

Assessing the Role of Aspiration in Pediatric Lung Disease

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Safe swallowing is a highly complex process. It requires the normal structure and function of the oral, nasal, pharyngeal, and laryngeal cavities with a reliable intestinal tract to ensure that the feed continues in an intestinal direction. We all aspirate small amounts—probably daily, and especially in sleep. The lungs and upper airways have developed careful strategies to deal with accidental soilage. Mostly, it is successful, and the lung damage is prevented. In children, the growing lung is particularly vulnerable to insults from aspiration. Proving that pathological aspiration has occurred and is responsible for the pulmonary findings can be extremely difficult. In addition, there are age-specific features of feeding and swallowing throughout childhood that need special consideration. Lung damage from aspiration is a common feature in pediatric practice, but it is not inevitable, and neither is it linear. The result of acute or repeated aspiration events on the airways produces a wide spectrum of unpredictable pathological end points. This article looks at the failings of the swallowing mechanism in children of different ages, in health and disease, and reviews the tests available to determine whether aspiration is occurring. The important role of the videofluoroscopic swallow study in children is highlighted. Steps to intervene and prevent damage in vulnerable children are reviewed, including the ethical dilemma of the child in whom aspiration is occurring, and yet oral feeding continues.

Introduction

WE ALL ASPIRATE occasionally. Sit alongside the public children's swimming pool for a few minutes and listen to the coughing and spluttering that occur as the playing kids do their best to protect their airways in an unpredictable liquid environment. As adults, we all recognize those moments when, talking over a coffee, we aspirate with a spasm of coughing and recover.

All mammals have evolved sophisticated mechanisms to prevent aspiration of a foreign material into their lungs. The whale, for example, is particularly vulnerable with a constant passage of fast-flowing seawater across the pharynx and has developed a protective anatomy dedicated to control the flow away from the airway. In humans, there are protective mechanisms throughout the respiratory tract to deal swiftly with inevitable soilage.

Normal physiology and anatomy dictate that although accidental aspiration occurs as part of normal life, the impact on the airways is limited.¹ The foreign material is swiftly expelled, and any injury is rapidly repaired.

This article reviews aspiration lung disease in children when the protective mechanisms fail and pulmonary consequences occur. We discuss the causes and assessment of dysphagia and aspiration with a particular focus on the role of the video-assisted fluoroscopic swallow study.

Swallowing—A Function of Delicate Balance

Shared functions and competing interests

The nasal, pharyngeal, laryngeal, and oral cavities have to provide us with 4 differing functions: breathing, swallowing, speech, and lubrication of the cavity's surfaces.

At different ages, different functions require prioritization:

- the neonate must suckle milk from the breast while maintaining regular nasal breathing in a semisupine position;
- the toddler must cope with the formation of a food bolus from solid foods and swallow precise manageable portions while seated;
- the schoolchild must breathe through his/her nose and swallow secretions while dealing with upper respiratory tract infections during sleep;
- the adolescent must learn to speak garrulously and simultaneously eat voraciously with friends, yet remain monosyllabic and slouched when dining with immediate family.

These competing and evolving demands of our aerophagic cavities make us uniquely vulnerable to aspiration as a species and enforced the development of sophisticated protective strategies.

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The normal swallow in a child

The complex process of the normal swallow in adults is well defined.² The anatomy and physiology involved in these mechanisms in the healthy infant and young child differ substantially from an adult—even without the additional considerations of prematurity, disordered development, and structural congenital malformations of the oropharyngeal structures.^{3,4} A specific expertise and knowledge base are required to evaluate swallowing in children.⁵

Conventionally, the swallowing process is considered as occurring in stages—oral preparatory and oral stage, pharyngeal stage, and esophageal stage. Although this analytical method usefully facilitates the definition of events during the different phases, final evaluation must consider them in continuity. Dysfunction at one stage may impact on another part of the sequence, that is, a child with a bulbar weakness may clearly demonstrate expected difficulty at the oral preparatory and oral stage, but the loss of control of food/liquid in the mouth may then directly alter the timing and coordination of the subsequent pharyngeal stage.

The oral preparatory phase. Bolus preparation begins with taking food or liquid into the mouth. It is mixed with saliva, chewed, and prepared into a soft bolus. This part of the process is voluntary, and food can be ejected if the taste is objectionable or the consistency is hard to manage or unpleasant. In small children, this can be a blessing (children can spit out food, which may be difficult to swallow and could cause a choking risk) or a curse (from experience when done on purpose will satisfactorily annoy a busy parent).

In babies, the early reflex of rooting for the nipple followed by latching on could be considered as oral preparation. The orofacial anatomy of the infant facilitates efficient nipple feeding. The tongue fills the mouth, and the mandible is relatively small. Sucking pads in the cheeks create stability to support negative pressure for proficient sucking. Breast-/bottle-fed infants initiate the oral phase as they begin anterior-posterior tongue action with a suckle pattern on nipple. The soft palate and epiglottis are in approximation to channel liquid, thus allowing safe feeding in a reclined position. Less laryngeal elevation is required during the swallow as the larynx is in a primary elevated position, further protecting the airway by bringing it closer to the tongue base than in an adult.⁶

There is no true bolus formation, as sucking is synonymous with oral-stage transfer. The duration of the oral preparatory phase varies depending on the food consistency. As children start to eat more chewable foods, as opposed to smooth weaning foods, this phase will take longer. Bolus formation emerges with transition to weaning foods, that is, spoon feeding, which occurs at a developmental age of 4–6 months.

The oral phase is completed by the tongue elevating and sequentially moving the bolus to the pharynx while the soft palate elevates against the posterior pharyngeal wall to seal off the nasopharynx.

The pharyngeal phase follows the oral phase seamlessly with a more involuntary sequence of events. In the past, the pharyngeal swallow was regarded as a reflex, but is now understood to be a pattern-elicited response, that is, the swallow trigger cannot be initiated by a single stimulus (as for example, occurs with the gag reflex), but requires a sequence of events, both motor and sensory, which sequentially trigger the next part of the swallowing process as the bolus travels through the mouth and pharynx.² The pha-

ryngeal phase function is crucial in preventing aspiration. As the bolus is propelled through the pharynx, several levels of airway protection are engaged, with laryngeal elevation and anterior displacement bringing it below the tongue base. Aryepiglottic folds cover the glottis, while the false vocal folds and vocal cords adduct to complete airway protection.

The esophageal phase. With a protected airway, there is relaxation of the cricoesophageal sphincter to allow passage into the esophagus. A stripping motion of esophageal musculature ensures that the bolus continues its movement to the stomach from when, ideally, it should not return.

The Lungs' Defensive Strategies against Aspiration

Throughout the normal pediatric respiratory tract, from the tip of the nose to the alveoli, there are defensive layers to prevent the aspiration of the foreign material and expel unwanted transgressors that bypass the systems.

- Nasal turbinates generate turbulent flow and enforce impaction on the mucous membranes.
- Sneezing and coughing are forceful physiological expellants.
- Mechanoreceptors and chemoreceptors are concentrated over the surface of the pharynx, epiglottis, arytenoid cartilages, and vocal cords.⁷
- Chemoreceptors are stimulated by water, salts, sugars, and acids penetrating the larynx and can trigger a chemoreceptor reflex, held responsible for reflex apnea and apparent life-threatening events in neonates.⁸
- A highly sophisticated mucociliary system contains 3 important components: a fluid layer of precise volume and tonicity; beating cilia; and a covering layer of mucus—precise in its elasticity, viscosity, cohesion, and adherence.
- Epiglottic closure provides the trapdoor protection to the larynx during some (but not all) phases of swallowing.
- Adduction of the true and false cords adds a further layer of structural defense.
- Bronchospasm (along with cough and apnea) may also be a defensive mechanism, narrowing the airway's lumen against a potential noxious influx—even before penetration through the larynx.^{9–11} The commonality of the vagus nerve system serving both the lower esophageal junction and the airway smooth muscle is a suggested mechanism.
- The alveolar macrophage-scavenging system mops up the final perpetrators at an alveolar and bronchiolar level.

Children at Risk of Recurrent Aspiration

There is no single satisfactory classification of the causes of aspiration. Etiology varies for differing age groups and is best grouped loosely into the following categories:

Structurally normal children

Premature infants would fall into this category requiring tube feeding until maturation of the swallowing mechanism. Similarly, the neonates with severe respiratory syncytial virus (RSV) infection and tachypnea may temporarily lose their ability to protect their airways.¹² Gastroesophageal reflux (GER) or esophageal dysmotility can also result in aspiration in otherwise structurally normal children confused by the sudden appearance of gastroesophageal contents in the pharynx.¹³

Oropharyngeal dysphagia can also occur in infants without any detectable risk factors who present with unexplained respiratory problems. This may represent some form of delay in the maturity of their swallowing integrity. The prognosis for resolution in these children is good, although it can take years.¹⁴⁻¹⁶

Congenital abnormalities of craniofacial and upper airway structures

Aspiration during swallowing can be common in congenital anatomical variants such as craniofacial syndromes, Pierre Robin sequence, and laryngeal clefts or vocal cord palsy.^{17,18}

Children with neurological abnormalities and disorders of swallowing strength and coordination

Feeding problems are common in children with neuro-motor impairments. In a community-based survey, oral motor dysfunction was demonstrated in more than 90% of a sample of 49 children with cerebral palsy¹⁹ and evidence of chronic aspiration in 41% in a separate community study.²⁰ Swallow function in children with Down syndrome is commonly abnormal. Children with spinal muscular atrophy and Duchenne muscular dystrophy eventually develop dysphagia with aspiration.²¹ Children with cerebral palsy, familial dysautonomia, and neuromuscular disorders may aspirate due to combined swallow dysfunction and GER.²²⁻²⁵

Iatrogenic interference

Long-term intubation and ventilation can impact on swallowing integrity and interfere with feeding for some time after extubation. Tracheal surgery and a tracheostomy tube may hinder the subglottic rise in tracheal pressure and necessary elevation of the larynx during swallowing.^{26,27} However, there is an ongoing conflict in the literature regarding the impact of long-term tracheostomy, with or without mechanical ventilation, and swallow function. Current thinking inclines to the view that the need for a tracheostomy, rather than the presence of the tube itself, indicates an underlying pathology (eg, respiratory failure, trauma, CHARGE syndrome) that could already predispose to aspiration risk.^{28,29}

A Classification of Pediatric Aspiration

Table 1 lists some well-described conditions of childhood associated with aspiration, classifying them according to 3 different mechanisms:

Over-the-top aspiration

Aspiration over the top refers to the cause of the aspiration event occurring during the swallowing process. This includes the aspiration of nasal or sinus secretions,

TABLE 1. CHILDHOOD CONDITIONS ASSOCIATED WITH ASPIRATION

<i>Aspiration over the top</i>	<i>Aspiration through the middle</i>	<i>Aspiration from below</i>
Structurally normal	Congenital	Gastroesophageal reflux
Prematurity	Tracheoesophageal fistula (TEF)	Primary GER
Fatigue aspiration	Bronchopulmonary foregut malformations	Idiopathic
Bronchiolitis	Bronchoesophageal fistula	Hiatus hernia
Bronchopulmonary dysplasia	Acquired	Secondary GER
Idiopathic oropharyngeal incompetence	Crohn's disease	Obesity
Accidental foreign body aspiration	Post tracheostomy	Neurological disorders
Structurally abnormal	Abrasive foodstuffs	Caffeine
Congenital	Caustic ingestants	Theophylline
Cleft palate	Poststent erosion	Esophageal dysmotility
Laryngeal cleft		Primary
Laryngomalacia/tracheomalacia		Achalasia
Choanal anomalies		Diffuse esophageal spasm
Micrognathia		Idiopathic
Pierre Robin sequence		Secondary
Macroglossia		Cerebral palsy
Pharyngeal pouch		Myasthenia gravis
Vascular rings and slings		Myotonic dystrophy
Cysts or tumors		SMA Type 1
Acquired		Familial dysautonomia
Tracheostomy		Hirschsprung's disease
Prolonged endotracheal intubation		Post-TEF repair
Vocal cord paralysis (also congenital)		Autoimmune disorders
Functionally abnormal		
Cerebral palsy		
Myasthenia gravis		
Moebius syndrome		
Worster-Drought syndrome		
Myopathy		
Myotonic dystrophy		
Hypotonia for example, Trisomy 21		
Spinal muscular atrophy		
Familial Dysautonomia		

GER, gastroesophageal reflux; SMA, spinal muscular atrophy.

oropharyngeal contents, swallowed liquids, purees, and solids, and accidental foreign body aspiration due to a wide range of abnormalities as listed. Children with structurally normal upper airways, those with congenital abnormalities, and those with neurological conditions are all at risk via this mechanism as summarized in Table 1.

Aspiration through the middle

The commonest of these malformations is tracheoesophageal fistula (TEF). A TEF may be congenital, that is, H-type TEF,³⁰ or more rarely secondary.^{31,32}

Aspiration from below: gastroesophageal reflux disease

Although this review is principally looking at the consequences of aspiration over the top, it would be remiss not to briefly consider the impact of GER and the lung—part of the spectrum of gastroesophageal reflux disease. The prevalence appears very high in most pediatric practices, although it remains extraordinarily hard to prove.¹⁰ The very complex and controversial area of the interrelationship between pediatric lung and airway conditions is beyond the scope of this article. However, there is a chicken-and-egg situation:

GER and aspiration may cause respiratory disease.

- A direct effect of aspirate on pulmonary tissue causing a laryngitis, tracheitis, pneumonia, atelectasis, lung abscess, bronchiectasis, or bronchiolectasis.^{13,33–35}
- Indirect neural reflexes with laryngospasm, bronchospasm, or apnea caused by esophageal acidification without aspiration.^{9,11}

Respiratory diseases may potentially exacerbate GER. A number of respiratory conditions increase GER with potential worsening of the clinical course. Common examples include

- chronic lung disease of prematurity,³⁶
- repaired tracheoesophageal fistula,
- repaired congenital diaphragmatic or hiatus hernia,
- cystic fibrosis (particularly after lung transplant),³⁷
- asthma,
- cerebral palsy.

Proposed mechanisms for this association include hyperinflation and diaphragmatic flattening with secondary stretching of the crura,³⁸ changes in abdominopleural pressure gradients caused by more negative intrathoracic pressure, and increased abdominal pressure from coughing.³⁹

Diagnosing Aspiration

Clinical assessment

The history and clinical features of pulmonary aspiration are variables ranging from clear choking episodes to entirely silent events with no evidence even on careful history, clinical examination, or swallowing evaluation by an experienced therapist.⁴⁰ Estimates of silent aspiration in children with severe cerebral palsy and dysphagia undergoing videofluoroscopy range from 31% to 97%.^{41,42}

TABLE 2. CLINICAL FEATURES OF ASPIRATION ON PRESENTATION—IN ROUGH ORDER OF FREQUENCY

Chronic cough
Gagging, choking with feeds
Increased respiratory mucous and congestion/pooling of oral secretions
Unexplained oxygen dependency
Refusal to feed (may be associated with GER)
Stridor or hoarseness
Recurrent wheezing, asthma
Prolonged feeding, abnormal tearing
Failure to thrive
Apnea or acute life-threatening event/foreign-body aspiration
Recurrent pneumonia/chronic endobronchitis
Bronchiectasis with clubbing
Unexplained chest X-ray changes which may include areas of atelectasis or hyperinflation

The history, examination, and swallow assessment need to be tailored toward the age of the child. Some features are common across all pediatric ages, and others are age specific. Common modes of presentation are listed in Table 2.

History and examination.

- In neonates, a history of cough since birth, apneas, cyanosis, and bradycardia; prolonged or irritable feeding; pooling of secretions during or after feeds; failure to thrive; or the observation of excessive tearing while feeding are all common findings.
- In the toddler, one would consider clinical features to include avoidance of certain textures or lumpy food, coughing or choking, especially with fluids, food refusal, or recurrent wheeze. This is a vulnerable age for foreign-body inhalation. Recurrent aspiration pneumonias may present with recurring fevers, and undetected aspiration may be mislabeled as asthma.
- The older vocal child may be able to describe a sensation of reflux, lumps in the throat, and exhibit recurrent hoarseness or croup. Night-time coughing, especially, soon after going to bed may also be a feature. Most commonly, in this age group, the child has developmental delay, and aspiration may be silent. Dental erosions, in particular, of posterior teeth may be present.⁴³

Observation of feeding. The feeding assessment will normally be observed by a pediatric speech and language therapist with expertise in this area. Careful attention is paid to oral control, the suck/swallow/breathe pattern, in the neonate. During the feed, increase in wheeze and changes in the respiratory status with auscultation before, during, and after the feed are noted. Eye tearing, throat clearing, delayed cough after feed, and color changes are useful clinical signs. Wet voice, wet breathing, and cough have been shown to be good clinical markers for children with oropharyngeal aspiration on thin fluid, but not on puree.⁴⁴ Some authors advocate the use of a 3-oz water challenge test as a screening tool for aspiration.⁴⁵

Radiological imaging

A plain chest X-ray is traditionally the first radiological investigation for suspected aspiration. It is useful to detect

acute areas of collapse or overinflation and will also demonstrate chronic changes such as bronchial wall thickening and established bronchiectasis. However, it is not a sensitive tool for early or subtle changes. The current principle behind the investigation and management of aspiration in children is to assess and act at the earliest signs of aspiration lung damage, and from this perspective, the plain chest film contributes little.⁴⁶

High-resolution computed tomography (CT) imaging plays an increasing role in the detection of early-airway and parenchymal changes in children who aspirate. The findings of aspiration on a high-resolution CT scan include areas of hyperinflation and ground-glass opacity (mosaicism), frank bronchiectasis, the tree-in-bud appearance of small-airway thickening, and the rarer finding of interstitial changes.³³ None of these changes are specific for aspiration, but a characteristic distribution to the basilar and apical segments of the lower lobes in a clinical setting that favors aspiration makes the CT scan a useful supportive diagnostic tool.⁴⁷⁻⁴⁹ Unfortunately, the radiation exposure limits its use as a method for repeated monitoring.

A recent study of CT scans in children with laryngeal clefts revealed changes in all 67 pediatric patients. Although the lower lobes were more frequently involved, no area was spared, and there was a range of radiological changes, although consolidation and reticular opacities predominated.⁵⁰

Functional and Instrumental Tests of Swallowing Integrity in Children

The videofluoroscopy swallow study

The videofluoroscopy swallow study (VFSS) is a dynamic radiological investigation procedure that assists the evaluation of complex dysphagia in children, where the pathology may be structural, functional, or both. It allows simultaneous viewing of the oral-preparatory, oral, pharyngeal, and esophageal stages of swallowing, visualizing the way in which these stages interact, and thus identifying the elements of dysfunction.⁵¹ The use of the VFSS to assess swallow function in children has become increasingly available in recent years, and the procedure is well described across all age ranges.³ It will usually be undertaken by a radiologist and a dysphagia-trained speech and language therapist working in tandem. Its disadvantages are those of exposure to ionizing radiation, hence a time limit on the study duration and a need for patient cooperation. Dose-limiting techniques, such as pulsed fluoroscopy and tight coning, will be effective in eliminating unnecessary radiation exposure to the brain and soft tissue areas not relevant to the swallowing process (Fig. 1).

VFSS can detect tracheal aspiration, which is silent on clinical assessment. Characteristics of aspiration and pharyngeal function in a large sample of infants and children with suspected clinical dysphagia were assessed with VFSS.⁴¹ Aspiration was observed on the VFSS in 48 (26%) of 186 children, primarily on liquid, before or during swallows. Aspiration was trace (<10% of a bolus) and silent in 94%. In children with cerebral palsy, aspiration has been shown to be silent in up to 97% of the patients.⁴¹

The procedure was performed in a fluoroscopy suite, with the child seated lateral to the X-ray beam and as close proximity to the image intensifier as possible (Fig. 2). Food

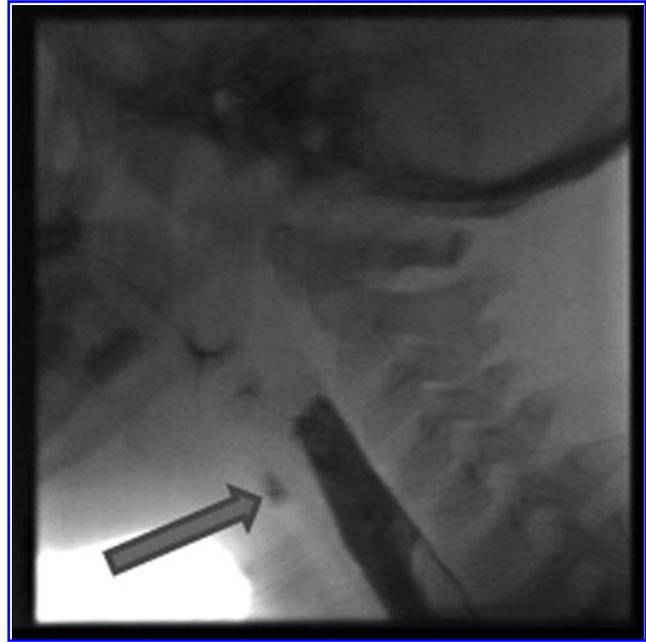


FIG. 1. A VFSS still film demonstrating the coned view; while the bulk of the contrast has entered the esophagus, a trace of aspiration into the trachea (arrowed) is witnessed. VFSS, videofluoroscopy swallow study.

and liquid, to which a contrast material has been added, were offered, and the results recorded onto storage media. The aspects of the swallow identified by a successful study are listed in Table 3.

Abnormality in the oral-preparatory and oral phases is usually identified by the prerequisite clinical assessment before referral for VFSS, and its presence does not generally require identification with a radiological evaluation. However,



FIG. 2. A child undergoing a VFSS being fed by his father.

TABLE 3. ABNORMAL SWALLOW FEATURES IDENTIFIABLE FROM A SUCCESSFULLY PERFORMED VIDEOFUOROSCOPY SWALLOW STUDY

The presence of any structural or motility disorders in the oral cavity or pharynx, including the tongue
Interaction of the phases of swallowing
A dynamic record of how different food and liquid consistencies are swallowed/managed, possibly demonstrating the safest consistency
The adequacy of airway protection during swallowing
Whether there is any progressive deterioration in function associated with fatigue, for example, in children with cardiac or neuromuscular conditions
Identification of the presence of silent aspiration

the VFSS can clarify the nature of this disorder, for example, by visualizing the effect of reduced range and strength of oral movement patterns. Visual observation of the ability of a dysfunctional tongue to manage a variety of consistencies and bolus sizes is often informative. The VFSS can frequently identify aspiration occurring before the pharyngeal swallow is triggered as a result of the oral-stage and tongue movement abnormality, leading to uncontrolled spillage of the food/liquid over the base of the tongue into the pharynx.

The VFSS can identify a delay in the pharyngeal transit time and disordered velopharyngeal closure, with possible escape of food into the nasal passages. Clear laryngeal penetration and aspiration, before or during the swallow, will be identified and distinguished on the VFSS.

Flexible endoscopic examination of swallowing

Flexible endoscopic examination of swallowing (FEES) is widely used in adults in assessing dysphagia using a flexible endoscope to directly visualize the hypopharynx during the swallowing process.⁵² Although it has since been described as a feasible examination in pediatric patients,⁵³ it is not routinely used in the assessment of swallowing disorders in children in the United Kingdom. In practical terms, it is only suitable for either very young children or older children who are able to cooperate. Local experience of using FEES in a pediatric voice clinic has highlighted difficulty in achieving a functional assessment. Many children have not been comfortable with having the flexible scope passed or have refused to eat with the scope *in situ*. Using a restraint in neurologically vulnerable children impairs all attempts to obtain a normal swallowing environment, increasing the aspiration risk with invalid findings and negatively reinforcing adverse feelings about feeding.

There are currently no data regarding the sensitivity and specificity of FEES to detect aspiration in children.⁵⁴ However, in a small sample size study ($N=30$), FEES was concluded to be a comparable technique to the VFSS for diagnosis and treatment of pediatric patients in the acute care setting.⁵⁵

FEES visualizes events at the pharyngeal stage in virtual isolation.⁵⁶ Swallowing is a continuum, and different phases of the swallow may impact on each other. We consider that the use of the VFSS, in experienced hands and with usual seating and feeding practices, provides a far better tool to evaluate the continuity of the process in its entirety, enabling a dynamic study of each phase of the swallow in progression.

Contrast studies

Children with feeding difficulties may frequently undergo an upper gastrointestinal contrast study (UGI). Vazquez⁵⁷ reviewed radiological findings in infants who had undergone both upper gastrointestinal contrast studies and VFSS. Swallow dysfunction was seen in 19 patients, in 10 of whom the difficulties were only observed on the VFSS. They concluded that UGI is not a substitute for VFSS.

The most commonly used method of diagnosis for TEF is a pullback tube esophagram. This involves the insertion of a nasogastric tube, which is withdrawn up the esophagus, as contrast is simultaneously injected through its tip under pressure. It is reported that a contrast swallow performed under controlled conditions may be as effective to diagnose a TEF.⁵⁸

Scintigraphy tests

The salivagram, although not widely used, is reported by some centers as a useful method of demonstrating salivary aspiration into the lungs. In reality, however, if aspiration has been demonstrated, salivary aspiration is almost certainly going to occur to some degree, and further testing is not warranted.

In the salivagram, Tc-99m sulfur colloid, 0.5–1.0 mCi in <1 mL, is instilled into the mouth and allowed to mix with the saliva. Sequential supine posterior images of the thorax are obtained, monitoring tracheal activity for an hour, until the oropharynx is cleared of the radiotracer.⁵⁹ Correlation with other tests of aspiration is however poor.⁶⁰ Investigators in this field are also exploring the possibility of radiolabeling a food bolus to demonstrate pulmonary contamination.⁶¹

The milk scan with radiolabeled milk was primarily designed to demonstrate reflux. It does have the advantage of potentially showing aspiration into the lung, although the anatomical accuracy is often lacking. The test can be prolonged over a few hours to capture pulmonary deposition, which is both an advantage and a disadvantage. It has not yet been shown to be a sufficiently sensitive marker of proven aspiration secondary to GER.^{13,60}

Bronchoscopy

A rigid bronchoscopy, mostly in the form of a micro-laryngobronchoscopy, is the investigation of choice to exclude and remove foreign bodies and also to evaluate the larynx for a small (type 1) cleft. The opening of an H-type TEF may also be visualized bronchoscopically. Fully mobile and functioning vocal cords should also be documented, as there is a vulnerability to aspiration with vocal cord paralysis.⁶²

Both the rigid and flexible scopes can be very useful for assessing laryngomalacia and tracheomalacia, both of which can increase vulnerability to aspiration over the top.⁶³

Flexible bronchoscopy provides an opportunity to examine the airway lumen for anatomical defects and the gross effects of aspiration such as inflammation, abnormal secretions, and erosions. The flexible bronchoscope can select a specific pulmonary lobe for lavage studies.

Tests for Aspirated Materials

Bronchoalveolar lavage

Although the principle of detecting aspirated material in the lungs intuitively seems sensible and reliable, what to

measure in the lavaged fluid remains a hot topic of debate. The presence of lipid-laden macrophages (LLMs), for example, is nonspecific. Quantification of LLM numbers with an LLM index (LLMI) appears to improve the specificity of this test in children.⁶⁴ Theoretically, an increase in the LLMI is consistent with aspiration—both over the top and secondary to reflux.⁶⁵ There are however a number of intrinsic lung conditions that can cause the presence of LLMs.⁶⁶ These cells may be observed with cystic fibrosis, endogenous lipid pneumonias, and with lipid infusion therapy.^{67,68} The technique is labor intensive, and comparisons of studies reveal a wide range of normal⁶⁹ with poor differentiation between endogenous and exogenous sources of lipid.⁴⁶ There is also a considerable controversy over the ideal method of scoring the numbers of LLMs. Although the score by Colombo is in common use, a number of variations have been published using the principle of counting a set number of macrophages and then scoring the density of their lipid load to arrive at an index.⁶⁴ The LLMI may provide clinically helpful information, but the sensitivity and specificity are insufficient to afford it the gold standard status.^{66,69} Current research is focusing on other markers within broncho-alveolar lavage (BAL) fluid: pepsin shows promise,⁷⁰ and bile salts⁷¹ deserve further study, although the dilutional factors continue to frustrate.

Histology

Biopsy of the lung is rarely employed in all, but the most demanding, diagnostic dilemmas when investigating aspiration. Findings are often nonspecific, although an inflammatory granulomatous process with lipid deposition and the presence of cholesterol clefts with periodic acid-Schiff-positive acellular debris are highly indicative of aspiration. Needle biopsies of the lung may miss the affected area, and many centers would employ a wedge resection by open thoracotomy⁷² or video-assisted biopsy techniques.⁷³

The Spectrum of Aspiration Lung Damage

First, there is the breach of the defenses. Then, mucosal inflammation with varying degrees of obstruction to the airways occurs followed by the lung attempts at expulsion and resolution.

What is now clear is that aspiration can result in almost any pathological endpoint in the lung. Examples of the range of lung pathology associated with aspiration damage are listed in Table 4.

TABLE 4. THE SPECTRUM OF LUNG PATHOLOGY ATTRIBUTED TO ASPIRATION EVENTS

Laryngeal swelling
Cobblestoning of the trachea
Acute atelectasis
Segmental overinflation from ball-valve effect
Chronic endobronchitis
Bronchiectasis
Bronchiolectasis
Obliterative bronchiolitis
Necrotizing pneumonia/abscess/empyema
Recurrent pneumonia
Chronic basal lobar collapse
Alveolar disease: fibrosing alveolitis, alveolar proteinosis
No pathological changes

The variability in the pulmonary manifestations of aspiration is likely to be related to a number of influencing factors.

The acidity and microbial content of the aspirated material

An acidic pH (below 2.5) results in a more severe and prolonged inflammatory and destructive reaction in the lung than neutral fluids in animal studies.^{34,74} However, alkaline saliva contains oral bacterial flora, and in vulnerable children with neurodevelopmental delay, poor oral and dental hygiene can result in an increased risk of aspiration pneumonia with anaerobic organisms.^{75,76}

The volume of the aspirated material

Large-volume aspirations (>0.8 mL/kg) are associated with rapid and acute hypoxia.⁷⁷ Small-volume aspirations (microaspirations) may cause a more chronic and insidious presentation and impact on more distal lung structures.

The structure of the aspirated material

Aspiration of a macroscopic, solid matter will result in acute hypoxia with airway obstruction that will cause sudden death, partial lung collapse (if the obstruction is complete), or a ball-valve effect with distal air trapping. Vegetable matter may induce a delayed, but exaggerated, inflammatory response.⁷⁸ Finely aerosolized liquid particles may produce an hypoxic response or generate a chronic inflammatory reaction as far distally as the terminal airways with a reduction in surfactant protein levels.⁷⁹

Silent aspiration

Microaspirations, occurring without clinical warning or cough clearance, can result in chronic damage with features of bronchiectasis, bronchiolectasis, and interstitial changes.³⁴

Coexistent pathology

The coexistence of additional pulmonary pathology such as cystic fibrosis, asthma, chronic lung disease of prematurity alters the effect of aspiration.¹⁰

A blunted host response

Aspiration events are a part of normal life, including during sleep. Intact defense mechanisms will protect the lungs from damage. A blunted host response to these normal events can result in pulmonary manifestations. Examples include neurodisability with ineffective cough protection, primary ciliary dyskinesia, cystic fibrosis with abnormal mucociliary clearance, immunodeficiency, and prematurity.

Strategies to Limit Aspiration and Prevent Lung Damage

Notwithstanding the limitations on attempting to prove and quantify aspiration, in much of the literature, and indeed in clinical practice, a linear relationship between the severity of oropharyngeal aspiration and the development of

pulmonary consequences is assumed. There is minimal evidence, however, to support this belief, and thus to determine an action or intervention threshold as to when a child is safe versus unsafe to feed orally.⁸⁰ Strategies to limit aspiration and prevent lung damage remain the cornerstone of individual feeding regimens and will usually incorporate the following considerations:

Altering consistencies and posture

A well-executed videofluoroscopy study not only provides evidence for aspiration but will also explore relative risks for different consistencies of feed and optimal posture during feeding. Advice regarding volumes, cups, spoons, bottles and teats, posture, thickeners, and consistency can significantly improve the aspiration risk and consequent lung health.^{5,81,82}

Nonoral feeding

For some children, the swallow control is too unreliable to provide sufficient calories safely via an oral route. The move to nonoral feeding will almost always involve careful discussion with the families. Feeding one's child is a strong and primitive need, and for some parents (and grandmothers), the move to gastrostomy feeds is a cause for considerable family distress.⁸³ Compromise positions are sometimes required to satisfy 3 pivotal questions:

- Is feeding safe?
- Is feeding sufficient?
- Are mealtimes enjoyable for the child and the family?

Often, the answer to these questions is simply answered by nonoral feeding and accepted by the families. The difficult clinical dilemmas as to when to intervene and how to deal with refusal to intervene are discussed below.

Gastrostomy insertion may exacerbate GER, and consideration will be given to the role of medical or surgical interventions to reduce reflux while gastrostomy feeding.^{46,84,85} A trial of nasogastric feeding or nasojejunal feeding may be required as an interim step.⁸⁶ For many children, especially those with neurological conditions, gastric tube placement can help with safe nourishment and adequate caloric intake while allowing the child to enjoy some oral feeds. Careful attention must be given to oral hygiene in children who are gastrostomy-fed, as there is a reported increase in oral contamination of secretions and pneumonia.⁸⁷

Secretion control

Notwithstanding successful interventions to remove the aspiration risk by moving to nonoral feeding, some children have repeated respiratory sequelae from salivary aspiration.

The use of agents to dry secretions can be helpful. The scopolamine patch is often advocated, but can be difficult to use, as it can provide an erratic drying response, especially if the patch is cut to try and limit the dose delivered, but results in unpredictable leeching of the drug through the cut edge. Oral anticholinergic agents such as glycopyrrolate or hydroxyzineat have the advantage of more frequent dosing and titration of effect, but can produce troubling side effects such as constipation, dry mouth, thick secretions, and tachycardia.^{46,88,89} Mucous plugging and respiratory distress can be troublesome in tracheostomized patients on oral anticholinergics.

Various surgical options have also been reported. Removal of salivary glands and ligation of the parotid ducts can reduce hypersecretory states.^{90–92} The use of Botox injection into the submandibular or parotid glands showed initial promise, especially in children with cerebral palsy.⁹³ It is a technically difficult procedure with a time-limited effect of a few months, and the need for repeated injections and the potential for antibody development have limited its acceptance.⁹⁴

For very resistant cases, some practitioners would advocate a tracheostomy insertion with or without a cuffed tube⁵⁴ and even complete laryngotracheal separation.⁹⁵

Dealing with Refusal to Stop Nonoral Feeding in the Presence of Aspiration

Pediatricians caring for neurodevelopmentally affected children will frequently encounter a situation where swallowing is insecure and aspiration is likely, but the family remains very reluctant to consider nonoral feeding. For many of these children, feeding is their only pleasure, and from the family's perspective, the child's participation in family mealtimes is crucial to their psychosocial well being. For parents, a gastrostomy may be seen as yet another step in pathologizing their child. Parents and professionals may be thrown into a confrontational situation where there is disagreement about which course of action is in the best interests of the child. Compromise positions need to be sought, but this leads to some imponderable questions: What is the definition of unsafe to feed, and how do we evaluate the harm accruing from oral feeding?

We know that individuals with cerebral palsy are subject to higher mortality than the general population.⁹⁶ Although several factors, including mobility, respiratory disease, and dysphagia, predict mortality,⁹⁷ these kind of epidemiological data are not particularly helpful in determining appropriate management in the individual clinical situation.

Aspiration of small amounts of gastric or oral secretions is said to occur in up to 45% of the healthy population and is not thought to be harmful,⁹⁸ but aspiration in disabled children is always assumed to be significant.

Given the lack of evidence-based guidelines, the pragmatic approach has been that any clinically demonstrated aspiration may be dangerous,⁹⁹ and that if first-line management such as posture, utensil, and texture modification fails to eliminate it, then nonoral feeding should be implemented to protect the lungs. Set against this view is the fact that nonoral feeding is often perceived by parents as a failure: the ability to eat is seen as a fundamental human right, central to our being, and survival. By the time nonoral options are discussed, the child may already be quite old. Acceptance of the need for nonoral feeding may imply that damage has occurred, and the parent's careful attention to alternative strategies was futile.

With substantial numbers of children and families now wanting a clearer indication of incipient damage before proceeding to nonoral feeding, there is a pressing need for better evidence-based guidelines that will assist them in deciding when the risk–benefit ratio of nonoral versus oral feeding favors a move to intervention. Further prospective study of the natural history of respiratory disease in children with aspiration is urgently required to explore risk factors for, and predictors of, pulmonary damage.

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