Chapter

# Foreign Body in the Airway

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## Abstract

Foreign Body (FB) aspiration incidence follows a bimodal distribution and is commonly seen in children under the age of 5 or adults with advanced age. The type of FB can be organic or non-organic and varies depending on age, region of the world, and socioeconomic status. In children, FB aspiration is often a consequence of development and exploration. Aspiration of FB in adults typically occurs when cough reflex is blunted due to altered sensorium (from drugs, medications, advanced age), trauma to the airway, poor swallowing, or anatomical variations in the GI tract (strictures, Zenker's Diverticulum, etc. Symptoms can range from cough to asphyxiation depending on the acuity of the aspiration event. Initial management is focused on ensuring there is no airway compromise leading to respiratory failure. Bronchoscopy is the treatment of choice to retrieve the FB. This chapter will review the incidence of FB aspiration in children vs. adults and will focus on diagnosis and treatment including bronchoscopy, role of ECMO, and surgical intervention.

**Keywords:** foreign body, aspiration, cough, chest radiograph, bronchoscopy, anesthesia

## 1. Introduction

Foreign Body (FB) aspiration incidence is commonly seen in children or adults with advanced age [1, 2]. It is one of the most common reasons for emergency department visits and as of 2017, FB aspiration with asphyxiation is one of the leading causes of death in infants and fourth most common cause of death among preschool children [3]. The incidence of FB aspiration in children is higher than adults and it is more common in males than females [4–9]. According to some studies, up to 80% of FB aspiration cases are seen in kids less than three years of age with peak incidence below 1–2 years of age [10–14].

The type of FB can be organic or non-organic and varies depending on age, region of the world, and socioeconomic status. In children, FB aspiration is often a consequence of development and exploration. Young children tend to explore objects by placing them in their mouths and accidental aspiration results in FB in the airway. Furthermore, swallowing involves delicate coordination of oropharynx and the gastrointestinal tract. In children, the swallowing mechanism is not well developed and asynchrony between actions such as crying, laughing, or breathing while eating results in aspiration into the airway more easily.

Adults have a developed cough and swallow reflex which induces a strong cough to expel the FB out of the airway. Aspiration of FB in adult typically occurs when

this reflex is blunted due to altered sensorium (from drugs, medications, advanced age), trauma to the airway, poor swallowing, or anatomical variations in the GI tract (strictures, Zenker's Diverticulum, etc). In adults, organic objects such as food is the most common FB that is aspirated. The type of food that is aspirated has a geographical variation and the type of cuisine that is available. In the western countries it is usually nuts such as peanuts, whereas in the southeast Asian countries it is typically bone fragments (from chicken, fish, etc) [15–17]. There are also cases of iatrogenic foreign bodies especially in the healthcare setting such as medical equipment that is accidentally dislodged into the airway. For example, there are reports of oral care equipment dislodged into the airway, pieces of bronchoscope, biopsy forceps, cytology brushes, and blood clots from airway blee ding [2, 17, 18].

## 2. Clinical presentation

Cough is the most common symptom with up to 96% of the patients reporting this after FB aspiration. The symptoms depend on the acuity of the aspiration, the type of FB that is aspirated, and location of FB in the airway. Acute aspiration of FB in the upper airway can either cause complete obstruction or partial obstruction. Common symptoms of partial obstruction are cough, wheezing, chest pain, and dyspnea [19]. Complete obstruction typically presents as stridor, hoarseness, choking and cyanosis. If the FB is in the smaller airways, the typical symptoms are cough and wheezing.

However, in up to 36% of the cases, the patients can have silent aspiration and can be asymptomatic. These patients could present with chronic symptoms such as cough, recurrent infections and further work up might show aspirated foreign bodies. Despite the high prevalence, FB aspirations are difficult to diagnose. A detailed history is key to diagnosis, especially a history of a choking event should increase suspicion for foreign body aspiration (FBA). Clinical presentation can vary from subtle respiratory symptoms to life threatening airway compromise. In children, if the aspiration event is not witnessed by a caregiver, the diagnosis can be delayed. In up to 50% of cases, initial symptoms of choking, cough, dyspnea can resolve within minutes and result in a symptom-free interval. These children present later with nonspecific symptoms including chronic cough and recurrent pneumonias [20]. A child presenting with cyanosis, altered mental status and or severe respiratory distress is indicative of complete or near complete airway obstruction and requires immediate intervention [21].

The most common presenting symptom in children is acute onset of cough but other signs and symptoms include tachypnea, dyspnea, stridor, wheeze, hemoptysis, hoarse voice, fever, chest, and throat pain [21]. Physical findings include wheeze, cough, stridor, rales, and decreased breath sounds [21]. Stridor is heard with inspiration and can indicate obstruction above the level of the thoracic inlet. Expiratory wheeze is heard with obstruction below the level of the thoracic inlet, and unilateral wheeze can indicate the general site of obstruction [21].

## 3. Diagnostic workup

Chest radiographs are performed as part of the initial workup. They are not recommended to rule out FBA. Chest radiographs may not show the aspirated FB in 25% of cases. Chest radiographs can have secondary signs that may assist with

diagnosis. These include air trapping or obstructive emphysema due to ball-valve effect of the FB in the bronchus. Chest radiographs may also show atelectasis, pneumonia, pneumothorax and pneumomediastinum. Films obtained in forced expiration and inspiration can highlight these signs. These may be difficult to obtain in younger children and thus lateral films can help reveal such signs when the impacted lung is in the dependent position [21]. Computed tomography of the chest is another option. Though more specific, its use is limited to the cooperation of the patient, use of sedation and increased radiation [21]. Definite diagnosis and treatment is bronchoscopy accompanied by removal of the FB with the appropriate instruments. Blood in the airway, increased airway secretions, granulation tissue or pneumonia may impair bronchoscopy visualization of the FB.

## 4. Airway

The approach to management of pediatric FB aspiration will depend on whether the obstruction is partial or complete and the level of consciousness [22].

Children who can cough, cry or speak have an incomplete airway obstruction. These patients are managed expectantly, as attempts to relieve the partial obstruction may dislodge the FB and worsen the degree of obstruction. When the patient shows signs of tiring or is progressing toward complete obstruction, removal should be considered. Attempts to remove the FB should be made in the operating room. Sedation with ketamine (1-2 mg/kg IV or 4 mg/kg IM) produces dissociation while maintain respiratory drive and airway reflexes. Once sedated, laryngoscope is inserted with anatomic visualization to identify any supraglottic FB [22].

A complete airway obstruction is indicated by loss of ability to phonate or cough. Chest wall movement persists with attempted respiratory efforts. Pediatric basic life support techniques should be used in the conscious patient with complete airway obstruction. The increased intrathoracic pressure is expected to expel the FB from the airway. In infants, this is done with child in a head down position, using cycles of back blows and chest compressions. In children older than 1 year, the Heimlich maneuver is recommended. The oropharynx should be examined first for a visible FB. If no FB is visualized, laryngoscopy can be attempted in the emergency department. A neuromuscular blocking agent is only recommended if the child has a clenched mouth other signs of muscle tone that is prohibiting the laryngoscopy. If a FB is identified, removal is attempted using Magill or alligator forceps. This should be done with caution as to avoid advancing the FB to a position where it becomes more tightly dislodged or unretrievable. If BLS and laryngoscopy are unsuccessful, the FB should be advanced distally into either mainstem bronchus using a stylet or endotracheal tube. The "lip to tip" distance should be measured using the Broselow-Luten tape or other formulas. The child would be intubated with the endotracheal tube and stylet advanced as deeply as possible. This should result in advanced of the obstructing material into the mainstem bronchus usually the right. The endotracheal tube should then be withdrawn back to the previously measured distance. This maneuver should allow ventilation through one lung. If increased resistance develops subsequently, organic material may have dislodged and obstructed the endotracheal tube tip. Replacement of the endotracheal tube using the appropriate insertion depth is performed [22].

Short acting agents are preferred for induction and maintenance of anesthesia as depth of anesthesia can be rapidly adapted to the procedure requirements. A percutaneous approach is rarely indicated in FB aspiration. Needle cricothyrotomy will only

be successful if the needle entry site is distal to the obstruction. If the FB is not visualized during laryngoscopy attempts, it is unlikely that the percutaneous approach will be distal to the object. Once the airway is secured after forced intubation or needle cricothyrotomy, the patient should be taken to the operating room for removal of the FB with a bronchoscope or thoracotomy [22].

In adults, similar challenges are encountered with partially or completely obstructed airway. In partially obstructed airway, any action or failure to take specific action can results into converting the partially obstructed airway into a completely obstructed. When a complete obstruction is present, bag-mask ventilation or insertion of extra glottic device can worsen the situation by dislodging the obstruction from supraglottic to below the vocal cords. Endotracheal intubation with bag ventilation may also result in a complete inability to move any air. Signs of incomplete airway obstruction in an adult patient include stridor, altered phonation, subjective difficulty breathing and sense of fear or panic [22].

Management of airway obstruction depends on the location of the FB and whether the obstruction is incomplete or complete. The location may be supraglottic, infraglottic or distal to the carina. In an incomplete FB obstruction where the patient is breathing spontaneously and saturating adequately, efforts should be made to plan for prompt removal in the operating room (OR). Emergency airway equipment should be immediately accessible in case the patient deteriorates. If transfer to an OR is not possible then decision for removal in the emergency department must be made. The first step may involve handing the patient a rigid suction device to attempt self-retrieval. If this fails, the next step is to attempt laryngoscopy. The patient should be preoxygenated and given topical anesthesia. A dissociative agent or titrate sedation should only be used if needed. The patient is placed semi supine, anesthetized and the laryngoscope is inserted with careful inspection at each level so as not to dislodge the FB. if the patient is unable to tolerate a semi supine position, laryngoscopy can be attempted with the patient sitting up. A flexible endoscope, inserted through the nose, can also be used to visualize the FB. Once identified, the instrument for removal is selected based on the characteristics of the FB. Once successfully removed, a repeat laryngoscopy should be performed to ensure no remaining particulate. The patient should be observed until recovered from anesthesia and based on clinical symptoms [22].

In complete airway obstruction the patient is unable to breathe or phonate and appears terrified. Oxygen saturation usually falls rapidly resulting in loss of consciousness. Initial management is determined by level of consciousness. If the patient is conscious, back slaps and then abdominal thrusts (such as Heimlich Maneuver) are recommended in the latest guidelines by the Internal Liason Committee on Resuscitation. If available, non-invasive anti-choking devices (such as LiveVac) can also be used. However, these devices should not be used first line as they can result in delay in treatment. If the abdominal thrust are unsuccessful, cardiopulmonary resuscitation chest thrusts should be initiated especially if loss of consciousness or impending cardiorespiratory arrest. At this point, immediate direct or video laryngoscopy should be performed. Bag mask ventilation should not be attempted before laryngoscopy for risk of dislodgement of the FB from supraglottic to infraglottic position [22].

Supraglottic obstructing FB is easily identified by direct/video laryngoscopy. A suitable instrument can be used to remove the FB. The patient may begin to ventilate spontaneously. If this does not occur, immediate intubation and positive pressure ventilation is initiated. If the FB is visualized but cannot be removed cricothyroidotomy should be performed to establish an airway. If no FB is identified by laryngoscopy, the

patient should be intubated and ventilated. Resistance with bag ventilation through the endotracheal tube indicates complete obstruction of the trachea [22].

Complete FB airway obstruction in the trachea requires three techniques. The first is to remove the FB with vigorous suction. After intubation, a neonatal meconium aspirator may be directly attached to the ETT and then connected to wall suction. For foreign bodies larger than the endotracheal lumen, both the tube and the FB are removed together with continuous suction. The patient is then reintubated. If this fails, the third technique is applied. This involves pushing the FB into a mainstem bronchus by advancing the ETT and then withdrawing it into the mid-trachea, thus allowing ventilation of one lung. If all above mentioned techniques are not successful, the patient either has a one mainstem bronchus obstruction and a tension pneumothorax on the other side. As a result, bilateral needle thoracostomy is performed as it is unclear which airway was obstructed. In the case that there is no pneumothorax, the only clinical possibility is that there is a bilateral mainstem obstruction from which survival is not possible [22].

## 5. Bronchoscopy

### 5.1 Rigid bronchoscopy

Bronchoscopy has become the standard of diagnosis and treatment for FB aspiration. The use of flexible versus rigid bronchoscopy depends on patient age, local resources, and expertise. Rigid bronchoscopy is usually required for successful removal of foreign bodies in children. FB aspiration (FBA) is most seen in the young and elderly. There are many risk factors that have been associated with this including alcohol intoxication, sedative/hypnotic drug use, poor dentition, senility, primary neurologic disorders with impairment of swallowing or mental status, seizures, Parkinson's disease, general anesthesia and Zenker's diverticulum. A detailed history and physical examination along with chest imaging are necessary [23].

Rigid bronchoscopy is the therapeutic instrument of choice for the airway. Its large size and stiff construction allow the endoscopist to access and manipulate the trachea and right and left proximal airways. Indications for rigid bronchoscopy include large tissue biopsies, removal of complex foreign bodies, management of massive hemoptysis and therapeutic interventions for intrinsic and extrinsic airway obstruction [23].

There are three components of a rigid bronchoscope: barrel, multifunction head and telescope/light source. There are two main types of scopes: rigid bronchoscopes and rigid tracheoscopes. Rigid bronchoscopes are longer and have side ventilation fenestrations allowing them to access the right and left bronchial tree. The barrel is a hollow metal tube with a beveled distal tip which helps with lifting the tongue and epiglottis and allows passage between vocal cords. The proximal end of the scope attaches to the multifunction head permitting ventilation and instrument access. The light source attaches to the proximal end of the scope or to the telescope lens. The inner diameter of the adult rigid bronchoscope ranges form 7-13 mm and outer diameter from 8 to 14 mm. larger scopes can accommodate larger stents and address tracheal and mainstem pathology. Smaller scopes are more suitable for distal left and right mainstem bronchi and up till bronchus intermedius pathology. Ancillary equipment including rigid forceps, suction catheters, stent, and stent deployers, scalpel, scissors, balloons, mechanical dilators, endoscopic resectors should be present [23].

Intubating a patient with the rigid bronchoscopy require appropriate sedation and proper patient positioning. Sedation and the use of paralytics depend on the clinical stability of the patient. The rigid construction of the scope requires straight and direct access to the larynx. The patient is positioned supine with either a towel roll under the shoulders or the head of bed should be dropped allowing the neck to maximally extended. This allows a more linear route through the vocal cords by elevating the larynx. The oral, pharyngeal and laryngeal axis should be aligned anteriorly in order to access the trachea. The bronchoscope is then used to intubate the trachea and advanced under direct visualization either directly down the barrel or through the telescope and camera optics [23].

The most common anatomic site for aspirated foreign bodies is the right bronchial tree due to the shorter and wider right main bronchus and anatomic angle. Initial attempt at FB extraction with flexible bronchoscopy is reasonable but prompt conversion to rigid bronchoscopy can prevent complications and need for surgical intervention. In cases of unstable airway due to FB aspiration, rigid bronchoscopy is the first tool of choice for extraction and management. In a retrospective study in 60 adults presents with FB aspiration, rigid bronchoscopy had a success rate of 96% while flexible bronchoscopy was successful in 61% of cases. In children, it is the preferred treatment method for FB extraction. In a prospective study evaluating the role of rigid and flexible bronchoscopes in children, determined that clinical and radiologic findings were useful in deciding between the two methods. The study reported that rigid bronchoscopes must be used if there is asphyxia, a radio-opaque FB in radiography and decreased air sounds along with obstructive overinflation in the chest radiograph [24].

The larger diameter of the rigid bronchoscope allows bronchoscopist to manage foreign bodies of varying size, shape and texture. The luminal diameter of the scope dictates only the size of the working instrument which will grasp and manipulate the FB. The FB, grasper and scope can be removed en masse if necessary to recover the FB.

In 2022 Han et al., reported 99.2% success rate of FB removal with flexible bronchoscopy. They reported the use of rigid bronchoscopy in only five of the cases [25]. In a meta-analysis published by Chantzaras et al. of 23 papers published between 2001 an d2021, in 2588 cases flexible bronchoscopy was successful in 87.1% of cases [26].

### 5.2 Flexible bronchoscopy

Bronchoscopy is the gold standard diagnostic and therapeutic intervention in management of FB aspiration in the airway. Rigid bronchoscope was first used by Dr. Gustave Killian in 1897 to remove a FB (bone) from main bronchus. It has remained the mainstay bronchoscopy technique especially in management of FB for almost 70 years until invention of fiberoptic bronchoscope by Shigeto Ikeda in 1968. Since its invention, it has expanded the therapeutic options available for management of FB removal [27–31].

Flexible bronchoscopy is able to navigate to distal airways due to its flexibility as well as length increasing the ability for smaller and more distal foreign bodies to be visualized and extracted. Therefore, it should be considered in every patient with concern for FB aspiration into airway to perform thorough examination of the entire airway. In many instances, the FB might not be seen on the chest imaging and bronchoscopy allows for direct visualization of the object and to see if it is causing obstruction of airways. Especially in chronic aspiration, there could be inflammatory changes and granulomatous reaction making the foreign object difficult to discern in imaging.

There are several accessories available for therapeutic management of FB aspiration in the airway that can be used with flexible bronchoscopy. The choice depends on various factors such as type of FB, consistency, location in the airway, and shape. Some of the accessories are similar to those used in other subspecialities such as Gastroenterology, Urology, and Interventional radiology. These tools will be discussed in detail below:

*5.2.1 Forceps*

Forceps that are used in flexible bronchoscopes come in different cup sizes, shapes, rotation mechanism, central fenestration or needles, or presence or absence of "teeth". The forceps can be used for biopsy or for grasping objects such as foreign bodies. The biopsy forceps have a central scooping in the cup with or without central spike and with or without teeth to allow for tissue removal (**Figure 1**). Grasping forceps allow you to grip onto an object to remove it. Grasping forceps include three-pronged, alligator jaw, rat-tooth, shark-tooth, W-shaped, and rubber tip grasping forceps (**Figure 2**).

The specific use of these grasping forceps depends on the type of FB. For example, in hard FBs rat-tooth, alligator-jaw, or shark-tooth are the most common forceps used as they provide a good grasp of the object due to their teeth. If the FB has smooth edges, or sharp edges, rubber tip forceps can help obtain better grasp on the object while minimizing damage to the surrounding structures (**Figure 2**). W-shaped and V-shaped damage to the surrounding structures (**Figure 1**). W-shaped and V-shaped forceps allow for more delicate maneuvers and allow to grasp a large FB because of

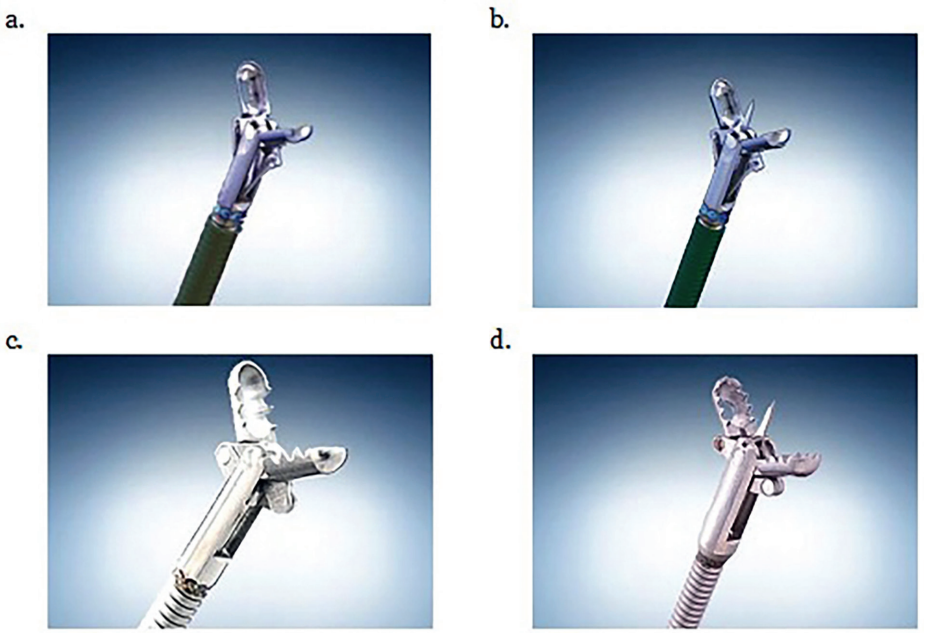


**Figure 1.**
*Biopsy Forceps in Bronchoscopy. a. Biopsy forceps with curved cup with ability to grasp and remove tissue; b. Biopsy forceps with central needle which enhances tissue collection; c. Biopsy Forceps with alligator jaw (jagged edges) allows tearing of tissue d. Biopsy Forceps with alligator jaw and central needle.*


**Figure 2.**
*Grasping Forceps in Bronchoscopy. a. Alligator Jaw; b. Rat-Tooth Jaw; c. Shark Tooth Jaw; d. Three-pronged; e. W-shaped; f. Rubber Tipped.*

their large cup opening width. Typically, grasping forceps are best suitable for inorganic/organic foreign objects with hard consistency (coins, nails, bones, etc). Other tools might be better suited for organic objects which will be discussed below.

*5.2.2 Baskets*

They are used for objects that are large, have irregular contours, or friable objects that are difficult to grasp. There are different types of baskets: some with a central net and some without which will be explained in detail below (**Figure 3**).

*5.2.2.1 Dormia basket*

It was invented by Italian Urologist, Dormia and has since been used by Gastroenterologists and Urologists to retrieve stones in the common bile duct or ureters. The basket is encapsulated by a Teflon catheter and when it is advanced into the

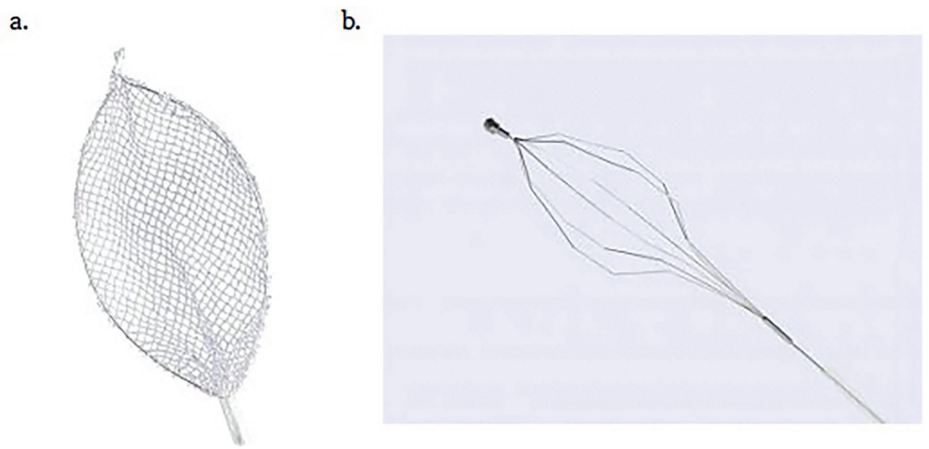


**Figure 3.**
*Grasping Baskets vs Fishnet Baskets. a. Alligator Jaw; b. Rat-Tooth Jaw; c. Shark Tooth Jaw; d. Three-pronged; e. W-shaped; f. Rubber Tipped.*

airway, its wings (flexible loops of metal) open exposing the basket which is maneuvered to capture the FB. The basket is then retrieved back to the catheter to close the basket around the FB. The FB is usually larger than the channel of bronchoscopy.

*5.2.2.2 Fishnet basket*

It is a modified version of a polypectomy snare, in which a mesh of thin thread is attached to the snare wire for easy folding and unfolding. It is helpful in retrieving large friable FB such as organic food material [31].

*5.2.2.3 Grasping baskets*

They have multiple wings that flare when advanced out of the sheath with space between them that can be used to trap rounded edges that are difficult to grasp with forceps [32, 33].

*5.2.2.4 Snares*

These are flexible wings without central mesh in between that can also be used. However, they are very difficult to maneuver in the airway and grasp onto an object so they are rarely used in FB removal [34].

*5.2.3 Balloon catheters*

Inflatable balloon catheters are one of the most underutilized tools in FB removal. These catheters are long tubular structures with distal balloon that can be inflated such as Fogarty catheter. This allows for the catheter to bypass the obstruction. The balloon is inflated distal to the obstruction and the FB can be pulled out of the airway slowly along with the FB slowly. This tool can be helpful in dislodging partially occluded FB more proximally and can even help in complete obstruction of airway from FB that is difficult to grasp.

### 5.2.4 Cryoprobe

The cryoprobe was first developed to freeze endotracheal or endobronchial tumor by Gage in 1968. Its use has since been expanded to include transbronchial tissue biopsy and FB removal. There is more literature in its use as an alternative to surgical lung biopsy in interstitial lung disease (ILD) and has even been included as part of guidelines in management of ILD if they are performed by an expert proceduralist.

Similarly, it is also used in the removal of FB. The cryotherapy system consists of cryogen, cryoconsole, and cryoprobe. Typical cryogens are nitric oxide or nitrogen which then undergo rapid gas- decompression in the cryoconsole which generates extremely low temperatures of -15C to -40C in the cryoprobe tip which is used to freeze and adhere to objects with water content such as human tissue and can then be pulled along with the probe. Therefore, it is extremely efficient in removing foreign objects that are rich in water content (food, blood clots, mucous balls, etc). The object can adhere to the cryoprobe tip and can be removed [35]. However, extreme caution should be maintained in making sure that the cryoprobe is not close to the mucosa when removing FB so that it does not inadvertently injure the mucosa.

### 5.2.5 Magnet extractor

It has a flexible probe with a magnetic cylinder at its tip and can be used for metallic foreign objects. It is especially useful in iatrogenic FBs such as broken cytology brushes, forceps biopsy tips, guidewires, etc. [36, 37].

### 5.2.6 Laser beam

Objects that cannot be removed by any of the techniques listed above or rigid bronchoscopy, LASER beam can be used to break it down into smaller pieces which can then be extracted. The neodymium-yttrium-aluminum-garnet (Nd:YAG) laser is the most commonly used type of laser. There are cases of LASER beam being used in breakdown of an aspirated chicken bone which was then retrieved using biopsy forceps [38]. Similarly, there are other reports of two patients where LASER beam is used in removal of thumbtacks [39]. It can cause airway fire similar to cautery tools and argon plasma tools in the airway, so anesthesia should be made aware that when using the laser beam, to decrease exhaled FiO2 to <30%.

### 5.2.7 Complications

#### 5.2.7.1 Bleeding

Bleeding is an expected complication from removal of FB. Organic FBs are known to cause mucosal irritation and the degree of damage depends on the type of the agent swallowed. For example, inorganic objects such as iron pills are extremely caustic with quick mucosal irritation and with prolonged exposure to mucosa can form ulceration and strictures which can bleed when attempting to remove. In some institutions, it is common practice to use a short course of steroids before removal of FB especially if it is a chronic FB to help with the inflammation [40, 41].

Therefore, it is important to make sure that one is prepared with tools to deal with massive hemorrhage. The proceduralist must have a rigid bronchoscope available as it is easier to manage hemoptysis using rigid bronchoscope. Other tools such as cold

saline, epinephrine, thrombin, electrocautery, and APC must be readily available for usage in these critical situations.

*5.2.7.2 Dislodging FB*

It is possible that when performing examination with bronchoscopy, manipulation of the airway can dislodge the FB which can cause the object to fall deeper into the airway causing further obstruction. If this dislodgement happens in proximal trachea it can lead to asphyxiation and can lead to cardiac arrest. Therefore, the inspection of the airway must be done carefully. In some institutions, in cases of partial obstruction from FB, the proceduralist may insert catheter and balloon distal to the FB and use the balloon to prevent dislodgement and use it to pull the object more proximal into the trachea.

Furthermore, in cases where the FB is large, it is important to have a tight grip on the accessory used to retrieve the FB and pull the accessory into the bronchoscope as much as possible and remove the accessory and bronchoscope together with complete visualization of the FB. This must be done with FBs that are sharp to make sure no mucosal or airway injury.

*5.2.7.3 Other complications*

Mortality rates of bronchoscopy for foreign bodies in children vary from 0.1% to 3.4%. Complications associated with bronchoscopy in children include failure to remove the FB, hypoxemia, laryngeal edema, and pneumothorax [42]. In a retrospective analysis done by Powers et al. on 2302 cases of FBA in children who underwent bronchoscopy, the most common comorbidity was structural pulmonary abnormality (10.5%) followed by sepsis (6.7%) and Asthma (6.5%). The overall rate of complication post bronchoscopy was low. Pneumonia (0.8%) was the highest followed by reintubation (0.4%). Intraoperative bleeding was seen in 4 patients (0.2%) and one patient (0.04%) experienced cardiac arrest and required CPR. Overall mortality rate was 0.4% within 30 days after bronchoscopy [43].

### 5.3 Flexible bronchoscopy vs rigid bronchoscopy

Flexible bronchoscopy can be just as successful in retrieval of FB as rigid bronchoscopy. According to a retrospective study by Sehgal et al., the success rate of flexible bronchoscopy in the removal of FB is as high as 92% [29]. The success rate is higher up to 97–99% when both rigid and flexible bronchoscopy are used in tandem [40]. Rigid bronchoscopy success rate ranges from 86 to 100%. Rigid bronchoscopy is better suited for FBs that are in larger proximal airways such as trachea or mainstem bronchi as they are easier to visualize and navigate to. FBs that are in distal airways typically need flexible bronchoscopy. However, the data varies between studies and this variability can be due to the experience of the proceduralist and the experience of the institution where the procedure is being performed. There are numerous reports of FB removal failure from rigid bronchoscopy but was successful via flexible bronchoscopy and vice versa.

In a study by Ng et al., they looked at the rate of successful FB removal between flexible bronchoscopy and rigid bronchoscopy. Flexible bronchoscopy was successful in 80% of the cases compared to 100% success rate in rigid bronchoscopy [44]. Further study of patients where flexible bronchoscopy failed showed that rigid

bronchoscopy was better in patients with no comorbidities, delay in FB aspiration diagnosis, and hard FBs. The correct modality of bronchoscopy depends on FB, the location in the airway and ultimately the experience and comfort of the proceduralist.

## 6. ECMO

There has been growing body of literature where extracorporeal membrane oxygenation (ECMO) has been used in cases of refractory respiratory failure in the setting of FB aspiration [45–50]. It originated from the invention and use of cardiopulmonary bypass in the OR. The Cardiopulmonary bypass was first successfully used in human in 1953 and initially involved use of "bubble" oxygenators where oxygen is bubbled through a reservoir of blood to create blood-gas interface and gas exchange [51]. It was later replaced by membrane oxygenators where there is separation of respiratory gases from blood making long term use of these devices possible. In 1972, Dr. Hill and colleagues used a membrane oxygenator to administer ECMO for extended periods outside the operating room. Further progress since then allowed its use in situations involving respiratory failure [52].

There are two types of ECMO, there is VV-ECMO (veno-venous ECMO) which provides respiratory support and VA-ECMO (veno-arterial ECMO) which provides cardiac and respiratory support. ECMO circuit is rather simple in its components and consists of mechanical pump, oxygenator, and a heat exchanger which is inserted into the patient [53].

In cases of FB aspiration, there are complications that arise such as complete occlusion of airway with inability to ventilate patient, pulmonary edema, bleeding, acute respiratory distress syndrome, and severe lung injury which can result in severe hypoxemic respiratory failure [48, 54]. ECMO was also used in cases where the FB is small particles such as sand or saw dust making the extraction difficult. In other cases, there may be resource limitation with limited access to rigid bronchoscopy or situations where bronchoscopic interventions fail and VV-ECMO can be used as a "bridging" therapy until further curative treatment can be performed.

According to a study by Anton-Martin et al., who studied ECMO use in children across 251 institutions with FB aspiration, it has been used in more than 10 cases. In all these cases, ECMO allowed for prolonged respiratory support and in this cohort, they reported survival of >90% [55]. Similarly, another study by Park et al., where they studied ECMO use in children where respiratory instability led to inability to perform bronchoscopy. ECMO allowed for stabilization with eventual bronchoscopic intervention with complete recovery of patients [56]. These case studies show that in institutions where there is no provider with expertise to perform bronchoscopic intervention, patients are too unstable, or institutions where there is easy ECMO access, it could be used as a rescue therapy for patients with FB aspiration with critical airway compromise to avoid respiratory arrest.

## 7. Surgical management

As mentioned prior, Bronchoscopy is the gold standard and the most successful option for removal of FB in the airway with success rates as high as 98%. However, in situations where endoscopic and bronchoscopic interventions fail or patients have trauma to the viscera due to penetrating trauma from the FB, or long-term

complication with failure to remove the FB, then surgery could be considered. Surgical options such as tracheostomy, thoracotomy, bronchotomy, or lung resection might be needed to remove FB [57–60].

## Abbreviations

| | |
|---|---|
| FB | foreign body |
| OR | operating room |
| ETT | endotracheal tube |

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