Fluoroscopic Swallowing Examination: Radiologic Findings and Analysis of Their Causes and Pathophysiologic Mechanisms

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Abbreviations: CP = cricopharyngeus, HLC = hyolaryngeal complex, PES = pharyngoesophageal segment, UES = upper esophageal sphincter

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SA-CME LEARNING OBJECTIVES

After completing this journal-based SA-CME activity, participants will be able to:

- Discuss the anatomy and imaging phases of swallowing.
- Describe abnormalities detected at fluoroscopic swallowing examination.
- Correlate the radiologic findings with their causes and pathophysiologic mechanisms.

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Dysphagia is a common symptom in the general population, and its prevalence increases with patient age. The deterioration of swallowing function has many acute and chronic causes, including cerebrovascular and neuromuscular diseases, radiation, and surgery. In an elderly population, diagnosis and treatment of swallowing abnormalities is a high priority because it improves the patient's quality of life and helps them to avoid medical complications. Fluoroscopic swallowing examinations and modified barium swallow studies are the most used and most reliable diagnostic procedures to evaluate swallowing disorders. Functional anomalies include disturbances of the oral preparatory, oral propulsory, and pharyngeal phases of swallowing as premature spillage from the mouth, nasal regurgitation, delayed initiation of pharyngeal swallowing, incomplete displacement of the hyolaryngeal complex, abnormal epiglottic tilt, incomplete laryngeal closure, and pharyngeal dysmotilities. Anatomic abnormalities of the pharynx include diverticula, benign strictures, and tumors. The abnormalities diagnosed on the basis of fluoroscopic examination have a variety of treatment strategies, and the choice of treatment depends on the cause of the anomaly and its pathophysiologic characteristics. The radiologist's interpretation of these characteristics is crucial to therapeutic decision making and achieving the best patient outcomes.

Online supplemental material is available for this article.

Introduction

Oropharyngeal dysphagia is prevalent in 20% of the general population and in 50% of nursing home residents in the United States (1). As the average age of the population continues to increase, there has been an increase in dysphagia and related complications. Fluoroscopically guided swallowing examinations are the most used technique for evaluation of deglutition disorders. The examination is called modified barium swallow when the diagnostic study includes a therapeutic test; in those cases, it is performed with the participation of a swallowing therapist or speech-language pathologist (2).

Fluoroscopic examination of swallowing and modified barium swallow should not be routine studies but should be custom-tailored techniques designed by radiologists and swallowing therapists on the basis of the patient's clinical history and symptoms. Radiologists should supervise or participate in the procedures and contribute their knowledge to adapt the technique to unexpected findings detected during examinations. They may decide during the study to include the evaluation of organs such as the esophagus that may explain or be associated with the patient's symptoms. The radiologic

TEACHING POINTS

- Fluoroscopic examination of swallowing and modified barium swallow should not be routine studies but should be custom-tailored techniques designed by radiologists and swallowing therapists on the basis of the patient's clinical history and symptoms. Radiologists should supervise or participate in the procedures and contribute their knowledge to adapt the technique to unexpected findings detected during examinations. They may decide during the study to include the evaluation of organs such as the esophagus that may explain or be associated with the patient's symptoms.
- For evaluation of the function of the PES, radiologists should correlate the following functional units: *(a)* the opening of the PES, *(b)* the elevation of the HLC, and *(c)* the pharyngeal contraction. Understanding the different possible mechanisms that cause the abnormal function of the segment is essential in deciding the best treatment strategies.
- As part of the fluoroscopic swallowing examination, a systematic evaluation of the air-filled structures and soft tissues of the neck may provide information about the causative or associated abnormalities relating to the patient's symptoms.
- The development of Zenker diverticula may involve anatomic and pathophysiologic causes that include an area of wall weakness, a distal obstruction due to the diminished opening of the CP, and increased pharyngeal intraluminal pressure as a consequence of mechanical obstruction of the outlet.
- The radiologic report should include all detected abnormalities and should not be limited to description of the visualization of penetration or aspiration. Because each abnormality has its own specific therapeutic approach, the description of radiologic findings and their correlation with the pathophysiologic mechanisms and possible causes should be stated clearly in the report. A meticulous radiologic diagnosis facilitates the decision making of referring physicians and swallowing therapists.

report should describe all the findings additional to penetration or aspiration and present the facts in a way that facilitates decision making by the referring physicians and swallowing therapists.

This article reviews the anatomy and physiology of swallowing, explains the indications for and techniques of fluoroscopic examination, describes abnormal radiologic findings, and discusses their pathophysiologic mechanisms.

The discussion includes the abnormalities of the pharyngoesophageal segment (PES) as diminished or delayed opening and early closing and the pathophysiology of the pharyngeal residue after swallowing, penetration, and aspiration. Complications of total laryngectomy are examined, such as leakage, pseudoepiglottis, anterior pharyngeal pouches, neopharyngeal dysmotilities, strictures, and malfunctioning of the tracheoesophageal prosthesis for voice reconstitution. We describe the radiologic findings of each abnormality and provide sample images and a discussion of the possible mechanisms, with consideration of the patient's clinical history.

Anatomy for Radiographic Interpretation

The *oral cavity* is bounded by the hard and soft palates superiorly, by the tongue inferiorly, and opens to the oropharynx posteriorly. The *nasopharynx* or *epipharynx* is bounded by the pharyngeal walls posteriorly and laterally, by the skull base superiorly, and by the soft palate inferiorly. It opens to the nasal cavity anteriorly and communicates with the oropharynx inferiorly through the palatopharyngeal isthmus or velopharyngeal seal.

The *oropharynx* or *mesopharynx* is bounded posteriorly and laterally by the pharyngeal walls and constrictor muscles and inferiorly by the superior surface of the epiglottis and the hyoid bone. It communicates with the nasopharynx superiorly and with the mouth anteriorly. The *laryngopharynx* or *hypopharynx* is bounded by the pharyngeal walls posteriorly and laterally and extends to the lower border of the cricoid cartilage inferiorly. It communicates with the oropharynx superiorly, with the cervical esophagus inferiorly, and with the laryngeal vestibule anteriorly (3–6) (Fig 1).

Phases of Swallowing

Oral Preparatory Phase

The *oral preparatory phase* involves chewing the food and mixing it with saliva. When the bolus is considered "swallowable," it is placed between the upper surface of the tongue blade and the palate. The tip of the bolus is held by a seal formed by the tongue and the soft palate that prevents premature leakage into the pharynx before swallowing (7,8) (Fig 2A).

Oral Propulsory Phase

During the *oral propulsory phase*, the bolus is propelled into the oropharynx by means of an upward and backward movement of tongue. During the passage of the bolus, the soft palate elevates to a right angle to oppose the contraction of the posterior and lateral pharyngeal walls that form the Passavant ridge to close the palatopharyngeal isthmus and prevent the penetration of material into the nasopharynx (Fig 2B).

Initiation of Pharyngeal Swallow

The next phase is the *initiation of the pharyngeal swallow*, when the bolus passes the pharyngeal pillars and enters into the oropharynx, triggering the reflex that initiates the nonvoluntary pharyngeal phase of swallowing.

Pharyngeal Phase

In the *pharyngeal phase*, the hyolaryngeal complex (HLC) elevates and shortens the pharynx, deflects the epiglottis, closes the larynx, and opens

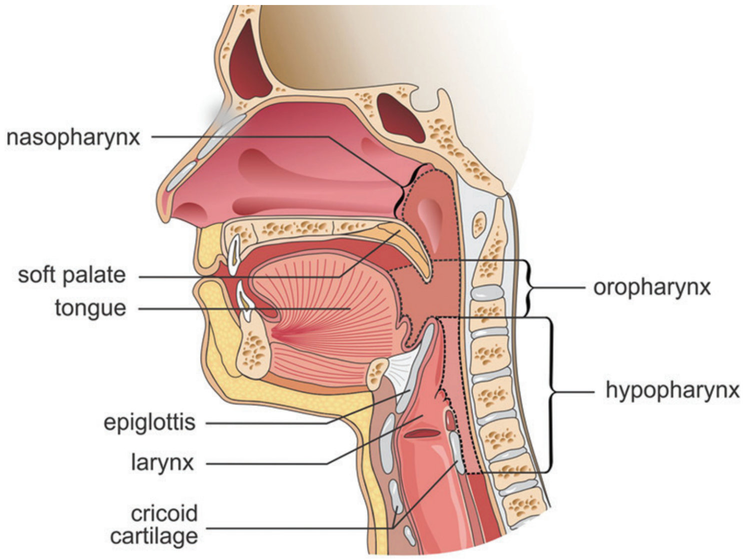

Figure 1. Illustration shows the anatomy of the pharynx.

the PES (Fig 2C). Laryngeal closure starts in the true vocal folds, followed by the false vocal folds, and ends in the laryngeal vestibule. Concurrently, the stripping contraction wave of the posterior and lateral pharyngeal walls begins and propels the bolus into the esophagus.

PES Opening Phase

The *PES opening phase* consists of *(a)* relaxation of the upper esophageal sphincter (UES); *(b)* upward and anterior traction of the cricoid cartilage, which is attached to the HLC; and *(c)* opening of the lumen by means of increased intrabolus pressure by the thrust of the dorsum of the tongue and the pharyngeal constrictors (Fig 2D) (9).

Esophageal Phase

The *esophageal phase* begins when the bolus is propelled through the esophagus into the stomach by means of esophageal peristalsis. Once the bolus passes into the esophagus, *(a)* the palatopharyngeal isthmus opens, reestablishing the communication between the nasopharynx and oropharynx and allowing the passage of air; *(b)* the HLC returns to resting position; *(c)* the larynx opens; *(d)* the epiglottis returns to upright position; *(e)* the PES closes, and *(f)* respiration resumes (Fig 2E).

Indications for Fluoroscopic Swallowing Examinations

Common indications for fluoroscopically guided swallowing examinations are oropharyngeal dysphagia (swallowing difficulty); globus sensation; choking and coughing during swallowing; prolonged intubation; cerebrovascular events (ie, stroke); and surgery, trauma, or radiation treatments to the head and neck (10).

Fluoroscopic Swallowing Examination Technique

The equipment used includes a radiologic apparatus with fluoroscopy and video recording with slow motion, reverse, and stop-frame capabilities (2,10–13). The patient should be upright or seated in a comfortable position, with their dentures in their mouth.

Lateral views are the most useful to evaluate all phases of swallowing and to detect penetrations into the airway. Oblique views are performed to visualize the PES without the shoulder in the way. Frontal views are used to diagnose asymmetric swallowing abnormalities.

Use of short exposure times and high kilovoltage is recommended to improve image resolution and minimize motion blurring of the bolus and anatomic structures. For a functional examination, the contrast material used is barium sulfate in a concentration of 40% to 60% weight/volume (mass of solute/volume of solution). Multiple barium viscosities such as thin liquid, nectar thick, honey thick, paste, and solids are used at the speech-language pathologist's discretion. Iodinated water-soluble contrast material is used when leakages or perforations are suspected (13).

Videofluoroscopic recording is used to detect functional abnormalities at 30 frames per second. Compared with videofluoroscopic recording, rapid-sequence digital images are acquired at fewer frames per second, but the images have better spatial resolution and are preferred for anatomic details.

The personnel included in a modified barium swallow examination are a radiographic technologist, a radiologist, and a speech-language pathologist. The role of the speech-language pathologist is to use strategies that may improve the efficiency

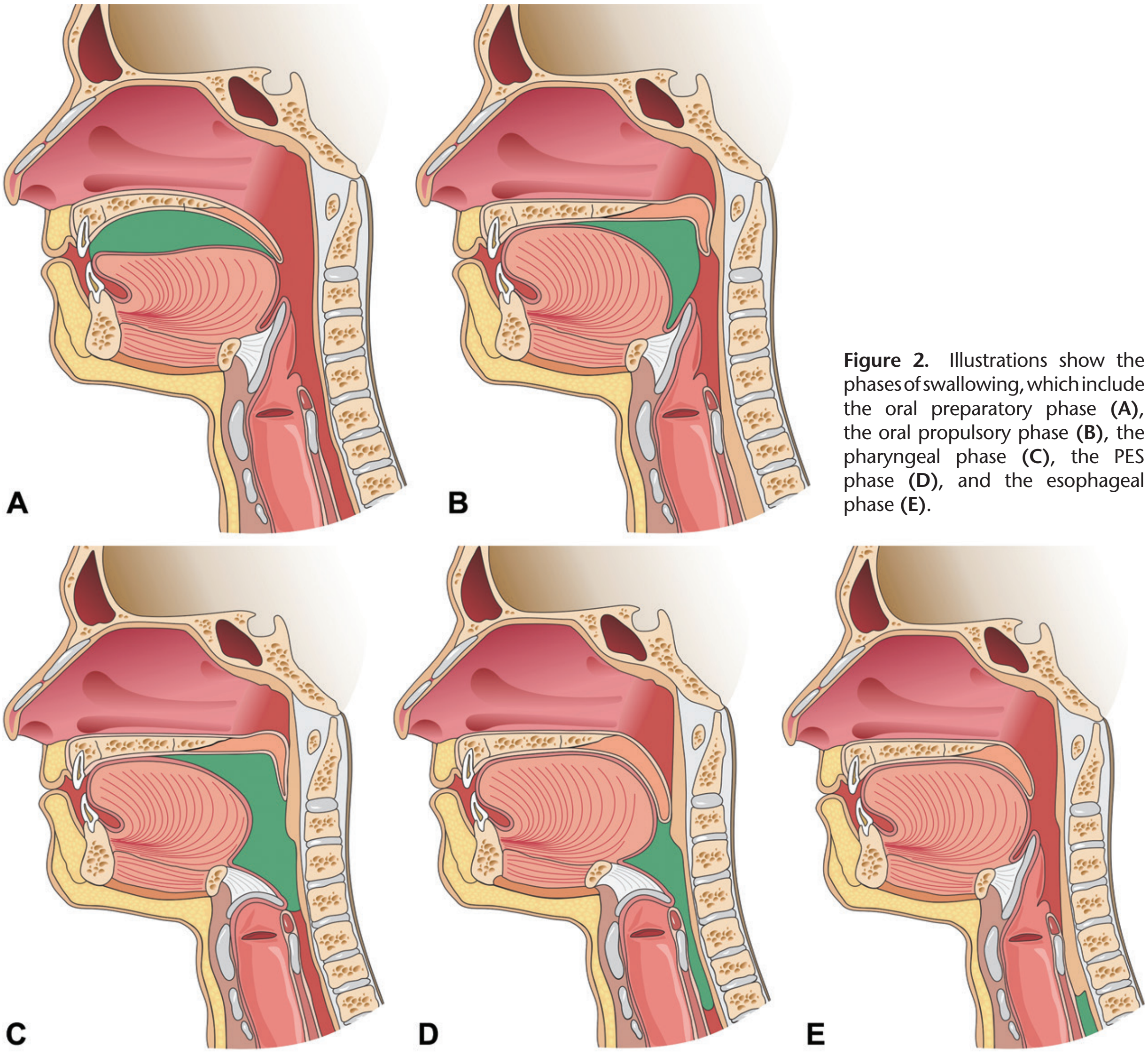

Figure 2. Illustrations show the phases of swallowing, which include the oral preparatory phase **(A)**, the oral propulsory phase **(B)**, the pharyngeal phase **(C)**, the PES phase **(D)**, and the esophageal phase **(E)**.

and safety of swallowing, to educate patients about their swallowing function, and to provide swallowing recommendations on the basis of the radiographic findings after study completion.

Evaluation of esophageal anatomy and motility is important. The anatomic site that the patient identifies as the source of the symptoms is not a reliable indicator of the location of the cause. Thus, radiologic examinations of patients with dysphagia should include a morphologic and functional evaluation of the esophagus and esophagogastric junction, which may be performed before or after the swallowing examination.

Functional Abnormalities

Abnormalities of Oral Preparatory Phase

The motion of the tongue is essential for bolus manipulation and the functions of chewing, mixing food with saliva, and holding the bolus in the mouth before swallowing. When the tongue is dysfunctional, images may show uncoordinated movements, fragmentation of the bolus, inability to hold it, and drooling and leaking of contrast material into the sulci of the cheeks and floor of the mouth (Fig 3). Causes of tongue failure can be secondary to atrophy, xerostomia, surgery, or severe nerve or brain injuries (7,14,15).

Premature Spillage from Mouth into Pharynx

The back of the tongue blade and the soft palate form the glossopalatal seal, which keeps the bolus in the mouth before swallowing. Premature spillage from the mouth into the pharynx may be caused by unilateral or bilateral incompetence of the seal, which may allow leakage of material into the pharynx before a swallowing attempt, leading to aspiration through an opened and unprotected airway (Fig 4). Seal ineffectiveness can be a result of weakness, atrophy, or poor muscular coordination of the tongue and soft palate due to aging,

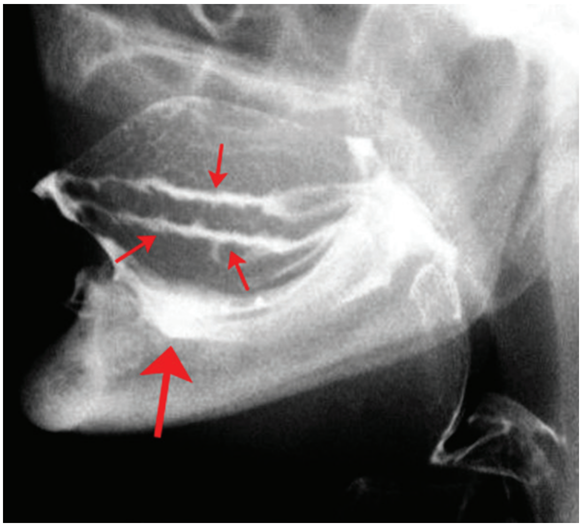

Figure 3. Leakage into the floor of the mouth in a 77-year-old woman. Lateral radiograph of the oral cavity after the swallow shows that contrast material has leaked into the mouth floor (large arrow) and the sulci of the cheeks (small arrows) because of incompetence of the tongue.

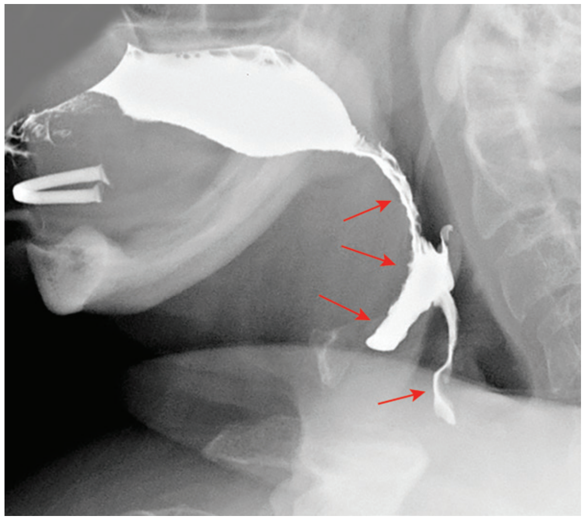

Figure 4. Leakage from the mouth into the pharynx in a 58-year-old woman. Lateral radiograph of the oral cavity and pharynx before swallowing shows contrast material leaking from the mouth bolus to the valleculae and hypopharynx (arrows) due to incompetence of the glossopalatal seal.

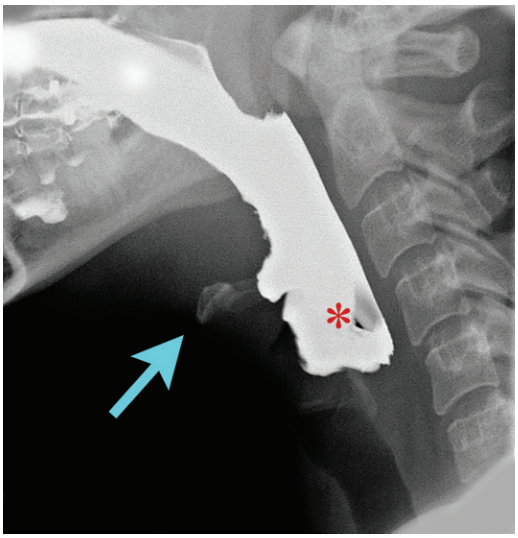

Figure 5. Delayed initiation of the pharyngeal swallow in a 55-year-old man. Lateral radiograph shows the bolus in the oropharynx and hypopharynx (∗), with the hyoid bone still in resting position (arrow) due to a delayed triggering of the swallowing reflex.

radiation, surgery, or a cerebrovascular accident. Atrophy of the tongue or soft palate can lead to compensatory hypertrophy of the opposite muscle (10,14).

Delayed or Slow Oral Propulsory Phase

When the bolus is judged to be "swallowable," it is placed in a midline depression in the upper surface of the tongue blade until it is transferred into the pharynx. A delayed initiation of tongue propulsion or a slow transportation of the bolus to the pharynx can be secondary to weakness or the inability of the tongue to function because of surgery, radiation, or acute and chronic neurologic illnesses. For example, patients with Parkinson disease may perform repetitive unsuccessful attempts to swallow the bolus (10,14).

Delayed Initiation of Pharyngeal Swallow

When the bolus reaches the oropharynx, it triggers the swallowing reflex that initiates the nonvoluntary pharyngeal phase of swallowing. The initiation of the pharyngeal swallow is recognized radiographically by the elevation of the hyoid bone as a component of the HLC. Hyoid elevation starts when the tip of the bolus crosses the angle of the mandible. A delayed swallowing initiation is identified when the contrast material is seen in the pharyngeal lumen but the hyoid bone remains in a resting position (Fig 5). Causes include decreased pharyngeal sensory perception due to injury of mucosal receptors or neurologic damage secondary to aging, radiation, a cerebrovascular accident, or surgery (7,14).

Nasal Regurgitation

The palatopharyngeal isthmus or seal should be closed during the bolus transportation from the mouth into the oropharynx. Nasal regurgitation is diagnosed radiographically by evaluating passage of the contrast material through a nonclosed seal into the nasopharynx (Fig 6). Nasal penetration can occur during transfer of the bolus from the mouth to the pharynx due to incompetence of the isthmus or after swallowing when the seal is open and there is regurgitation from the distal pharynx or esophagus due to an associated distal dysfunction or mechanical obstruction. The causes of an incompetent seal and nasal

Figure 6. Nasal regurgitation in a 62-year-old man. Lateral radiograph shows contrast material penetrating into the nasopharynx from the oropharynx (*) during bolus displacement because of insufficient closure of the palatopharyngeal isthmus.

Figure 7. Limited elevation of the hyolaryngeal complex in a 74-year-old man. Lateral radiograph during swallowing shows that the hyoid bone (blue arrow) did not reach the mandible at its maximum displaced position, as is expected in healthy patients. The limited displacement may be due to scarring of pharyngeal elevator muscles from radiation treatment. Associated findings are a poor pharyngeal contraction, an incomplete closure of the larynx with contrast material penetration (red arrow), and a diminished opening of the PES (yellow arrow).

Figure 8. Frozen pharynx in a 68-year-old woman with a history of radiation therapy. Lateral radiograph shows absent contractions and rigidity of the pharyngeal walls during the passage of bolus and penetration of contrast material into the larynx (arrow).

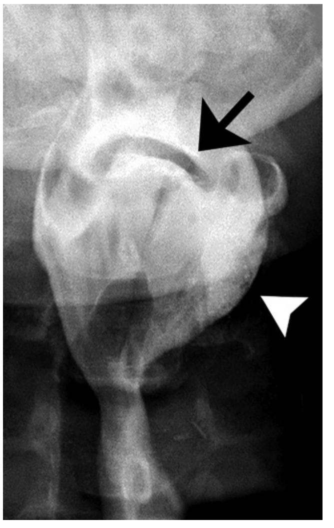

Figure 9. Hypotony of the left pharyngeal wall in a 59-year-old woman. Frontal radiograph of the pharynx during swallowing shows bulging of the left pharyngeal wall (arrowhead) and an asymmetric tilt of the epiglottis (arrow). Findings were due to a nerve injury during surgery for resection of a tumor in the base of the skull.

regurgitation include atrophy and insufficient elevation of the soft palate due to neurologic diseases, radiation, surgery, or congenital issues such as a cleft palate or a fistula (7,14,16). An oronasal fistula must be ruled out during the examination.

Slow or Incomplete Displacement of HLC

A full upward and forward displacement of the HLC is necessary to elevate and shorten the pharynx, deflect the epiglottis, close the larynx, and open the PES. The HLC is fully elevated when the hyoid bone is seen at the level of the inferior margin of the mandible. Slow or incomplete elevation of the HLC is due to weakness of the suprahyoid muscles and pharyngeal elevators (Fig 7). Muscular weakness is a consequence of atrophy and fibrosis secondary to aging, radiation, and neurologic or cerebrovascular diseases (14).

Weakness of Tongue and Pharyngeal Contraction

Adequate thrust of the dorsum of the tongue and the pharyngeal walls is required to increase intrabolus pressure and propel the bolus into the esophagus. Unilateral or bilateral weakness or atrophy of the muscles may prevent a timely and complete bolus displacement. In severe cases of atony, as with a “frozen pharynx,” the bolus mostly moves by means of gravity (Fig 8). Lack of appropriate contraction leaves residue in the pharynx after swallowing and increases the risk of aspiration. Reduced pharyngeal contraction may be caused by muscular or neurologic damage due to radiation, surgery, or neurovascular diseases. Weakness can be bilateral or unilateral (Fig 9) (7,10,14,15).

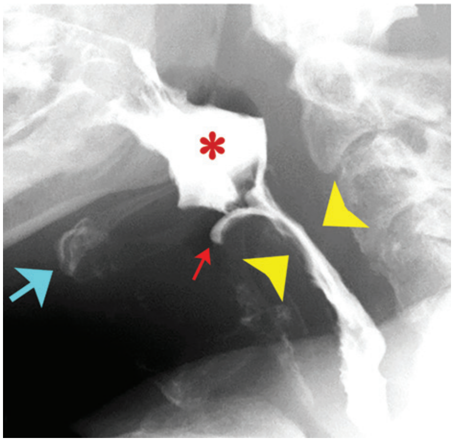

Figure 10. Nonpropulsive pharyngeal contractions in a 66-year-old man. Lateral radiograph of the pharynx during swallowing shows narrowing of the pharyngeal lumen (arrowheads) when the hyoid bone is still elevated (blue arrow). Because of premature pharyngeal closure, some contrast material was trapped in the oropharynx (∗) and penetrated the laryngeal vestibule (red arrow).

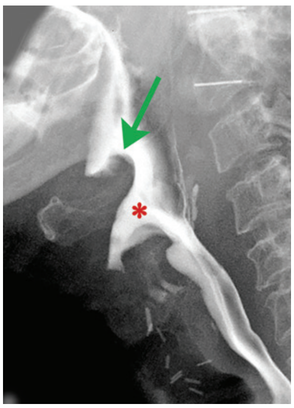

Figure 11. Incomplete epiglottis tilt in a 72-year-old man. Lateral radiograph shows a swelling epiglottis in upward position during the bolus passage (arrow). As a consequence of the insufficient tilt of the epiglottis, a partial obstruction of bolus displacement and penetration of contrast material into the laryngeal vestibule (∗) are visible.

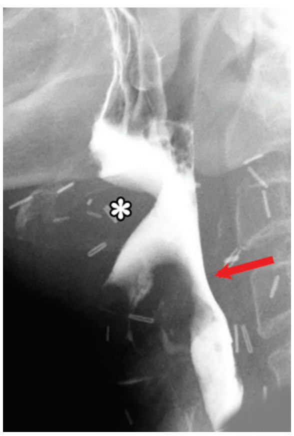

Figure 12. Insufficient closure of the laryngeal lumen during swallowing in a 69-year-old woman. Lateral radiograph of the pharynx during swallowing shows an opened laryngeal vestibule with penetration of contrast material. Additional findings are deformity of the epiglottis (∗), poor pharyngeal contractions, and a stricture of the PES (arrow) due to chemotherapy and radiation therapy.

Lack of Synchronization of Pharyngeal Contractions

Peristalsis is a wave-like involuntary contraction of the gastrointestinal tract with the purpose of transporting the bolus. It consists of stripping contractions of the proximal muscles to push the bolus and a distal relaxation to allow its passage. At fluoroscopy, abnormalities of pharyngeal peristalsis are recognized by the presence of nonpropulsive contractions that interrupt bolus passage and fragment the contrast material in the pharyngeal lumen (Fig 10). Residue left in the pharyngeal lumen after swallowing can lead to aspiration. The paralysis can be bilateral because of injury of the pharyngeal innervation that is secondary to radiation, inflammatory changes, or neurologic diseases or unilateral because of peripheral nerve injury during surgery (7,14).

Limited Tilt of Epiglottis

During swallowing, the tilt of the epiglottis protects the entrance of the laryngeal vestibule and deflects the bolus into the lateral food pathways (pyriform sinuses). As a consequence, an insufficient or absent epiglottic tilt may obstruct the passage of the bolus and risk penetration of material into the laryngeal inlet during swallowing (Fig 11). Causes of inadequate epiglottic tilt include insufficient displacement of the HLC, pharyngeal or laryngeal tumors, or fibrosis due to radiation (7,14).

Delayed or Incomplete Laryngeal Closure

Laryngeal closure starts with and continues as HLC displacement. It starts in an inferior to superior direction, beginning in the true vocal folds, followed by the false vocal folds, and ending in the laryngeal vestibule to expel penetrated material back into the hypopharynx. Closure of the laryngeal vestibule is recognized at fluoroscopy as the narrowing and disappearance of the air column in the laryngeal lumen during the HLC elevation. A delayed, slow, or incomplete closure of the larynx during swallowing may lead to aspiration (Fig 12). Failure of laryngeal closure may result from insufficient HLC elevation, cervical surgery, laryngeal fibrosis due to radiation, or weakness of the supraglottic adductors due to edema or fibrosis (14,17).

Incomplete Opening of PES

The UES is a high-pressure zone at the PES that is formed by muscular fibers of the thyropharyngeus, cricopharyngeus (CP), and circular fibers of the proximal esophagus. The PES is normally closed to prevent inhaled air from passing into the esophagus and gastroesophageal reflux from entering into the airway. It opens during swallowing to allow passage of the bolus, vomiting, or eructation. Opening the PES involves *(a)* neural relaxation of the tonically contracted UES muscles, *(b)* normal distensibility of the segment, *(c)* traction forces imparted by the opening of the UES muscles, and

Diagnosis and Treatment of Pharyngoesophageal Segment Dysmotilities

PES Dysmotility	PES Opening	Mechanism	Therapeutic Objective	Maneuvers
Delayed PES opening due to slow HLC displacement	Full opening only when the HLC is completely elevated	Delayed initiation of pharyngeal swallow	Improve speed of swallowing initiation	Bolus stimulation
Delayed PES opening due to impaired UES relaxation	Full opening only when UES is relaxed	UES spasm	Abbreviate the UES relaxation	Increase bolus volume and thickness
Incomplete PES opening due to nonrelaxation of CP (CP achalasia)	Incomplete	CP nonrelaxation	Improve CP relaxation	Endoscopic dilation Botulinum toxin A injection CP myotomy
Incomplete PES opening due to lack of elasticity of the CP (fibrosis)	Incomplete	CP lack of elasticity (fibrosis)	PES dilation	Effortful swallow Endoscopic dilation CP myotomy
Incomplete PES opening due to partial displacement of HLC	Incomplete	Weakness of HLC elevators	Strengthening of HLC elevators	Mendelsohn Effortful swallow Shaker
Incomplete PES opening due to weak pharyngeal contraction	Incomplete	Weak pharyngeal muscular contractions	Improvement of pharyngeal contraction	Base of tongue exercises Tongue hold Mendelsohn
Early PES closure due to premature HLC return	Full opening only when the HLC is completely elevated	Weakness of HLC elevators	Increase and extend the HLC elevation	Increase bolus volume and thickness; Mendelsohn
Early PES closure due to premature UES contraction	Full opening only when the UES is relaxed	UES spasm	Delay the UES contraction	Increase bolus volume and thickness PES dilation

Sources.— References 9,10,14,18–26.

(d) intrabolus pressure generated by contraction of the pharynx.

Primary causes of incomplete opening of the UES during the passage of the bolus are *(a)* incomplete relaxation of the UES (achalasia) or lack of coordination with the pharyngeal contraction (dyskinesia), *(b)* abnormal elasticity and distensibility of the CP as result of degeneration of muscle fibers and replacement with fibroadipose tissue, *(c)* noncomplete displacement of the HLC during swallowing, and *(d)* insufficient intrabolus pressure to open the lumen due to impairment of the tongue and pharyngeal constrictor muscles (Table) (7,9,14,18–26). Narrowing of the PES prevents the free and complete passage of the bolus into the esophagus, resulting in incomplete clearance and residue in the pyriform sinuses, with potentially postdeglutitive aspiration.

On a lateral view, the diminished opening of the PES is recognized by a posterior protrusion (CP bar) between C3 and C6 during the trans-sphincteric passage of the bolus (Fig 13). For evaluation of the function of the PES, radiologists should correlate the following functional units: *(a)* the opening of the PES, *(b)* the elevation of the HLC, and *(c)* the pharyngeal contraction. Understanding the different possible mechanisms that cause the abnormal function of the segment is essential in deciding the best treatment strategies.

Delayed Opening of PES

During swallowing, the PES opens completely upon the arrival of the bolus to allow it to pass into the esophagus. Delayed opening of the PES is a consequence of delayed elevation of the HLC or retarded relaxation of the UES (Table). When the delayed opening is due to slow or retarded relaxation of the UES, the hyoid bone is already elevated when the PES is still closed (Fig 14). Because the PES remains closed on the arrival of the bolus, there is a transient luminal obstruction that augments the pressure and distends the lumen of the proximal pharynx, increasing the risk of aspiration (9,14).

Early Closure of PES

The PES should only close after the bolus has passed completely into the esophagus. A premature closure of the PES can be due to an early contraction of the UES before the HLC returns to resting position and the bolus pass is finished (Fig 15) or a premature return of the HLC to resting position (Fig 16) (Table). An early closure of the PES can block the bolus and leave residue

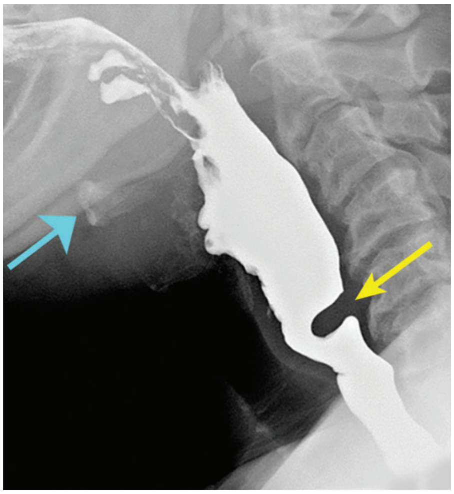

Figure 13. Diminished opening of the PES in a 44-year-old woman with gastroesophageal reflux. Lateral radiograph of swallowing shows a transverse filling defect in the posterior wall of the PES, called the CP bar (yellow arrow), when the hyolaryngeal complex is fully elevated (blue arrow). The luminal narrowing obstructs the passage of the bolus and distends the proximal pharyngeal lumen.

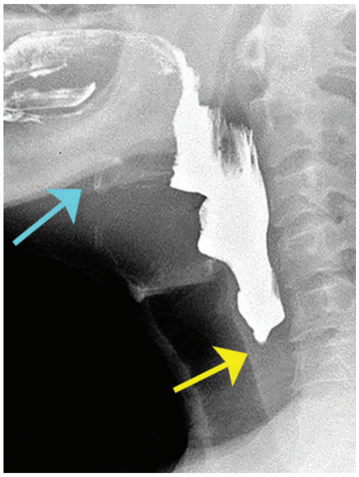

Figure 14. Delayed opening of the PES due to retarded relaxation of the UES in a 71-year-old woman. Lateral radiograph shows the bolus tip at the PES entrance, which remains closed (yellow arrow), even when the hyoid bone is fully elevated (blue arrow). On subsequent images (not shown), the PES opened completely, allowing the full passage of the bolus.

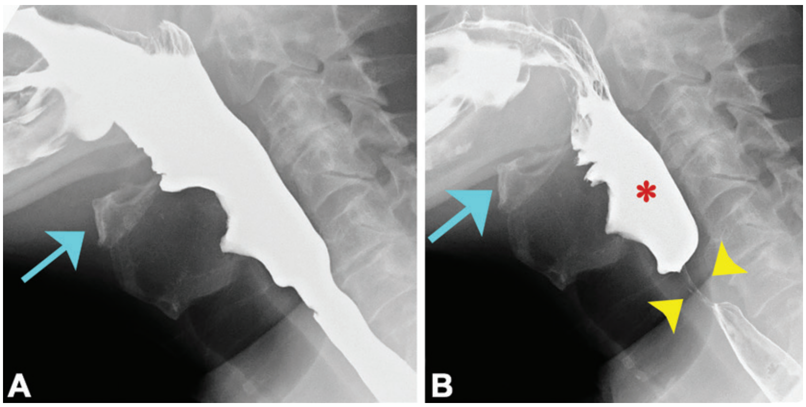

Figure 15. Early closure of the PES due to premature closing of the UES in a 62-year-old man. **(A)** Lateral radiograph shows a normal PES opening during the passage of the bolus. **(B)** Delayed lateral radiograph shows an early closing of the PES (arrowheads), while the hyoid bone is still elevated (arrow in **A** and **B**). The early closure of the PES interrupts the passage of the bolus, leaving residue in the hypopharynx (*), with increased risk of aspiration.

in the pyriform sinuses after swallowing, leading to aspiration when the airway reopens (9,14).

Residue in Valleculae and Pyriform Sinuses after Swallowing

After swallowing, no materials or contrast material should remain in the pharyngeal lumen. Residue in the vallecullae, pyriform sinuses, or pharyngeal walls may lead to postswallowing aspiration when respiration is resumed (Fig 17A–17C). After swallowing, pooling of contrast material in the valleculae can result from impaired backward movement of the dorsum of the tongue or insufficient epiglottic tilt. Residue in the pyriform sinuses may result from impaired pharyngeal contraction, PES dysmotilities, or mechanical obstruction. Unilateral pooling can be secondary to paralysis of the lateral pharyngeal wall due to a nerve or muscle injury (Fig 17D) (14).

Penetration.—No contrast material should penetrate the laryngeal vestibule before, during, or after swallowing. Penetration is diagnosed at fluoroscopy when contrast material is seen in the laryngeal lumen. During swallowing, penetrated material should be extruded back into the pharynx by laryngeal contraction (ie, *flash penetration*). In severe cases, contrast material may remain in the laryngeal vestibule, reach the vocal folds, and pass into the trachea. Whenever possible, the mechanism responsible for penetration should be recognized during the examination and stated in the report to allow decision making on the best therapeutic approach. Preswallowing penetrations are usually a consequence of delayed initiation of the swallowing reflex. Penetrations during swallowing can be due to one or multiple abnormalities such as incomplete or slow elevation of the HLC, epiglottis tilt, incomplete closure of the

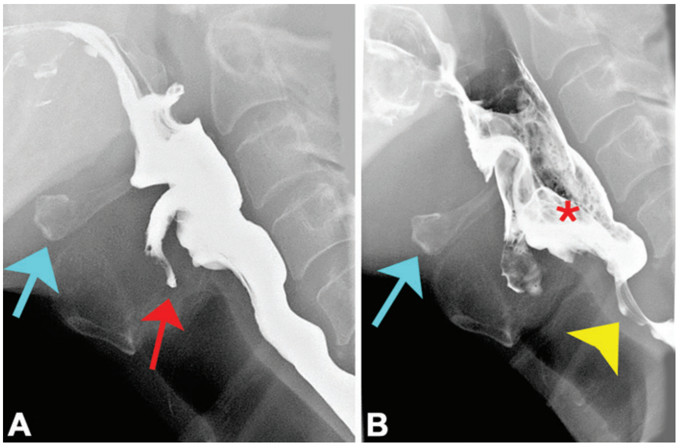

Figure 16. Early closure of the PES due to premature return of the hyolaryngeal complex in a 55-year-old woman. **(A)** Lateral radiograph shows normal opening of the PES during swallowing, with the hyoid bone fully elevated (blue arrow). An incidental finding is a penetration during swallowing (red arrow). **(B)** Delayed lateral radiograph of the same swallow shows an early closure of the PES (arrowhead) due to a premature return of the HLC, which is evidenced by the low position of the hyoid bone (blue arrow). The early closure of the PES interrupted the complete passage of the bolus and left residue in the hypopharynx (*).

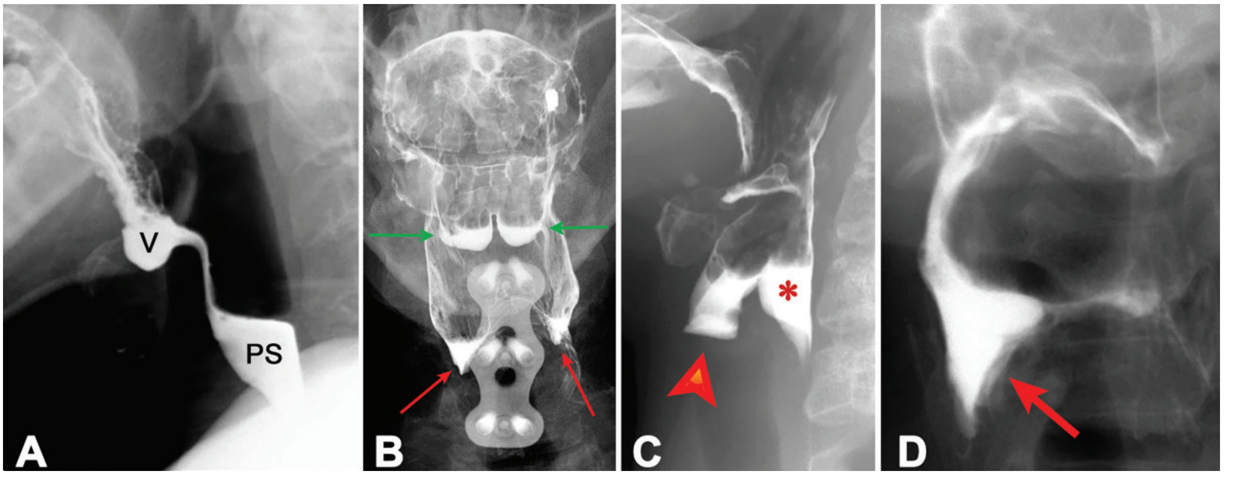

Figure 17. Residue in the valleculae and pyriform sinuses after swallowing. **(A)** Lateral radiograph of the pharynx in a 72-year-old man after swallowing shows contrast material pooling in the valleculae (*V*) and pyriform sinuses (*PS*). **(B)** Frontal radiograph in a 40-year-old man after spinal fixation shows bilateral residue in the valleculae (green arrows) and pyriform sinuses (red arrows). **(C)** Lateral radiograph in a 67-year-old woman after swallowing shows the penetration of residual contrast material (arrowhead) into the larynx from the pyriform sinuses (*). **(D)** Frontal radiograph in a 72-year-old man after right-sided skull base surgery shows residue in the right pyriform sinus (arrow) due to unilateral deficiency of the pharyngeal contraction.

laryngeal vestibule, or motility disorders of the pharynx or PES. Pharyngeal residue is responsible for penetrations after swallowing (14).

Aspiration.—Aspiration is diagnosed when contrast material is seen in the tracheal lumen, below the vocal cords (Fig 18). Aspiration is a more severe complication than penetration and may be minimal, moderate, or massive when the contrast material reaches the carina and bronchus. Aspirated materials in the trachea may generate a protective cough to expel them back into the pharynx or may be nonsensate (ie, silent). A delayed or absent cough reflex is valuable information by which to estimate severity, because silent aspirators have a greater risk of developing pneumonia. In addition to the causes of penetration, a delayed or insufficient closure of the vocal folds due to edema, radiation fibrosis, or surgery of the vocal cord adductors may contribute to aspiration. External-beam radiation treatment for neck cancer is a frequent cause of aspiration because it may impair all phases of swallowing.

Anatomic Abnormalities

Radiography of the Neck

As part of the fluoroscopic swallowing examination, a systematic evaluation of the air-filled structures and soft tissues of the neck may provide information about the causative or associated abnormalities relating to the patient's symptoms. The patient should be evaluated for *(a)* soft palate atrophy due to radiation or surgery or compensatory hypertrophy due to tongue atrophy (Fig E1); *(b)* tongue atrophy due to aging, radiation, or surgery (Fig E2); *(c)* epiglottis enlargement due to acute radiation (Fig E3), infection, and tumors or atrophy due to radiation; *(d)* swelling of prevertebral soft tissues due to chemotherapy, radiation, or surgery (Fig E4) and tumors, abscesses, or hematomas; *(e)* air

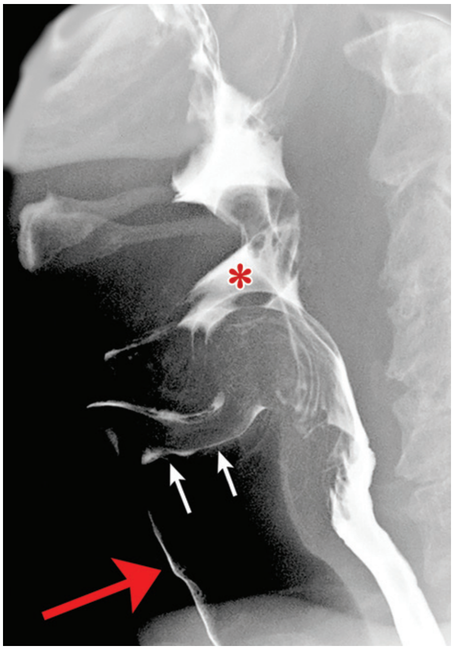

Figure 18. Aspiration in a 77-year-old man. Lateral view of swallowing shows contrast material penetration into the laryngeal vestibule (*) and aspiration into the tracheal lumen (red arrow) through the vocal folds (white arrows).

Figure 19. Web in a 66-year-old woman. Lateral radiograph of the pharynx during swallowing shows a thin horizontal linear filling defect in the anterior wall of the hypopharynx that obstructs the lumen (arrow).

Figure 20. Radiation stricture in a 77-year-old man. Lateral radiograph of swallowing shows a short severe luminal stricture in the pharynx due to scarring (arrow), with a mild proximal luminal distention.

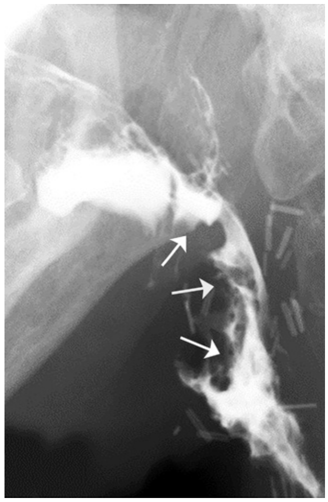

Figure 21. Pharyngeal tumor in a 78-year-old man. Swallowing examination shows an irregular luminal narrowing of the pharynx, with posterior displacement due to a large infiltrating mass (arrows).

in the prevertebral soft tissues due to trauma (Fig E5), gastrointestinal perforations (Fig E6), diverticula (Fig E7), or in other locations as postsurgical leakage (Fig E8); *(f)* soft-tissue-attenuation obstructive masses in the lumen of pharynx (Fig E9), larynx (Fig E10), or PES (Fig E11); *(g)* pharyngeal deformities as a nonclosed PES at rest due to fibrosis because of radiation therapy (Fig E12) or esophageal dilations due to achalasia (Fig E13) or scleroderma; *(h)* abnormal soft-tissue calcifications; and *(i)* bone and postsurgical abnormalities.

Pharyngeal Strictures

Webs are thin mucosal folds that are frequently seen in the anterior wall or circumference of the hypopharynx or proximal esophagus. Webs are associated with gastroesophageal reflux and syndromes such as Plummer-Vinson or epidermolysis ampullosa and are seen as 2–4-mm-thick transverse linear filling defects in the hypopharynx and cervical esophagus that may partially obstruct the lumen and passage of the bolus (Fig 19) (27).

Radiation strictures are a delayed complication of radiation due to vascular damage, ischemia, and collagen deposition, with subsequent fibrosis and scarring (Fig 20) (27,28).

Cervical esophageal tumors can be seen radiographically as irregular or lobulated filling defects protruding into the lumen of the pharynx or larynx on radiographs or swallowing examinations (Fig 21) (27). Cervical tumors are more accurately detected and staged with cross-sectional imaging such as CT, MRI, or PET.

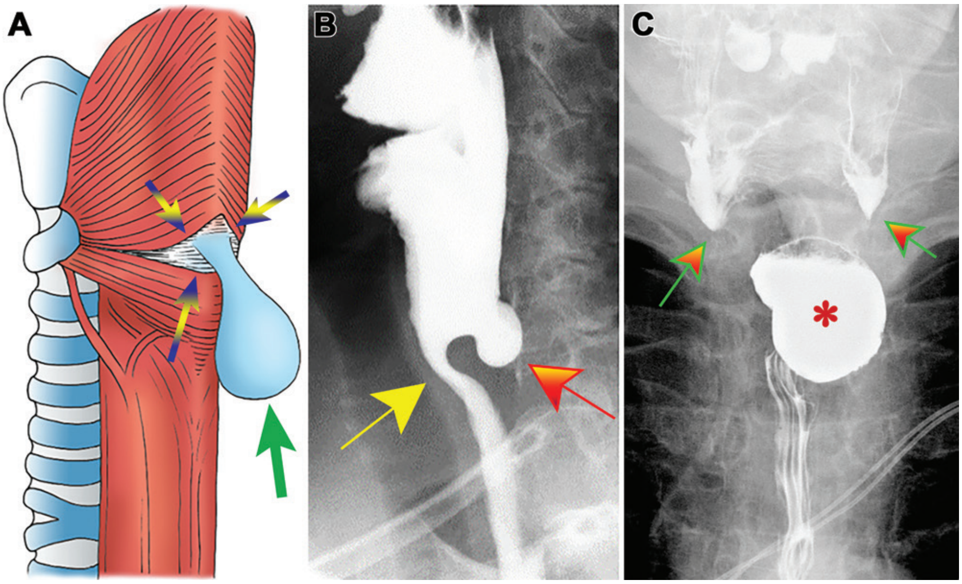

Figure 22. Zenker diverticulum in two patients. **(A)** Illustration shows a diverticulum (green arrow) emerging from a triangular-shaped area in the posterior wall of the hypopharynx (blue and yellow arrows), which was formed superiorly by the oblique fibers of the thyropharyngeus and inferiorly by horizontal fibers of the cricopharyngeus. **(B)** Lateral radiograph during swallowing in a 74-year-old woman shows a diverticulum in the posterior wall of the hypopharynx (red-orange arrow) above the CP bar (yellow arrow). **(C)** Frontal radiograph in a 79-year-old man after swallowing contrast material shows the diverticulum mildly displaced to the left side of the patient (*) and residue in both pyriform sinuses (arrows).

Zenker Diverticula

Zenker diverticula are outpouchings lined by squamous epithelial mucosa and submucosa and are often surrounded by fibrous tissue, with absent muscular fibers. They are located in an area of muscular weakness called the *Killian dehiscence* or the *triangle of Laennec* in the posterior wall of the hypopharynx and are limited by the oblique fibers of the thyropharyngeous superiorly and laterally and by the horizontal fibers of the CP inferiorly (Fig 22A).

The development of Zenker diverticula may involve anatomic and pathophysiologic causes that include an area of wall weakness, a distal obstruction due to the diminished opening of the CP, and increased pharyngeal intraluminal pressure as a consequence of mechanical obstruction of the outlet. Strong evidence now shows that acquired Zenker diverticula are, in most cases, secondary to a poorly compliant but normally relaxing CP muscle that cannot fully distend during the process of sphincter opening. The increased resistance to flow during swallowing in an attempt to overcome the distal obstruction markedly increases the forces required to drive the passage of the bolus. Increased intrabolus pressure imparted to the area of relative muscular weakness (Killian dehiscence) over many years gives rise to a posterior herniation of the pouch (27,29,30).

Fluoroscopically, the diverticulum is seen during and after swallowing as an outpouching arising from the posterior hypopharyngeal wall above the prominence of the CP bar (Fig 22B). In frontal views, a small diverticulum is seen in the midline, but when it becomes larger, it may relocate laterally, more frequently to the left side (Fig 22C). After swallowing, the content of the diverticulum may empty back into the hypopharynx, increasing the risk of postswallowing aspiration.

Pseudo-Zenker diverticula are saclike collections of contrast material that are trapped in the same location as that of the Zenker diverticula (27). They are seen only after swallowing when the pharyngeal lumen is collapsed and not when the lumen is fully distended (Fig 23).

Killian-Jamieson Diverticula

Killian-Jamieson diverticula are outpouchings from the anterior lateral wall of the cervical esophagus through a gap between the inferior margin of the cricoid cartilage and CP and the lateral wall of the suspensory ligament of the esophagus (Fig 24A) (27). They are seen during swallowing studies as lateral or anterior outpouchings below the level of the CP (Fig 24B).

Complications of Total Laryngectomy

Surgical Technique

Total laryngectomy is indicated for advanced or nonradiosensitive laryngeal or cervical tumors.

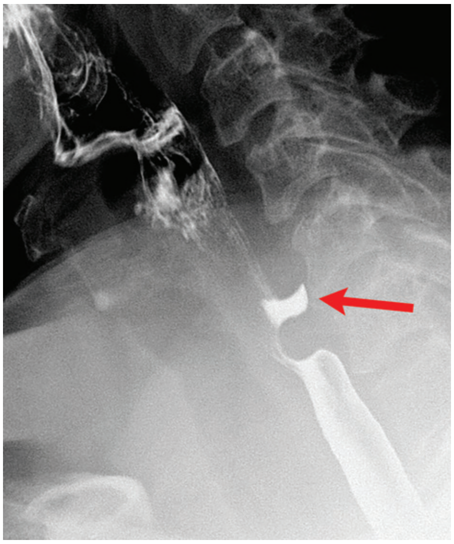

Figure 23. Pseudo-Zenker diverticulum in a 69-year-old woman. Lateral radiograph of the pharynx after swallowing shows an outpouching in the location of the Zenker diverticula (arrow). The outpouching was not identified when the pharyngeal lumen was fully distended during the passage of the bolus (not shown).

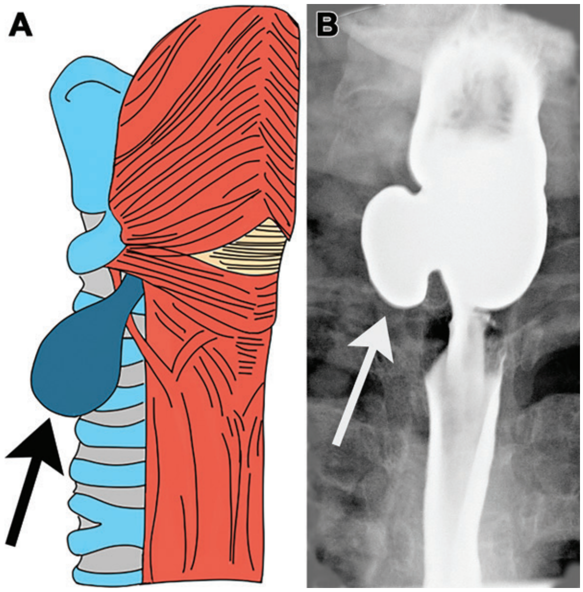

Figure 24. Killian-Jamieson diverticulum in a 72-year-old man. **(A)** Illustration shows a diverticulum emerging from the anterolateral wall of the cervical esophagus (arrow) below the CP muscle. **(B)** Frontal radiograph during swallowing shows a right lateral diverticulum (arrow).

The surgical technique consists of removal of the hyoid bone, thyroid and cricoid cartilages, epiglottis, and vocal folds (Fig 25A), followed by reconstruction and closure of the anterior defect with mucosa, pharyngeal muscles, and skin (Fig 25B). Finally, optional vocal restoration can be achieved through creation of a fistula between the tracheostoma and the esophagus, with placement of a silastic prosthesis of varying length and diameter in the fistula to allow the one-way passage of air for speech rehabilitation (Fig 25C). In patients with the tracheoesophageal fistula, the evaluation of prosthesis position and function and PES motility during phonation should be included as part of the swallowing evaluation (31–33).

Anastomotic Leakage

Anastomotic leakage is a frequent complication in the early postoperative period. Risk factors include oral infection, salvage total laryngectomy, and prior radiation therapy. Leakages are detected at a swallowing examination as blind outpouchings outside the neopharyngeal lumen (sinus tracts) or as an extraluminal tract of contrast material that communicates with the skin (Fig 26) (27,34,35).

Pseudoepiglottis

A *pseudoepiglottis* is an enlargement of the folds at the base of the tongue due to the pull of pharyngeal constrictors when a patient attempts to swallow. The abnormality is seen as an anterior linear defect at the base of tongue and the entrance of neopharynx that resembles an epiglottis (Fig 27). The fold is more prominent when the patient swallows and may narrow the entrance of the neopharynx and obstruct the bolus transit from the mouth. Increased intrabolus pressure proximal to the obstruction contributes to the formation of a proximal pocket, where residue and food may accumulate (27).

Anterior Pharyngeal Pouches

Anterior pharyngeal pouches are pockets or outpouchings located at the anterior wall between the base of tongue and the neopharynx entrance. The mechanism of formation is multifactorial, including a localized weakness due to absence of a muscular layer and/or increased intrabolus pressure against a more distal mechanical or functional obstruction. Radiologic images show an anterior outpouching at the entrance of the neopharynx with contrast material pooling after the swallow (Fig 28). If the pouch enlarges considerably, it may extend into the skin, creating a pharyngo-cutaneous fistula (36).

Neopharyngeal Dysmotilities

Neopharyngeal dysmotilities may be secondary to resection of the laryngeal and pharyngeal structures that support the tongue and pharyngeal muscles and/or due to damage of the pharyngeal muscles and nerves by the tumor, surgery, or radiation therapy. Dysmotilities are seen on images from swallowing studies as a limited thrust of the base of tongue and/or pharyngeal walls,

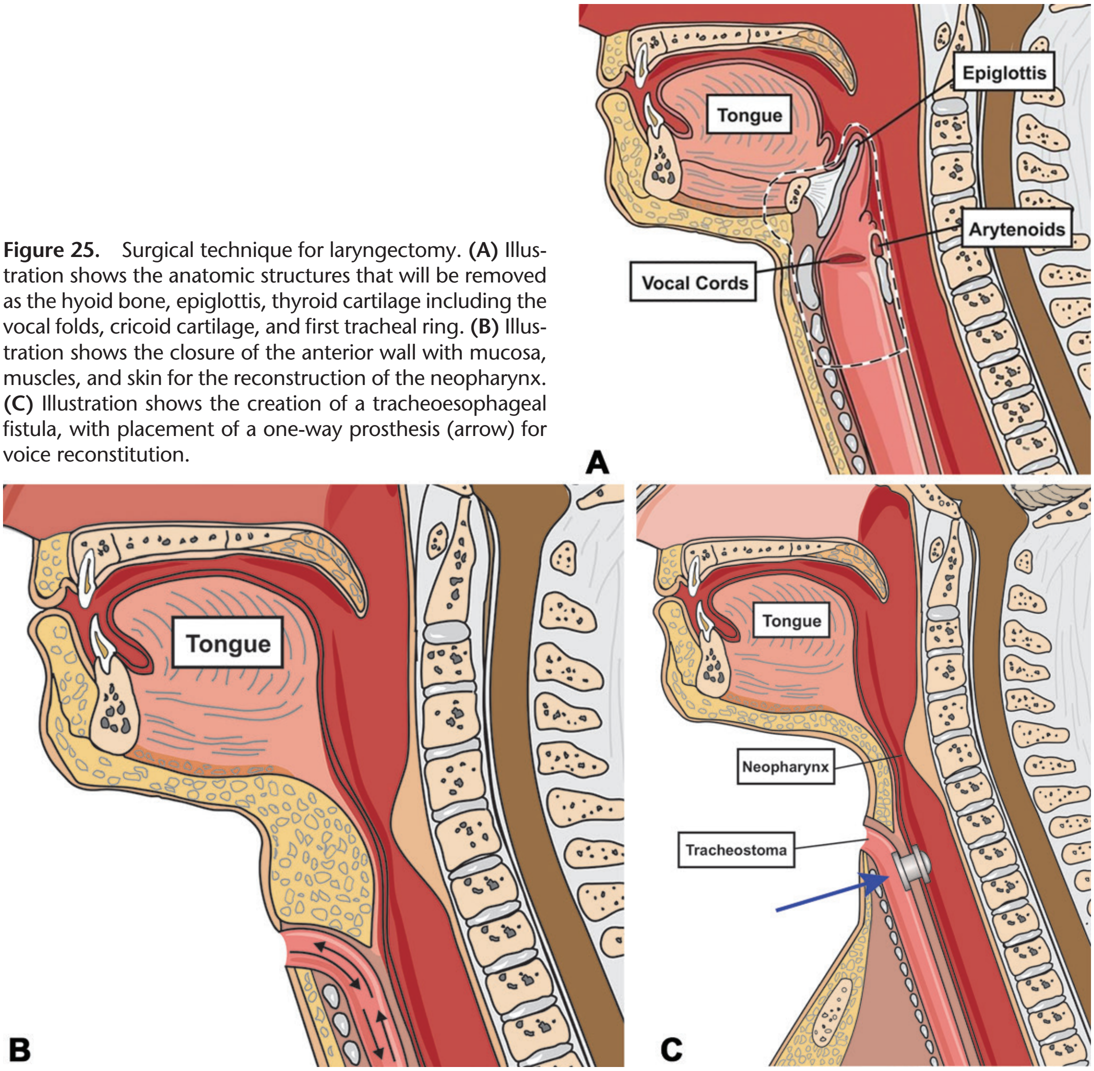

Figure 25. Surgical technique for laryngectomy. **(A)** Illustration shows the anatomic structures that will be removed as the hyoid bone, epiglottis, thyroid cartilage including the vocal folds, cricoid cartilage, and first tracheal ring. **(B)** Illustration shows the closure of the anterior wall with mucosa, muscles, and skin for the reconstruction of the neopharynx. **(C)** Illustration shows the creation of a tracheoesophageal fistula, with placement of a one-way prosthesis (arrow) for voice reconstitution.

with weakening of the pharyngeal propulsion, impaired coordination of peristalsis, reversed peristalsis, and outflow resistance across the PES (Fig 29). Because of neopharyngeal dysmotility, bolus transit time is prolonged, and pharyngeal clearance is incomplete, with stasis and residue (27,36).

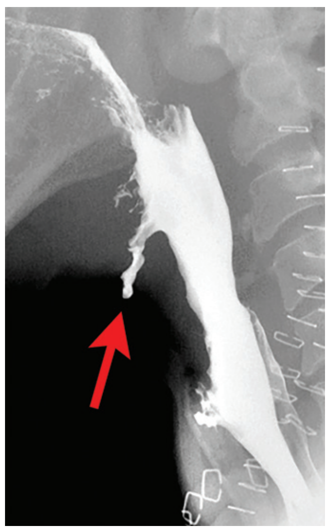

Figure 26. Sinus tract in a 78-year-old man. Lateral radiograph of swallowing after total laryngectomy shows a leakage from the proximal neopharynx into the anterior soft tissues of the neck (arrow).

Dysfunctions of PES

Dysfunctions of the PES should be evaluated during and after swallowing during voice generation. Fluoroscopically, they are seen as an insufficient or delayed opening or early closing of the PES (Fig 30). These findings may be a consequence of impaired pharyngeal propulsion or increased resistance at the bolus passage through the PES due to resection of the cricoid cartilage or fibrosis secondary to radiation therapy (27,36).

Benign Strictures

Benign strictures of the neopharyngeal lumen are secondary to surgical scarring and/or chemotherapy and radiation therapy. The strictures may partially or completely obstruct the bolus flow, distending the proximal lumen and retaining material the patient swallows (Fig 31) (37).

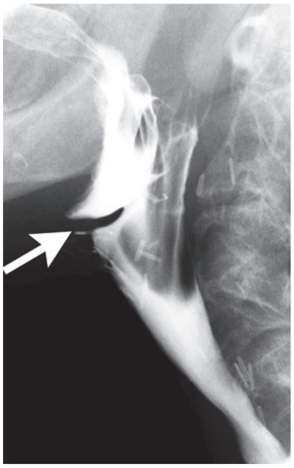

Figure 27. Pseudoepiglottis in a 78-year-old man who underwent a total laryngectomy. Lateral radiograph during swallowing shows a linear horizontal filling defect in the anterior wall of the proximal neopharynx that resembles the epiglottis and partially obstructs the passage of the bolus (arrow).

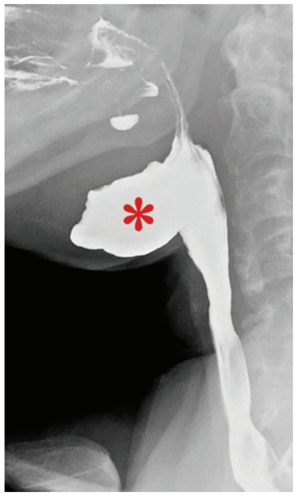

Figure 28. Anterior pharyngeal pouch in a 72-year-old woman. Lateral radiograph shows contrast material pooling in an outpouching at the base of the tongue at the entrance of the neopharynx (∗).

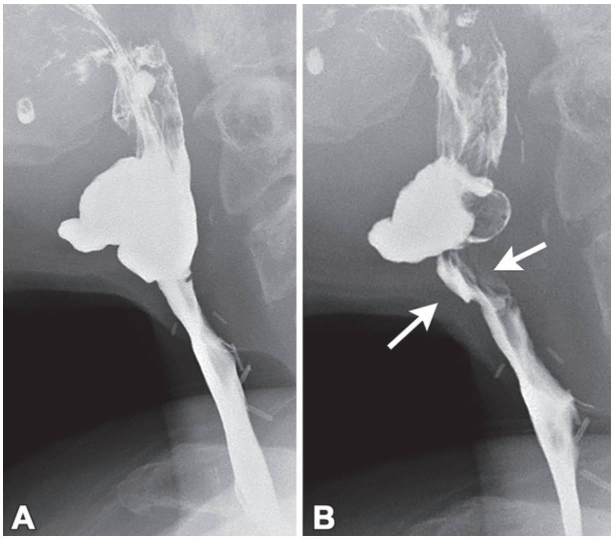

Figure 29. Neopharyngeal dysmotility in a 70-year-old man. Sequential lateral radiographs of swallowing show a premature closure of the neopharynx during the passage of the bolus (arrows in **B**), with residue in the proximal lumen.

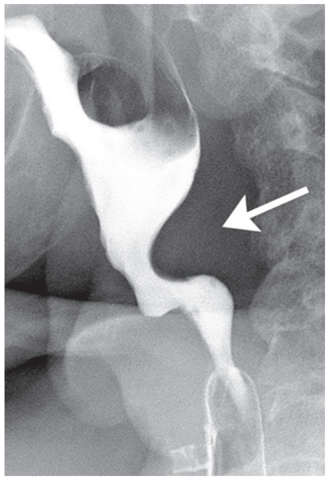

Figure 30. PES dysmotility in a 72-year-old woman. Lateral radiograph of swallowing shows PES narrowing during the passage of the bolus (arrow).

Complications of Tracheoesophageal Fistula and Prosthesis

A malpositioned or a too-large prosthesis may protrude into the lumen of the tracheostoma and obstruct it (Fig 32A). When the prosthetic flange is located in the esophageal lumen instead of being attached to the wall, the flange may cause obstruction and interference in the passage of the bolus and in phonation (Fig 32B). A too-short prosthesis may lead to closure of the fistula, with associated inflammatory changes. Esophageal contents can pass around the prosthesis (ie, periprosthetic) and into the tracheostoma during swallowing, because the diameter of the prosthesis is too narrow compared with that of the stoma (Fig 32C) or through the prosthesis because of malfunction (Fig 32D). The prosthesis should be removed and replaced after diagnosis of these complications (38–41).

Conclusion

Swallowing is a complex mechanism that involves at least 37 pairs of striated muscles, five cranial nerves, and multiple supportive anatomic structures that are controlled by the central nervous system (10). As we have discussed in this article, numerous anatomic and functional abnormalities can impair swallowing and can be detected at fluoroscopy.

The presence or supervision of a radiologist during the examination may contribute to correlation of the perceived abnormalities with the patient's symptoms and prior treatments and imaging studies. On the basis of this preliminary analysis, the radiologist can decide, in conjunction with the speech-language pathologist, if additional images or structures should be included in the examination before the patient leaves the radiography department.

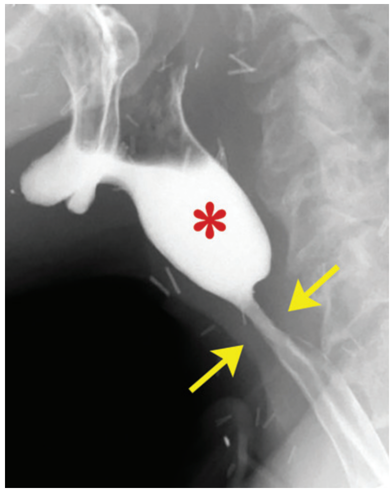

Figure 31. Postradiation stricture in a 75-year-old man. Lateral radiograph of swallowing after total laryngectomy shows a stricture in the neopharynx (arrows), with proximal pharyngeal dilatation (*).

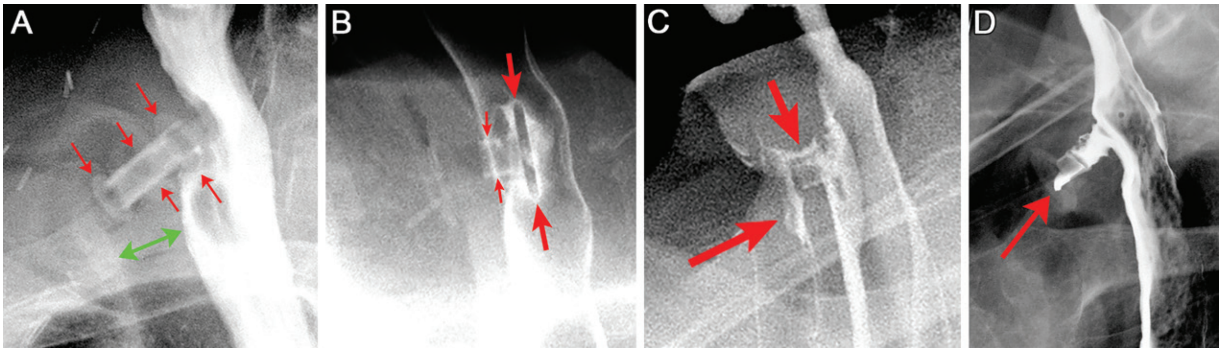

Figure 32. Complications of a tracheoesophageal prosthesis in four patients. **(A)** Oblique radiograph of swallowing in an 81-year-old woman shows migration of the prosthesis (red arrows) into the lumen of the tracheostoma (green double-headed arrow). **(B)** Oblique radiograph in a 74-year-old man after swallowing shows the esophageal flange of the prosthesis (arrows), which is malpositioned in the lumen of the proximal esophagus instead of being attached to the wall. **(C)** Oblique radiograph in a 79-year-old patient after swallowing shows contrast material leaking from the esophagus into the tracheal lumen through the surrounding cephalad margin of the prosthesis (arrows). **(D)** Oblique radiograph in a 72-year-old man shows contrast material dripping into the trachea through the lumen of prosthesis (arrow).

The radiologic report should include all detected abnormalities and should not be limited to description of the visualization of penetration or aspiration. Because each abnormality has its own specific therapeutic approach, the description of radiologic findings and their correlation with the pathophysiologic mechanisms and possible causes should be stated clearly in the report. A meticulous radiologic diagnosis facilitates the decision making of referring physicians and swallowing therapists.

Information obtained from swallowing examinations is useful to determine the oral capabilities of the patient and whether they should initiate, maintain, or discontinue oral intake without risking development of pneumonia. A good-quality examination and report not only improve early diagnosis and treatment of a patient's swallowing disorders but also reduce morbidity, mortality, length of hospital stay, and health care costs.

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