
Foreign Body Aspiration: Imaging Aspects

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Contents

1	Introduction.....	306
2	Etiology/Types of Foreign Bodies.....	306
3	Mechanisms of Airway Obstruction.....	310
4	Clinical Findings and Differential Diagnosis.....	312
5	Imaging Techniques	313
6	Imaging Findings	317
7	Complications.....	318
8	Conclusion	321
	References.....	321

Abstract

Foreign body aspiration is the most frequent pediatric domestic accident, and has serious and sometimes fatal sequelae. Most cases occur under the age of 4 years. The history of choking followed by persistent cough is the most reliable clue for the diagnosis, but many patients present with various nonspecific clinical symptoms. When the history of a foreign body aspiration is definite, bronchoscopy is the modality of choice for both diagnosis and management. In the absence of such a history diagnosis can be overlooked, and many children present with unresolved pneumonia, atelectasis, or other complications. The role of the radiologist in such cases is not only to confirm a clinically suspected diagnosis, but also to suggest the diagnosis in patients with nonspecific clinical symptoms and radiologic features that could be related to long-standing foreign bodies. Many clinical and imaging findings are the result of a one-way obstruction mechanism. A normal inspiratory chest radiograph does not rule out a foreign body. Expiratory films are important to demonstrate air-trapping. The high kilo-voltage (kV) copper filter technique is valuable for demonstrating a nonopaque foreign body, and fluoroscopy can be very useful. Computed Tomography (CT) has become more valuable by virtue of its wide availability, high resolution, and the multiplanar, three-dimensional and additional image reconstruction capabilities. CT can indicate the exact location of a foreign body, suggest alternative diagnoses, and can demonstrate any associated complications. The role of other imaging modalities is not as well established. An understanding of the mechanisms of obstruction and their resultant clinical and imaging manifestations, can lead to earlier diagnosis and lower the complication rate. This chapter discusses imaging techniques and findings related to the various types and mechanisms of obstruction and to the complications of foreign body aspiration.

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1 Introduction

Aspiration of foreign bodies into the respiratory tract can occur at any age, but is most common in young children and in the elderly population. Foreign body aspiration is the most frequent pediatric domestic accident, and has serious and sometimes fatal sequelae (Black et al. 1984; Fitzpatrick and Guarisco 1998; Bhana et al. 2000; Ciftci et al. 2003; Qureshi and Mink 2003; Li et al. 2009; Gang et al. 2012; Pan et al. 2012; Foltran et al. 2013; Bamber et al. 2013). Most cases occur under the age of 4 years (Mantel and Butenandt 1986; Esclamado and Richardson 1987; Piepsz 1988; Schmidt and Manegold 2000; Oguz et al. 2000; Lima and Fischer 2002; Roda et al. 2008; Kitcher 2009; de Sousa et al. 2009; Tang and Chen 2009; Goktas et al. 2010; Orji and Akpeh 2010; Paksu et al. 2012; Pan et al. 2012; Boufersaoui et al. 2013). When the history of a foreign body aspiration is definite, bronchoscopy is the modality of choice for both diagnosis and management (Cohen et al. 2009; Ezer et al. 2011; Mortellaro et al. 2013; Samkani et al. 2013). Until recently, rigid or flexible bronchoscopy was used for diagnosis, while removal of foreign bodies was carried out by rigid bronchoscopy only (Friedman 2000; Lima and Fischer 2002; Ayed et al. 2003; Ciftci et al. 2003; Lima et al. 2008; Cohen et al. 2009; Albirmawy and Elsheikh 2011). With the advance of technology, removal of foreign bodies can now be done by flexible bronchoscopy, which is a shorter and safer procedure (Swanson and Edell 2001; Tang et al. 2006; Zhijun et al. 2008; Rodrigues et al. 2012a; Falase et al. 2013). The complication rate of bronchoscopy varies between 1 and 8 % (Black et al. 1984; Steen and Zimmermann 1990; Zerella et al. 1998; Zaytoun et al. 2000; Ayed et al. 2003; Ciftci et al. 2003; Cohen et al. 2009; Kiyani et al. 2009), and the mortality rate is as low as 0.25–1 % (Mu et al. 1990, 1991; Steen and Zimmermann 1990; Hoeve and Rombout 1992; Ciftci et al. 2003; Zhijun et al. 2008; Tang and Chen 2009; Tang et al. 2009; Rodrigues et al. 2012b).

In many cases, however, the aspiration event is not witnessed, and the classical triad of choking followed by cough, focal decreased breath sounds, and wheeze is missing. Diagnosis is then delayed or overlooked, and many children present with unresolved pneumonia, atelectasis, or other complications. The role of the radiologist in cases of foreign body aspiration is not only to confirm a clinically suspected diagnosis, but also to suggest the diagnosis in patients with nonspecific clinical symptoms and radiologic features that could be related to long-standing foreign bodies. Often the radiologist is the first to raise the possibility of foreign body aspiration.

This chapter discusses imaging techniques and findings related to the various types and mechanisms of obstruction and to the complications of foreign body aspiration.

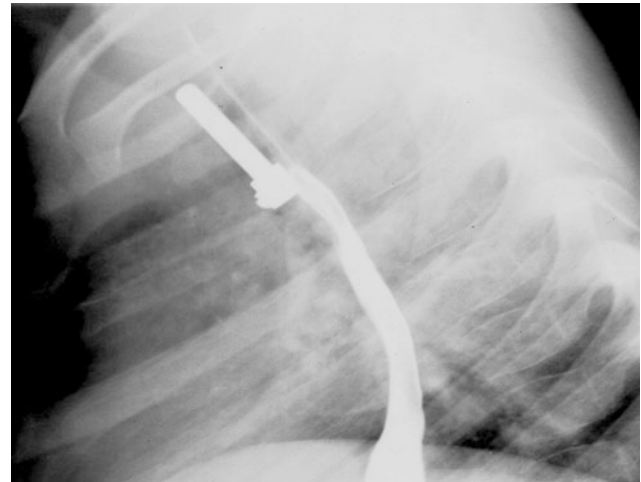


Fig. 1 Lateral view of a barium swallow shows a metallic bolt in the trachea of a 2-year-old boy

2 Etiology/Types of Foreign Bodies

Most cases of foreign body aspiration occur between the age of 6 months and 3 years, with the highest incidence during the second year of life (Mantel and Butenandt 1986; Piepsz 1988; Fitzpatrick and Guarisco 1998; Lima and Fischer 2002; Witt 1985; Roda et al. 2008; Kitcher 2009; de Sousa et al. 2009; Tang et al. 2009; Orji and Akpeh 2010; Pan et al. 2012; Paksu et al. 2012; Boufersaoui et al. 2013; Sidell et al. 2013; Tenjovic et al. 2013). Infants and toddlers in this age group are already ambulatory and can therefore “disappear” from parent or guardian supervision for varying periods of time. They tend to act as “vacuum cleaners,” and examine new objects of any size or shape by inserting them into their mouth. The combination of natural curiosity, lack of posterior dentition, inadequate control of deglutition, and a startle response facilitates entry of solids into the larynx (Witt 1985; Byard 1994). The size and variety of objects that can pass through the vocal cords are quite astonishing (Fig. 1) (Blazer et al. 1980).

Food particles and organic materials constitute the vast majority of aspirated objects (Blazer et al. 1980; Keith et al. 1980; Svensson 1985; Mantel and Butenandt 1986; Piepsz 1988; Mu et al. 1990; Linegar et al. 1992; Black et al. 1994; Baharloo et al. 1999; Metrangelo et al. 1999; Diaz et al. 2000; Siddiqui et al. 2000; Brkic et al. 2001; Lima and Fischer 2002; Ayed et al. 2003; Roda et al. 2008; Ugrinovic et al. 2009; Chik et al. 2009; de Sousa et al. 2009; Albirmawy and Elsheikh 2011; Huankang et al. 2012). The nature of the aspirated material varies according to geographic and sociologic circumstances. Peanuts are the most common aspirated particles in North America, Europe, India, and South Africa (Teixidor de Otto et al. 1980; Mantel and Butenandt 1986; Mu et al. 1990; Linegar et al. 1992; Diaz

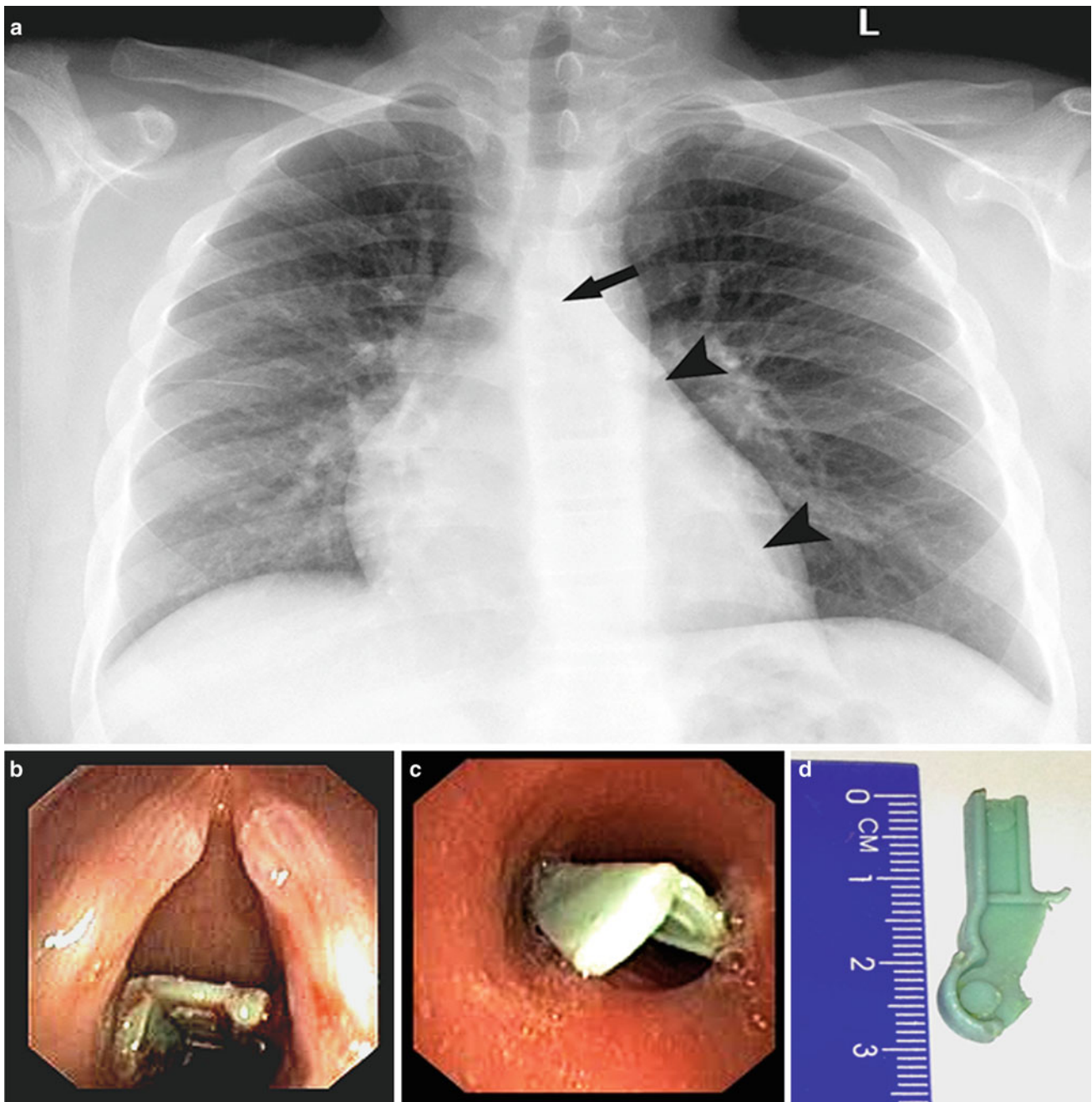


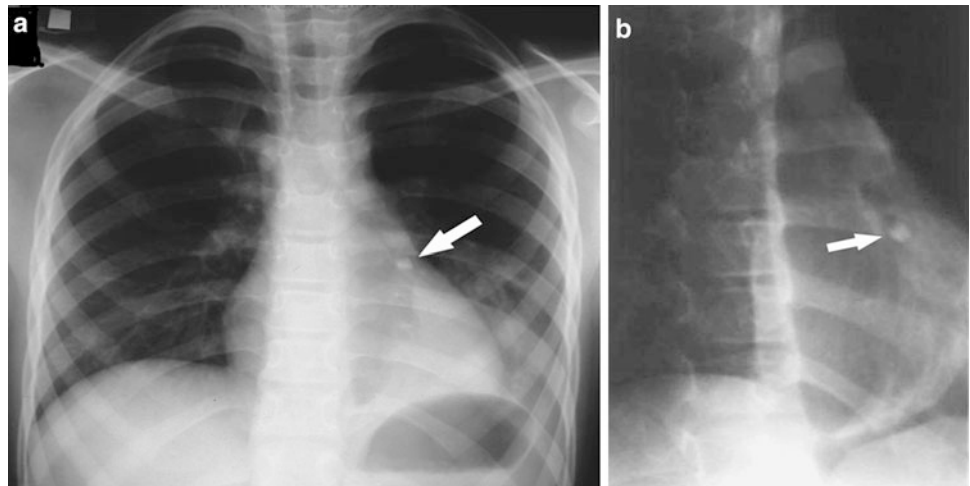
Fig. 2 Posteroanterior chest radiograph demonstrating “absence” of the left main bronchus (“interrupted bronchus” sign, *arrow*, (a)) in a 13-year-old boy who held a plastic piece of a toy between his lips while playing a computer game. Note resultant left lower lobe

atelectasis (*arrowheads*) as well as left upper lobe hyperinflation. At bronchoscopy, the plastic was initially seen under the vocal cords (b), then migrated to the orifice of the left lower bronchus (c). Note the size of the extracted piece (d)

et al. 2000; Sehgal et al. 2002; Shivakumar et al. 2003), whereas earthnuts, grains, sunflower seeds, and watermelon seeds are more common in the South America, Middle East, and eastern Asia (Farkash et al. 1982; Elhassani 1988; Oguz et al. 2000; Pasaoglu et al. 1991; Cataneo et al. 2008; Zhijun et al. 2008; Chik et al. 2009; Saki et al. 2009; Oncel et al. 2012; Gang et al. 2012; Pan et al. 2012). Due to their high protein concentration, most organic foreign bodies absorb

water from bronchial secretions and tend to increase in size. Candies have been reported to have a similar effect due to their high sugar concentration (Mearns et al. 1975). Oil, salt, and vegetable proteins in cooked food irritate the mucosa, causing edema and formation of granulation tissue with resultant narrowing of the bronchial lumen. Hence, an organic foreign body can grow to be larger than the original diameter of the bronchus, and what was initially a partial

Fig. 3 Posteroanterior chest radiograph (a) of a 10-year-old girl and an oblique view (b) (obtained at fluoroscopy): a deciduous tooth (arrow) is present in the left lower lobe bronchus obstructing some of the basal segments and causing volume loss. Bronchiectasis, evident in the left lower lobe, is better demonstrated by the oblique projection



obstruction can progress to become a complete obstruction (Fig. 2a) (Aytac et al. 1977; Cataneo et al. 1997).

Grass inhalation is not uncommon and has some unique characteristics. The literature contains reports describing aspiration of several types of grass heads, all with the same structure of side spurs along the main stem. When inhaled stump-first, the spikes carry the grass heads distally into the bronchial tree and lung parenchyma. Being resistant to organic decay, they can remain in the chest for a long time and can cause unusual infections, as well as other complications (Spencer et al. 1981; Maayan et al. 1993; Dindar et al. 1994; Basok et al. 1997; Newson et al. 1998; Ammari et al. 2000).

Nonorganic objects comprise 5–20 % of the foreign bodies aspirated by children (Farkash et al. 1982; Mortellaro et al. 2013). Of these, coins are the most common (Reilly and Walter 1992), followed by plastic toy pieces and sharp objects such as pencils and pull-tabs from aluminum cans (Rogers and Igini 1975; Burrington 1976; Blazer et al. 1980; Strickland et al. 1987; Applegate et al. 2001). Inert foreign bodies have little effect on the bronchial mucosa and, unless they cause an obstruction by virtue of their size, can remain undiagnosed for long periods of time (Adegboye et al. 2003). Aspiration of pacifiers is not uncommon among toddlers (Jain et al. 1986; Barrett and Debelle 1995). Partially inflated balloons and Nylon bags are particularly hazardous (Abdel-Rahman 2000; Anas and Perkin 1983).

A tooth can be aspirated by a sleeping child at the age of permanent tooth eruption. This happened to a 10-year-old girl who had a loose deciduous tooth when she fell asleep at night. When she woke up the next morning the tooth had disappeared from her mouth. The episode was forgotten; 10 days later she developed symptoms of left lower lobe pneumonia, with no response to antibiotic therapy over several months. When she was admitted to the hospital, the missing tooth was evident in the left lower lobe bronchus on

a chest radiograph, with atelectasis of most of the basal segments (Fig. 3). The tooth was removed by bronchoscopy; 2 months later residual bronchiectatic changes could still be seen in the left lower lobe.

Aspiration of tooth, dental fillings, crowns, or dental treatment equipment can also occur during dental treatment (Steelman et al. 1997), following minor trauma (Holan and Ram 2000), during anesthesia, and intubation or resuscitation procedures, especially in victims of road traffic accidents, and following tracheostomy canula replacement in debilitated patients.

Aspiration of gravel, dirt, or sand can happen during a traffic accident, in a cave-in or accidental burial, in a near-drowning event, or while playing in sand (Bergeson et al. 1978; Wales et al. 1983; Avital et al. 1989; Choy and Idowu 1996; Glinjongol et al. 2004; Arun Babu and Anantha-krishnan 2013). Airway obstruction has also been reported as a result of nonaccidental trauma, when forcible introduction of a foreign body caused tracheal obstruction, with a resultant death reported in one case (Barrett and Debelle 1995; Nolte 1993). Aspiration of headscarf needles (Turban pins) has been reported in young girls and adolescents in Islamic populations (Ucan et al. 1996; Kaptanoglu et al. 1999; Murthy et al. 2001; Kaptanoglu et al. 2007; Al-Sarraf et al. 2009; Hamad et al. 2010; Albirmawy and Elsheikh 2011; Ilan et al. 2012). Aspiration of other sharp metallic objects occurs more commonly among adolescents (Ludemann and Riding 2007; Walz et al. 2013). Such an aspirated pin, an office thumbtack, or a sewing needle can get stuck in the bronchial wall in one or both ends, a condition in which simple bronchoscopic extraction is not possible. In such cases, the use of additional, advanced endoscopic techniques is necessary in order to enable a successful bronchoscopic extraction and obviate the need for possible thoracotomy (Jabbardarjani et al. 2010).

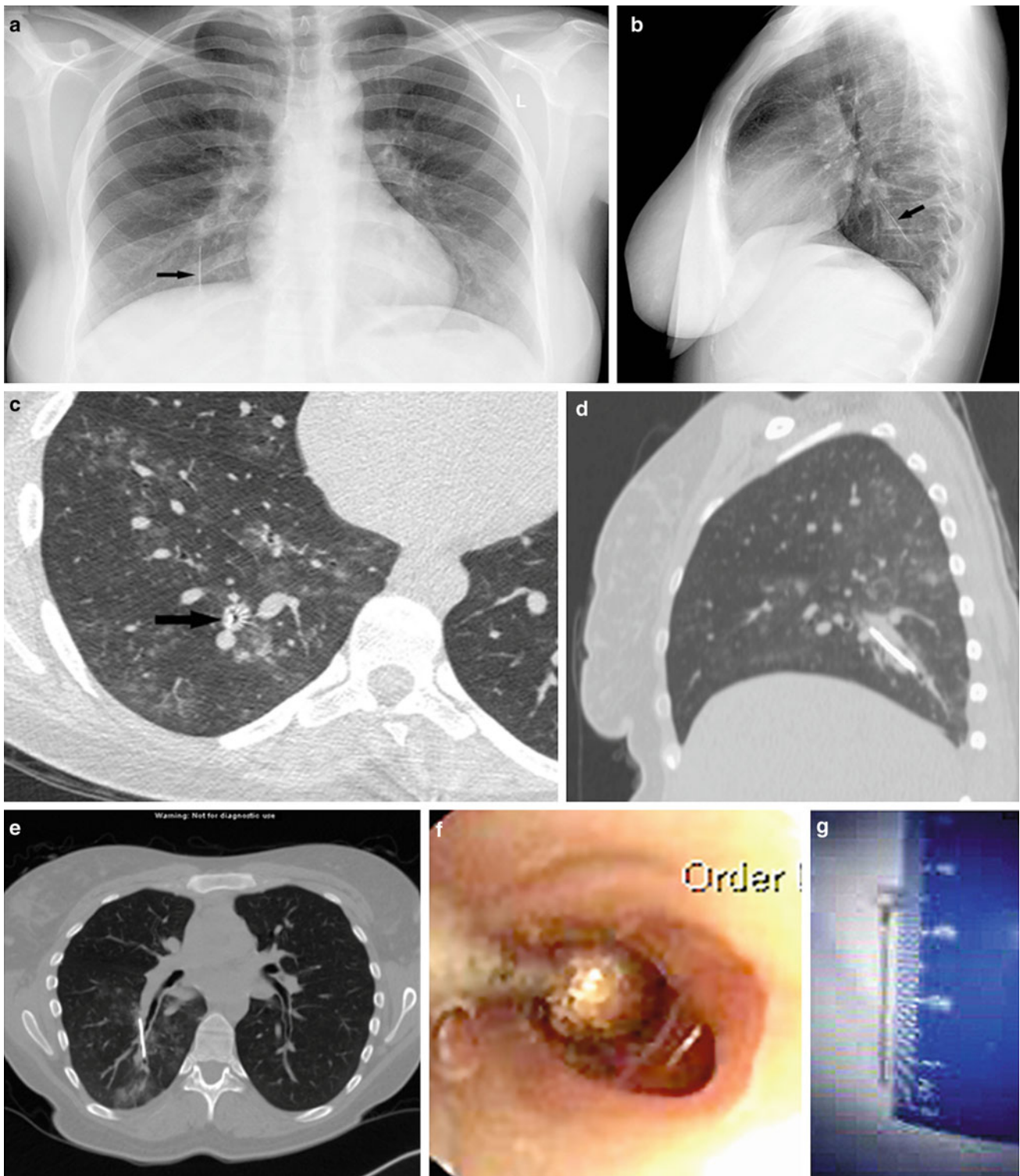


Fig. 4 Posteroanterior (a) and lateral (b) chest radiograph demonstrating a hairpin aspirated into the right lower lobe (*arrow*). Axial (c), semicoronal (d), and sagittal (e) reformats of a CT scan demonstrated the oblique position of the pin with its end protruding through the

bronchial wall, as demonstrated at bronchoscopy (f). Extraction of the pin (g) was accomplished without further bronchial wall destruction only after it was heated and bent

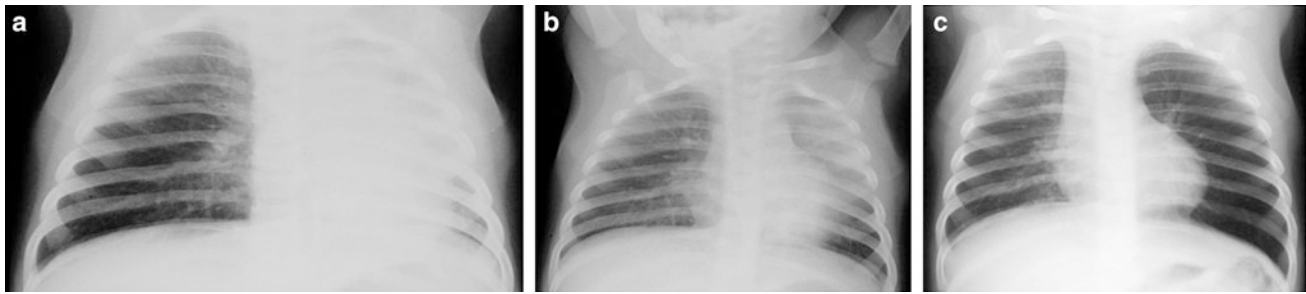
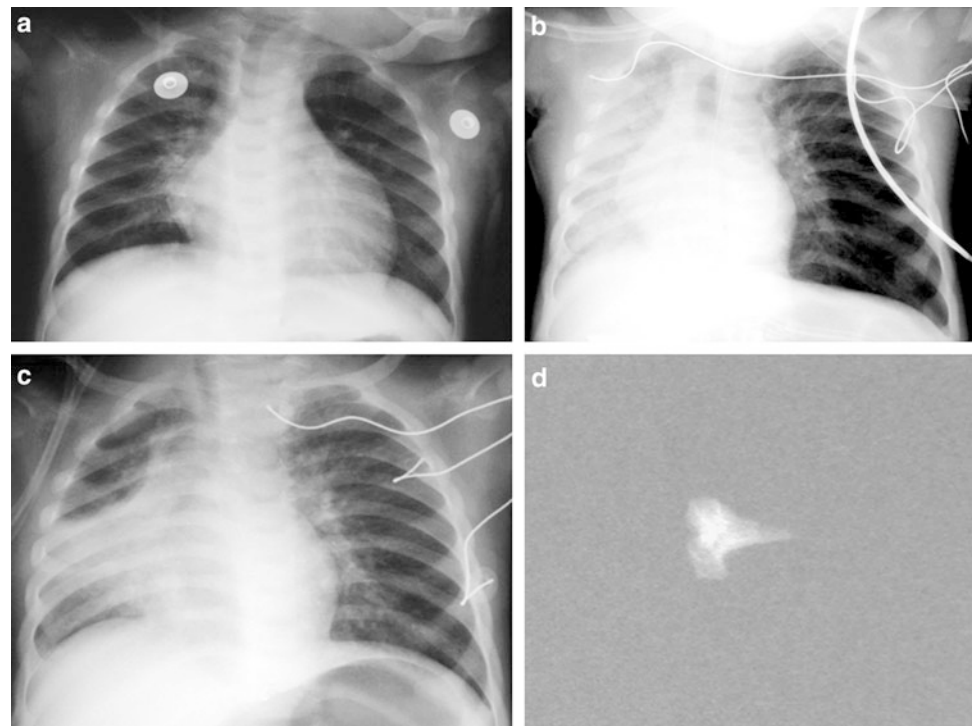


Fig. 5 A 10-month-old girl with cough, low fever, and mild tachypnea for 4 days. Initial chest radiograph was normal. Follow-up chest radiographs 24 h later, on day 5 (a), showed collapsed left lung.

24 h later, on day 6 (b), there was left upper lobe collapse; 48 h later, on day 8 (c), emphysema of the left lung was seen. Bronchoscopy found two foreign bodies: a wood splinter and a piece of plastic

Fig. 6 A 10-month-old boy with rickets aspirated a chicken bone. Initial chest radiograph (a) was normal (the chicken bone was missed). Follow-up chest radiographs 24 h (b) and 48 h (c) later showed progressive collapse of the right lung. A chicken bone (d) was removed from the right main bronchus on bronchoscopy



3 Mechanisms of Airway Obstruction

A foreign body in the respiratory tract does not necessarily cause an obstruction, i.e., air can be inhaled and exhaled freely around the foreign body. This is known as a “two-way valve mechanism,” and occurs when the foreign body, which is usually located in the trachea, is small in relation to the airway. A foreign body can cause complete obstruction when air entry is blocked during inspiration and the air cannot be exhaled during expiration. This is called a “no-way valve mechanism.” A foreign body can allow air entry during inspiration but prevent the exit of air during expiration in a “one-way valve mechanism.” This mechanism is explained by the larger diameter of the airway during inspiration due to higher intrathoracic negative pressure, and the smaller diameter during expiration.

Chest X-rays performed in cases of a nonobstructive tracheal or bronchial foreign body demonstrate uniform aeration bilaterally both in inspiration and expiration. In partial obstruction due to the one-way valve mechanism, the chest radiograph usually demonstrates air-trapping. Inspiratory films are often normal, and the air-trapping may become evident only in an expiratory study. In cases of complete airway obstruction (most commonly at the level of a bronchus), we often notice a combination of air-trapping in the non-dependent lobes with atelectasis of the dependent lobes. This is due to mucus plugging and the accumulation of secretions in the bronchial tree of the dependent segments (Figs. 2, 4, 5).

The incidence of right and left bronchial foreign bodies is almost equal in infants and young children (Mu et al. 1990; Black et al. 1994; Burton et al. 1996; Cataneo et al. 1997;

Fig. 7 A broken piece of a metal zipper partially blocking the distal trachea of a 2.5-year-old girl causing bilateral hyperinflation as seen in an AP (a) and lateral (b) chest radiograph. During rigid bronchoscopy, the foreign body got stuck between the vocal cords and the child could neither be ventilated nor intubated. Bradycardia and decrease in oxygen saturation necessitated resuscitation and emergency tracheostomy. The foreign body was pushed down to the right bronchus (c). Following completion of tracheostomy, the metal piece (d) was pulled up to the level of the cords by flexible bronchoscopy and dislodged using surgical forceps

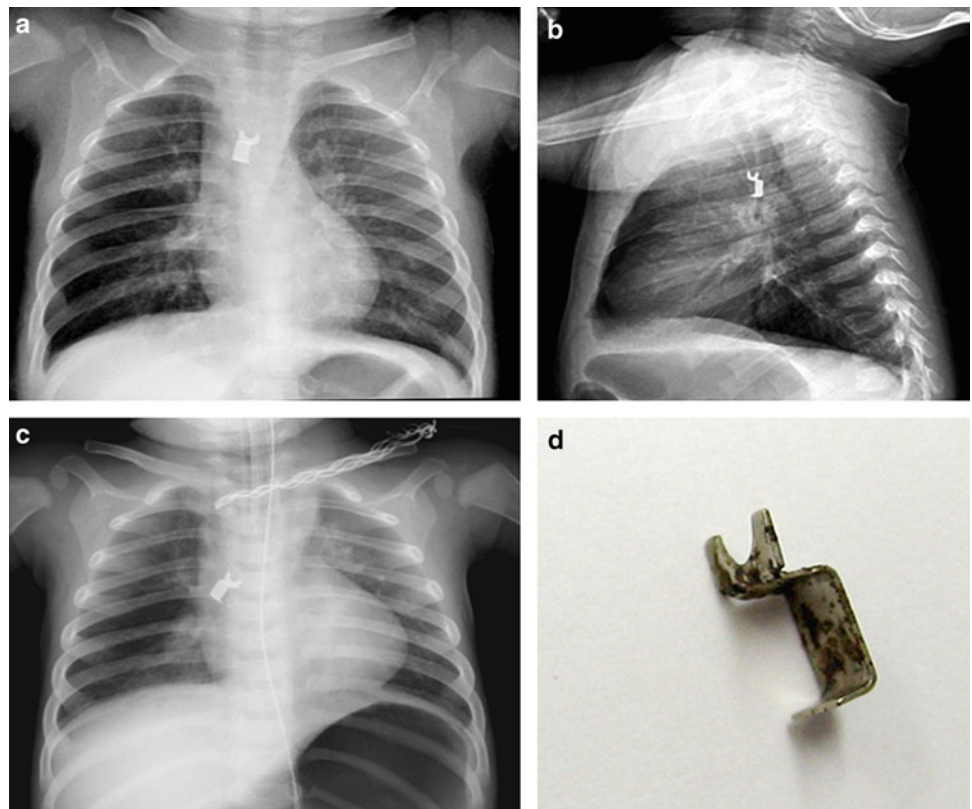
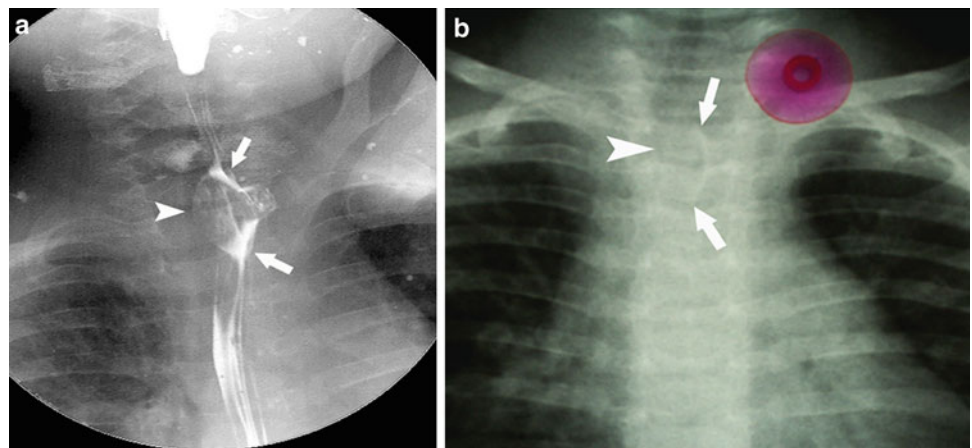


Fig. 8 A rubber-made vacuum hanger was swollen by a 2-year-old boy causing stridor and salivation. Oblique view of a barium swallow study (a) demonstrated the rubber hanger in the proximal esophagus (arrows), causing marked posterior compression and narrowing of the trachea (arrowhead). Magnified AP chest radiograph (b) demonstrated the rubber hanger in the upper esophagus, with a similar one illustrated on the top left corner of the film



Senkaya et al. 1997; Metrangolo et al. 1999; Oguz et al. 2000; Van Looij et al. 2003; Ayed et al. 2003; Pinto et al. 2006; Zhijun et al. 2008; Cohen et al. 2009; Rodriguez et al. 2013), as opposed to predominance of the right bronchial tree in older children, adolescents, and adults (Baharloo et al. 1999; Fraga Ade et al. 2008; Roda et al. 2008; Kitcher 2009; de Sousa et al. 2009; Tang et al. 2009; Saki et al. 2009; Falase et al. 2013; Sidell et al. 2013). These differences can partly be explained by the almost symmetrical tracheobronchial angle in younger children (Cleveland 1979) and by the position of the carina that is more

commonly seen left to the midline (Tahir et al. 2009). Migration of a small foreign body within the airways during different phases of the respiratory cycle, secondary to alterations of posture or following cough is rare, but does occur, and can change the clinical and imaging findings (Figs. 5, 6) (Metrangolo et al. 1999). The authors witnessed a case in which a foreign body that was located in the right main bronchus migrated to the right upper lobe bronchus when the father of the child turned her upside down in an attempt to expel the foreign body from the airway. Since in those days only rigid bronchoscopy was available, the

foreign body could not be endoscopically removed and the patient required thoracotomy and lobectomy. Migration of a foreign body can also occur during bronchoscopy, if the foreign body detaches from the bronchoscopic forceps on its way out or if it is partially lodged into the tracheal or bronchial wall and has to be manipulated prior to its extraction.

4 Clinical Findings and Differential Diagnosis

The clinical manifestations of aspirated foreign bodies vary according to the location and degree of obstruction.

Laryngeal and subglottic foreign bodies make up about 5 % of foreign bodies in the airways (Mantel and Butenandt 1986; Esclamado and Richardson 1987; Cohen et al. 1993; Black et al. 1994; Baharloo et al. 1999). When large enough, their presence in the major airway causes dyspnea, and when located adjacent to the vocal cords they may induce hoarseness, sudden loss of voice, and inspiratory stridor (Blazer et al. 1980; Hanukoglu et al. 1986; Laks and Barzilay 1988). Cyanosis may occur secondary to laryngeal spasm (Halvorson et al. 1996; Baharloo et al. 1999; Ciftci et al. 2003). Similar symptoms can be induced by other processes such as a laryngeal web (Chen et al. 1998), viral or bacterial croup, epiglottitis, papilloma or hemangioma, angioneurotic edema, or hypocalcemic tetany (Grad and Taussig 1990; Ibrahimov et al. 2013). Laryngeal or tracheal hirudiniasis following leech infestation while drinking infected stream water can cause the same symptoms due to mechanical obstruction. In addition, the combination of the grasp of the mucosa by the leech cutting plates and secretion of an anticoagulant causes hemorrhage that can result in prolonged hemoptysis and anemia (Mohammad et al. 2002; Yazici et al. 2012).

Tracheal foreign bodies constitute 4–13 % of foreign bodies in the airways (Mu et al. 1990, 1991; Black et al. 1994; Burton et al. 1996; Metrangelo et al. 1999) (Figs. 1, 7). In one series, they represented 23 % of the cases with early diagnosis and 7 % of the cases with late diagnosis (Oguz et al. 2000). In most patients there is a history of choking and dyspnea, yet they tend to be diagnosed later than bronchial foreign bodies, probably because they cause less severe respiratory symptoms (Esclamado and Richardson 1987). Inspiratory or biphasic stridor and wheeze can also be caused by tracheomalacia or external compression on the trachea by a vascular structure. Vascular rings usually cause a focal narrowing, but can have a hazardous effect by blocking a small foreign body that would have otherwise be aspirated into a more distal bronchus, thus turning a partial, distal bronchial obstruction to a

potentially fatal tracheal obstruction. Other causes of external compression include bronchogenic cysts, enlarged lymph nodes (secondary to viral or bacterial infection or due to tuberculosis), mediastinal tumors (e.g., lymphoma), or an esophageal foreign body (Fig. 8). A hollow foreign body located in the larynx or trachea can be almost asymptomatic and thus presents a unique diagnostic challenge (Jain et al. 2013).

Bronchial foreign bodies The majority of aspirated foreign bodies (67–85 %) are found in the main bronchi (Blazer et al. 1980; Mantel and Butenandt 1986). A history of sudden choking is the most important clue for diagnosis (Esclamado and Richardson 1987; Silva et al. 1998; Zerella et al. 1998; Metrangelo et al. 1999; Oguz et al. 2000; Ciftci et al. 2003). Such a history, however, was documented in only about one third of the cases in one series (Oguz et al. 2000). The classical triad of a choking episode, cough, and wheeze was found in over 90 % of the patients in another series (Blazer et al. 1980). Hemoptysis can be a presenting symptom (even in cases of a blunt foreign body) (Scully et al. 1983; Maayan et al. 1993; Fabian and Smitheringale 1996; Cataneo et al. 1997; Zuniga et al. 2000; Abellan Martinez et al. 2000; Mohammad et al. 2002). Physical examination will reveal unequal chest expansion during inspiration, as well as decreased breath sounds over the obstructed lung (Laks and Barzilay 1988; Oguz et al. 2000; Orji and Akpeh 2010; Roda et al. 2008; Huankang et al. 2012). Occasionally, a slapping sound of a loose foreign body can be heard (Felman 1982).

In cases of delayed diagnosis, pneumonia is a common presentation. The presence of an aspirated foreign body should be suspected in any patient with unexplained chronic pulmonary symptoms. Foreign body aspiration, however, is by no means the most common cause of recurrent pneumonia. Recurrent or persistent pneumonia can also result from bacterial infections, gastroesophageal reflux, impaired clearance of secretions from the tracheobronchial tree as in asthma, ciliary dysmotility (primary ciliary dyskinesia), cystic fibrosis, infected bronchiectasis or secondary to an immune deficiency (Kumar et al. 2009). Tumors of the tracheobronchial tree are uncommon in children, but, when present, may cause a varying degree of airway obstruction. Foreign bodies can sometimes coexist with other medical conditions that elicit similar symptoms such as allergic asthma, recurrent infections, or acute bronchiolitis (Ezer et al. 2011). Persistent symptoms and lack of improvement despite appropriate medical therapy should raise suspicion for the presence of a foreign body.

Esophageal foreign bodies can mimic foreign bodies in any location of the airway due to external compression of the larynx, trachea, or bronchi (Fig. 8). Such compression can cause laryngeal or tracheal spasm, resulting in respiratory

Fig. 9 Anteroposterior chest fluoroscopy at inspirium (a) and expirium (b) demonstrating minimal change in volume and lucency of the hyperinflated, obstructed right lung as opposed to volume loss and change in opacity of the deflated left lung in expiration (b). Note the arched and more superior position of the left hemidiaphragm and the mediastinal shift toward the unobstructed left lung at expiration

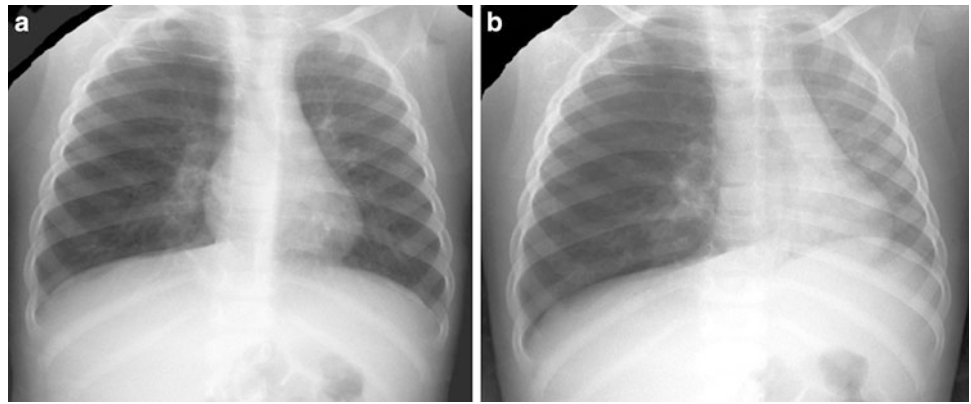
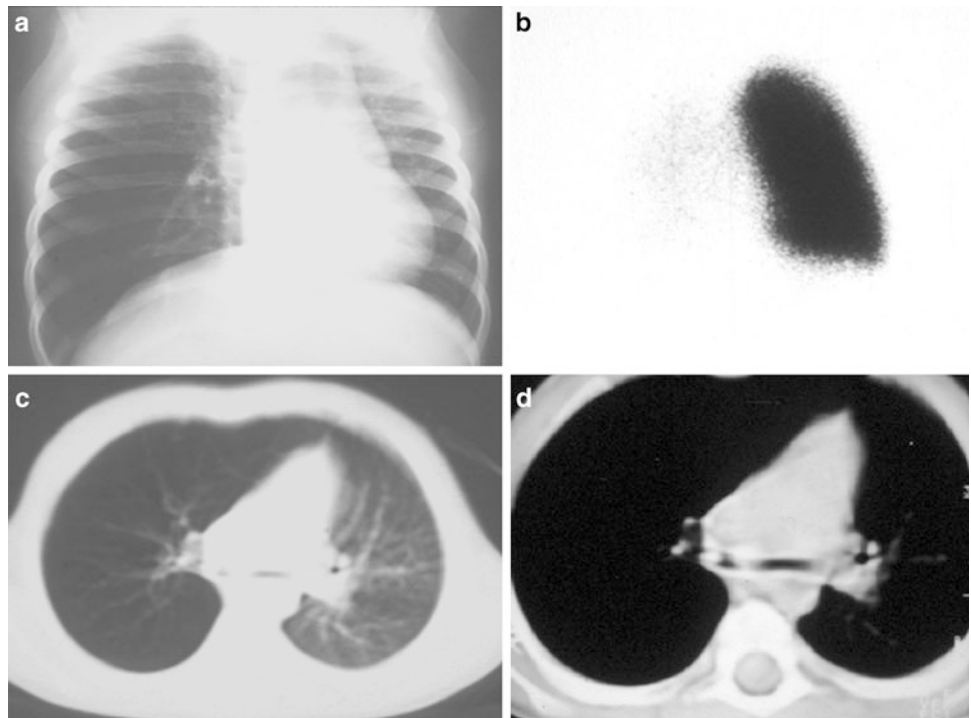


Fig. 10 A 20-month-old boy had a choking episode. Initial chest radiograph (a) demonstrated obstructive emphysema of the right lung; bronchoscopy failed to reveal a foreign body. Lung scan (b) showed lack of perfusion to the right lung. Chest CT demonstrated obstructive emphysema of the right lung with contralateral mediastinal shift (c), as well as a foreign body in the right main bronchus (d). Repeat bronchoscopy identified a lentil



distress, stridor, or wheeze (Smith et al. 1974). In infants operated for congenital esophageal atresia, the combination of esophageal dilatation proximal to a stenotic anastomosis and an inherent tracheomalacia can result in severe tracheal narrowing, stridor, and a respiratory arrest. A tracheoesophageal fistula may develop as a result of a decubitus ulcer caused by an esophageal foreign body of long-standing duration (Szold et al. 1991; Li et al. 2009).

Nasal foreign bodies, when present for a long time, usually cause swelling of the nostrils or nasal discharge that may be foul smelling. They can ulcerate and damage the nasal septum, dislodge into the nasopharynx, and seldom can be aspirated into the tracheobronchial tree (Cohen et al. 1993; Fini-Storchi and Ninu 1996; Qureshi et al. 2009).

5 Imaging Techniques

Chest Radiograph. The plain chest X-ray remains the initial study in the evaluation of a suspected aspirated foreign body. Abnormal findings are found in 40–88 % of chest X-rays in children with proven foreign bodies (Laks and Barzilay 1988; Mu et al. 1990; Black et al. 1994; Oguz et al. 2000; Cataneo et al. 2008; Fraga Ade et al. 2008; Sidell et al. 2013). These rates increase when using inspiratory–expiratory techniques (Black et al. 1984, 1994; Losek 1990). Opaque foreign bodies are easily identified, but most are radiolucent (Figs. 1, 2, 11).

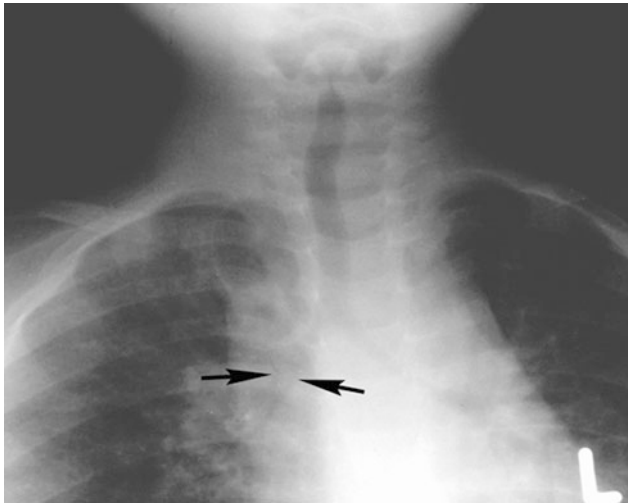


Fig. 11 High kV copper filter technique of the tracheobronchial tree of a 15-month-old girl. A nonopaque foreign body (*arrows*) surrounded by air is seen at the carina and in the right main bronchus. The inspiration and expiration films did not reveal air trapping or any other pulmonary pathology

In cases of a nonopaque foreign body, inspiratory and expiratory films can provide important information. Comparison of the two hemithoraces is mandatory. The inspiratory film is often normal or near normal, while the expiratory film shows obvious air-trapping. The obstructed lung is of larger volume and more radiolucent. The decrease in ventilation of the obstructed lobe causes an increase in $p\text{CO}_2$. The higher $p\text{CO}_2$ leads to arterial vasoconstriction and therefore to reduced pulmonary perfusion. Thus, the vessels in the obstructed region become narrow and sparse. This finding, characteristic of obstructive emphysema, can be seen on both plain films and Computed Tomography (CT). There is usually a mediastinal shift to the opposite side in expiration, as well as a lower ipsilateral hemi diaphragm (Figs. 9, 10).

In young children, whose cooperation is not always optimal, two lateral decubitus films, one on each side, can replace the inspiratory–expiratory films (Capitanio and Kirkpatrick 1972). An unobstructed, dependent lung shows smaller volume and crowded vessels as a result of gravitational forces on the abdominal and mediastinal organs. In cases of partial obstruction, the dependent lung does not deflate as expected. The relative hyperinflation of the dependent lung thus indicates the presence of partial bronchial obstruction.

Alternatively, expiratory films can be obtained in non-cooperative patients by applying manual pressure on the upper abdomen using a lead glove during the examination (Wesenberg and Blumhagen 1979). In infants this can also be done by inflating a blood pressure cuff, wrapped around the abdomen. Careful monitoring must be performed to

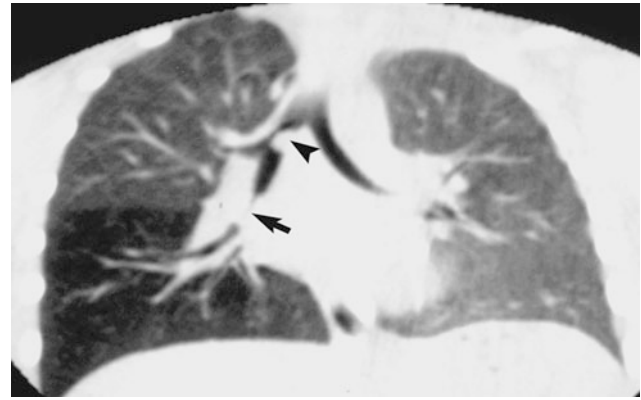


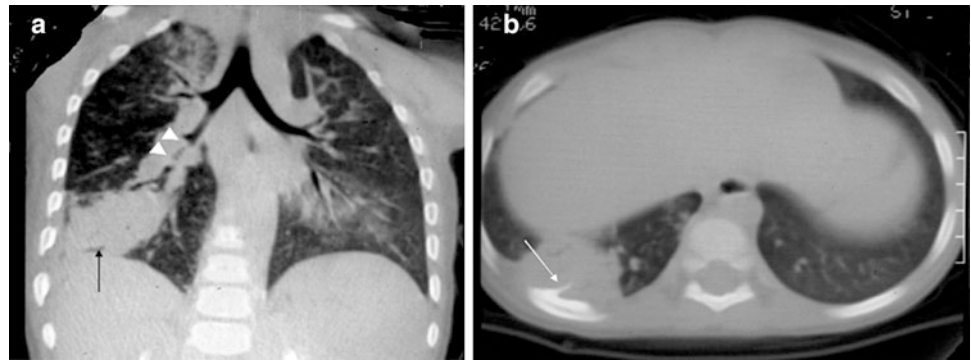
Fig. 12 A semicoronal chest CT (lung settings) of a 2-year-old boy, obtained in expiration. Soft tissue density is demonstrated in the bronchus intermedius causing a partial obstruction (*arrow*). This is the equivalent of the “absent segment” sign that results from the presence of an obstructing foreign body and inflammatory changes in the adjacent bronchial wall. Note also the obvious air trapping in the right lower lobe as compared to the normal-sized right upper lobe and left lung. Another partially obstructing foreign body is seen adjacent to the medial wall of the right main bronchus (*arrowhead*)

ascertain that at no time the pressure in the cuff exceeds the child’s systolic blood pressure. Oblique projections enable better visualization of the trachea and main bronchi, and may demonstrate an otherwise “hidden” foreign body or discontinuation of the air column, depicted as an “absent segment” of the airway (Figs. 2, 3).

The High kilo-voltage (kV) Copper Filter Technique increases the visibility of the major airways and of non-opaque foreign bodies (Fig. 11). This technique combines the use of high kV with filters that absorb most of the low energy photons. As a result, the contrast between soft tissue and bone is reduced and the contrast between air and all other tissues is increased. Thus, the airway and its contents are sharply delineated over the background of the other tissues. Various filters have been used; however, the combination of 0.4 mm of tin, 0.5 mm of copper, and 0.75 mm of aluminum is probably the most useful. The use of this technique enables improved visualization of the major airways with reduced radiation dose (Joseph et al. 1976).

The sensitivity, specificity, and accuracy of chest radiographs for the detection and diagnosis of aspirated foreign bodies have been shown to be low when compared to bronchoscopy or to clinical signs in several retrospective studies (Svedstrom et al. 1989; Hoeve and Rombout 1992; Hoeve et al. 1993; Barrios Fontoba et al. 1997; Silva et al. 1998; Zerella et al. 1998; Sehgal et al. 2002; Ayed et al. 2003; Pinto et al. 2006; Cataneo et al. 2008; Kiyani et al. 2009; Zaupa et al. 2009; Hitter et al. 2011). In some series, up to 50 % of chest X-rays obtained in children with proven foreign bodies were found to be normal when filmed in the early period (within 3 days) following aspiration; however, expiratory

Fig. 13 A 3-year-old boy aspirated a branch of Timothy grass. Semicoronal (a) and axial (b) chest CT demonstrate narrowing and irregularity of the bronchus intermedius (arrowheads), distal atelectasis, and abscess formation (arrow). Also note sclerosis of the adjacent rib representing osteomyelitis (white arrow in (b))



radiographs were not routinely obtained in these studies (Zerella et al. 1998; Oncel et al. 2012). Expiratory films have a high diagnostic value, but without clinical suspicion of foreign body aspiration, they will not be routinely performed. Therefore, it is mandatory that the clinician provide this sort of information to the radiologist in charge of the exam. Chest X-rays can also be normal in cases of a radiolucent tracheal foreign body that is not large enough to cause obstruction (Chang and Pereira 2013) and in cases of bilateral bronchial foreign bodies (Wiseman 1984; Musemeche and Kosloske 1986; Laks and Barzilay 1988).

Fluoroscopy can still raise a significant contribution to the investigation of foreign body aspiration. The proponents of this modality advocate its use because it is widely available, easy to use, and rapidly diagnostic in up to 90 % of cases of a bronchial foreign body (Blazer et al. 1980; Zerella et al. 1998). In our practice, fluoroscopy is seldom used. Nevertheless, the radiologist can optimally visualize the airways and detect obstruction or the presence of an opaque foreign body with fluoroscopy (Fig. 3b), especially if a copper filter is used adjacent to the X-ray tube or close to the patient (W.E. Berdon, personal communication). Mediastinal shift toward the obstructed side during inspiration and towards the contralateral side during expiration is easily recognized (Fig. 9) (Theander 1970; Laks and Barzilay 1988; Mu et al. 1990). Unequal descent or ascent of the hemidiaphragms on inspiration and expiration can be seen and is more easily noticed in crying babies and in older children when requested to sniff rapidly. Diminished excursions of the diaphragmatic leaflets are invariably seen on the affected side, either with hyperinflation (in partial obstruction) or with volume loss (in complete obstruction) (Theander 1970). Use of any technique for assisted expiration, as described earlier, can facilitate demonstration of air-trapping. Digital subtraction fluoroscopy has been described as a sensitive method for the demonstration of tracheal and bronchial narrowing secondary to the presence of a radiolucent aspirated foreign body (Ikeda et al. 2001). The use of “last image hold” and “last fluoroscopy hold” applications currently installed in most modern fluoroscopy

machines enables quick exclusion or confirmation of suspected bronchial obstruction with minimal radiation exposure.

Computed tomography (CT), due to its high contrast resolution, enables demonstration of foreign bodies that are frequently not visible on the chest X-ray. CT is usually utilized as a part of work-up for unclear cases of persistent, nonresolving respiratory symptoms, for which foreign body aspiration can be one of the reasons. When initial imaging studies or bronchoscopy are negative, CT may reveal the presence and location of a previously undiagnosed foreign body (Berger et al. 1980; Bertolani et al. 1999). CT is a very sensitive modality for demonstrating small dense objects, such as thin fish or chicken bones, that may not be detected on plain films (Braverman et al. 1993; Mignon et al. 1997; Bai et al. 2011; Hitter et al. 2011; Sattar et al. 2011; Manach et al. 2013).

CT is also an efficient tool for the demonstration of small plastic toy particles such as LEGO pieces (Applegate et al. 2001) or rubber products. The presence and location of an intraluminal lesion can easily be detected and multiple intrabronchial findings can at times be identified (Figs. 4, 10, 12, 13), as well as the “interrupted bronchus” sign. Intravenous contrast administration can enhance discrimination between an intraluminal foreign body and other endobronchial, bronchial wall, or extrinsic findings, such as a hemangioma or lymph nodes. By varying window width and level, one can see not only the foreign body, but also the reaction of the tissue around and distal to it. One can also assess the presence and extent of complications such as air-trapping, atelectasis, pneumonia, alveolar hemorrhage, empyema, bronchiectasis, or chest wall involvement (Figs. 4, 10, 12, 14) (Haliloglu et al. 2003; Kosucu et al. 2004; Adaletli et al. 2007). Air-trapping is well demonstrated by decubitus scans (Fig. 15) (Garcia-Pena et al. 1999; Lucaya et al. 2000; Choi et al. 2002). Scanning in the semicoronal plane had been used to demonstrate accurate localization of the obstructing foreign body (Figs. 12, 13) (Bar-Ziv and Solomon 1990). However, with current helical, multidetector scanners using volumetric acquisition of

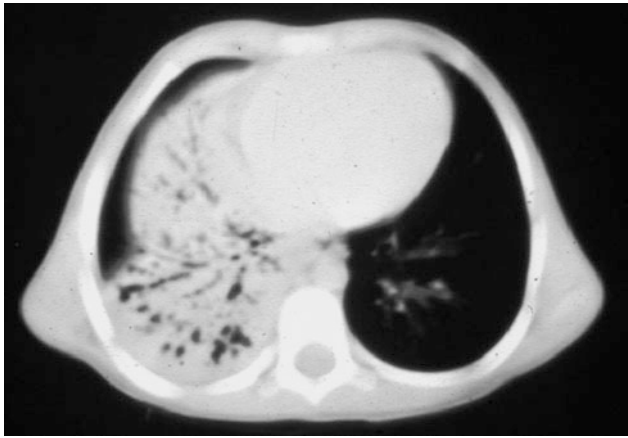


Fig. 14 Axial CT of the lower chest in a case of chronic foreign body aspiration into the right intermediate bronchus, causing collapse and bronchiectasis in the right middle lobe and right lower lobe

data, a high pitch and a short scanning time, accurate multiplanar reconstructions can be obtained, thereby replacing the semicoronal scans.

We routinely use a helical technique with 3-mm collimation, 3-mm reconstructions for adolescents and children, with the smallest possible field of view. For infants and toddlers we may use 2-mm collimation with 1-mm reconstructions. Tube current can be reduced to as low as 25–30 mA for such studies, and kV can be reduced to as low as 80–90, depending on child age and weight. Multiplanar reconstructions are helpful in detecting airway foreign bodies (Kosucu et al. 2004; Kocaoglu et al. 2006; Adaletli et al. 2007; Bai et al. 2011). Virtual bronchoscopy can further contribute to the diagnosis and location of a presumed aspirated foreign body when a chest radiograph is not informative (Konen et al. 1998; Haliloglu et al. 2003; Kosucu et al. 2004; Kocaoglu et al. 2006; Adaletli et al. 2007; Cevizci et al. 2008). Virtual bronchoscopy has the advantage of demonstrating smaller airways than possible to view with conventional bronchoscopy, as well as the airways beyond an obstructed bronchus (Haliloglu et al. 2003; Kosucu et al. 2004; Adaletli et al. 2007; Cevizci et al. 2008; Bhat et al. 2010). However, reconstructions are time consuming and have not been shown to contribute additional information over multiplanar reconstructions (Kosucu et al. 2004; Kocaoglu et al. 2006). The major disadvantage of CT examinations is the inherent radiation exposure of the young patient, despite improved technology and increasing awareness of both manufacturers and radiologists to minimize radiation dose. Therefore, it is imperative to weight the potential benefit of the additional data yielded as a result of each study against the potential risk, especially in cases when conventional bronchoscopy, that might be both diagnostic and therapeutic, is to be carried out as well (McHugh 2005; Manach et al. 2013).



Fig. 15 Right lateral decubitus chest CT demonstrates air-trapping in the right (dependent) lung, following aspiration of a piece of an eraser

Nuclear medicine is not recommended for the diagnosis of a bronchial foreign body. When used, however, the lung scan can be helpful in defining regional decrease in ventilation and perfusion (Fig. 10b), as well as air-trapping, and can thus guide endoscopy to the area of suspected obstruction (Holland and Trumbull 1979; Lull et al. 1980; Balink et al. 2012).

Magnetic resonance imaging (MRI) studies are also rarely used for investigating suspected foreign body aspiration, especially because at present the use of sedation is mandatory. Nevertheless, several reports have described the utility of MRI in the management of foreign body aspiration. Due to the multiplanar nature of this modality, MRI can accurately locate the foreign body prior to bronchoscopy, and can also reveal foreign bodies in multiple sites during the same study (Imaizumi et al. 1994; Morijiri et al. 1994). The high fat content of aspirated peanuts, as well as the high water content of most organic foreign bodies enable clear delineation of their size and site (O'Uchi et al. 1992; Tashita et al. 1998).

Ultrasound (US) can be of value in defining the presence, nature, and extent of complications of foreign bodies, such as consolidation with an air bronchogram, pleural effusion or empyema, loculated pockets of fluid, chest wall abscess, or rib osteomyelitis (Seibert et al. 1986; Giudicelli et al. 1996). Ultrasound can presumably demonstrate the foreign

body within the collapsed lung; however, the authors do not have experience in this.

6 Imaging Findings

Imaging findings in cases of foreign body aspiration are determined by the presence and the degree of airway obstruction, the site of the foreign body, its type, and the time that has elapsed between aspiration and the performance of imaging studies.

A foreign body can be present in the airway without causing obstruction. This situation almost always involves an oblong foreign body in the trachea, small enough to have been aspirated yet not large enough to block the (relatively) larger airway. In such a case the chest radiograph and fluoroscopy will usually be negative, although pneumonia might be present (Esclamado and Richardson 1987; Mu et al. 1990; Cataneo et al. 1997). Fluoroscopy or a high kV soft tissue technique with a copper filter may reveal the foreign body (Fig. 11). CT (Gupta and Berry 1991; Malis and Hayes 1995; Bertolani et al. 1999) and MR imaging (O'Uchi et al. 1992; Imaizumi et al. 1994; Morijiri et al. 1994; Tashita et al. 1998) can demonstrate the presence and often the nature of such a foreign body when the initial imaging is negative.

Obstruction of the airway can vary in severity and occur at different levels of the tracheobronchial tree. Laryngeal or subglottic foreign bodies tend to be thinner and are often arranged in an anteroposterior direction (sagittal plane) in the region of the vocal cords, as opposed to esophageal foreign bodies, which lie in a transverse direction (coronal plane). If the foreign body is a thin, rounded object (e.g., a coin or an egg shell), it will be seen as a thin line on the anteroposterior chest radiograph when located between the vocal cords, and as a rounded shadow when located in the esophagus. Tracheal foreign bodies usually cause no obstruction or incomplete obstruction. The imaging findings, when present, are often bilateral: either bilateral volume loss or bilateral hyperinflation (Fig. 7). In the latter case, the diaphragms are flattened and in a low position. When small enough, the foreign body may move in the tracheobronchial tree during the different phases of the respiratory cycle, as a result of coughing or following treatment with inhaled bronchodilators, with consequent changes in the clinical and imaging findings (Figs. 5, 6) (Metrangelo et al. 1999).

About three quarters of airway foreign bodies are found in the main bronchi (Blazer et al. 1980; Mantel and Butenandt 1986; Zhijun et al. 2008; Kitcher 2009; Saki et al. 2009), where they cause partial or complete obstruction. Plain films and fluoroscopy seldom demonstrate a nonopaque foreign body. An oblique projection obtained with these modalities,

placing the upper airway over the mediastinal soft tissues, creates better contrast and enhances demonstration of the foreign body (Fig. 3). This technique may also indirectly reveal the presence of a foreign body by virtue of focal absence of the air column in the obstructed bronchus, the so-called "absent segment" or the "interrupted bronchus" sign (Fig. 2) (Grunebaum et al. 1979; Lim-Dunham and Yousefzadeh 1999). Partial obstruction results in localized air-trapping distal to the site of the foreign body, with resultant widening of the intercostal spaces, and flattening of the ribs and diaphragms, and blunting of the costophrenic angles (Laks and Barzilay 1988; Mu et al. 1990; Ernst and Mahmud 1994; Black et al. 1994; Oguz et al. 2000). Segmental or lobar emphysema due to air trapping has been reported to be present in ~40 % of children with proven foreign body aspiration (Bai et al. 2011; Sattar et al. 2011; Boufersaoui et al. 2013; Mortellaro et al. 2013); in some studies, this is indicated as the most specific finding in the chest radiograph (Hitter et al. 2011; Sattar et al. 2011; Boufersaoui et al. 2013). Pulmonary hyperexpansion with sparse vascularity or displacement of the mediastinum to the contralateral side on expiration indicates the presence of obstructive emphysema (Figs. 2, 5, 6, 9, 10) (Mu et al. 1990). Complete obstruction also causes segmental or lobar atelectasis (Figs. 2, 3, 5, 6), or even total collapse of the ipsilateral lung (Figs. 5, 6). The collapsed area may initially be homogeneously opaque, due to the absence of air in the alveoli and bronchi. Collateral diffusion of air to the bronchioles distal to the obstructing foreign body may result in a faint air bronchogram. In cases with lobar atelectasis, compensatory emphysema of the ipsilateral respected lobes and of the contralateral lung is often present (Theander 1970). In contrast to obstructive emphysema, pulmonary vessels are prominent in compensatory emphysema.

The presence of lobar collapse with localized pneumothorax should suggest the diagnosis of acute bronchial obstruction of any etiology (Berdon et al. 1984; Nimkin et al. 1995) (Fig. 16). The combination of increased pressure and the presence of a sharp object in the bronchi can result in a bronchopleural fistula. This complication, as well as pneumonia secondary to focal obstruction, may give rise to pleural effusion or empyema (Dogan et al. 1999). Pleural effusion as the only imaging sign of foreign body aspiration has also been reported (Auerback 1990). In prolonged cases, localized or multifocal bronchiectasis may develop and be evident on the plain radiograph (Fig. 3) or on CT (Fig. 14); these are best evaluated by high-resolution CT with thin section collimation (Kuhn 1993). Subacute or chronic infection and inflammatory response may form a parenchymal abscess adjacent or distal to the foreign body, or a chest wall abscess and rib osteomyelitis (Fig. 13).

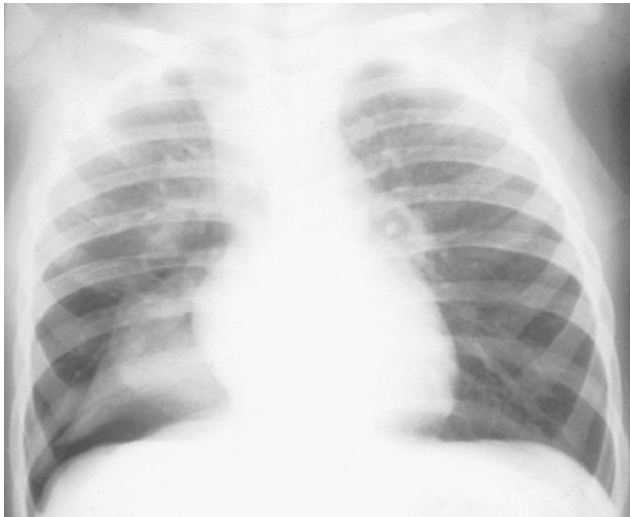


Fig. 16 Collapsed right lower lobe with localized pneumothorax due to acute foreign body aspiration

7 Complications

Complications of foreign body aspiration can be immediate or long term. A foreign body can cause *fatal asphyxia and death* when there is complete obstruction of the major airways (Buntain et al. 1979; Black et al. 1984, 1994; Byard 1994; Bhana et al. 2000; Ciftci et al. 2003). This occurrence is rare, although it was described in 5–7.5 % of foreign body aspiration cases in one report (Menendez et al. 1991; Foltran et al. 2013). This high incidence has not been observed in the author's experience and is not corroborated in most other reports. Complete obstruction can develop abruptly when a relatively small foreign body is aspirated into a trachea with a pre-existing (sometimes unknown) focal narrowing caused by a vascular ring, tracheomalacia or external compression. Complete obstruction can also occur during bronchoscopy for extraction of a foreign body (Fig. 7).

Asphyxia and hypoxemia can result in hypoxic-ischemic encephalopathy, convulsions, severe neurologic deterioration over varying period of time and death within several days or following several months or years (Northcote 1983; Bamber et al. 2013).

Atelectasis is reported by some as the most common complication of foreign body aspiration (Mu et al. 1990; Cataneo et al. 1997; Oguz et al. 2000), and is seen in 21–50 % of the patients who are diagnosed 24 h or more after the suspected aspiration event (Figs. 2, 3, 5, 6, 16) (Wiseman 1984; Mortellaro et al. 2013). Though atelectasis usually develops gradually, collapse of the entire lung may occur within an hour. When this happens on the right side,

kinking of the superior vena cava may cause a sudden decrease of venous return to the heart and lead to loss of consciousness. Elevation of jugular venous pressure should alert the examining physician to the possibility of such a complication.

Pneumonia appears in 20–50 % of patients with an aspirated foreign body diagnosed 3 days or later consequent to the aspiration event (Cataneo et al. 1997; Oguz et al. 2000; Diaz et al. 2000; Tenjovic et al. 2013). The pneumonia in these cases is usually located in the lower lobes, does not resolve following antibiotic therapy and is frequently associated with a pleural effusion. Pneumonia may at times be due to uncommon pathogens (Cavens et al. 1973; Baethge et al. 1990), and can be accompanied with the formation of multiple lung abscesses. Dirt or shallow water aspiration can lead to diffuse pneumonitis (Mangge et al. 1993; Li et al. 2009).

Air leak A sudden increase in alveolar pressure due to proximal obstruction can cause an air leak into the interstitial space, leading to interstitial emphysema, pneumomediastinum (Hanukoglu et al. 1980; Burton et al. 1989; Ramadan et al. 1992; Bratton and O'Rourke 1993; Oliveira et al. 2002; Ciftci et al. 2003; Ogun et al. 2008; Li et al. 2009; Zielinski et al. 2011; Nimrey-Atrash et al. 2012; Hu et al. 2013), pneumothorax (Fig. 16) (Berdon et al. 1984; Esclamado and Richardson 1987; Ramadan et al. 1992; Nimkin et al. 1995; Cataneo et al. 1997; Newson et al. 1998; Carron and Derkay 2000; Ciftci et al. 2003) or pneumopericardium (Tjhen et al. 1978; Bro and Thamsen 1989). The abrupt onset of an air leak in a child under 2 years of age, without a history of chest trauma or asthma, should raise the suspicion of an aspirated foreign body (Cataneo et al. 1997).

Long-term complications The incidence and severity of long-term complications are directly related to the length of time that has passed between the actual event of aspiration and establishment of the diagnosis (Auerback 1990; Linegar et al. 1992; Schmidt and Manegold 2000; Karakoc et al. 2002). Positive radiological findings are more common in cases diagnosed 24 h later consequent to the suspected aspiration (Esclamado and Richardson 1987; Mu et al. 1990); the longer the delay in diagnosis, the higher the rate of complications (Levy et al. 1983; Mu et al. 1990; Karakoc et al. 2002; Shlizerman et al. 2010). In most cases of delayed diagnosis, the original episode passed unnoticed and the parents or physician do not relate recent, recurrent signs and symptoms as being linked to such an episode or to each other (Mantel and Butenandt 1986). In such cases the presentation can be that of recurrent events of hyper-reactive airway disease, with incomplete response to treatment,

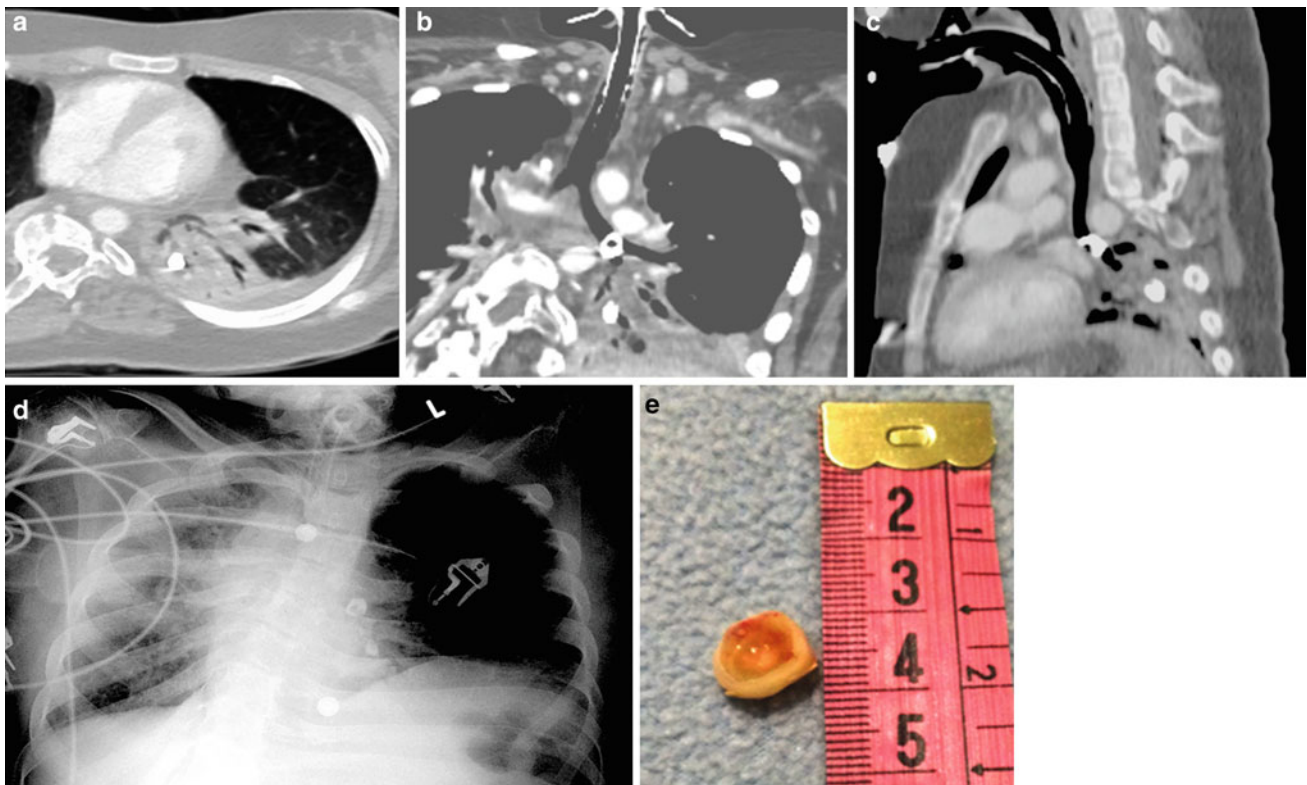


Fig. 17 7-year-old debilitated girl was referred from another institution for a chest, abdomen, and pelvis CT scan as part of an evaluation for acute deterioration and suspected intestinal obstruction. Left lower lobe atelectasis and bronchiectasis were noted in the axial images (a) and the curved coronal (b) and sagittal (c) reformats, as well as two bronchial opaque structures resembling teeth, one in the left main

bronchus and one in the left lower lobe. These were in retrospect identified in a previous chest radiograph (d) and were thought to have dropped into the trachea during a previous tracheal cannula replacement. A dental crown (e) was extracted from the left main bronchus at bronchoscopy; extraction of the more distal crown was not carried out as it was considered too complicated and risk-bearing

or of recurrent pneumonia, with or without abscess formation, pleural effusion, or empyema (Burton et al. 1989; Auerback 1990; Dogan et al. 1999; Li et al. 2009).

Chronic bronchitis and bronchiectasis (Figs. 3, 14, 17) secondary to long-standing foreign body aspiration constitute approximately 5 % of chronic suppurative lung disease. The presence of a bronchial foreign body of long duration causes atelectasis that can become infected and lead to the development of bronchiectasis. This can become so severe that bronchoscopic extraction of the foreign body might not be possible, and surgical treatment may eventually be required (Spencer et al. 1981; Gatch et al. 1987; Maayan et al. 1993; Nikolaizik and Warner 1994; Cataneo et al. 1997; Scully et al. 1998; Karakoc et al. 2002; Adegboye et al. 2003).

Grass heads of different types have been reported to cause a unique sequence of complications (Ammari et al. 2000). If they have spikes that are soft and close together, as is the case of Timothy grass, they will soften with moisture following aspiration and will not penetrate into the lung

periphery. The grass head may lodge in the bronchial tree and occlude it causing obstructive emphysema, collapse, pneumonia, and lung abscess. If the spikes are stiff and do not become soft when moistened, or when inhaled stump-first, respiratory actions and cough can cause them to advance. Being carried by the spikes distally into the bronchial tree, they can penetrate the lung tissue and ultimately even extrude spontaneously through the chest wall (Hilman et al. 1980). During this process they can cause lung abscess (Fig. 13), bronchocutaneous fistula (Cavens et al. 1973; Baethge et al. 1990; Maayan et al. 1993; Dindar et al. 1994), rib osteomyelitis (Figs. 13, 18), chest wall abscess, or pneumocutaneous fistula (Cheng et al. 1991). Among several of our patients who suffered such a complication, one was a 3-year-old boy who had aspirated a branch of Timothy grass. Subsequently, the child developed cough and fever. A chest radiograph obtained several weeks later showed consolidation and volume loss in the right lower lobe. A semi-coronal chest CT study revealed irregularity and narrowing of the right lower lobe bronchus, partial consolidation, and

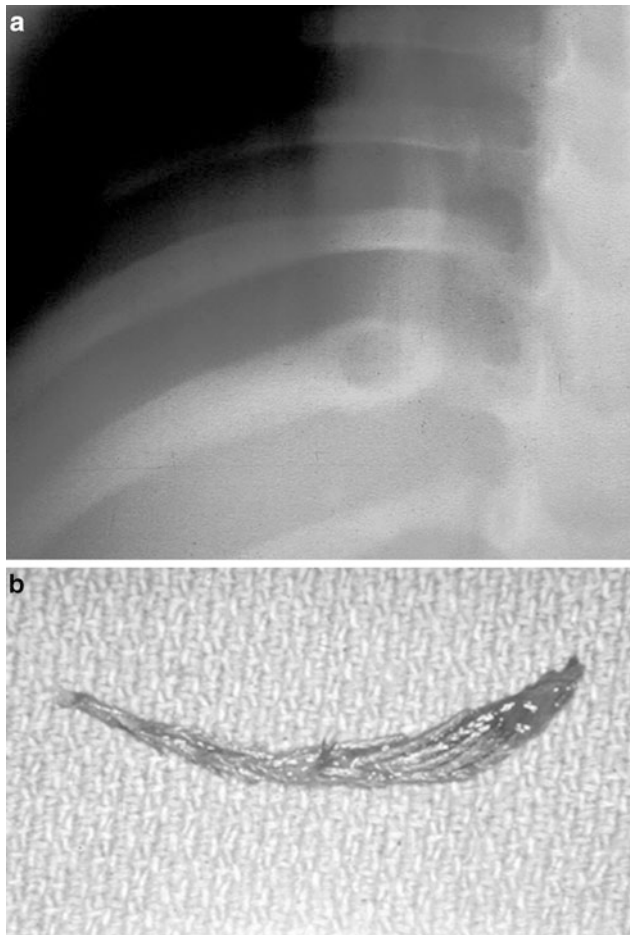


Fig. 18 A 2-year-old girl had repeated episodes of right lower lobe pneumonia for several months following an episode of choking around Christmas. Chest radiograph (a) showed an osteolytic lesion with thickening and sclerosis in a rib at the right lower chest. At surgery, a pine tree needle (b) was found in the rib, with osteomyelitis

atelectasis of the right lower lobe with abscess formation. Thickening, sclerosis, and irregularity of the inner border of the adjacent rib were also noted (Fig. 13). Pathology of the resected right lower lobe revealed the presence of Timothy grass within the bronchus of the lateral basal segment with bronchiectasis and abscess formation.

Brain abscesses have been reported in association with foreign body aspiration, presumably due to faulty pulmonary capillary filter mechanisms (Spencer et al. 1981; Sane et al. 1999; Fuentes et al. 2001; Shachor-Meyouhas et al. 2009; Dabbah et al. 2009).

Prolonged presence of a tracheal or an esophageal foreign body can result in a decubitus ulcer that can progress to a *tracheoesophageal fistula* (Fig. 19) with possible mediastinitis, which might require surgery (Szold et al. 1991; Li et al. 2009).



Fig. 19 A 6-week-old baby girl had suffered from respiratory symptoms since the age of 2 weeks. Tube esophagogram demonstrated a filling defect in the upper esophagus and a tracheoesophageal fistula. A pistachio nutshell was surgically removed and the fistula excised

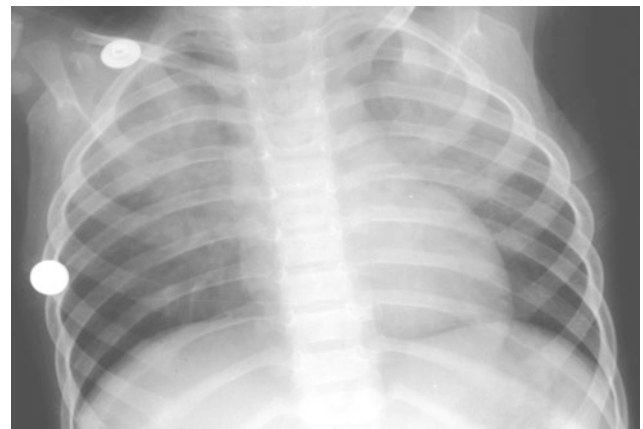


Fig. 20 Anteroposterior chest radiograph demonstrating ill-defined increased capacity of the upper zones bilaterally as a result of pulmonary edema following relief of obstruction after extraction of a foreign body

Pulmonary edema may occur subsequent to relief of an upper airway obstruction, regardless of the etiology (Fig. 20). The pathophysiology of the pulmonary edema in these cases is not fully understood. It is thought that pulmonary congestion develops during obstruction as a result of raised pleural negative pressure, which increases venous return to the heart, in the presence of decreased left ventricular function. The hypoxia causes pulmonary hypertension and increased capillary permeability. This combination leads to greater pulmonary vascular volume, which may be

radiographically difficult to detect because of associated air trapping. Once the obstruction is relieved and lung aeration returns to normal, the pulmonary edema becomes apparent (Sofer et al. 1984a, b, 1985).

8 Conclusion

A wide variety of opaque or nonopaque foreign bodies can be aspirated by infants and young children. The history of choking is the most reliable clue for the diagnosis of foreign body aspiration, but many patients reach medical attention because of various nonspecific clinical symptoms. The role of the radiologist in these cases is crucial. Knowledge of the imaging features of a foreign body in the respiratory tract is essential for diagnosis. Many clinical and imaging findings are the result of a one-way obstruction mechanism, most commonly affecting one of the main bronchi. A normal inspiratory chest radiograph does not rule out an endotracheobronchial foreign body. Hence, expiratory films are extremely important to demonstrate air trapping. Alternatively, lateral decubitus or assisted expiration films can be used. The high kV copper filter technique is valuable for demonstrating the foreign body, and for indirectly showing an area of deficient aeration in the tracheobronchial tree, the “absent segment” sign.

Fluoroscopy can be very useful, but unfortunately the art of fluoroscopy is now almost lost. CT has become more valuable by virtue of its wide availability, high resolution, and the multiplanar, three-dimensional, and additional image reconstruction capabilities. CT can establish the diagnosis of a foreign body, indicate its exact location, and often show its composition, as well as any associated complications. Other imaging modalities can be used, though their role is not as well established. Nuclear scans are of some value only in cases of obstructive endobronchial foreign body. MRI has great potential and may be used extensively in the future. Currently, however, it is not widely available and usually requires sedation of the child. Ultrasound is being used to demonstrate complications such as pleural effusion or chest wall abscesses.

An understanding of the mechanisms of obstruction and their resultant clinical and imaging manifestations, especially when foreign body aspiration is highly suspected, can lead to earlier diagnosis and lower the complication rate.

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