the awake individual to prevent air from entering the esophagus during respiration. During sleep the muscle loses its tonic contraction. Together with the cricoid lamina, the cricopharyngeal muscle fibers form the valve into the esophagus known as the cricopharyngeal (CP) region, the upper esophageal sphincter (UES), or the pharyngoesophageal sphincter (PE segment) (Jacob, Kahrilas, Logemann, Shah, & Ha, 1989). A secondary role for the UES is to reduce the risk of material backflowing from the esophagus and into the pharynx (Kirchner, 1958; Parrish, 1968). The UES is defined as a 2- to 4-cm zone of elevated pressure capable of withstanding pressures of up to 11 cm of water in the esophagus. The cricopharyngeal sphincter has greatest pressure immediately prior to the swallow and during inspiration. Increase in pressure during inhalation ensures that no air is pulled into the esophagus (Parrish, 1968). At the appropriate moment during swallowing, the cricopharyngeal sphincter opens to allow the bolus to pass into the esophagus. The opening of this sphincter is complex.

The esophagus is a collapsed muscular tube approximately 23 to 25 cm long with a sphincter or valve at each end: the upper esophageal sphincter (UES) at the top and the lower esophageal sphincter (LES) at the bottom. This is in contrast to the pharynx, which is a part of the upper airway and is an open cavity except during the moment of the pharyngeal swallow when the larynx closes. The esophagus has two layers of muscle, the inner circular and the outer longitudinal. Each layer is made up of striated muscle in the upper third, a combination of striated and smooth muscle in the middle third, and smooth muscle in the lower third (Hansky, 1973; Ponzoli, 1968). The esophagus passes through the neck, then the chest, through the diaphragm to attach to the stomach. In the neck the esophagus sits behind the trachea, sharing a soft tissue wall so that the posterior wall of the trachea is the anterior wall of the esophagus. The valve at the bottom of the esophagus is the LES, marking the boundary between the esophagus and the stomach. Its primary purpose is to keep food and secretions, including stomach acid, in the stomach.

At the base of the tongue, the pharynx opens into the larynx, which serves primarily as a valve to keep food from entering the airway during swallowing, as shown in Figure 2.1. The topmost structure of the larynx is the epiglottis, the top third to half of which rests against the base of the tongue, attached into the hyoid bone by a ligament, the hyoepiglottic ligament. The base of the epiglottis is attached by ligament to the thyroid notch. The wedge-shaped space formed between the base of the tongue and the epiglottis is the valleculae. The valleculae is subdivided by the hyoepiglottic ligament so that on an anterior–posterior radiographic view, the valleculae appears "scallop shaped," with the hyoepiglottic ligament in the middle. Together, the valleculae and the two pyriform sinuses

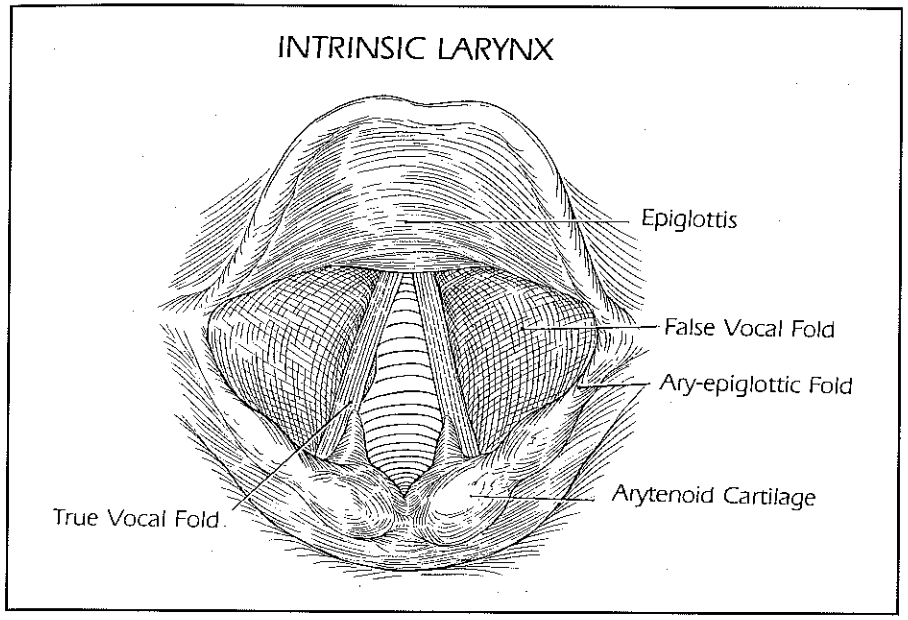


Figure 2.9. Superior view of the instrinsic laryngeal structures.

are known as the pharyngeal recesses or side pockets, into which food may fall and reside before or after the pharyngeal swallow triggers. The lingual tonsils are located against the base of the tongue and take up a small amount of the vallecular space. The opening into the larynx is known as the laryngeal vestibule, or laryngeal additus, and is bounded by the epiglottis, aryepiglottic folds, and arytenoid cartilage, and ends at the superior surface of the false vocal folds.

The intrinsic structures of the larynx are shown in Figures 2.9 and 2.10. The aryepiglottic folds, containing the aryepiglottic muscle, quadrangular membrane, and cuneiform cartilages, are attached to the lateral margins of the epiglottis and run laterally, posteriorly, and inferiorly to surround the arytenoid cartilages. The aryepiglottic folds form the lateral walls of the laryngeal vestibule. The two arytenoids are positioned on the rim of the cricoid cartilage posteriorly. Muscular pull on these arytenoid cartilages controls movement of the true vocal folds. The posterior cricoarytenoid muscle, attaching from the posterior surface of the cricoid lamina to the muscular process of the arytenoid, opens or abducts the arytenoids and the true vocal folds for respiration. The lateral cricoarytenoid (attaching from the top edge of the cricoid cartilage at the side to the muscular process of the arytenoid) and the interarytenoid muscles (attaching between the two arytenoid cartilages) adduct or close the arytenoids and thus close the true vocal folds across the top of the airway (Pressman & Keleman, 1955).

The arytenoids also tilt anteriorly during swallowing. This motion is thought

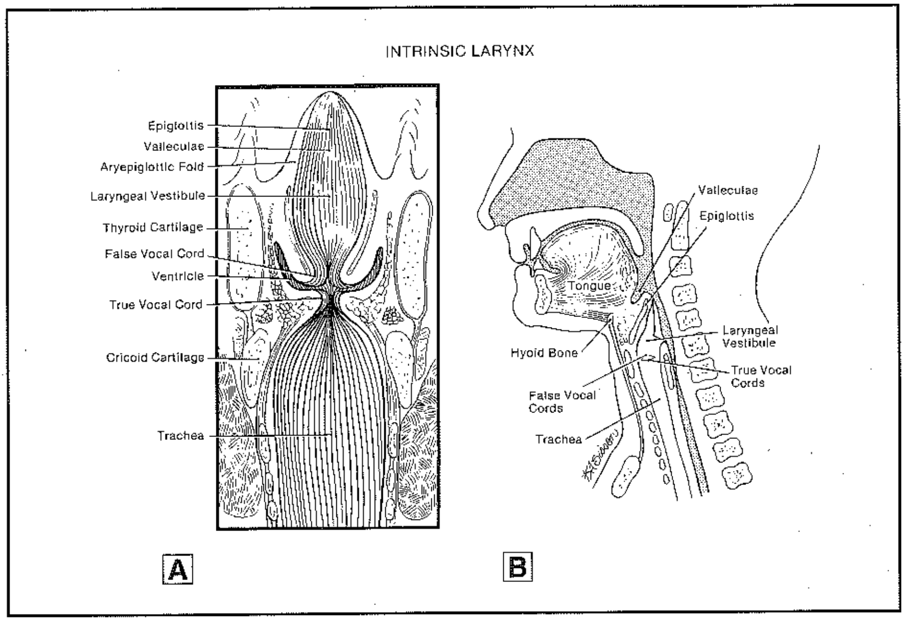


Figure 2.10. Frontal (A) and lateral (B) views of intrinsic structures of the larynx.

to result from the pull of the thyroarytenoid muscle fibers. This anterior tilting contributes to closure of the airway entrance. As shown in Figure 2.10, the aryepiglottic folds end inferiorly in the false vocal folds, two shelves of muscle and connective tissue running anteriorly to posteriorly immediately above the level of the true vocal folds. The false vocal folds are superior to but parallel with the true vocal folds. Like the true folds, the false vocal folds form shelves of soft tissue projecting from the sides of the larynx, anteriorly to posteriorly. The space that is formed between the false and true vocal folds on each side is known as the laryngeal ventricle. The true vocal folds, composed of vocalis and thyroarytenoid muscle, are attached from the vocal processes of the arytenoids posteriorly, to the inside surface of the thyroid lamina laterally, and to the thyroid notch anteriorly. These then form two more shelves of soft tissue that, when adducted or closed, project into the airway and effectively close the larynx. The true vocal folds form the last level of airway protection before entering the trachea. Together the epiglottis and aryepiglottic folds; the arytenoids, base of epiglottis, and false vocal folds; and the true vocal folds form three levels of sphincter in the larynx, capable of completely closing the larynx from the pharynx and preventing penetration of food or liquid during swallowing (Lederman, 1977; Pressman & Keleman, 1955).

The larynx and trachea are suspended in the neck between the hyoid bone superiorly and the sternum inferiorly, as shown in Figure 2.11. A number of

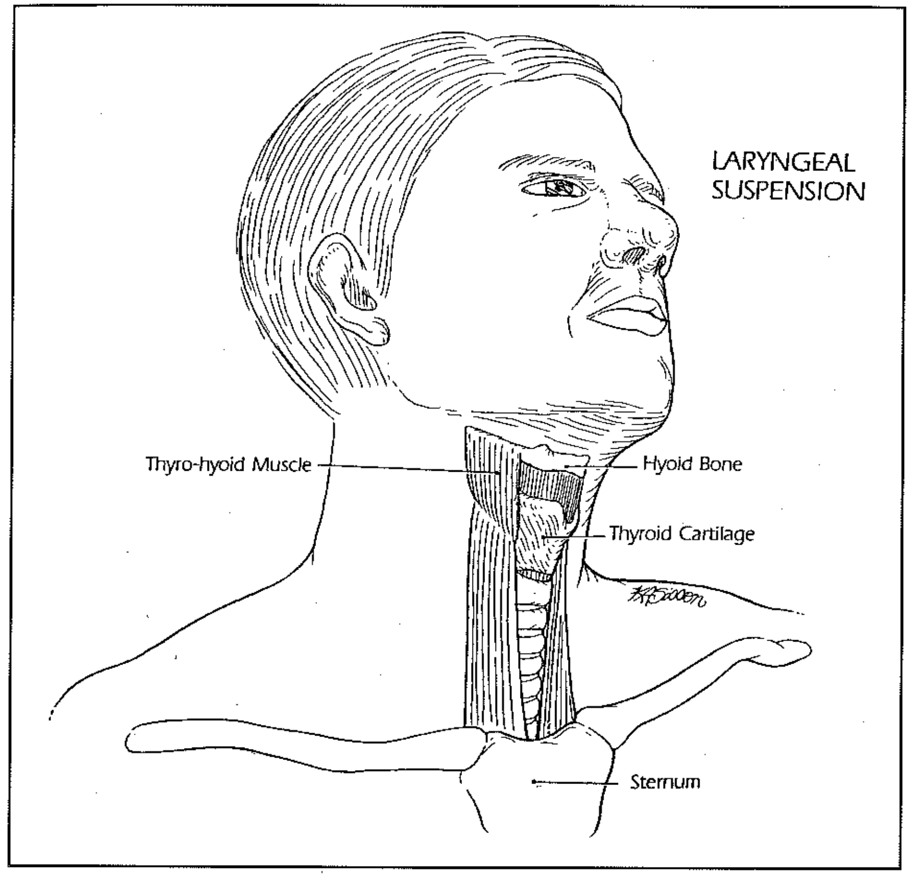


Figure 2.11. Frontolateral view of the strap muscles suspending the larynx in the neck between the hyoid bone and the sternum.

muscles, categorized as the laryngeal strap muscles, contribute to this suspension and, together with the elasticity in the trachea itself, permit the larynx to be elevated, pulled anteriorly, and/or lowered for various activities. The hyoid bone also serves as the foundation for the tongue, which rests on it. Thus, there is a close anatomic relationship between the floor of the mouth, tongue, hyoid bone, and larynx. When one of these structures moves, it often pulls on and moves other structures attached to it.

Physiology

Classically, the act of deglutition is described in four phases: (1) the oral preparatory phase, when food is manipulated in the mouth and masticated if necessary, reducing it to a consistency ready for swallow; (2) the oral phase of the swallow, when the tongue propels food posteriorly until the pharyngeal swallow is triggered; (3) the pharyngeal phase, when the pharyngeal swallow is triggered and the bolus is moved through the pharynx; and (4) the esophageal phase, when esophageal peristalsis carries the bolus through the cervical and thoracic esophagus and into the stomach. The duration and characteristics of each of these phases depend on the type and volume of food being swallowed and the voluntary control exerted over it (Kahrilas, Lin, Chen, & Logemann, 1996; Kahrilas & Logemann, 1993; Kahrilas, Logemann, Krugler, & Flanagan, 1991). Thus, there are many types of normal swallows that occur predictably based on the characteristics of the food swallowed and voluntary control.

The frequency of deglutition varies with activity (Lear, Flanagan, & Moorrees, 1965; Logan, Kavanagh, & Wornall, 1967). Swallowing frequency is greatest during eating and least during sleep, with other activities taking an intermediate place. Mean deglutition frequency is approximately 580 swallows per day. Records during sleep have shown periods of 20 minutes or more when no swallow occurs.

Swallowing and respiration are reciprocal functions; that is, respiration halts during the pharyngeal phase of deglutition in humans of all ages, including infants. Storey (1976) described swallowing as an airway-protective reflex because of this reciprocity. For purposes of this discussion, the neuromuscular functions of the oropharyngeal swallow are discussed first according to these phases even though some types of swallows do not involve all phases. For example, swallows of saliva in the pharynx usually do not include any oral preparation or oral stage of swallow. The normal systematic variations in swallow observed under various conditions are discussed later in this chapter.

Oral Preparatory Phase

Sensory recognition of food approaching the mouth and being placed in the mouth is critical before any oral preparatory movements can be initiated. Movement patterns in the oral preparatory phase of the swallow vary, depending on the viscosity of the material to be swallowed and the amount of oral manipulation the individual uses in savoring a particular food. From the time the material is placed in the mouth, labial seal is maintained to ensure that no food or liquid falls from the mouth. This requires an open nasal airway and nasal breathing. During liquid swallows, the extent of oral manipulation of the bolus varies greatly from individual to individual. When placed into the mouth, a liquid bolus has a certain degree of cohesiveness that may be maintained as the bolus is held between the tongue and the anterior hard palate in preparation for the pharyngeal swallow. In this case, the tongue cups around the liquid bolus with

the sides of the tongue sealed against the lateral alveolus. The food may be held between the midline of the tongue and the hard palate with the tongue tip elevated and contacting the anterior alveolar ridge, or it may be held on the floor of the mouth in front of the tongue. Dodds et al. (1989) termed these two normal hold positions "tippers" and "dippers," respectively. Approximately 20% of normal swallowers are dippers. Some individuals may desire to move the liquid around in the mouth prior to swallowing it, and may in the process spread the bolus evenly or unevenly throughout the oral cavity. However, prior to initiating the swallow, the material is generally pulled together into a cohesive ball or bolus by the tongue, and held in either the tipper or the dipper position. Holding the bolus more anteriorly between the tongue and the anterior teeth is an abnormal preswallow position in adults, and often indicates that a tongue thrust swallowing pattern will be used. The tongue thrust pattern, in which the tongue moves anteriorly with the bolus often pushing food from the mouth, is often seen in adults with frontal lobe damage and in children with cerebral palsy.

Oral manipulation of thicker consistency materials again depends somewhat upon the preference of the individual. As with liquids, the material is introduced into the oral cavity as a cohesive bolus. In preparation for the swallow, it may be maintained as such and held in either the tipper or dipper hold position, with the sides and front of the tongue sealed around the maxillary alveolus. Or, the individual may choose to manipulate the bolus in the mouth, lateralize it, and masticate it somewhat by moving the mandible and tongue in a lateral rotary motion before bringing the material into a cohesive bolus and initiating the swallow. The natural cohesiveness of the paste bolus after entry into the oral cavity sometimes makes patients with reduced tongue control prefer this consistency. However, if the consistency of the paste is too thick, it may be more difficult for individuals with reduced tongue control to propel the material posteriorly and to keep it from adhering to the hard palate. During this oral preparatory phase, if there is no active chewing, the soft palate is pulled down and forward (Figure 2.12), sealing off the oral cavity from the pharynx (Fletcher, 1974; Negus, 1949; Robbins, Logemann, & Kirshner, 1982; Shedd, Scatliff, & Kirchner, 1960; Storey, 1976; Wildman, 1976).

The oral preparatory phase of deglutition for materials requiring mastication involves a rotary lateral movement of the mandible and tongue. The tongue positions material on the teeth. When the upper and lower teeth have met and crushed the material, the food falls medially toward the tongue, which moves the material back onto the teeth as the mandible opens. The cycle is repeated numerous times before forming a bolus and initiating the oral phase of the swallow. In addition to this cyclic movement during mastication, the tongue mixes the food with saliva (Lowe, 1981). It has been postulated that the rhythmic movements of mastication are controlled by a central pattern generator. In addition, peripheral feedback is important in positioning the bolus on the teeth and

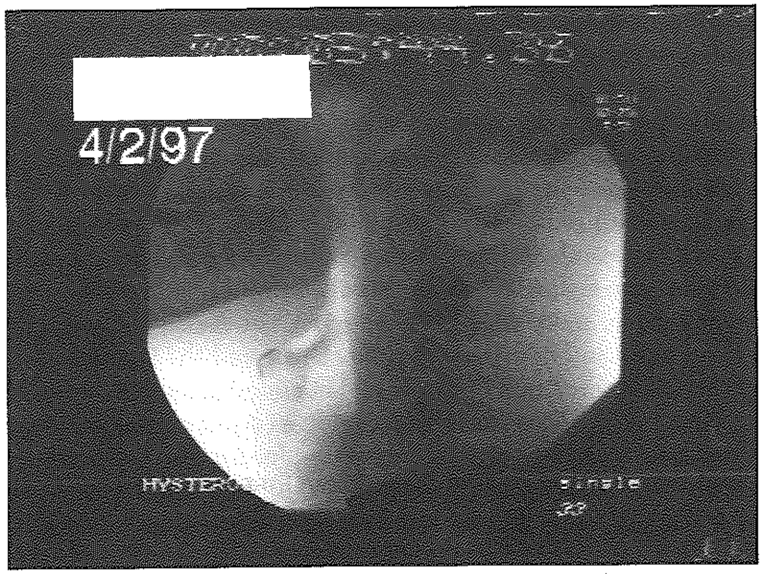


Figure 2.12. The soft palate is pulled down and forward in this lateral videoprint while the bolus is being held in the oral cavity prior to initiation of the oral phase of the swallow.

preventing injury to the tongue during chewing (Lowe, 1981). Tension in the buccal musculature closes off the lateral sulcus and prevents food particles from falling laterally into the sulcus between the mandible and the cheek (Bosma, 1973). Rotary tongue and jaw motion is continued until the food has been adequately cleared. After chewing, the tongue pulls the food into a semicohesive bolus or ball before the oral stage of swallow is initiated. During active chewing, the soft palate is not pulled down and forward and premature spillage is common and entirely normal (Palmer, Rudin, Lara, & Crompton, 1992). Such premature spillage is not normal during the hold phase before swallows of liquid and paste or pudding materials.

The volume of bolus swallowed varies with the viscosity of the food. For thin liquids, the volume ranges from 1 ml (saliva bolus) to 17 to 20+ ml (cup drinking). As the bolus viscosity increases, the maximum volume swallowed decreases so that swallows of pudding may be 5 to 7 cc on average, whereas swallows of thicker mashed potatoes may be 3 to 5 cc and meat may average 2 cc. This downsizing with viscosity allows easier passage of the bolus through the pharynx and particularly the upper esophageal sphincter. If larger volumes of these thicker foods are placed in the mouth, the tongue subdivides the food after chewing, forming only part of it into a bolus to be swallowed at one time and sequestering the rest on the side of the mouth for later swallows.

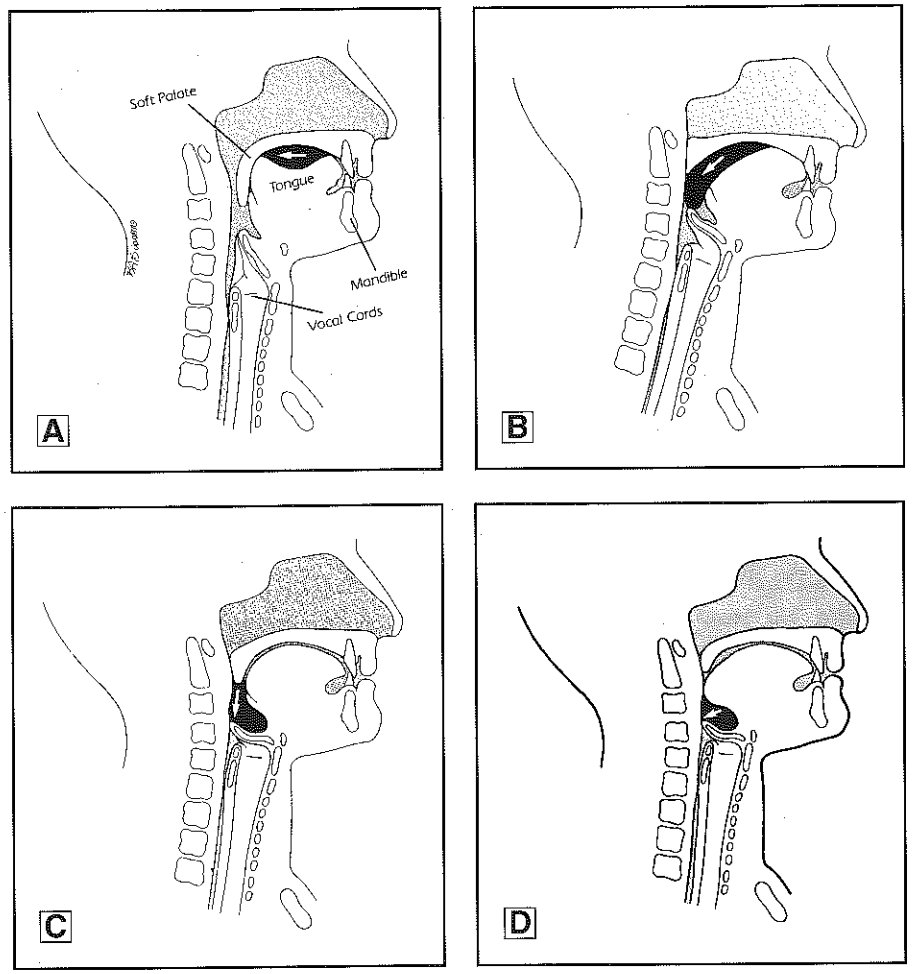
The larynx and pharynx are at rest during the oral preparatory phase of swallowing. The airway is open and nasal breathing continues. Clearly, if an individual loses control of a part of the bolus during this oral preparatory phase and it trickles into the pharynx, the material may continue to drop down and enter the open airway. The pharyngeal swallow rarely triggers in response to this material unless the food starts to enter the larynx, possibly because the oral stage of swallow has not been initiated (Pouderoux, Logemann, & Kahrilas, 1996).

During this oral preparation, a great deal of sensory information is processed from sensory receptors throughout the oral cavity, including the tongue. It is likely that information on bolus volume comes from the shape of the tongue as it surrounds the bolus prior to the swallow. The sequence of the movements of the upper aerodigestive tract during deglutition is illustrated in Figure 2.13.

Oral Phase

The oral stage of the swallow is initiated when the tongue begins posterior movement of the bolus. If the bolus is held in the dipper position, the tongue tip moves forward and lifts the bolus onto the tongue and into the tipper position. This is done in a smooth action, which moves directly into the oral stage of tongue propulsion. Tongue movement during this oral phase has often been described as a stripping action, with the midline of the tongue sequentially squeezing the bolus posteriorly against the hard palate (Ardran & Kemp, 1951; Kahrilas, Lin, Logemann, Ergun, & Facchini, 1993; Lowe, 1981; Negus, 1949; Shawker, Sonies, & Stone, 1984). Another way to describe this tongue movement is as an anterior to posterior rolling action of the midline of the tongue, with tongue elevation progressing sequentially more posteriorly to push the bolus backward. The sides and tip of the tongue remain firmly anchored against the alveolar ridge. During this time, a central groove is formed in the tongue, acting as a ramp or chute for food to pass through as it moves posteriorly (Ramsey, Watson, Gramiak, & Weinberg, 1955; Shedd et al., 1960). As food viscosity thickens, the pressure of the oral tongue against the palate increases, requiring greater muscle activity (Dantas & Dodds, 1990). Thicker foods require more pressure to propel them cleanly and efficiently through the oral cavity and pharynx (Reimers-Neils, Logemann, & Larson, 1994). Several authors also have described the contribution of negative pressure created by slight inward movement and increased tension of the buccal musculature in propelling the bolus posteriorly (Shedd, Kirchner, & Scatliff, 1961). The oral stage of the swallow typically takes less than 1 to 1.5 seconds to complete. It increases slightly as bolus viscosity increases.

In summary, the normal oral stage of the swallow requires intact labial musculature to ensure an adequate seal to prevent material from leaking out of the oral cavity, intact lingual movement to propel the bolus posteriorly, intact buccal musculature to ensure that material does not fall into the lateral sulci,



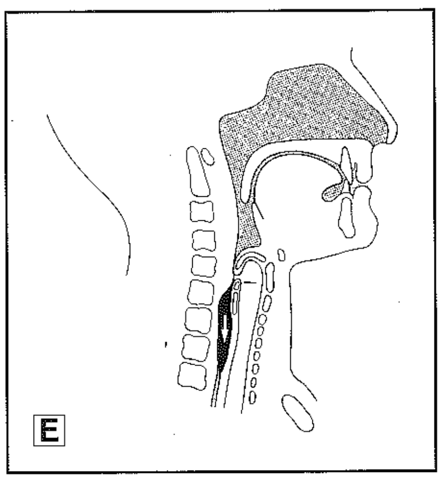


Figure 2.13. Lateral view of bolus propulsion during the swallow, beginning with the voluntary initiation of the swallow by the oral tongue (A); the triggering of the pharyngeal swallow (B); the arrival of the bolus in the vallecula (C); the tongue base retraction to the anteriorly moving pharyngeal wall (D); and the bolus in the cervical esophagus and cricopharyngeal region (E).

normal palatal muscles, and the ability to breathe comfortably through the nose (Campbell, 1981; Cleall, 1965).

Triggering of the Pharyngeal Swallow

As the tongue movement propels the bolus posteriorly, sensory receptors in the oropharynx and tongue itself (particularly deep proprioceptive receptors) are stimulated, sending sensory information to the cortex and brainstem. It is hypothesized that a sensory recognition center in the lower brainstem (medulla) in the nucleus tractus solitarus decodes the incoming sensory information and identifies the swallow stimulus, sending this information to the nucleus ambiguous, which initiates the pharyngeal swallow motor pattern (Doty, Richmond, & Storey, 1967; Miller, 1972). When the leading edge of the bolus, or the "bolus head," passes any point between the anterior faucial arches and the point where the tongue base crosses the lower rim of the mandible (see Figure 2.14), the oral stage of the swallow is terminated and the pharyngeal swallow should be triggered. If the pharyngeal stage is not triggered by that time, the pharyngeal swallow is said to be delayed. In the first edition of this book, the trigger point for the pharyngeal swallow was defined as the anterior faucial arch. This was based on studies of young and middle-aged adults. The point of triggering of the pharyngeal swallow has been lowered in response to more recent observations of older normal swallowers whose pharyngeal swallow triggers when the bolus head has reached the lower level (Robbins, Hamilton, Lof, & Kempster, 1992; Tracy et al., 1989). Individuals of all ages should trigger the pharyngeal swallow by the time the bolus head reaches the point where the mandible crosses the tongue base, as seen radiographically.

In younger, normal individuals, the triggering of the pharyngeal swallow occurs at the anterior faucial arch, and timing is such that posterior movement of the bolus is not interrupted (Jean & Car, 1979; Lederman, 1977; Tracy et al., 1989). There is no pause in bolus movement while the pharyngeal swallow triggers. Pommerenke (1928) and others have established the base of the anterior faucial pillars as the most sensitive place for elicitation of the pharyngeal swallow. Hollshwandner, Brenman, and Friedman (1975) and Storey (1976) postulated receptors in the tongue, epiglottis, and larynx as additional centers for elicitation of the pharyngeal swallow. Older (over age 60) normal individuals are not seen to trigger the pharyngeal swallow until the bolus head reaches approximately the middle of the tongue base (Robbins et al., 1992; Tracy et al., 1989). Observations of neurologically impaired patients corroborate these variations. In some patients, the pharyngeal swallow is not triggered until material has fallen into the pyriform sinuses.

There is much that is not known about the triggering of the pharyngeal swallow. However, it is clear that humans cannot swallow unless there is

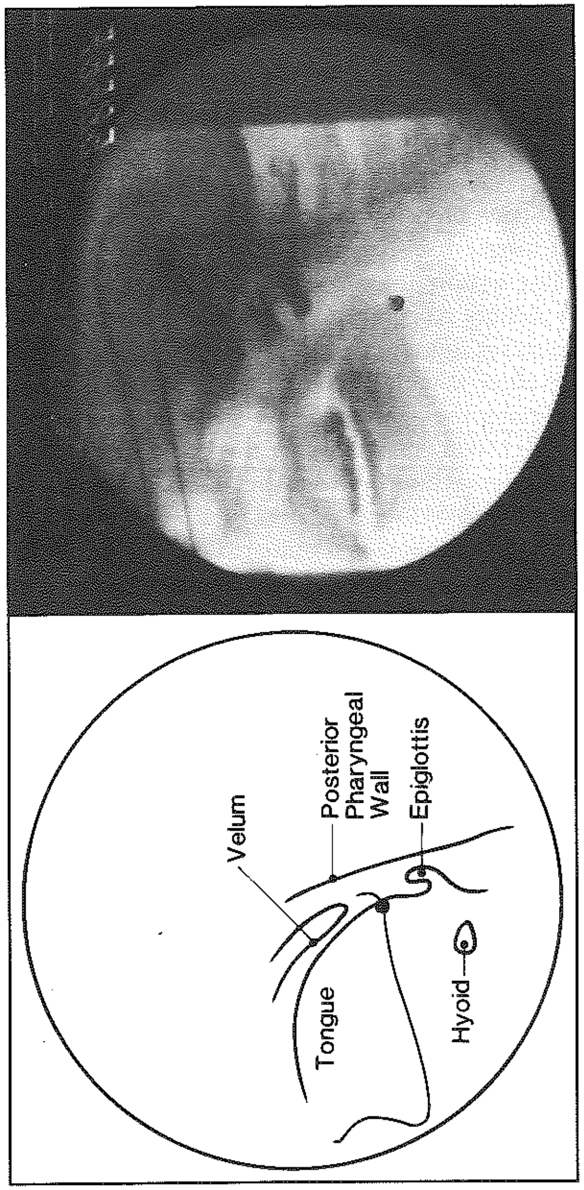


Figure 2.14. Lateral diagram and videoprint of the oral cavity and pharynx with a black dot indicating the point where the mandible crosses the tongue base. When the head of the bolus reaches this point (black dot on the videoprint and diagram), the pharyngeal swallow should be initiated.

something in their mouth, either food, liquid, or saliva. If one attempts to swallow four times in rapid succession, it is difficult to continue past the second or third swallow because these dry swallows have depleted saliva in the mouth.

No doubt, a relationship exists between voluntary attempts to swallow and triggering of the pharyngeal swallow. The exact nature of that relationship, however, is not understood. It is clear that simply placing food or liquid in the mouth will not trigger the pharyngeal swallow unless there is the voluntary initiation of swallowing. Direct stimulation to the areas of the mouth where the pharyngeal swallow is triggered, using a light touch or stronger stimulation, will usually not stimulate the swallow unless saliva or other material is present and the patient is also attempting voluntarily to initiate the swallow. Roueche (1980) probably stated it best: "Both voluntary and reflex components are involved in the normal swallow. Neither mechanism alone is capable of producing swallowing with the regularity and immediacy which is necessary during the normal process of oral feeding."

The pharyngeal stage of the swallow begins as the pharyngeal swallow is triggered. Cumming and Reilly (1972), Dobie (1978), Donner and Silbiger (1966), and others have suggested that the sensory portion of the pharyngeal swallow is carried by cranial nerves IX, X, and XI. The impulses travel to the medullary reticular formation, or swallowing center, located within the brainstem (Doty et al., 1967; Goldberg, 1976; Miller, 1972; Sumi, 1972). This center acts as a neuronal pool to organize the synergy necessary for normal pharyngeal swallowing. The motor portion is carried by nerves IX and X. Nerve VII may additionally contribute to the sensory portion. Nerves V, VII, and XII have been identified as possible contributors to the afferent portion.

The role of the cerebellum in control of swallowing is unclear. The work of Brooks, Kozlovskaya, Atkin, Horvath, and Uno (1973), Kent and Netsell (1975), and Larson and Sutton (1978) indicates cerebellar input into the velocity of movement and, thus, at least into mastication and the preparatory phase of the swallow. Cortical input into the control of swallowing is not well understood, although abnormal swallowing is observed in patients after damage to cortical areas, and swallowing is usually facilitated by voluntary attempts to swallow (Bieger & Hockman, 1976). Cortical recognition of food or liquid approaching the mouth and placed in the mouth is critical to the initiation of the oral phase of swallow or of oral preparation if chewing is needed.

Pharyngeal Swallow

A number of physiological activities occur as a result of pharyngeal triggering, including (1) elevation and retraction of the velum and complete closure of the velopharyngeal port to prevent material from entering the nasal cavity; (2) elevation and anterior movement of the hyoid and larynx; (3) closure of the larynx at all three sphincters—the true vocal folds, the laryngeal entrance (i.e., the false vocal folds, the anteriorly tilting arytenoids, and thickening of the epiglottic base as the larynx elevates), and epiglottis—to prevent material from entering the airway; (4) opening of the cricopharyngeal sphincter to allow material to pass from the pharynx into the esophagus; (5) ramping of the base of the tongue to deliver the bolus to the pharynx followed by tongue base retraction to contact the anteriorly bulging posterior pharyngeal wall; and (6) progressive top to bottom contraction in the pharyngeal constrictors (Bosma, 1957; Cook, Dodds, Dantas, Kern, et al., 1989; Cook, Dodds, Dantas, Massey, et al., 1989; Doty & Bosma, 1956; Jacob et al., 1989; Kahrilas et al., 1991; Kahrilas, Logemann, Lin, & Ergun, 1992; Logemann et al., 1992; Vantrappen & Hellemans, 1967).

Velopharyngeal Closure

Velopharyngeal closure varies somewhat from person to person and may involve some elements of elevation and retraction of the soft palate, inward movement of the posterior and/or lateral pharyngeal walls, and an anteriorly bulging adenoid pad. Velopharyngeal closure enables the buildup of pressure in the pharynx. Functional swallowing is possible without velopharyngeal closure if all other physiologic aspects of the pharyngeal swallow are normal, particularly the tongue base and pharyngeal wall movement and contact.

Elevation and Anterior Movement of the Hyoid and Larynx

During the swallow the larynx and hyoid bone elevate and move anteriorly by the pull of the floor of mouth muscles (i.e., the anterior belly of digastric, mylohyoid, geniohyoid, and the laryngeal elevator, the thyrohyoid). In young men, the hyoid elevates approximately 2 cm (Jacob et al., 1989). The elevation contributes to closure of the airway entrance, and the forward movement contributes to opening of the upper esophageal sphincter.

Closure of the Larynx

Ardran and Kemp (1952, 1956) described the closure of the larynx as beginning at the level of the vocal folds and progressing upward to the laryngeal vestibule. These researchers' cineradiographic studies, as well as more recent studies using videofluoroscopy (Logemann et al., 1992), indicate that closure is effected from below upwards, with the contents of the laryngeal vestibule being expressed into the pharynx. This action clears any penetration (i.e., entry of food, liquid, etc. into the airway to the level of the top surface of the true vocal folds) that may occur. During closure of the airway at the vestibule, there is a downward, forward, and inward rocking movement of the arytenoid cartilages, which narrows

the laryngeal opening (Ardran & Kemp, 1967). At the same time, the larynx is elevated and pulled forward. This elevation thickens the base of epiglottis, assisting with closure of the laryngeal vestibule (Ardran & Kemp, 1956; Negus, 1949; Ohmae, Logemann, Kaiser, Hanson, & Kahrilas, 1995). In normal adults the airway entrance is closed for approximately one third to two thirds of a second during single swallows. During sequential cup drinking, the airway may be closed 5 seconds or more (Martin, Logemann, Shaker, & Dodds, 1994). Vocal fold closure occurs when the larynx has elevated to approximately 50% of its maximum elevation (Gilbert et al., 1996).

Cricopharyngeal Opening

Cricopharyngeal opening occurs by a complex series of actions (Cook, Dodds, Dantas, Massey, et al., 1989; Jacob et al., 1989). First, tension in the cricopharyngeal muscular portion of the sphincter is released. Approximately 0.1 second later, laryngeal anterior superior motion is seen to begin to open the sphincter; thus, the sphincter is yanked open by the motion of the larynx resulting from the upward and forward pull of the floor of the mouth muscles. The leading edge of the bolus reaches the sphincter as it opens, and the pressure within the bolus widens the opening (Jacob et al., 1989). As the bolus passes through the sphincter, the larynx lowers and the cricopharyngeus muscle returns to some level of contraction.

Tongue Base and Pharyngeal Wall Action

As the pharyngeal swallow triggers, the tongue base assumes a ramp shape, directing the food into the pharynx. Then, tongue base retraction and pharyngeal wall contraction occur when the bolus tail reaches the tongue base level. The tongue base and pharyngeal walls should make complete contact during the swallow (Kahrilas et al., 1992). As the two structures move toward each other, pharyngeal pressure builds. When the two structures make contact, the pharyngeal wall contraction continues progressively down the pharynx to the upper esophageal sphincter, where esophageal peristalsis takes over bolus propulsion. The pharyngeal contraction wave is no longer called peristalsis because *peristalsis* is defined as progressive contraction down a muscular tube. The pharynx is not a muscular tube; therefore, the term is inappropriate when describing progressive contractions down the pharyngeal constrictors during swallow. The constrictors comprise only the lateral and posterior pharyngeal walls, and not the anterior pharyngeal wall which is made up of the skull base, palate, tongue base, and larynx. Pressure generated by the tongue base retraction and pharyngeal wall contraction increases as bolus viscosity increases. Pressure is always applied to the tail of the bolus, as shown in Figure 2.15.

Typically, in normal swallowers, velopharyngeal closure and hyolaryngeal

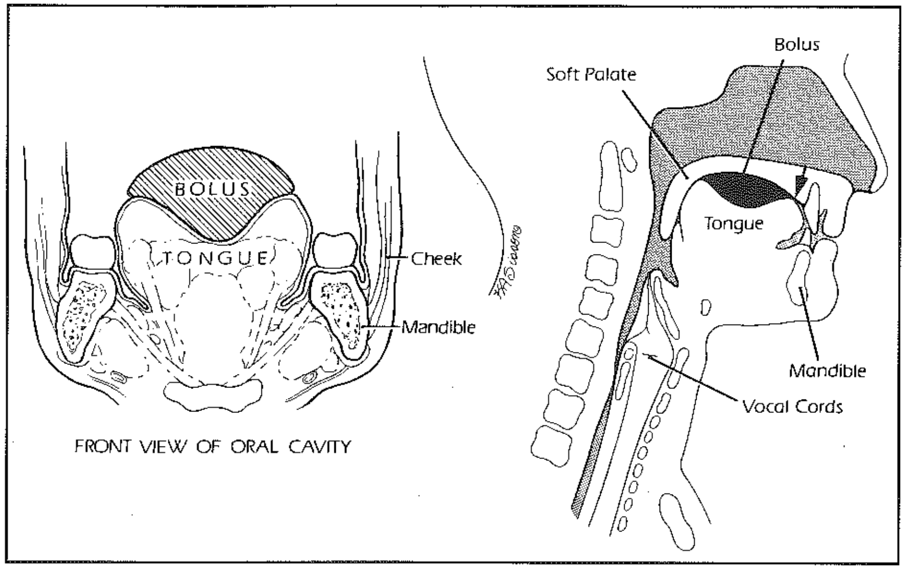


Figure 2.15. Lateral drawing of the head and neck with an arrow indicating the point where pressure is being applied to the bolus tail.

upward and forward movement occur almost simultaneously. Opening of the upper esophageal sphincter and closure of the airway usually begin essentially simultaneously. Pressure on the bolus begins as the oral tongue pushes against the tail of the bolus. When the tail of the bolus reaches the tongue base and pharyngeal walls, these structures move toward each other until they make contact, thus applying pressure to the bolus.

Without the triggering of the pharyngeal swallow, none of these physiologic activities would occur. If the oral tongue propels the bolus posteriorly and no pharyngeal swallow is triggered, the bolus is likely to be propelled by the tongue into the pharynx, where it may come to rest in the valleculae or pyriform sinuses. If the material is liquid, it may splash into the pharynx and into the open airway. No pharyngeal swallow actions will occur until the pharyngeal swallow triggers, so the bolus may rest in the valleculae until the pharyngeal swallow is triggered. Or, depending on consistency, the food may drain from the valleculae, down the aryepiglottic folds and into the pyriform sinuses, or may fall into the airway where it may or may not be expectorated, depending upon the patient's sensitivity in the trachea and larynx. It is important to remember that a swallow comprised of velar, pharyngeal, tongue base, and laryngeal activity occurs only as a result of the triggering of the pharyngeal swallow. Patients can be taught to voluntarily protect their airway or to open the cricopharyngeal sphincter or UES voluntarily, as seen in sword swallowers (Devgan, Bross, McCloy, & Smith, 1978; Kahrilas et al., 1992; Logemann et al., 1992) and some alaryngeal speakers, as described in Chapter 5; however, there is no way to voluntarily initiate or modify pharyngeal wall contraction (Hollis & Castell, 1975). Patients may struggle and exhibit repeated laryngeal and/or tongue base movements, but these are not in the context of a full pharyngeal swallow.

Pharyngeal transit time—the time taken for the bolus to move from the point at which the pharyngeal swallow is triggered through the cricopharyngeal juncture into the esophagus—is normally 1 second or less. During this transit, the bolus does not hesitate for any length of time anywhere in the pharynx, but moves smoothly and quickly over the base of the tongue through the pharynx and into the cervical esophagus. As the bolus moves through the pharynx, it usually divides at the valleculae, with approximately half flowing down each side of the pharynx through the pyriform sinuses. Approximately 20% of normal subjects swallow down only one side (Logemann, Kahrilas, Kobara, & Vakil, 1989). The purpose of the epiglottis appears to be to direct the food around the airway rather than over the top of the airway. The two portions of the bolus join again at about the level of the opening of the esophagus (Ardran & Kemp, 1951). When the pharyngeal phase of the swallow is over, normally very little residual food is left in the pharynx, even in older individuals.

Esophageal Phase

Esophageal transit times can be measured from the point where the bolus enters the esophagus at the cricopharyngeal juncture or UES until it passes into the stomach at the gastroesophageal juncture or LES. Normal esophageal transit time varies from 8 to 20 seconds (Dodds, Hogan, Reid, Stewart, & Arndorfer, 1973; Mandelstam & Lieber, 1970). The peristaltic wave, which begins at the top of the esophagus, pushes the bolus ahead of it and continues in sequential fashion through the esophagus until the lower esophageal sphincter opens to allow the bolus to enter the stomach.

Motility disorders in the esophagus can be defined during a videofluoroscopic study, as described in Chapter 5. However, because the esophageal phase of the swallow is generally not amenable to any kind of therapeutic exercise regimen, the videofluoroscopic study of oropharyngeal deglutition usually does not involve examination of the esophagus. Patients with esophageal disorders should be referred to a gastroenterologist or for a standard barium swallow or upper gastrointestinal series. Unfortunately, the barium swallow does not always define gastroesophageal reflux (i.e., the backflow of food from the stomach into the esophagus). A referral to a gastroenterologist may be more productive in identifying the etiology and optimal treatment for the patient's esophageal disorder.

The Mechanism as a Set of Tubes and Valves

The upper aerodigestive tract can be conceived as a series of tubes and valves. The tubes are the oral cavity, which is a horizontal tube as shown in Figure 2.16, and the pharynx, which is a vertical tube. Within these two tubes, there are a number of valves that serve several functions: (1) directing the food in the appropriate way to keep it from going down the airway or up the nose, for example, and (2) applying pressure to the food to propel it along. The valves consist of (1) the lips anteriorly, which keep food in the mouth; (2) the oral portion of the tongue, which can make complete contact with any point along the hard palate and soft palate or can approximate the palate to any degree; (3) the velopharyngeal region, which closes to keep food from entering the nose; (4) the larynx, whose primary biologic function is to prevent food from entering the trachea; (5) the tongue base and pharyngeal walls, which make complete contact during the pharyngeal swallow to generate pressure and drive the bolus cleanly through the pharynx; and (6) the cricopharyngeal region, which opens at the appropriate time to allow the bolus into the esophagus. A seventh valve is in the digestive tract at the base of the esophagus (i.e., the lower esophageal sphincter). The lower esophageal sphincter (LES) functions quite differently from the UES and is anatomically quite distinct. Whereas the UES or cricopharyngeal

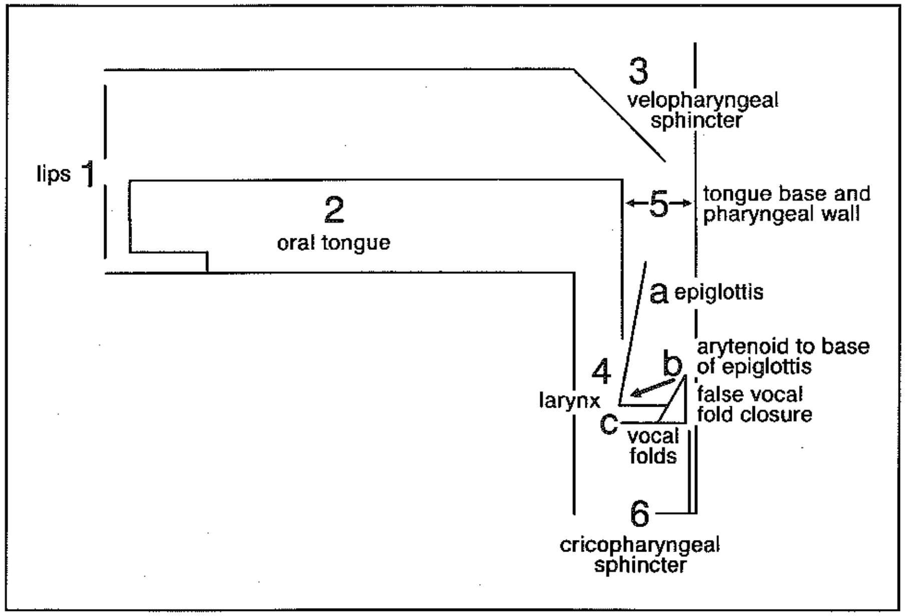


Figure 2.16. A diagram of the valves of the upper aerodigestive tract involved in swallowing

region is a musculoskeletal valve made up of the cricopharyngeus muscle and the cricoid cartilage, the LES is a muscular sphincter that relaxes to open and contracts to close. The LES is designed to keep food and stomach acid in the stomach, that is, to prevent reflux or the backflow of food from the stomach into the esophagus. To produce a normal swallow, all of these valves must function both in appropriate timing and appropriate range of movement. One way to evaluate this mechanism is to systematically examine each of the valve functions to determine whether it is opening and closing at the right times during the swallow and whether its range of movement is normal. Many of these same valves function for speech. However, swallowing generally requires greater muscular contraction, demands greater range of motion, and generates higher pressures than speech (Perlman, Luschei, & DuMond, 1989).

Changes with Age

Variations in Normal Anatomy and Physiology

The normal anatomy of the upper airway in a young infant differs from that of the adult.

Infants and Young Children

In infants and young children, the anatomic relationship between the structures of the oral cavity and the pharynx is different from that in adults. In the infant, the tongue fills the oral cavity, the fat pads in the cheeks narrow the oral cavity laterally, and the hyoid bone and larynx are much higher than in adults (Figure 2.17), affording more natural protection for the airway (Bosma, 1986a, 1986b; Newman, Cleveland, Blickman, & Hillman, 1991). The velum usually hangs lower, with the uvula often resting inside the epiglottis, forming a pocket in the valleculae. As described later, with repeated tongue pumps, the bolus is often collected at the back of the mouth in front of an anteriorly bulging velum or in the vallecular pocket. During the first 21 years of life, the face continues to grow. The jaw grows down and forward, carrying the tongue down and enlarging the space between the tongue and the palate, thereby developing an oral cavity space. The larynx lowers as does the hyoid bone, thereby elongating and enlarging the pharynx. The greatest elongation of the pharynx and downward displacement of the larynx occur during puberty.

According to Dellow (1976), swallowing begins in the fetus, with sucking movements, drinking of amniotic fluid, and occasional presentation of the thumb in the mouth. Swallow physiology in the infant is quite different from that in the adult. When sucking from a nipple, the infant repeatedly pumps the

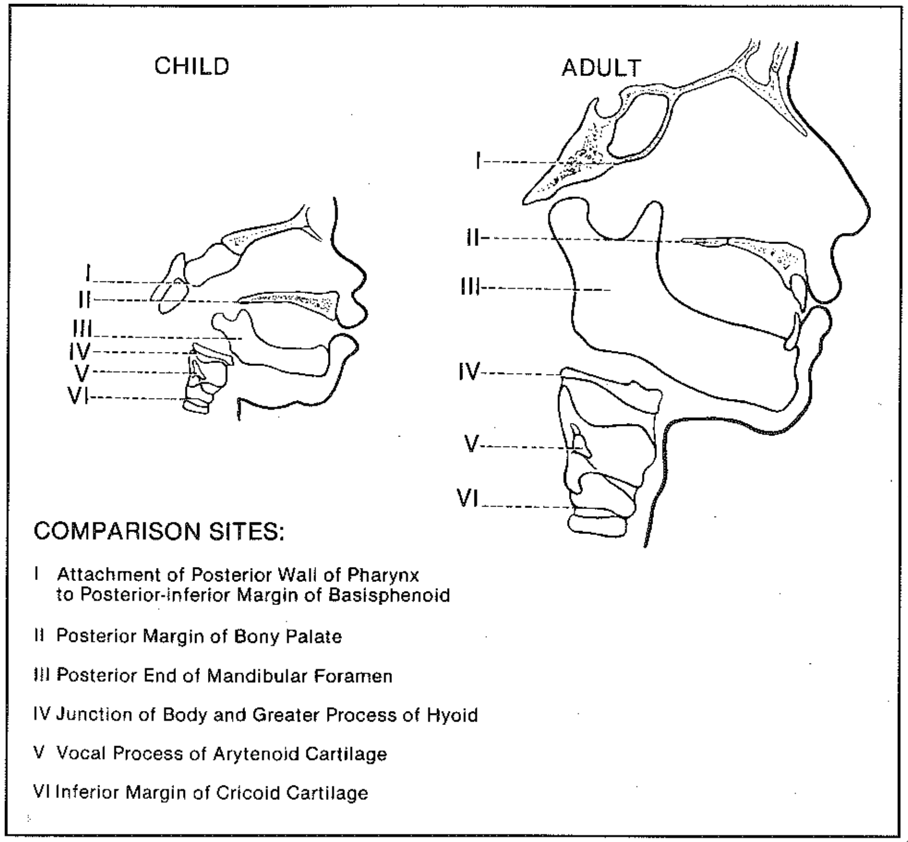


Figure 2.17. Lateral drawings of the infant and adult head and neck indicating the relative position of oral and pharyngeal structures.

tongue (initially the tongue and jaw together), expressing milk from the nipple with each pump and collecting this liquid at the faucial arches (in front of the anteriorly bulging soft palate) or in the valleculae. Each infant tends to use a pattern of a particular number of tongue pumps predominantly, with some variability. Normal infants may use anywhere from 2 to 7 tongue pumps (Burke, 1977; Newman et al., 1991). More than that would be considered abnormal. Usually the number of tongue pumps used relates to the amount of liquid expressed from the nipple by a single tongue movement (i.e., fewer tongue pumps if a large amount of liquid is expressed with each tongue movement, more tongue pumps if less liquid is expressed). When a bolus of adequate size has been formed, the pharyngeal swallow triggers. If given a small liquid bolus (1 ml) on a spoon, an infant usually produces an oral and then pharyngeal swallow similar to that of an adult.

The pharyngeal swallow in the infant is similar to that of the adult with two exceptions. Laryngeal elevation is much reduced, since the larynx is anatomically elevated under the tongue base and does not need to move upward. In normal infants, the posterior pharyngeal wall is often seen to move much further anteriorly during swallow than is observed in adults.

According to Bosma (1973), bite is achieved at approximately 7 months, and chewing begins at approximately 10 to 12 months, although there is great variability in the time when the normal adult chewing pattern is achieved, which can be up to 3 to 4 years. Once the infant moves to discrete swallows of pureed or soft foods, the oral and pharyngeal swallow physiology is similar to that of an adult, with the exception of reduced laryngeal elevation.

Older Adults

A number of studies have been done to define the changes in normal swallowing patterns throughout adulthood. Feldman, Kapur, Alman, and Chauncey (1980) studied masticatory function in older adults. High masticatory performance was maintained regardless of age in normal individuals with complete, or almost complete, dentition. These authors did find an increase in the number of chewing strokes used to prepare food for swallowing related to age and dental status. More strokes are needed in patients with poor dentition or dentures.

Several studies have examined the structure and function of swallowing in normal aging adults (Blonsky, Logemann, Boshes, & Fisher, 1975; Mandelstam & Lieber, 1970; Robbins et al., 1992; Tracy et al., 1989). These studies have shown that some minor but statistically significant changes in the physiology of deglutition occur until individuals reach their 80s.

With age, ossification in the thyroid and cricoid cartilages and the hyoid bone increases, so that these structures may appear more prominent during fluoroscopy. Also, as adults reach age 70 and beyond, the larynx may begin to lower in the neck, approaching the 7th cervical vertebra. With age, the incidence of cervical arthritis increases. Arthritic changes in the cervical vertebrae may impinge on the pharyngeal wall, decreasing its flexibility. This may be responsible for some reported reduction in the strength of pharyngeal contraction, resulting in some need to swallow a second time to clear residual material from the pharynx after the swallow.

Some statistically significant changes in oropharyngeal swallow physiology have been noted in normal individuals over age 60 (Robbins et al., 1992; Tracy et al., 1989). Older individuals tend to more frequently hold the bolus on the floor of the mouth and pick it up with the tongue tip as the oral stage of swallowing is initiated—that is, the dipper swallow (Dodds et al., 1989). The oral stage of swallowing is slightly longer in older adults as is the "normal" delay in triggering the pharyngeal swallow (Figure 2.18).

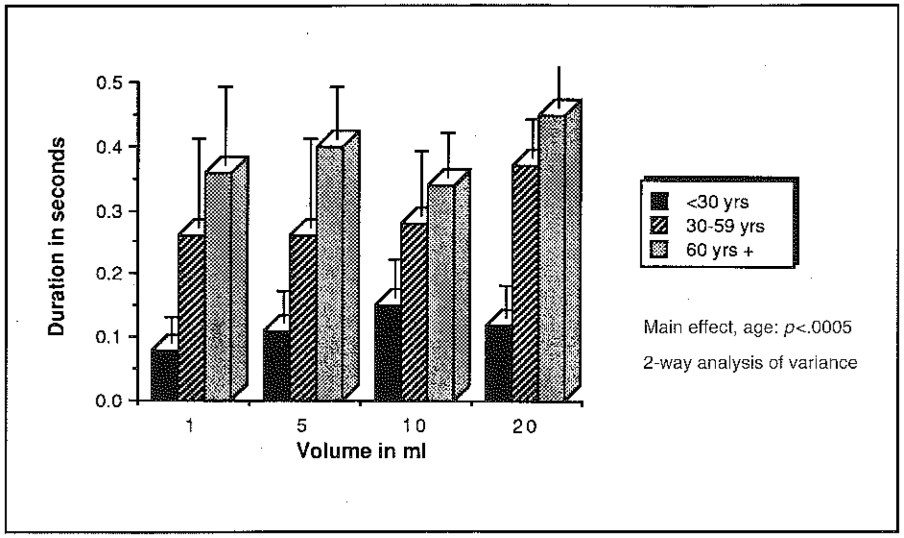


Figure 2.18. A bar graph showing duration of pharyngeal delay in the oropharyngeal swallow in younger and older normal adults. The difference in pharyngeal delay time is significant with age.

A very small increase has been observed in frequency and extent of oral or pharyngeal residue in individuals over 60. Penetration of material into the laryngeal vestibule is reported as increasing in frequency with age, but there is no increase in aspiration in older adults (Robbins et al., 1992; Tracy et al., 1989). Figures 2.19A and 2.19B illustrate the extremes of pharyngeal residue (least and most) observed in older normal subjects in our videofluorographic studies. In contrast to these small changes in oropharyngeal swallow physiology in older adults, esophageal function deteriorates more significantly with age so that esophageal transit and clearance are slower and less efficient (Mandelstam & Lieber, 1970).

My colleagues and I have completed a comparative study of oropharyngeal swallow in young men (21 to 29 years old) and old men (80 to 94 years old) (Logemann, Pauloski, Rademaker, & Kahrilas, 1996). Results revealed reduced maximal laryngeal and hyoid anterior and vertical movement in the old men, indicating reduced neuromuscular reserve. As shown in Figure 2.20, the vertical movement of the hyoid and larynx in the old and young men was identical until each accomplished cricopharyngeal opening. After cricopharyngeal opening was attained, hyoid and laryngeal elevation continued in the young men but remained stable in the old men. The young men had excess laryngeal and hyoid motion. This difference between necessary movement and actual motion is known as "reserve." The old men had no reserve.

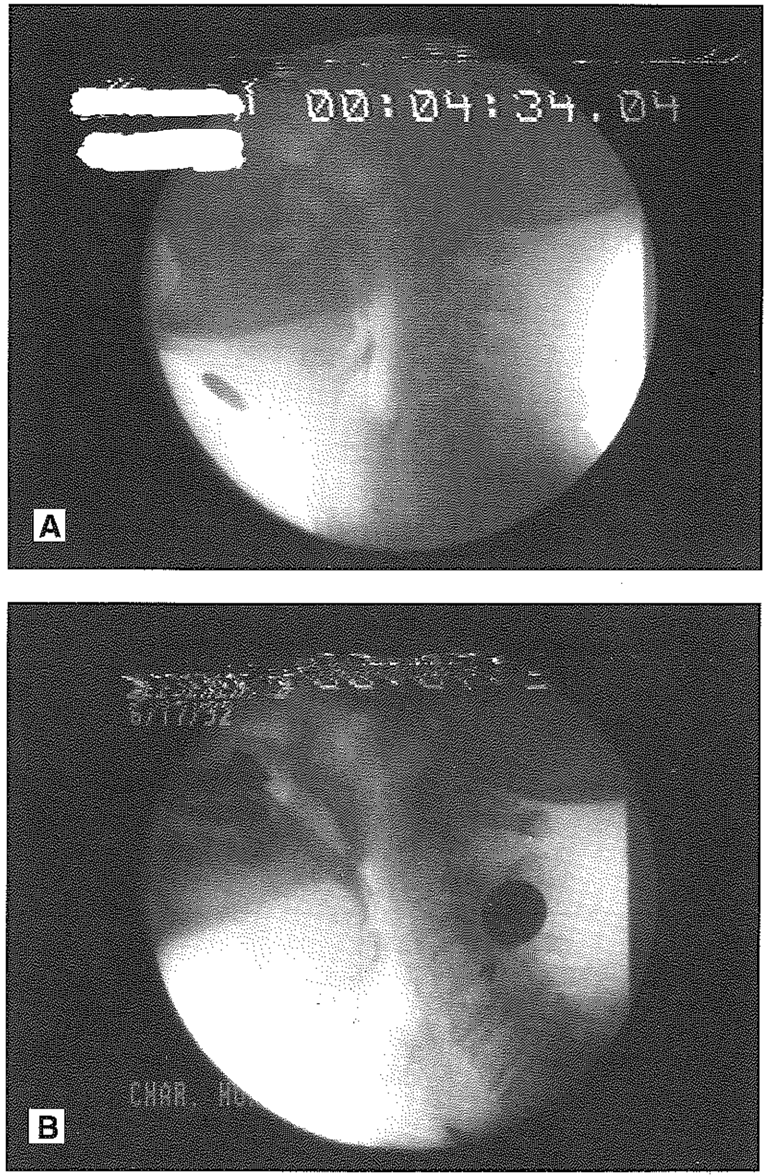


Figure 2.19. Lateral videoprints of the least (A) and most (B) residue in the pharynx in the oldest subjects in our studies, ages 80 to 93.

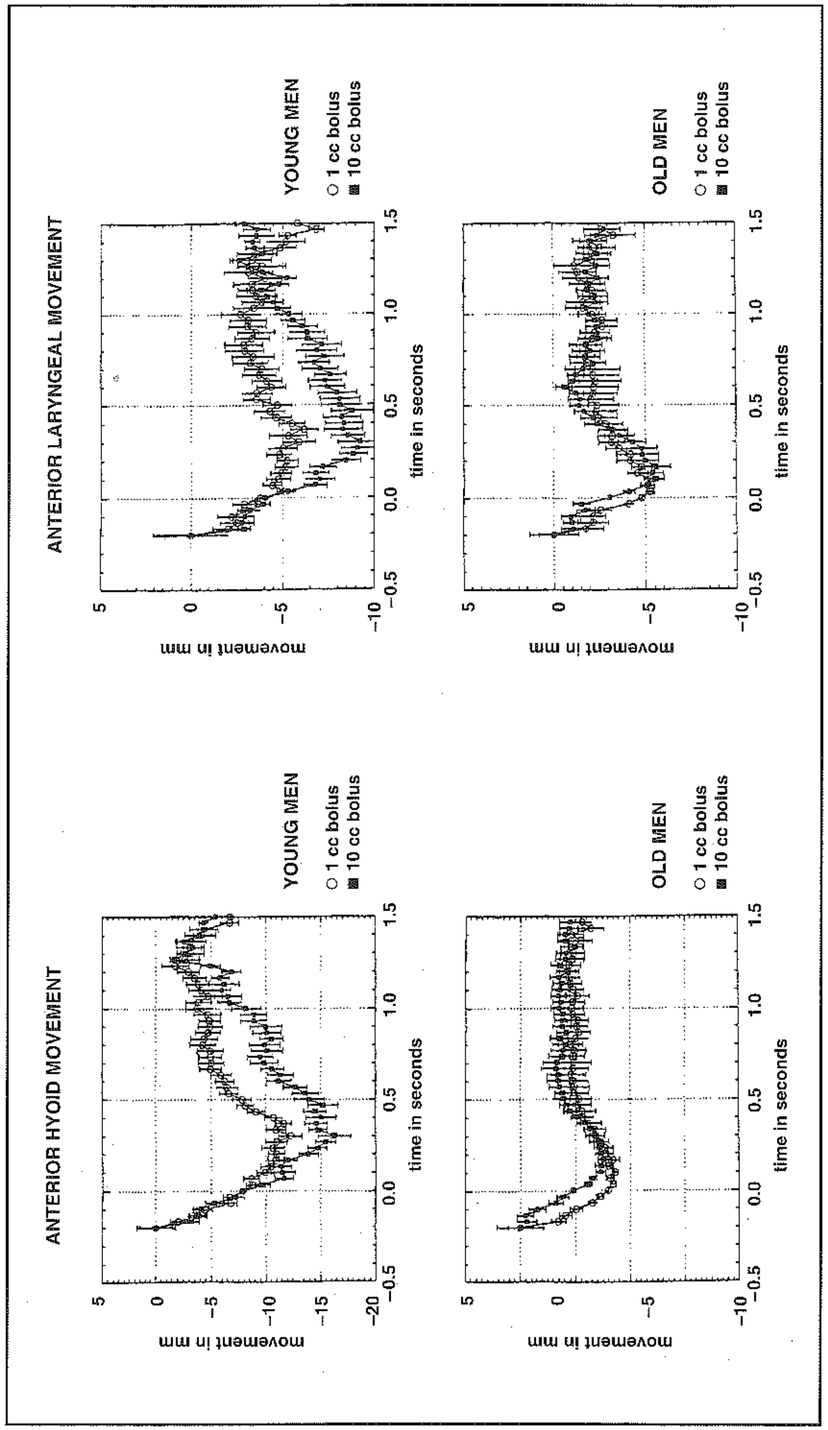


Figure 2.20. The anterior movement of the hyoid and larynx in young and old men from the onset to the termination of the swallow. Time 0.0 is the onset of opening of the upper esophageal sphincter.

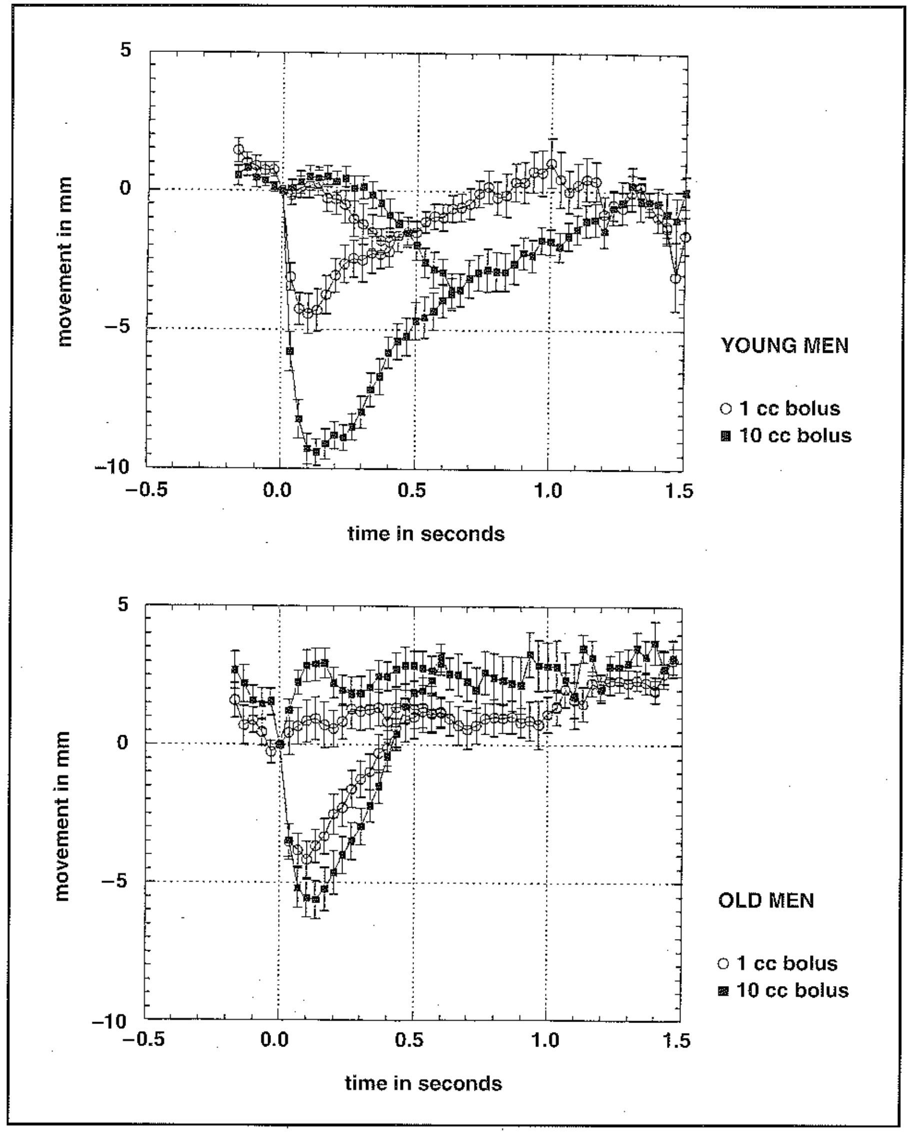


Figure 2.21. Cricopharyngeal (CP) opening profile in young and old men swallowing several volumes of liquid. Time 0.0 is onset of opening of the upper esophageal sphincter.

Examination of changes in cricopharyngeal opening (Figure 2.21) in the two groups revealed reduced flexibility in the old men, that is, less change as volume increased. Reduction in reserve and flexibility in neuromuscular control has been found to characterize normal aging of the motor system. Both of these characteristics in the swallows of the "oldest old" put them at increased risk for developing swallowing problems if they become physically weak as a result of any illness, even if it is not in the region of the head and neck.

Taste

Taste is a chemical sense in the oropharyngeal region and is activated during eating and drinking (Frank, Hettinger, & Mott, 1992). With age, rating of the intensity of taste and smell are reduced (Cowart, 1989), smell perhaps more than taste. Loss of interest in nutritious food may develop in the elderly as taste sensation is affected. Taste supplements may be added to food to increase intake (Schiffman & Warwick, 1989) but must be done carefully as foods can be sweetened or salted to unhealthy levels. Some medications can result in an unpleasant metallic taste in the mouth, including tetracycline (an antibiotic), lithium carbonate (an antipsychotic), penicillamine (an antiarthritic), and captopril (an antihypertensive) (Coulter, 1988; Greenberg et al., 1989; Hochberg, 1986; Magnasco & Magnasco, 1985).

Coordination of Respiration and Swallowing

Several studies have examined the coordination between respiration and swallowing in normal individuals of various ages (Martin et al., 1994; Nishino & Hiraga, 1991; Preiksaitis, Mayrand, Robins, & Diamant, 1992). During swallow, the airway closes for a fraction of a second. The airway closure period, when there is no respiration, is known as the apneic period. The apneic period usually corresponds to the closure of the airway during the pharyngeal stage of swallowing and the cessation of chest wall movement. The duration of the airway closure tends to increase as bolus volume increases (Logemann et al., 1992). The airway is open during the oral preparatory, oral, and esophageal stages of swallow. There is a predominant pattern of swallow–respiratory coordination, with a great deal of variability. The predominant pattern of coordination involves the swallow interrupting the exhalatory phase of the respiratory cycle (Martin et al., 1994; Nishino, Yonezawa, & Honda, 1985; Preiksaitis et al., 1992; Selley, Flack, Ellis, & Brooks, 1989a, 1989b; Smith, Wolkove, Colacone, & Kreisman, 1989). Usually the individual returns to exhalation after the swallow. This coordination is thought to be safer than interrupting inhalation to swallow. By interrupting exhalation and returning to exhalation, the normal individual has a slight airflow through the larynx and pharynx after the swallow, which may help to clear any mild residue from around the airway entrance. At least one study has found that at larger bolus volumes, more swallows were preceded by inspiration (Preiksaitis et al., 1992).

There are indications that dysphagic patients may more often interrupt inhalation to swallow, which may increase their risk of aspiration (Selley et al., 1989b). There are also data indicating that it takes infants approximately 2 to 3 months to stabilize their swallow–respiratory coordination to be more like the adult pattern (i.e., so that swallowing interrupts the exhalatory phase of respiration) (McPherson et al., 1992).

Variations in Normal Swallowing

Normal swallowing consists of a number of different types of swallows. This helps to explain why some patients indicate they can swallow a certain type or volume of food but not another. The characteristics of the food are a major factor in making systematic changes in the oropharyngeal swallow. The other factor is volitional control exerted over the swallow.

Volume Effects

In general, changes in bolus volume create the greatest systematic changes in the oropharyngeal swallow. Whereas a small volume swallow (1 to 3 ml) is characterized by an oral phase followed by pharyngeal swallow triggering, the pharyngeal phase, and then the esophageal phase, a large volume swallow (10 to 20 ml) is usually characterized by simultaneous oral and pharyngeal activity. This is necessary in order to safely clear the large bolus from both the oral cavity and the pharynx (Kahrilas & Logemann, 1993; Shaker et al., 1993). As bolus volume increases, the timing of tongue base retraction to contact the anteriorly and medially moving pharyngeal walls occurs later in the swallow. The commonality across swallows is that the tongue base and pharyngeal walls move toward each other and make contact at the time when the tail of the bolus reaches the tongue base. This ensures that all of the pressure generated by the movement of the tongue base and pharyngeal walls toward each other is directed at the bolus tail.

Increasing Viscosity

As bolus viscosity increases, the pressure generated by the oral tongue, tongue base, and pharyngeal walls increases and muscular (electromyographic) activity increases (Dantas & Dodds, 1990; Dantas et al., 1990; Reimers-Neils et al., 1994). In addition, valve functions, such as velopharyngeal closure and upper esophageal opening and laryngeal closure, all increase slightly in duration as viscosity increases.

Cup Drinking

Cup drinking, if it is sequential, is characterized by early airway closure and some preelevation of the larynx as the cup is approaching the lips with airway closure extending across all of the sequential swallows. The duration of airway closure on cup drinking may last anywhere from 5 to 10 seconds, depending upon the number of consecutive swallows produced (Martin et al., 1994). During these sequential swallows, the velopharyngeal area is closed, the lips maintain seal around the cup or glass, the tongue repeatedly propels the consecutive swallows from the oral cavity, and the tongue base and pharyngeal walls make contact at the tail of each sequential bolus. The upper esophageal sphincter opens repeatedly as each bolus approaches. Patients with respiratory problems may not be able to cup drink because they cannot sustain the duration of airway closure needed.

Straw Drinking

In straw drinking, the bolus is brought into the mouth via suction created in the oral cavity. To create the suction, the soft palate is lowered against the back of the tongue and the muscles of the cheek and face contract and create suction intraorally to bring material into the mouth. When material has reached the mouth, the suction is discontinued, and the soft palate elevates as the oral stage of swallow is initiated by the tongue. Thus, straw drinking is simply a way to modify food placement into the mouth. There is, however, an inappropriate or dangerous way to straw drink which involves sucking via inhalation rather than intraoral suction. This can usually be easily observed at the bedside by watching the patient attempt to straw drink. If the suction is timed with inhalation, it is likely that the patient is straw drinking inappropriately with the airway open. This increases the patient's risk of material entering the airway as he or she is bringing the material into the oral cavity if it spills over and is sucked into the airway.

"Chug-a-Lug"

Some individuals can "chug-a-lug" a can of soda or other beverage without swallowing. To do this, they pull their larynx forward, which opens the upper esophageal sphincter volitionally; hold their breath to close the airway at the larynx; and then literally dump material through the oral cavity and pharynx by gravity into the esophagus and stomach. This is much the way a sword swallower manages to swallow the sword. The sword swallower aligns the oral cavity, pharynx, esophagus, and stomach vertically; opens the upper esophageal sphincter by forward pull of the larynx; holds his or her breath to protect the airway; and allows the sword to pass straight through the mouth, pharynx, and esophagus. Then the person relaxes the lower esophageal sphincter to enable the sword to enter the stomach. This action clearly represents tremendous volitional control over the mechanism, which indicates the potential that patients may have to compensate for their oropharyngeal dysphagia.

Pharyngeal Swallow with No Oral Swallow

If secretions are collecting in the pharynx or if there is chewing with premature spillage, which is building up in the valleculae and the pyriform sinuses, the individual may produce a pharyngeal swallow with little or no oral swallow. Generally, if chewing is taking place, the individual will stop chewing, produce a pharyngeal stage swallow, and then return to chewing. Thus, it is quite possible to have a pharyngeal stage swallow with no oral swallow at all. This again represents volitional control over the mechanism.

Components of All Swallows

All swallows must have certain physiologic components in order to clear food from the oral cavity and pharynx with no residue and with good airway protection. The components that must be present are (1) oral propulsion of the bolus into the pharynx, (2) airway closure, (3) upper esophageal sphincter opening, and (4) tongue base–pharyngeal wall propulsion to carry the bolus through the pharynx and into the esophagus. The variations on normal swallow generally involve changing the relative timing of these elements, but all must be present and normal for the bolus to be cleared safely and efficiently.

The behaviors characterizing normal swallowing are rapid acts, each involving voluntary and involuntary aspects requiring complex neuromotor control. Although all of the aspects of neural control of swallowing are not entirely understood, the physiology of normal deglutition has been moderately well defined and forms a basis for comparison of the abnormalities in swallowing described in Chapter 3.

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