6 Indications and Risks of Flexible Bronchoscopy in Children

Cori L. Daines and Emily M. DeBoer

Indications

General Considerations

Flexible bronchoscopy in children is generally well tolerated and should be considered as a tool anytime it is the safest, easiest, and most effective way to obtain information and to intervene in the airway of the child [1]. Advantages that the flexible instrument has over the rigid bronchoscope include the ability to evaluate the entire upper and lower airway without artificial airway manipulation and to do so while the child is under light anesthesia. Also, only a flexible instrument is able to be passed through an endotracheal tube. Flexible bronchoscopes come in sizes appropriate for neonates to adults and can be used safely in a variety of settings. These scopes can be used in an outpatient setting with light sedation and can be used at bedside for an inpatient, making flexible bronchoscopy a useful tool in the neonatal and pediatric intensive care units [2–4]. With its utility, there are many indications for pediatric flexible bronchoscopy. Generally, there are two broad categories of indications for the procedure discussed here, diagnostic and therapeutic [5, 6].

Diagnostic Indications

A diagnostic indication is one in which flexible bronchoscopy is done to discern an etiology of a respiratory problem. Diagnostic indications commonly include chronic or recurrent symptoms, such as chronic cough, or chronic or recurrent diagnoses, such as recurrent pneumonia. Also in the category of diagnostic indications is the need for an airway evaluation. In this last category, a symptom may or may not be present; the bronchoscopy may be done only to see the airway such as in the case of a child that is ready to be extubated or have a tracheostomy tube removed. The general need to obtain a specimen, such as bronchoalveolar lavage fluid (BALF), might also be considered an indication, even without symptoms.

Chronic/Recurrent Symptoms

Children commonly have respiratory symptoms such as cough. The indication for bronchoscopy occurs when the symptom is chronic or recurrent and problematic. This usually means that medical treatment for remediation has been tried and failed prior to the bronchoscopy. Common

C. L. Daines
Pediatric Pulmonary and Sleep Medicine, Department of Pediatrics, University of Arizona, Tucson, AZ, USA
e-mail: cdaines@email.arizona.edu

E. M. DeBoer (✉)
Pediatric Pulmonary and Sleep Medicine, Department of Pediatrics, University of Colorado, Aurora, CO, USA
e-mail: Emily.deboer@childrenscolorado.org

S. Goldfarb, J. Piccione (eds.), *Diagnostic and Interventional Bronchoscopy in Children*, Respiratory Medicine, https://doi.org/10.1007/978-3-030-54924-4_6

Table 6.1 Common Symptom Indications

Cough
Wheeze
Stridor
Hoarseness
Epistaxis
Hemoptysis
Cyanosis

symptoms leading to flexible bronchoscopy are listed in Table 6.1 [7].

Chronic cough is one of the most common indications for bronchoscopy in children. The most common causes of chronic cough are asthma, gastroesophageal reflux disease, and postnasal drip [8]. Treatment of presumed causes should occur first; and bronchoscopy should be performed if symptoms are unremitting or if other worrisome factors are present, such as hemoptysis, localized wheezing, or immunocompromised patient.

Wheeze is also a common indication for bronchoscopy. Wheeze is found in asthma, but if the wheeze is unresponsive to bronchodilator or anti-inflammatory medications or if the wheeze is localized, evaluation by bronchoscopy is indicated. Issues such as foreign body, tracheobronchomalacia, and intrinsic or extrinsic airway narrowing may be the cause and are best found on direct visualization [9–11].

Stridor in infants is often benign and due to laryngomalacia if ongoing or due to infectious croup if acute and self-limited. Stridor causing cyanosis or respiratory distress not relieved by acute treatment should be evaluated, as other lesions such as epiglottitis, papillomatosis, laryngeal-esophageal clefts, growing hemangioma, vascular compression, or foreign body could also be causal and are best diagnosed with flexible bronchoscopy [12–15]. Here the flexible bronchoscope has the advantage of being used without airway manipulation in a spontaneously breathing child to see from where the noise originates.

Hoarseness often presents to otolaryngologists instead of pulmonologists but should be evaluated if persistent. Congenital or acquired vocal cord paralysis or paresis and vocal cord nodules or papilloma may be causative [16]. Vocal cord dysfunction may lead to further evaluation such as a swallowing study to rule out aspiration or a brain MRI to rule out brainstem compression.

Hemoptysis in children is not as common as it is in adults but can be a significant problem. Blood from the airway may range from sputum streaked with blood in the case of bronchitis to massive hemoptysis from bronchovascular fistula. Bronchoscopy can help isolate hemoptysis from hematemesis or epistaxis, can help localize the bleeding site, or can help therapeutically manage the bleeding with the application of epinephrine, thrombin solutions, or use of a ballooned catheter [17–19].

Cyanosis alone may not be a common indication for flexible bronchoscopy, but its presence is concerning for worrisome pulmonary problems. A source should be found if a child is chronically hypoxic.

When a symptom leads to a flexible bronchoscopy, the procedure is able to evaluate the anatomy for lesions causing the symptom and also allow the bronchoalveolar lavage to potentially identify a specific etiology such as a specific infection. An example is a child who has had a chronic cough, has tried asthma therapy (bronchodilators and inhaled or systemic steroids), and persists in symptoms. Bronchoscopy evaluates the airway to find anatomical causes such as airway compression or malacia, airway inflammation or intrinsic airway narrowing and the bronchoalveolar lavage will then diagnose any infection or cellular inflammation.

Chronic/Recurrent Diagnoses

Children commonly have respiratory diagnoses. All children experience upper airway infections, often recurrent upper airway infections that do not require bronchoscopy. Flexible bronchoscopy is used when there is a chronic or recurrent process that is causing distress or harm to the child. The same as when a flexible bronchoscopy is done for a symptom, when it is done for a problem, structural airway abnormalities are visualized, and samples are obtained to find an etiology. Common diagnoses that lead to bronchoscopy are listed in Table 6.2 [7].

Croup is a common diagnosis in young children with viral infections. Treatment is based on

Table 6.2 Common diagnoses indications

Croup
Pneumonia
Atelectasis
Aspiration
Pulmonary Infiltrates
Bronchiectasis
Uncontrolled Asthma

severity of symptoms and the symptoms are generally self-limited. Recurrent croup, especially in an older child, may deserve bronchoscopy to evaluate for an anatomical issue leading to the symptoms. Children with subglottic stenosis or vocal cord issues will be more prone to croup. A child who wakes suddenly in the middle of the night without specific infectious triggers might have spasmodic croup triggered by gastroesophageal reflux. A bronchoscopy in this later case might diagnose upper airway and/or laryngeal inflammation along with evidence of aspiration of lipid on bronchoalveolar lavage.

Previous surveys of indications for bronchoscopy in children show that *pneumonia* or *recurrent pneumonia* is the most common indication [20]. The diagnostic yield of bronchoscopy for pneumonia depends on the circumstances. If a child is too young to expectorate sputum, a BAL is a nice alternative to obtain a specimen for microbiology. If a child is immunosuppressed (e.g., cancer or HIV), bronchoscopy with BAL is useful to find opportunistic infections such as fungal pathogens or pneumocystis. All bronchoscopy for active infection is best done if the child is off of antibiotics, as antibiotics may suppress the growth of organisms. In the case of recurrent pneumonia, bronchoscopy is useful to determine if airway abnormalities, foreign bodies or microaspiration could be causative [21, 22].

Atelectasis is a radiographic abnormality that may warrant bronchoscopy. Common etiologies are mucus plugging, foreign body, or airway obstruction from intrinsic (airway wall edema) or extrinsic (vascular compression) causes [23]. While this problem may also lead to a therapeutic bronchoscopy, often the main indication for the bronchoscopy is diagnostic to find the etiology of the atelectasis.

Pulmonary infiltrates are another radiologic indication for bronchoscopy. These may be synonymous with pneumonia, but may be more diffuse, fleeting or recurrent. Here, in addition to performing a BAL for culture, a BAL and airway evaluation may diagnose other reasons to have alveolar disease, such as microaspiration.

Bronchiectasis on chest radiograph or chest CT scan indicates airway damage and understanding why this has occurred may be a bronchoscopic indication. Bronchiectasis in children occurs with underlying diseased such as cystic fibrosis, primary ciliary dyskinesia, or immunodeficiency and can also occur after a single severe inflammatory event such as a bad pneumonia or foreign body aspiration. Additionally, bronchiectasis occurs with chronic aspiration of stomach contents, swallowing aspiration, or aspiration of saliva. The bronchoscopy and BAL is able to help determine the underlying and acute causes by visualizing the airway and by obtaining BALF for culture and cytology.

Uncontrolled asthma may be an indication for bronchoscopy if there is a suspicion that something else is contributing, such as indolent infection or aspiration of GER. Bronchoscopy here allows the visualization of the airway for inflammation and gets a BALF to understand the cellular inflammation and other potential contributors [24].

Remember that even if the indication is a respiratory problem, the main reason for the bronchoscopy may simply be to get BALF to guide therapy. Young children often do not spontaneously produce sputum and getting induced sputum requires a cooperative patient. BALF may be desired for culture, to look for aspiration or simply to follow up on a previously abnormal BALF. While the indication is a respiratory problem and these are diagnostic procedures, bronchoscopy is almost always done in order to guide a therapeutic change.

Airway Evaluation

This set of indications result from either a known or a suspected airway abnormality. Flexible bronchoscopy evaluates the airway from the nares to the bronchi, both upper and lower airway

issues. While airway evaluation might be undertaken primarily due to suspicion of a single site problem, a full airway evaluation should be done in almost every flexible bronchoscopic procedure. It might be a symptom or a diagnosis or a radiographic study that leads to the suspicion of an airway issue. Once an airway abnormality is known, the flexible bronchoscopy indication is to reevaluate the problem. Bronchoscopy guides the decision for intervention (e.g., surgery, decannulation) or for further evaluation (e.g., CT scan or videofluoroscopic evaluation of swallowing) [25]. It also can be a follow-up to evaluate the success of an intervention. Upper airway problems that may be seen on flexible bronchoscopy are listed in Table 6.3.

Careful evaluation of the upper airway should be part of any routine flexible bronchoscopy [26]. Starting at the nares in a child under light general anesthesia who is spontaneously breathing is best to evaluate the upper airway [11]. Evaluating for inflammation, mucus, obstruction, and other upper airway problems is part of a routine upper airway endoscopy and will aid in diagnosis of overall respiratory issues [27].

The lower airway also should be fully evaluated as well with light anesthesia. A symptom such as wheeze may indicate a lower airway abnormality. Lower airway problems that may be seen on flexible bronchoscopy are listed in Table 6.4.

As with upper airway abnormalities, these lesions may be suspected or known, and bronchoscopy may be used for initial discovery or following up a previous issue. While radiographic studies may give an indication of lower airway pathology, direct vision of the airway under light anesthesia is generally much better. Tracheobronchomalacia, for example, may be implied on CT scan or fluoroscopy, but in controlled studies the sensitivity of flexible bronchoscopy is significantly better [28, 29].

A small subset of bronchoscopic procedures for airway evaluation are done specifically because a child is unable to be extubated. The clinical team may not know what the issue is and may request a procedure to evaluate the airway for lesions that are preventing that extubation. Along these same lines, a common anatomical evaluation is done in preparation for decannulation or if a child is failing the common steps towards decannulation. If a child with a tracheostomy cannot tolerate capping, for instance, a bronchoscopy is able to help determine why and then guide subsequent interventions for the lesion [25]. In conjunction with surgeons, a flexible bronchoscopic evaluation can determine the success of a surgical intervention. Examples include airway visualization after tracheoesophageal fistula repair or after airway reconstruction for subglottic stenosis [30].

Diagnostic Bronchoalveolar Lavage

Part of the flexible bronchoscopy procedure is performing a bronchoalveolar lavage (BAL). This is done as an adjunct to most diagnostic procedures, but it is also done as the primary reason for the bronchoscopy. An example is a child with cystic fibrosis who has decreased lung function and needs to be treated with antibiotics but is unable to cough up adequate sputum for a culture. If there is concern that the epiglottic culture does not reflect the lower airway, BALF can be sent for bacterial, viral, fungal, and atypical pathogens.

Table 6.3 Upper airway findings/indications

Choanal atresia	Laryngomalacia
Adenotonsillar hypertrophy	Laryngeal stenosis/web
Sinus/nasopharyngeal drainage	Vocal cord paralysis/paresis/nodule
Nasal polyps/obstruction	Laryngoesophageal cleft
Pharyngeal collapse	Glottic stenosis
Glossoptosis	Subglottic stenosis

Table 6.4 Lower airway findings/indications

Tracheal stenosis	Bronchomalacia
Complete tracheal rings	Bronchial stenosis
Stoma issues (granulation/collapse)	Bronchial compression (Vascular/Tumor)
Tracheomalacia	Granulation tissue
Tracheal compression (Vascular/Tumor)	Hemangioma
Tracheoesophageal fistula or pouch	Foreign body

This same indication is true for other children in whom BALF culture is desired but they are unable to produce adequate sputum. These include children with primary ciliary dyskinesia, children with immunodeficiency and a fever, and even children where tuberculosis is suspected and a culture is needed. A final indication of BAL as a primary reason for a bronchoscopy would be a child who has been determined to be brain dead and needs BALF collected to determine if the lungs might be used in organ donation [1].

Endobronchial Biopsy

Here forceps or brush is introduced through the bronchoscope to obtain a cellular sample. Tissue can be a useful adjunct to diagnosing granulomatous disorders and tuberculosis. It can also be used to obtain ciliated epithelial cells for the diagnosis of primary ciliary dyskinesia [31]. Multiple research studies have utilized bronchial biopsies in inflammatory diseases such as asthma and cystic fibrosis to better understand the underlying immunologic processes [31–35].

Transbronchial Biopsy (TBB)

This is a procedure done commonly in adult flexible bronchoscopy in order to obtain peripheral airway cells for diagnosis and culture. The utility of this procedure to identify and stage acute rejection in lung transplant patients has been well established. Diagnosing infection in these same individuals is also readily possible [36]. TBB is also used to diagnose chronic rejection, bronchiolitis obliterans, and interstitial lung disease. The diagnostic yield in these latter conditions is not as good but still possible [37, 38]. TBB is difficult to perform in infants and young children, limited by the size of the bronchoscope necessary to introduce biopsy forceps into the small airways [39]. TBB is done with fluoroscopic guidance to place the biopsy forceps where expected and needed.

Transbronchial Needle Aspiration (TBNA) with Endobronchial Ultrasound (EBUS)

The procedure is used frequently in adult patients for the diagnosis of cancer. In children, the main utility is for the diagnosis of tuberculosis from airway lymph nodes and evaluation of peripheral pulmonary nodules with fluoroscopic guidance. The procedure is limited by the size of bronchoscope needed, currently a 4.0 mm bronchoscope with a 2.0 mm channel for radial EBUS, and by the size of the airway. For very small children, a biopsy might be limited to the main carina. Utility is not very well established, and this technique is only useful for individuals specially trained in this technique [40].

Therapeutic Indications

The second large category of indications is therapeutic. Here a flexible bronchoscopy is undertaken in order to have a therapeutic effect on the child. Often these indications occur in children who are hospitalized, in the intensive care unit, or intubated. Here a flexible bronchoscopy may often be safely performed at the bedside to achieve the desired effect [2]. Remember that many of these techniques may be utilized at once to achieve therapy and that techniques that seem to be best achieved with the rigid bronchoscope can often be aided by the flexible bronchoscope [6].

The first therapeutic indication is unremitting *atelectasis*. In a child who has persistent atelectasis on a chest film, a bronchoscopy can be done to remove any airway obstruction. The airway obstruction is commonly due to mucus plugging that can be suctioned away. Use of a flexible bronchoscope allows suction to be applied but also allows mucolytic medications to be applied directly to the plug [1]. Other tools to remove a large thick plug may include biopsy forceps or cryoprobe. Variations on mucus plugging include airway obstruction with blood clots or the extreme of obstruction with *plastic bronchitis*. This last category occurs in individuals with cardiac defects and sickle cell disease. Plastic bronchitis causes airway filling with thick casts (heavily lymphocytic) that require extensive suctioning, usually with the aid of medications or other instruments to remove the plugs. The use of tissue plasminogen activator directly on the plugs of plastic bronchitis has been effective [41].

Another therapeutic application is use of *whole lung lavage* for individuals with alveolar proteinosis or other alveolar filling process [39]. These patients have a collection of proteinaceous material in their alveoli from a surfactant processing error. The alveoli fill with material over several months and serial whole lung lavage is done to remove the material. One lung at a time is filled with repeated aliquots of warmed saline and then drained. This is done until the drained fluid clears. The second lung is done on a separate day. This is repeated whenever the lung symptoms become difficult. Eventually many children go into remission.

Aid to Intubation is a procedure often useful with a flexible bronchoscope, especially in a difficult airway, like that in a child with craniofacial abnormalities [39, 42]. This is one of the most common indications for flexible bronchoscopy in the critical care arena [2]. An ETT is slipped over the bronchoscope and inserted into the airway over the scope once the bronchoscope is in position in the lower airway. Most intubations occur via a nare, but this technique can also be used orally with the aid of a laryngeal mask or blade tongue retraction. An ETT as small as 2.5 mm may be inserted with the help of a 2.2 mm bronchoscope.

Foreign body removal is a somewhat controversial use of the flexible bronchoscope. There are multiple reports in the literature of foreign bodies being successfully retrieved by flexible bronchoscopes [43–50], but glottic and large foreign bodies may become dislodged more easily from the flexible bronchoscope and lead to frank airway obstruction. These foreign bodies should be removed by the rigid instrument. If a secure airway is in place and the foreign body is in a position to be easily removed by the flexible bronchoscope, this technique may be safely used. A rigid bronchoscope should, however, be available if necessary [39]. More distal, difficult to visualize with the rigid scope, objects may be best initially manipulated by the flexible bronchoscope. A flexible bronchoscope may always be used to visualize the airway and confirm the presence and location of a foreign body and may be used to help clean up the airway after foreign body removal.

Occasionally mass lesions will obstruct or partially obstruct the airway of a child. Granulomas, hemangiomas and bronchial carcinoid tumors are examples. When the lesion is an acquired lesion such as granulation tissue from deep suctioning in a patient with a tracheostomy tube, use of the *KTP laser* through a flexible bronchoscope can be helpful. The KTP laser allows for desiccation of the lesion with small energy bursts that will not harm the underlying bronchus [51, 52]. Removal of larger pieces of tissue may be achieved with biopsy forceps through the flexible bronchoscope. Use of the flexible bronchoscope may be useful for distal, smaller lesions in particular. These techniques may take a long time if the lesion is large and if there is a risk of bleeding (i.e., hemangioma or vascular lesion), the flexible bronchoscope is less able to control the bleeding.

When tracheal or bronchial stenosis is present, several modalities may be used via flexible bronchoscope. They include *balloon dilation*, laser and stent placement with or without application of medications such as mitomycin or steroids [39]. While traditionally a rigid bronchoscope is used, a larger flexible scope with a 2.0 mm working channel through an LMA can be used for angioplasty balloons [53]. Balloon dilation often needs to be repeated serially to achieve the final result and can be combined with the other dilating therapies. There are also risks of bleeding or airway rupture with this procedure.

The flexible bronchoscope may be used to *instill medications* directly to affected portions of the lung. This includes the already mentioned placement of epinephrine on a bleeding airway but also included placing mucolytics such as recombinant human DNase, n-acetylcysteine, hypertonic saline, or sodium bicarbonate to a mucus-plugged bronchus [39]. Additionally, medications such as surfactant may affectively be placed in the bronchial tubes [54].

Stent placement is typically thought of as a procedure done with a rigid bronchoscope. The flexible instrument, however, is able to deliver and/or check placement of a stent before it is expanded or finalized. There are three main types of stents: silicone, metal mesh, and biodegrad-

able. The flexible scope can ensure the patency of the airway after a stent is placed and can be used to check for complications such as stent slippage or formation of granulation tissue [39].

The flexible bronchoscope is able to identify the location of a bronchopleural fistula by placing an occluding balloon through the bronchoscope and inflating to see if the leak from the chest tube disappears [55]. Once the site of the fistula is known, the flexible bronchoscope can deliver methacrylate adhesive (airway glue) to the site of a persistent air leak from the bronchopleural fistula. The tube of glue is delivered in the working channel of the flexible bronchoscope and then delivered through the catheter out of the end of the bronchoscope once in place [56]. This technique is especially useful when the operative risk for the patient is too high.

Cryotherapy is a technically generaly reserved for adult patients. Many cryoprobes require a large channel for use. The cryoprobe, however, has been used to not only desiccate tissue mass, as in a granuloma, but also to freeze a mucus plug or blood clot and effectively remove it in one piece [57, 58].

The overall category of therapeutic indications is growing rapidly. The advent of newer tools such as the cryoprobe, EBUS/TBNA, and bronchial thermoplasty has already changed the way adult flexible bronchoscopy is performed. These tools are being reformulated for smaller people and smaller bronchoscopes. At the same time, bronchoscopes are improving with better optics, more maneuverability and larger working channels for the same size bronchoscope. Indications will change as tools advance.

Risks/Complications

Pediatric bronchoscopy is generally a safe and effective procedure for diagnosis and therapeutic management of a number of diseases. With any procedure, especially those requiring general anesthesia, there are risks that must be evaluated and minimized. Much care should be taken to determine that the patient has appropriate indications for bronchoscopy. Preparation is necessary to avoid unnecessary risk. Timing, location of procedure, and best anesthetic should be considered, appropriate and properly working tools should be gathered, and all personnel should be well-trained in bronchoscopy. When involved, trainees should be accompanied by staff experienced in teaching bronchoscopy.

Risks Associated with Anesthesia

Flexible bronchoscopy can be performed in multiple locations with varying levels of sedation/anesthesia. Although anesthetic medications each have their own side effect profile, symptoms associated with impaired ventilation, oxygenation, and airway irritation can be seen. General anesthesia is also associated with postoperative confusion, nausea and vomiting, and other systemic symptoms. In a large multisite prospective cohort of children who were sedated for various procedures performed outside of an operative room, hypoxemia, defined as oxygen desaturation below 90% for more than 30 seconds, was the most common complication [59]. Whereas children having flexible bronchoscopy often have indications of airway and pulmonary symptoms, this group were relatively healthy with less than 2% having preexisting airway or lung disease. Other rare complications in the cohort were stridor, laryngospasm, unexpected apnea, and aspiration [59].

In an attempt to limit laryngospasm and cough, topical analgesic, traditionally lidocaine, may be applied before and during the procedure to the vocal folds, carina, or both. When the bronchoscopy is beginning, the anesthesiologist must be attentive to the patient's level of sedation. Patients who are inadequately anesthetized are at risk for laryngospasm. The amount of lidocaine administered by the anesthesiologist and the bronchoscopist should be monitored closely. Although rare, lidocaine toxicity can result in seizures, and general anesthesia can lower the seizure threshold in those patients who are prone to them. Amitai and colleagues reported no complications after applying 3–8 mg/kg of topical lidocaine in 15 children [60]. A "spray-as-you-go"

approach is recommended for optimum effectiveness while limiting the overall lidocaine dose to a maximum of 3–5 mg/kg total during the procedure.

Multiple studies have shown association between number of anesthetic exposures in children less than 3 years of age and future cognitive ability and academic achievement [61, 62]. Although general anesthetics are not definitively causative, it may be appropriate to limit or delay procedures in young children when possible. Increased risk has been reported in children undergoing flexible bronchoscopy combined with other procedures above those undergoing flexible bronchoscopy alone [63]; however, the risk of performing those additional procedures under separate anesthetics was not evaluated.

Risks and Complications

A flexible bronchoscope occupies space in the airway of a child who even prior to the procedure has varying degrees of respiratory symptoms and impairment. Impaired ventilation during the procedure is therefore fairly unique to flexible bronchoscopy. The size of the scope, the size of the child's airway, and any airway device used for ventilation (laryngeal mask airway, tracheostomy, endotracheal tube) affect the amount the airway is obstructed. Small children have low functional reserve and the effect of the scope on ventilation and oxygenation is more dramatic. In children with a 4.0 mm inner diameter endotracheal tube, a 2.8 mm outer diameter bronchoscope will occlude the airway by 49–70%, significantly increasing the resistance to airflow [64]. Although it is tempting to choose the largest scope that will fit in the breathing tube, the indication for the bronchoscopy and the child's tolerance of airway occlusion should be considered. When bronchoscopes are introduced through the nares, most infants greater than or equal to 3 kg can breathe adequately around the 3.5 mm flexible bronchoscope, and infants greater than 1.5 kg can breathe around the 2.8 mm scope [65].

Because of these impairments to ventilation, hypoxemia is the most common complication reported during flexible bronchoscopy [63, 66, 67]. The definition of hypoxemia as a complication vary based on institutional reports. Some report if the hypoxemia prolongs the duration of the procedure [5] and others provide more quantifiable definitions such as SpO2 < 90% for 30 seconds of time [8]. Post-op hypoxemia is also common [66]. The technique of bronchoalveolar lavage necessarily washes surfactant out of selected segments of the lung, thereby predisposing to post-op atelectasis, which likely contributes to this post-op hypoxemia.

Airway irritation, airway edema, laryngospasm, and post-op stridor can be seen with general anesthesia but are also risks of the flexible bronchoscope irritating the child's airway mucosa. Rates of laryngospasm of 1–5% are reported in large cohorts [63, 66, 68]. Bronchospasm can occur from irritation to the airway and lung in this high-risk population. The bronchoscopy team should remember that poor airflow without wheezing may be from extreme bronchospasm, and the use of intraoperative albuterol can allow the procedure to continue. Low levels of cigarette smoke exposure can cause increased airway edema [69], although the effects on flexible bronchoscopy outcomes in children exposed to secondhand smoke are not known.

Vagal stimulation and cardiorespiratory complications including cardiac arrest are rare but significant complications from flexible bronchoscopy [63, 70]. Death is a rare complication in pediatric flexible bronchoscopy attributed to sepsis in the few reported cases [71, 72].

Bleeding is more common in adult bronchoscopy than general pediatric bronchoscopy. Rates of <5% are seen in diagnostic pediatric flexible bronchoscopy [68, 73]. Bleeding and hemoptysis are also indications for bronchoscopy, and the bronchoscopy team must be prepared for acute bleeding. This includes checking a complete blood chemistry and coagulation profile prior to the procedure, performing high-risk procedures in an appropriate location (the operating room), and having equipment to intubate the patient and access to drugs to stop bleeding immediately available. Epistaxis can be seen with laryngoscopy and flexible bronchoscopy [68, 73].

Pneumothorax is reported although rarely in diagnostic bronchoscopy with lavage [70, 74]. To minimize risk of pneumothorax, bronchoscopists are taught to instill low flow oxygen only when the scope is in large airways and to use CPAP but not positive pressure ventilation while the scope is wedged during BAL collection. When these guidelines are followed, and the airway is not manipulated with biopsy forceps or other tools, the cause of pneumothorax is not always clear.

Infection

Whenever a foreign object is introduced into the body, a risk of infection exists. Guidelines for cleaning and sterilizing bronchoscopes based on manufacturer recommendations must be employed, followed, and reevaluated regularly by those responsible for bronchoscopy programs. Bacteria can grow in wet and drying bronchoscopes after high-level disinfection [75], and outbreaks of multidrug-resistant bacteria have been reported from the use of contaminated bronchoscopes [76]. With strict adherence to guidelines, current sterilization techniques appear to adequately limit this risk in flexible bronchoscopy; however, ongoing study in this area is needed.

A theoretical risk of contamination of oral, nasal, and tracheal flora into the lower airways exists with flexible bronchoscopy. Nose and mouth commensal organisms can be found in cultures from BAL; however, the exact contribution from the flexible bronchoscope is not clear [77]. For example, seeding of laryngeal and tracheal secretions to the lower airways after repeated endoscopy is a theoretical cause of recurrent laryngotracheal papillomatosis spreading to lung parenchyma [78]. Decreasing risk in patients with these infections and in immunocompromised patients at risk of infection should be considered when determining the method of bronchoscopy. An endotracheal tube can be placed to minimize contact between these surfaces and the flexible bronchoscope prior to BAL acquisition. Postoperative fever >38 degrees Celsius can occur within 24 hours of bronchoscopy with lavage in approximately 50% of patients [79]. This is likely due to stimulation of pyrogens from BAL rather than true infection. In a prospective study, increased risk of postoperative fever was observed in younger children and those with abnormal bronchoscopy findings [79]. In immunocompetent children there was no bacteremia at the time of fever [79].

Risks in Critically Ill Children

Children with critical illness in the intensive care unit are at increased risk of procedures although often will have increased benefit. The risk of adverse events in the ICU are approximately 13%, with hypotension and hypoxemia the most common; however, only 2% of patients required intervention for these events [2]. Extracorporeal membranous oxygenation (ECMO) may be both an indication and a relative contraindication for flexible bronchoscopy. In general, children on ECMO can tolerate flexible bronchoscopy without significant pump flow rate or sweep gas flow changes [3]. Blood-tinged airway secretions and oozing are more common in this population (6–35%) both during and post-procedure [3, 80].

Risk of Therapeutic and Interventional Bronchoscopy

Therapeutic and interventional procedures have risk based on procedure and preoperative severity of illness. In adults, thermoplasty has risk of symptoms associated with airway irritation resulting in worsening asthma symptoms within 1 day of the bronchoscopy [81]. In a double-blind prospective control study, 8% of adults with severe asthma who had thermoplasty were hospitalized during the study protocol versus 2% of the subjects who received sham therapy; however, the other improvements due to the treatment of thermoplasty likely outweighed this risk [81].

Children who have had lung transplantation will likely have multiple surveillance and diagnostic bronchoscopies. Post-transplant is the most common indication for transbronchial biopsy, which is associated with a 0.8–3.4% risk of pneumothorax

in this population [82]. Pulmonary hemorrhage due to laceration can be a severe complication in children with lung transplantation occurring approximately 1–5% in this population [82].

Foreign body removal via flexible or rigid bronchoscopy has reported risk of pneumonia and when unsuccessful may require repeat surgery [83]. In a cohort of over 2000 pediatric cases of airway foreign body, hypoxemia was again the most common complication [84]; however, severe complications including death has been reported in multiple series [83–85]. In these cases, damage from the foreign body itself appeared to be the cause of the complications rather than the surgery, although this cannot be universally assumed. In one case series, increased rates of complications were associated with unwitnessed aspiration and infiltrates on preoperative chest radiograph [85].

See individual sections for specific risks of other interventional procedures.

Risks to Medical Team

The flexible bronchoscopy procedure has the potential to expose the bronchoscopy team to infected aerosols. The American College of Chest Physicians and American Association for Bronchology recommend all members of the bronchoscopy team employ "infection control" precautions including gown, gloves, mask, and eye shields [86]. N95 particulate respirator or higher-grade respiratory precautions is recommended if mycobacterial infection is suspected and increased precautions should be used for highly contagious organisms.

Flexible bronchoscopy is a typical diagnostic procedure to determine the cause of cough or other respiratory symptoms; therefore, children with communicable diseases including mycobacterial disease, pertussis, and influenza may be typical patients. Based on the differential diagnosis, appropriate workup including sputum culture, viral testing, tuberculin skin testing, etc., should be completed before bronchoscopy. Bronchoscopists should have a low threshold to perform bronchoscopy in a negative pressure room and to wear fitted masks that prevent aerosol exposure in high-risk patients. Hospital epidemiologists should be consulted if highly transmissible infections are isolated from BAL fluid.

Risk of Damage to Equipment

Flexible bronchoscopes are essential but expensive investments for bronchoscopy programs. Pediatric bronchoscopes are thin, fragile, and easily broken. The time and cost to repair the scopes can affect not only productivity of the program but patient care. Patients must be appropriately sedated to prevent them from biting the bronchoscope and bite blocks should be used. Bronchoscopes must be transported and stored carefully by qualified individuals. Biopsy forceps and other tools must be used carefully to limit wear and tear on the bronchoscopy channel that is a known risk of this equipment.

Conclusion

Bronchoscopy is an integral component of diagnosis of pediatric pulmonary disease and is used increasingly for therapeutic and interventional procedures. An often-quoted risk of bronchoscopy is obtaining the wrong answer or no answer from the procedure. Planning for adequate anesthesia, obtaining the proper equipment and team, and performing the appropriate tests will help create the circumstances to obtain the correct answer from the procedure. The importance of completing a "normal bronchoscopy" may be as useful as defining an abnormality.

The rare but statistical risk of serious complications including pneumothorax, cardiac complications, and cardiac arrest can affect the bronchoscopist in addition to the patient. Bronchoscopists should contemplate that indications for bronchoscopy are appropriate, the patient and their family provide adequate consent, and preparation for the procedure is thorough and repeatable. Problems with any component of flexible bronchoscopy should be reviewed by the program to continually limit risk.

When procedures are planned appropriately, bronchoscopy is generally a safe procedure. General anesthesia, while allowing the success of bronchoscopy, provides innate risk that should also be considered. Surgeons should be aware of pre-procedural risk, which may be increased in critically ill children. Severe complications including death, although statistically unlikely, do occur. As in all medical care, bronchoscopists should weigh the risks and benefits from the procedure and discuss these with patients and their families.

References

1. Faro A, Wood RE, Schecter MS, et al. Official American thoracic society technical standards: flexible airway endoscopy in children. Am J Respir Crit Care Med. 2015;191(9):1066–80.
2. Field-Ridley A, Sethi V, Murthi S, Nandalike K, Li ST. Utility of flexible fiberoptic bronchoscopy for critically ill pediatric patients: a systematic review. World J Crit Care Med. 2015;4(1):77–88.
3. Kamat PP, Popler J, Davis J, et al. Use of flexible bronchoscopy in pediatric patients receiving extracorporeal membrane oxygenation (ECMO) support. Pediatr Pulmonol. 2011;46(11):1108–13.
4. Peng YY, Soong WJ, Yee YS, Tsao PC, Yang CF, Jeng MJ. Flexible bronchoscopy as a valuable diagnostic and therapeutic tool in pediatric intensive care patients: a report on 5 years of experience. Pediatr Pulmomol. 2011;46(10):1031–7.
5. Soyer T. The role of bronchoscopy in the diagnosis of airway disease in children. J Thorac Dis. 2016;8(11):3420–6.
6. Midulla F, de Blic J, Barbato A, et al. Flexible endoscopy of paediatric airways. Eur Respir J. 2003;22:698–708.
7. Barbato A, Magarotto M, Crivellaro M, et al. Use of the paediatric bronchoscope, flexible and rigid, in 51 European centres. Eur Respir J. 1997;10:1761–6.
8. Irwin RS, Boulet LP, Cloutier MM, et al. Managing cough as a defense mechanism and as a symptom: a consensus panel report of the American College of Chest Physicians. Chest. 1998;114:133S.
9. Scellhase DE, Fawcett DD, Schutze GE, et al. Clinical utility of flexible bronchoscopy and bronchoalveolar lavage in young children with recurrent wheezing. J Pediatr. 1998;132(2):312–8.
10. Wood RE. The emerging role of flexible bronchoscopy in pediatrics. Clin Chest Med. 2001;22(2):311–7.
11. Boesch RP, Baughn JM, Cofer SA, Balakrishnan K. Trans-nasal flexible bronchoscopy in wheezing children: diagnostic yield, impact on therapy, and prevalence of laryngeal cleft. Pediatr Pulmonol. 2018;53:310–5.
12. Mancuso RF. Pediatric otolaryngology. Stridor in neonates. Pediatr Clin N Am. 1996;43(6):1339–55.
13. Erdem E, Gokdemir Y, Unal F, Ersu R, Karadag B, Karakoc F. Flexible bronchoscopy as a valuable tool in the evaluation of infants with stridor. Eur Arch Otorhinolaryngol. 2013;270(1):21–5.
14. Vijayasekaran D, Kalpana S, Ramachandran P, Nedunchelian K. Indications and outcome of flexible bronchoscopy in neonates. Indian J Pediatr. 2012;79(9):1181–4.
15. Najada AS, Dahabreh MM. Bronchoscopy findings in children with recurrent and chronic stridor. J Bronchology Interv Pulmonol. 2011;18(1):42–7.
16. Parnell FW, Brandenburg JH. Vocal cord paralysis: a review of 100 cases. Laryngoscope. 1970;80:1036–45.
17. Raoof S, Mehrishi S, Prakash UBS. Role of bronchoscopy in modern medical intensive care unit. Clin Chest Med. 2001;22(2):241–61.
18. Freitag L. Development of a new balloon catheter for management of hemoptysis with bronchofiberscopes. Chest. 1993;103:593.
19. Saw E, Gottlieb L, Yokoyama T, et al. Flexible fiberoptic bronchoscopy and endobronchial tamponade in the management of massive hemoptysis. Chest. 1976;70:589–91.
20. Bhat JI, Wani WA, Ahmad QI, et al. Flexible bronchoscopy in non-resolving pneumonia. Indian J Pediatr. 2017;84(9):681–4.
21. Knauer-Fischer S, Ratjen F. Lipid-laden macrophages in bronchoalveolar lavage fluid as a marker for pulmonary aspiration. Pediatr Pulmonol. 1999;27:419–22.
22. Bauer ML, Lyrene RK. Chronic aspiration in children: evaluation of the lipid-laden macrophage index. Pediatr Pulmonol. 1999;28:94–100.
23. Abu-Hasan MN, Chesrown SE, Jantz MA. Successful use of bronchoscopic lung insufflation to treat left lung atelectasis. Pediatr Pulmonol. 2013;48(3):306–9.
24. Maggi JC, Nussbaum E, Babbitt C, Maggi FE, Randhawa I. Pediatric fiberoptic bronchoscopy as adjunctive therapy in acute asthma with respiratory failure. Pediatr Pulmonol. 2012;47(12):1180–4.
25. Sachdev A, Ghimiri A, Gupta N, Gupta D. Predecannulation flexible bronchoscopy in tracheaostomized children. Pediatr Surg Int. 2017;33(11):1195–200.
26. Midyat L, Cakit E, Kut A. Upper airway abnormalities detected in children using flexible bronchoscopy. Int J Pediatr Otorhinolaryngol. 2012;76(4):560–3.
27. Adil E, Gergin O, Kawai K, Ranbar R, Watters K. Usefulness of upper airway endoscopy in the evaluation of pediatric pulmonary aspiration. JAMA Otolaryngol Head Neck Surg. 2016;142(4):339–43.
28. Su SC, Masters IB, Buntain H, et al. A comparison of virtual bronchoscopy versus flexible bronchoscopy in the diagnosis of tracheobronchomalacia in children. Pediatr Pulmonol. 2017;52(4):480–6.
29. Sanchez MO, Greer MC, Masters IB, Chang AB. A comparison of fluoroscopic airway screening with

flexible bronchoscopy for diagnosing tracheomalacia. Pediatr Pulmonol. 2012;47(1):63–7.
30. Platnaris A, Lianou D, Kaditis AG. Recurrent tracheoesophageal fistula in children with repaired esophageal atresia and the usefulness of flexible bronchoscopy. Arch Bronconeumol. 2015;51(1):49–50.
31. Bush A, Pohunek P. Brush biopsy and mucosal biopsy. Am J Respir Crit Care Med. 2000;162:518–22.
32. Cokugras H, Akcakaya N, Seckin I, Camicoglu Y, Sarimurat N, Aksoy F. Ultrastructural examination of bronchial biopsy specimens from children with moderate asthma. Thorax. 2001;56:25–9.
33. Payne DNR, Adcock IM, Wilson NM, Oates T, Scallan M, Bush A. Relationship between exhaled nitric oxide and mucosal eosinophilic inflammation in children with difficult asthma after treatment with oral prednisone. Am J Respir Crit Care Med. 2001;164:1376–81.
34. Payne DN, Rogers AV, Adelroth E, et al. Early thickening of the reticular basement membrane in children with difficult asthma. Am J Respir Crit Care Med. 2003;167:78–82.
35. Payne D, McKenzie SA, Stacey S, Misra D, Haxby E, Bush A. Safety and ethics of bronchoscopy and endobronchial biopsy in difficult asthma. Arch Dis Child. 2001;84:423–6.
36. Whitehead B, Scott JP, Helms P, et al. Technique and use of transbronchial biopsy in children and adolescents. Pediatr Pulmonol. 1992;12:240–6.
37. Scott JP, Higenbottam TW, Smyth RL, et al. Transbronchial biopsies in children after heart-lung transplantation. Pediatrics. 1990;86:698–702.
38. Fan LL, Kozinetz CA, Wojezak HA, Chatfield BA, Cohen AH, Rothenberg SS. Diagnostic value of transbronchial, thorascopic, and open lung biopsy in immunocompetent children with chronic interstitial lung disease. J Pediatr. 1997;131:565–9.
39. Eber E, Anton-Pacheco JL, de Blic J, et al. ERS statement: interventional bronchoscopy in children. Eur Respir J. 2017;50:1–19.
40. Goussard P, Gie RP, Kling S, et al. The diagnostic value and safety of transbronchial needle aspiration biopsy in children with mediastinal lymphadenopathy. Pediatr Pulmonol. 2010;45:1173–9.
41. Gibb E, Blount R, Lewis N, et al. Management of plastic bronchitis with topical tissue-type plasminogen activator. Pediatrics. 2012;130(2):e446–50.
42. Finer NN, Muzyka D. Flexible endoscopic intubation of the neonate. Pediatr Pulmonol. 1992;12:48–51.
43. Ramirez-Figueroa JL, Gochicoa-Rangel LG, Ramirez-San Juan DH, Vargas MH. Foreign body removal by flexible fiberoptic bronchoscopy in infants and children. Pediatr Pulmonol. 2005;40:392–7.
44. Tang LF, Xu YC, Wang YS, et al. Airway foreign body removal by flexible bronchoscopy: experience with 1027 children during 2000–2008. World J Pediatr. 2009;5:191–5.
45. Jayaraj AK, Jayaraj PK, Murugesh M, Aruchamy S, Yousefzadeh A, Siddiqui NT. Tracheal foreign body removal using flexible bronchoscopy in a pediatric patient. Am J Respir Crit Care Med. 2017;196(8):1071–2.
46. Hata A, Nakajima T, Ohashi K, et al. Mini grasping basket forceps for endobronchial foreign body removal in pediatric patients. Pediatr Int. 2017;59(11):1200–4.
47. Soong WJ, Tsao PC, Yee YS, Yang CF. Retrieval of tracheobronchial foreign bodies by short flexible endoscopy in children. Int J Pediatr Otorhinolaryngol. 2017;95:109–13.
48. Tenenbaum T, Kahler G, Janke C, Schroten H, Demiracka S. Management of foreign body removal in children by flexible bronchoscopy. J Bronchology Interv Pulmonol. 2017;24(1):21–8.
49. Mansour B, Elias N. Foreign body aspiration in children with the focus on the role of flexible bronchoscopy: a five year experience. Isr Med Assoc J. 2015;17(10):599–603.
50. Matsushita K, Uchida K, Otake K, et al. The "multiport airway adapter" in flexible bronchoscopy for peripheral bronchial foreign bodies in children. Int J Pediatr Otorhinolaryngol. 2015;79(12):2470–2.
51. Azizkhan RG, Lacey SR, Wood RE. Acquired symptomatic bronchial stenosis in infants: successful management using an argon laser. J Pediatr Surg. 1990;25:19–24.
52. Bagwell CE. CO2 laser excision of paediatric airway lesions. J Pediatr Surg. 1990;25:1152–6.
53. Xin Y, Wang G, Gao X, et al. Interventional bronchoscopy via laryngeal mask airway (LMA) under general anesthesia in children using adult flexible bronchoscope. Kawait Med J. 2016;48:317–22.
54. Nakamura CT, Ripka JF, McVeigh K, Kapoor N, Keens TG. Bronchoscopic instillation of surfactant in acute respiratory distress syndrome. Pediatr Pulmonol. 2001;31:317–20.
55. Baumann MH, Sahn SA. Medical management and therapy of bronchopleural fistulas in the mechanically ventilated patient. Chest. 1990;97:721–8.
56. Wood RE, Lacey SR, Azizkhan RG. Endoscopic management of large postresection bronchopleural fistulae with methacrylate adhesive (Super Glue). J Pediatr Surg. 1992;27:201–2.
57. Mathur PN, Wolf KM, Busk MF, et al. Fiberoptic bronchoscopic cryotherapy in the management of tracheobronchial obstruction. Chest. 1996;110(3):718–23.
58. Zhang L, Yin Y, Zhang J, Zhang H. Removal of foreign bodies in children's airways using flexible bronchoscopic CO2 cryotherapy. Pediatr Pulmonol. 2016;51(9):943–9.
59. Cravero JP, Blike GT, Beach M, Gallagher SM, Hertzog JH, Havidich JE, et al. Incidence and nature of adverse events during pediatric sedation/anesthesia for procedures outside the operating room: report from the Pediatric Sedation Research Consortium. Pediatrics. 2006;118(3):1087–96.
60. Amitai Y, Zylber-Katz E, Avital A, Zangen D, Noviski N. Serum lidocaine concentrations in children during bronchoscopy with topical anesthesia. Chest. 1990;98(6):1370–3.

61. Hu D, Flick RP, Zaccariello MJ, Colligan RC, Katusic SK, Schroeder DR, et al. Association between exposure of young children to procedures requiring general anesthesia and learning and behavioral outcomes in a population-based birth cohort. Anesthesiology. 2017;127(2):227–40.
62. Backeljauw B, Holland SK, Altaye M, Loepke AW. Cognition and brain structure following early childhood surgery with anesthesia. Pediatrics. 2015;136(1):e1–12.
63. DeBoer EM, Prager JD, Kerby GS, Stillwell PC. Measuring pediatric bronchoscopy outcomes using an electronic medical record. Ann Am Thorac Soc. 2016;13(5):678–83.
64. Khan EK, Baker CD. Endotracheal or tracheostomy tube occlusion during pediatric flexible bronchoscopy. Pediatr Pulmonol. 2018;
65. Wood RE. In: Wilmott RW, Deterding RR, Li A, Ratjen F, Sly P, Zar HJ, et al., editors. Kendig's disorders of the respiratory tract in children. 9th ed: Elsevier; 2018. p. 134–46.
66. Carlens J, Fuge J, Price T, DeLuca DS, Price M, Hansen G, et al. Complications and risk factors in pediatric bronchoscopy in a tertiary pediatric respiratory center. Pediatr Pulmonol. 2018;53(5):619–27.
67. Schnapf BM. Oxygen desaturation during fiberoptic bronchoscopy in pediatric patients. Chest. 1991;99(3):591–4.
68. Nussbaum E. Pediatric fiberoptic bronchoscopy: clinical experience with 2,836 bronchoscopies. Pediatr Crit Care Med. A journal of the Society of Critical Care Medicine and the World Federation of Pediatric Intensive and Critical Care Societies. 2002;3(2):171–6.
69. Strulovici-Barel Y, Omberg L, O'Mahony M, Gordon C, Hollmann C, Tilley AE, et al. Threshold of biologic responses of the small airway epithelium to low levels of tobacco smoke. Am J Respir Crit Care Med. 2010;182(12):1524–32.
70. Wood RE. Spelunking in the pediatric airways: explorations with the flexible fiberoptic bronchoscope. Pediatr Clin N Am. 1984;31(4):785–99.
71. Wagener JS. Fatality following fiberoptic bronchoscopy in a two-year-old child. Pediatr Pulmonol. 1987;3(3):197–9.
72. Picard E, Schlesinger Y, Goldberg S, Schwartz S, Kerem E. Fatal pneumococcal sepsis following flexible bronchoscopy in an immunocompromised infant. Pediatr Pulmonol. 1998;25(6):390–2.
73. Raine J, Warner JO. Fibreoptic bronchoscopy without general anaesthetic. Arch Dis Child. 1991;66(4):481–4.
74. Rock MJ. The diagnostic utility of bronchoalveolar lavage in immunocompetent children with unexplained infiltrates on chest radiograph. Pediatrics. 1995;95(3):373–7.
75. Ofstead CL, Quick MR, Wetzler HP, Eiland JE, Heymann OL, Sonetti DA, et al. Effectiveness of reprocessing for flexible bronchoscopes and endobronchial ultrasound bronchoscopes. Chest. 2018;154(5):1024–34.
76. Alipour N, Karagoz A, Taner A, Gaeini N, Alipour N, Zeytin H, et al. Outbreak of hospital infection from biofilm-embedded pan drug-resistant pseudomonas aeroginosa, due to a contaminated bronchoscope. J Prev Med. (Wilmington). 2017;2(2):1.
77. Reynolds HY. Bronchoalveolar lavage and other methods to define the human respiratory tract milieu in health and disease. Lung. 2011;189(2):87–99.
78. Kramer SS, Wehunt WD, Stocker JT, Kashima H. Pulmonary manifestations of juvenile laryngotracheal papillomatosis. AJR Am J Roentgenol. 1985;144(4):687–94.
79. Picard E, Schwartz S, Goldberg S, Glick T, Villa Y, Kerem E. A prospective study of fever and bacteremia after flexible fiberoptic bronchoscopy in children. Chest. 2000;117(2):573–7.
80. Prentice E, Mastropietro CW. Flexible bronchoscopy for children on extracorporeal membrane oxygenation for cardiac failure. Pediatr Crit Care Med. A journal of the Society of Critical Care Medicine and the World Federation of Pediatric Intensive and Critical Care Societies. 2011;12(4):422–5.
81. Castro M, Rubin AS, Laviolette M, Fiterman J, De Andrade LM, Shah PL, et al. Effectiveness and safety of bronchial thermoplasty in the treatment of severe asthma: a multicenter, randomized, double-blind, sham-controlled clinical trial. Am J Respir Crit Care Med. 2010;181(2):116–24.
82. Wong JY, Westall GP, Snell GI. Bronchoscopic procedures and lung biopsies in pediatric lung transplant recipients. Pediatr Pulmonol. 2015;50(12):1406–19.
83. Roberts CA, Carr MM. Morbidity and mortality in children undergoing bronchoscopy for foreign body removal. Laryngoscope. 2018;128(5):1226–9.
84. Boufersaoui A, Smati L, Benhalla KN, Boukari R, Smail S, Anik K, et al. Foreign body aspiration in children: experience from 2624 patients. Int J Pediatr Otorhinolaryngol. 2013;77(10):1683–8.
85. Sjogren PP, Mills TJ, Pollak AD, Muntz HR, Meier JD, Grimmer JF. Predictors of complicated airway foreign body extraction. Laryngoscope. 2018;128(2):490–5.
86. Mehta AC, Prakash UB, Garland R, Haponik E, Moses L, Schaffner W, et al. American College of Chest Physicians and American Association for Bronchology [corrected] consensus statement: prevention of flexible bronchoscopy-associated infection. Chest. 2005;128(3):1742–55.