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## Pediatric Bronchoscopy

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### 1. Introduction

#### Particular aspects of upper airways anatomy in the child

The small size of the child's airway, differences in the anatomy of the larynx and the different pathologies according to age group, are characteristics that shows the endoscopic examination of the child quite unique and different from adults.

The infant larynx presents some different aspects compared to the adult. Its location is higher in the neck, the cricoid cartilage being located approximately at the fourth cervical vertebra. With the growth of the child the cricoid cartilage will gradually descend to the level of the seventh cervical vertebra, which is the location in adulthood. The size of the larynx in the newborn is about 1 / 3 of the adult. Their structures such as the vocal process of arytenoid, cuneiform cartilage, the arytenoids and the soft tissue that makes up the supraglottic larynx are also bigger. The epiglottis is proportionally more posterior and narrower and more tubular or omega-shaped (Figure 1).



Fig. 1. Tubular or omega-shaped epiglottis of children.

The normal glottis of the infant, has a very small opening, about 7 mm in anteroposterior dimension and 4 mm in the posterior transverse dimension, so that 1 mm of edema may cause an obstruction of the airway in 35% of normal. Similarly, cartilage, muscle and submucosal tissues are softer and friable, providing a greater inflammatory reaction with

edema and significant reduction of airway lumen. The cricoid region has been described as narrowest of the airways, but recent studies in anesthetized children have shown that the glottis is narrower than the cricoid in all age groups.

## 2. Anesthesia for pediatric bronchoscopy

Anesthesia for invasive procedures on the airways has always been a challenge. The success of pediatric bronchoscopy relies on careful planning and constant communication between the bronchoscopist and the anesthetist throughout the procedure. In most cases the pediatric patient does not tolerate bronchoscopy whilst alert. Flexible bronchoscopy is usually performed with the use of sedation or sometimes local anaesthetic in infants and neonates, while rigid bronchoscopy requires general anesthesia. Our aim is to analyze some aspects that directly affect the actions and decisions of the anesthetist involved in the assistance.

The pre-anesthetic evaluation for this procedure consists of the child's history, physical examination and laboratory tests. The anesthetist should explain to parents how the anaesthesia will be administered and must be sure the child has been fasting. Infants under 1 year are recommended to fast for 6 hours if fed on formula, 4 hours if breast-fed and 2 hours after the ingestion of clear fluids only. Children over 1 year must fast for 6h after the ingestion of food or milk and 2h if only clear fluids were ingested. Only healthy children with no risk of slow gastric emptying may be allowed to have clear fluids before the procedure.

The best anesthetic technique and the most appropriate anesthetics should be considered according to some factors such as the child's physical status; an assessment of airways to identify chemical and /or physical lesions; the presence of lower respiratory infection with concomitant bronchospasm, secretions and edema, hypoxia and acidosis (due to severely compromised respiratory function); any co-existent disease; the needs of the bronchoscopist (some procedures during the bronchoscopy such as bronchoalveolar lavage or removal of foreign body increase the time of the examination) and the skills of the anesthetist. The consideration of all these aspects is essential to ensure the safety of the child, with minimal risk of complications. The risk of adverse events related to general anesthesia is associated with the physical status of the patient, thus being prudent to apply the scale of classification of physical status, established by the American Society of Anesthesiologists (Table 1).

In many cases, the pre-anesthetic use of bronchodilators and or anti-cholinergic drugs can improve the oxygen saturation and alveolar ventilation besides preventing, or attenuating, vagal responses of bradycardia and bronchoconstriction during the airway manipulation as well as reducing secretions.

ASA I	Patient is entirely fit and healthy.
ASA II	A mild systemic disease is present, but does not limit activity.
ASA III	Patient has a severe systemic disease that limits activity, but is not incapacitating.
ASA IV	Patient has a chronic condition, which is a constant threat to life.
ASA V	Patient is likely to die within 24h, with or without treatment.
ASA VI	A declared brain-dead patient whose organs are being removed for donor purposes.

\*ASA: American Society of Anesthesiologists

Table 1. ASA\* classification of physical status

It is important to make sure the equipment for advanced life support is available and to be aware that these data on requires as much care as general anesthesia. The minimal mandatory monitoring equipment includes: pulse oximetry, stethoscope, capnograph, electrocardiogram (rhythm and rate more important than ST-T wave changes), non-invasive blood pressure (Doppler assistance useful for small children) and temperature. It is also crucial to closely monitor skin color, skin perfusion, respiratory rate and pattern, diaphragmatic and intercostal activity and any evidence of airway obstruction such as croup, retractions, tracheal tugging or stridor.

As a general rule, the smaller the children, the more incomplete their metabolism, specially concerning drugs. This group is more sensitive to depressant cardiovascular effects and to take longer to recover from anesthetics (exception must be made to the faster metabolism of remifentanyl on neonates). Neonates and small children have reduced intracellular stores of calcium and reduced muscular mass of the myocardium, being susceptible to cardiac depressant effects of anesthetics. Neonates, especially prematures, are prone to post-anesthesia apnea, the greater incidence occurring in those < 60 weeks post-conceptual age. They also have reduced demands of inhalational agents to produce adequate levels of anesthesia. In children above 2 years, the larger fraction of cardiac output to kidneys and liver in proportion to their weight is responsible for a faster elimination rate of drugs.

The available devices for bronchoscopy are the facemask, the nasopharyngeal prong, the laryngeal mask (LM) and the endotracheal tube. Both endotracheal tubes and laryngeal masks have proved to be safe, but, according to some studies, the LM (reusable) is more appropriate than other supraglottic devices, and in children above 2 years, it causes less morbidity.

After the bronchoscopy has finished and if the child is stable, the patient will be moved to a recovery room and kept in the left lateral position. The child should still be monitored until awake and in control of the airway.

The most common complication is laryngospasm, related to light plane of anesthesia, pain, manipulation of the airway or cough. Hipoxemia can be caused by prolonged bronchoscopy, secretions or blood in the airway, bronchospasm or decreased cardiac output. Anesthetic agents can cause hypotension, especially in younger children. Bronchospasm can occur during the procedure. Malignant hyperthermia is rare.

### **3. Indications and contraindications of bronchoscopy in children**

Bronchoscopy is indicated in any chest or lung disease where the tracheobronchial tree may be involved directly or indirectly. You should always consider whether the benefits of information and / or therapy provided by the examination outweigh the risks because it is not free of complications. It can be performed using rigid or flexible devices. The best bronchoscopic techniques should be chosen according to each case individually.

Indications for flexible and rigid bronchoscopy are similar. However, in the evaluation of congenital malformations, the rigid bronchoscope provides better visualization, manipulation of anatomical structures, measurements of length and diameter of stenosis,

preoperative evaluation, as well as photographic documentation. In cases of removal of foreign bodies, preference is also rigid bronchoscopy.

### 3.1 Rigid bronchoscopy

The rigid bronchoscopes are straight metal tubes with side ventilation holes at the distal end. They have lighting system projecting light on its distal end. Rigid bronchoscopy can be performed under direct vision, but it is limited due to the small caliber of the airways of the child. Proximal illumination for rigid bronchoscopy is provided by prismatic light deflectors. An optical system magnifies the view. It can be coupled to a micro-camera generating the image on the display screen. Video monitoring can be used. This allows the team to anticipate needs and problems and to feel more a part of the procedure. A videorecorder can be used for bronchoscopy documentation (Figure 2). Tables 2 and 3 provide the indications for rigid bronchoscopy.



Fig. 2. Endoscopic instrumentation described from bottom to top: rigid bronchoscope (Storz) size 3.0 (20 cm), the optics of straightforward  $0^{\circ}$  telescope, metallic suction tube and laryngoscope.

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Persistent unexplained cough or wheeze
Unexplained dyspnea or stridor
Suspected congenital anomalies
Hemoptysis
Recurrent infections of the airways or lungs
Persistent abnormalities on chest radiograph
Atelectatic lung, lobe or segment
Diagnostic bronchoalveolar lavage
Suspected tracheoesophageal fistula or bronchoesophageal fistula
Mediastinal tumor
Chemical or thermal burns of the tracheobronchial tree
Suspected foreign body in tracheobronchial tree
Tracheobronchial stenosis
Lung abscess
Assessment of endotracheal tube placement
After airway reconstruction
Thoracic trauma

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Table 2. Major indications for diagnostic bronchoscopy

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Bronchial toilet, retained secretions, mucous plug, clots  
 Tracheobronchial mucosa necrotic  
 Removal of foreign bodies in tracheobronchial tree  
 Hemoptysis  
 Strictures and stenosis  
 Bronchogenic cysts (drainage)  
 Mediastinal lesions  
 Endotracheal tube placement and replacement  
 After airway reconstruction  
 Cystic Fibrosis  
 Asthma  
 Thoracic trauma

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Table 3. Major indications for therapeutic bronchoscopy

In the last century, rigid bronchoscopy was performed by chest surgeons or otorhinolaryngologist. But with the advent of the flexible bronchoscope in the 70's, rigid bronchoscopy has been used less, although it is still considered an indispensable tool, especially in the removal of foreign bodies in the airway.

Although bronchoscopy training should include both the device and the floppy drive, it has been observed in most services increased use of flexible bronchoscopy.

In Brazil, 45% of the members of the Department of Respiratory Endoscopy of the Brazilian Thoracic Society, who perform bronchoscopy feel able to perform rigid bronchoscopy. Less than 15% of them had some experience with therapeutic bronchoscopy.

In children, usually rigid bronchoscopy needs to be performed under general anesthesia and assisted ventilation. Even one of the most important advantages of rigid bronchoscopy is to allow control of the airway because the device is already inside the trachea, allowing adequate ventilation. However, manipulation with the rigid bronchoscope that is introduced orally, increases the risk of subglottic edema. This situation can be minimized by choosing the appropriate size of the bronchoscope according to age group (Table 4).

Patient age: mean (range)	size	outside diameter (mm)
Premature infant	2,5	3,7
Term newborn (birth - 3 mo)	3	4,8
6 mo (3 - 18 mo)	3,5	5,7
18 mo (1 - 3 y)	3,7	6,3
3 y (1 ½ - 5 y)	4	6,7
5 y (3 - 10 y)	5	7,8
10 y (> 10 y - adolescent)	6	8,2

Table 4. Size of the rigid bronchoscope according to age

Another advantage is the possibility of using various accessories instruments introduced through the bronchoscope such as suction tubes, forceps for biopsy, tumor resection and

removal of foreign bodies (Figure 3, 4). There are four types of forceps: cupped forceps (biopsy), alligator forceps, scissors and punch or cutting forceps (biopsy). Forceps for flexible bronchoscopes are more limited in size and strength than forceps for rigid bronchoscopes. They include biopsy forceps, baskets, claws and balloons.



Fig. 3. Forceps and brush washed.



Fig. 4. Tracheal dilators can be used in children for dilation of subglottic stenosis.

Another limitation of rigid bronchoscopy is the difficulty in accessing the bronchi of smaller caliber, as well as the upper lobe bronchus. Table 5 shows the advantages and disadvantages of rigid bronchoscopy.

Advantages	Disadvantages
Excellent control of the airway	Need for general anesthesia
Inside diameter allowing use of instruments accessories	Difficulty in assessing the dynamics of normal vocal cords
Greater ability to suction secretions, blood or tissue biopsy	Increased risk of trauma to the airway
Performed in the operating room facilitating management of complications	Inability to reach into the the upper lobes and segmental bronchi
Lower cost	Difficulty in obtaining BAL
Better image quality	

Table 5. Advantages and disadvantages of rigid bronchoscopy

Rigid bronchoscopy is most suitable for therapeutic procedures in particular the extraction of foreign bodies in the airways, tracheobronchial structures for dilation, stent placement for airway, control of hemoptysis and CO<sub>2</sub>-laser therapy (Figure 5, 6).

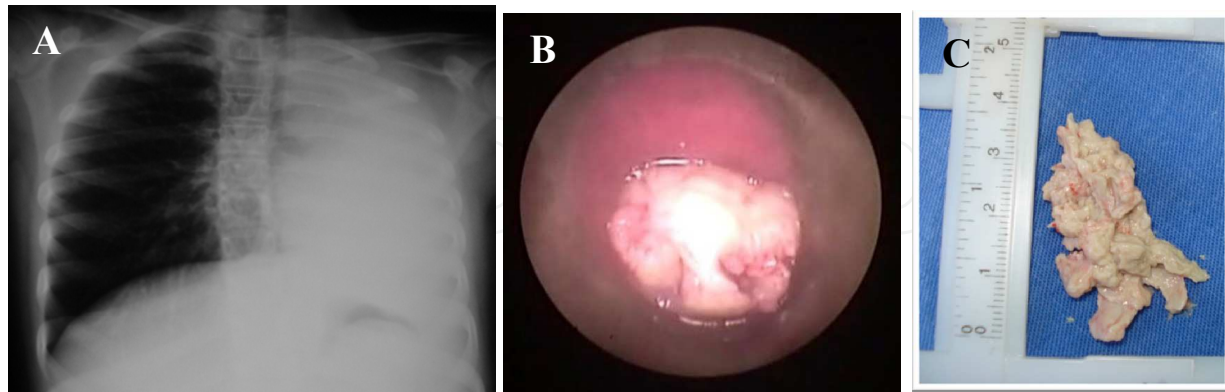


Fig. 5. Total left pulmonary atelectasis (A) due to bronchial casts filling the left bronchus (B) that was removed (C).

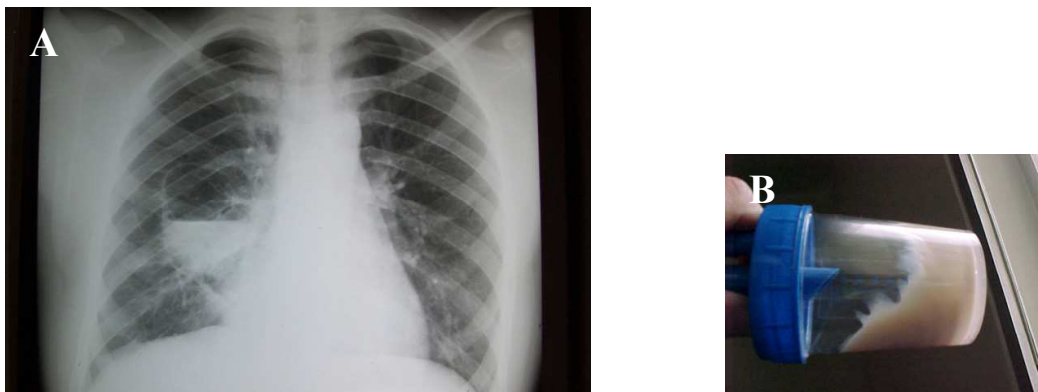


Fig. 6. Chest radiograph shows pulmonary abscess (A) and pus aspirated by bronchoscopy (B).

### 3.2 Flexible bronchoscopy

Since 1981, the flexible bronchoscope (FB) has been used routinely in pediatric patients. Robert Wood was the forerunner in the use of this type of bronchoscope in children. FB are made of flexible fiber optic rods that transmit light and generate a magnified image through a lens system (Figure 7, 8).

Table 6 shows the types of flexible bronchoscopes used in children. In adults, the FB has an outer diameter of 6 mm and 2.2 mm working channel while the most commonly used in children has an outer diameter of 3.6 mm and working channel of 1.2 mm. Currently there is available a flexible bronchoscope with a 2.2 mm outside diameter can be used in preterm infants, but do not have a working channel. The small diameter working channel prevents the introduction of accessories instruments. FB is indicated in sample collection and in the exploitation of airway. However some treatment can be indicated in FB as alveolar proteinosis and lipoid pneumonia due to aspiration of mineral oil.



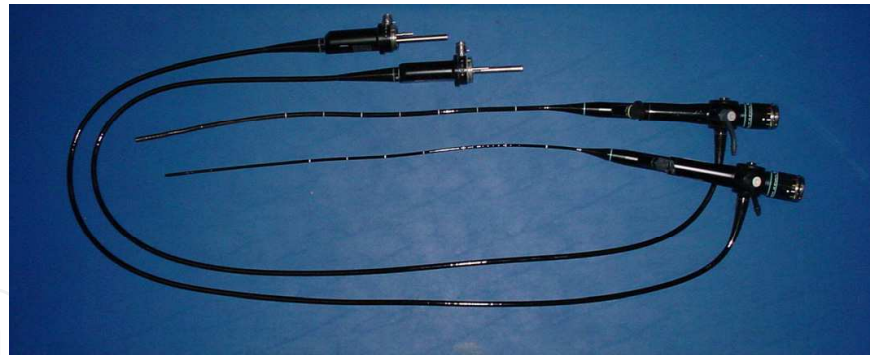


Fig. 7. Flexible bronchoscope 3,6 mm and 4,9 mm (OD).



Fig. 8. Flexible bronchoscope showing the various dimensions (3,6 mm and 4,9 mm OD).

<b>Outside diameter (OD)</b>	4,9 mm	3,6 mm	2,8 mm	2,2mm
<b>Working channel</b>	2,2 mm	1,2 mm	1,2 mm	Nenhum
<b>Viewing angle</b>	100°	95°	90°	75°
<b>Endotracheal tube</b>	≥5,	≥4,5	≥4,5	≥3,5
<b>Age of child</b>	> 4 y	standard pediatric	< 4 y	newborn

Table 6. Flexible Bronchoscopes used in pediatrics

In most cases, the flexible bronchoscopy can be performed without general anesthesia using lidocaine and topical anesthesia with sedation. Then it can be performed outside the operating room. The FB can be inserted through the nostrils, laryngeal masks, endotracheal tubes, tracheostomy tube or through the rigid bronchoscope. It also has the advantage of allowing the examination of segmental and subsegmental bronchi, optimizing the exploitation of the distal airway.

It is suitable for exploration of the airways, for intra-operative assessment and also post-operative assessment, for obtain biological samples such as bronchoalveolar lavage, transbronchial biopsy and bronchial brushing, for diagnosis of pneumonia in immunocompromised patients, interstitial pneumonia, hemosiderosis, sarcoidosis, alveolar proteinosis, Langerhans, endoluminal obstructive disease and aspiration syndromes (Figure 9).

The therapeutic application is more limited compared with rigid bronchoscopy, but can be used in endobronchial secretions aspiration, instillation of drugs, guide in difficult

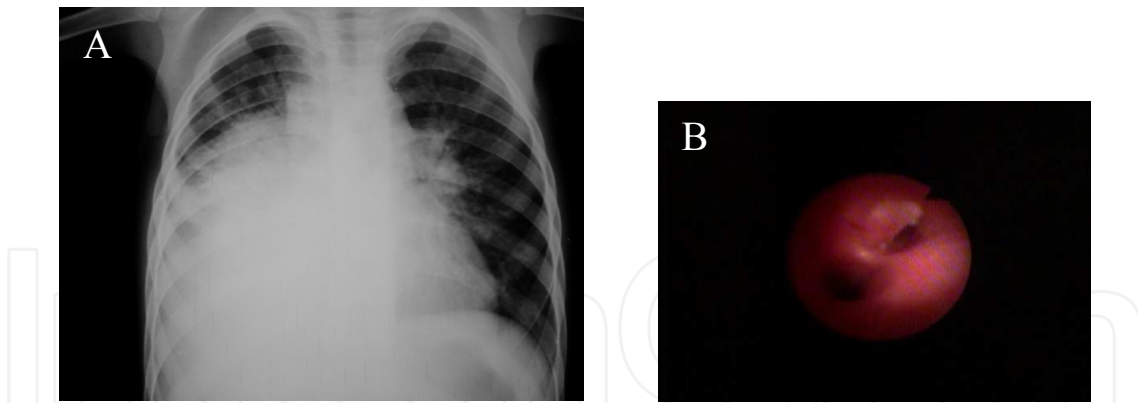


Fig. 9. Chronic pneumonia in the right lung (A). Bronchoscopy image shows enlargement of the main carina and narrowing of the right main bronchus due to extrinsic compression (B). BAAR and culture of BAL isolated *M.tuberculosis*.

intubations, monitoring and patient follow-up, to help as tracheotomy, and the extraction of same cases of foreign bodies (table 7).

Nowadays came a new generation of bronchoscopes that have a chip on its distal end. These are the videobronchoscopes, with higher resolution and image storage in digital format. Pediatric models are available in size with outside diameter of 3.6 y 4.9 mm. The disadvantage is the high cost of equipment.

New techniques are being developed, such as endobronchial ultrasound since 1999 and most recently ultrasonic bronchoscope with transbronchial needle, but without experience in the child population.

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Stridor

Persistent atelectasis

Recurrent or / and persistent infiltrations

Pulmonary lesions of unknown etiology

Chronic cough

Hemoptysis

Removal of some foreign body

Evaluate the position, patency, or other changes related to ETT or tracheostomy

Assess the damage of inhalation or aspiration

Samples

Bronchoscopic lung biopsy

Remove secretions or mucus plaques

BAL therapy

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Table 7. Indications for flexible bronchoscopy in pediatrics

### 3.3 Contraindications

In general there is no absolute contraindication to bronchoscopy. Wood RE related that the only absolute contraindication to bronchoscopy is the lack of a rational indication. However it is contraindicated in cases of unstable cardiovascular status or life-threatening cardiac

arrhythmia, extremely severe hypoxemia and an inadequately trained bronchoscopist and bronchoscopy team.

Rigid bronchoscopy is relatively contraindicated in micrognathia, microstomia, cervical spine instability and mandibulomaxillary trauma or disease.

Flexible bronchoscopy is relatively contraindicated in some foreign body aspiration, hemorrhagic diathesis, severe hypoxemia and respiratory distress. Trombocytopenia is not a contraindication to pediatric bronchoscopy.

#### **4. Bronchoalveolar lavage in children**

Since the 80's with the advent of a flexible bronchoscope, bronchoscopy is being increasingly used as a diagnostic tool in several lung diseases in children.

The bronchoalveolar lavage (BAL) is a resource used in bronchoscopy that has helped to increase the sensitivity and specificity of the bronchoscopy. Several studies have been published using the BAL for the diagnosis of various lung diseases, especially persistent or recurrent pneumonia, interstitial infiltrates, severe pneumonia in patients in intensive care units and pulmonary infiltrates in immunocompromised patients. Examination of BAL fluid can identify the etiologic agent in these types of pneumonia. BAL is considered a safe procedure and fast, with low percentage of complications, even in infants, and in many cases makes open lung biopsy unnecessary.

In children the BAL is commonly used for diagnosis of opportunistic infections in immunocompromised patients. BAL has a sensitivity and specificity comparable to those of open lung biopsy. However, unlike this, has much lower morbidity and mortality, although it is also an invasive procedure.

Another indication is in the cases of recurrent or persistent pulmonary infiltrates of unknown etiology. BAL is an diagnosis tool for children under age 6 who have difficulty, because of the age, to collect sputum for microbiological studies. Molecular biology allows identification of pathogens from small samples. In addition, analysis of cellular and non cellular components of BAL fluid can define the diagnosis of non-infectious causes of pulmonary infiltrates. Thus, the diagnosis of diseases such as alveolar proteinosis, hemosiderosis, lipid aspiration pneumonia, interstitial pneumonia, can be done by BAL.

The study of BAL has also contributed to understanding the pathogenesis of interstitial lung diseases and it has now been used to evaluate the treatment and prognosis of these diseases. Analysis of BAL solutes, including proteins and inflammatory mediators can be studied.

The BAL can be indicated as therapy in cases of alveolar proteinosis, for removal of secretions in cystic fibrosis and, in severe cases of status asthmaticus. BAL can be both a diagnostic or therapeutic tool even in critically ill children.

##### **4.1 Techniques of BAL and the laboratory processing**

Flexible bronchoscopy with bronchoalveolar lavage should be done safely in intensive care unit, special procedures areas and operating rooms.

In children bronchoscopy is performed under intravenous sedation (0.05 – 0.3 mg/kg Midazolam) and topical lidocaine anesthesia of the upper airways (4% lidocaine gel to the nasal passage and 1% lidocaine through the bronchoscope to the glottic region) using a flexible bronchoscope (external diameter of 2.8 / 3.6mm for small children and a diameter of 4.6 / 4.9 mm for >9 yrs of age).

Each child should have an intravenous access and should be monitored with pulse oximetry, and heart rate and administered O<sub>2</sub> by nasal catheter. Immediate access to supplemental oxygen, resuscitation equipment and antagonists for sedative agents (naloxone and flumazenil) should be readily available. A swivel Y connector should be used in endotracheal tube, in intubated children. Cough can be controlled if small amount of 1% lidocaine is administered through the channel of bronchoscopy when it reaches the trachea.

It is carried out careful inspection of the tracheobronchial tree and the FB is wedged into the involved segments previously indicated by CT scan or if the disease is diffuse, the most suitable segments are the right middle lobe or the lingula.

BAL is carried out using normal sterile pyrogen-free saline previously warmed to body temperature (37°C) with a syringe attached to the suction channel of the FB for controlled aspiration with a suction trap. Negative pressure of 120 mmHg is adequate for obtaining return of BAL. It is instilled 3 aliquots of 1 ml/kg body weight in each compromised segment or lobe previously indicated by CT scan. Each instillation must be followed by sufficient air to ensure that the channel's dead space is empty and it should be immediately recovered by manual suction through a syringe or using the mechanical aspiration. The first aliquot collected should be used for culture because it probably represents bronchial origin. The others are pooled and processed for cytological studies and analysis of BAL solutes (Table 8).

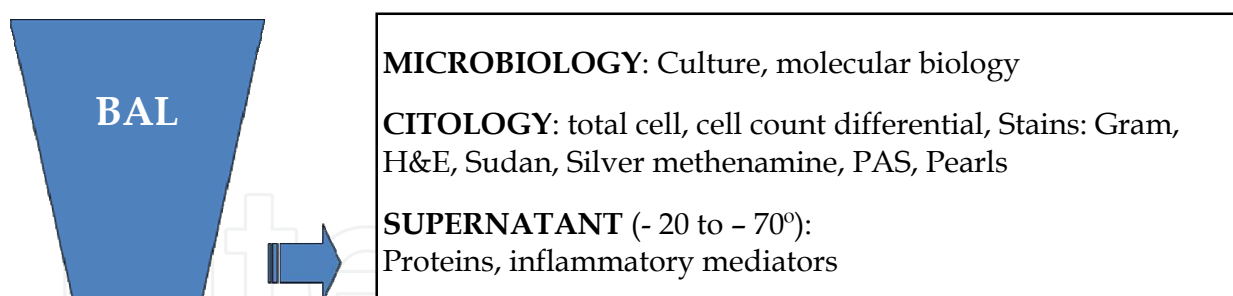


Table 8. Laboratory processing of BAL

Some authors use functional residual capacity (FRC) to get the BAL. The total volume has been used at a rate of 5 to 15% of FRC, which is proportional to the total volume per FRC used in adults. BAL can be considered technically adequate if the recovery is more than 40% and contains few epithelial cells. BAL fluid must be transported under refrigeration and processed in a maximum of 1 hour.

The macroscopic aspect of the BAL should be evaluated because it may suggest some diseases. In lipoid pneumonia the BAL fluid has milky appearance, floating fat globules and numerous Sudan positive foam macrophages. (Figure 10). In hemorrhagic syndromes the BAL can be xanthochromic.



Fig. 10. Macroscopic aspect of BAL in children with Lipoid pneumonia: milky appearance with floating fat.

Routine laboratorial analysis for bacteria (routine aerobic, *Legionella*, *Nocardia*, *Mycobacteria* including *Mycobacterium tuberculosis*, Virus (CMV, RSV, Influenza, Parainfluenza, Enterovirus) and or cultivation of anaerobes, anaerobic transport media containing reducing agents may be used and the BAL fluid must not be exposed to air.

Cell counts are determined in Neubauer chamber and cell viability by trypan blue exclusion dye. Cytospins prepared after 5 min at 200g speed, are stained for bacterial (Gram), lipid-laden macrophages (Sudan or Oil red), lipoproteins in pulmonary alveolar proteinosis (PAS—periodic acid-Schiff), hemosiderin in idiopathic pulmonary hemosiderosis, Wegener's granulomatosis and Goodpasture's disease (Pearls), pulmonary histiocytosis X (monoclonal antibody OKT-6), fungi (Silver methenamine or Gomori-Grocott), *Mycobacterium tuberculosis* (Ziehl Neelsen) and Papanicolaou and May-Grunwald-Giemsa. Glutaraldehyde fixation for electron microscopy is performed if is necessary. (Figure 11, 12, 13).

The BAL cytology in healthy children is similar to that observed in healthy adults. In children the total cell counts tend to be higher in younger children (Table 9).

The interpretation of the differential cytology of BAL fluid can suggest the diagnosis of different types of lung diseases. Macrophages are the predominant cells followed by lymphocytes while the percentage of neutrophils appears to be higher in children under than 12 months. In general, in the absence of infection, the BAL of children have higher percentages of macrophages (upper to 90%) while those suffering from viral or bacterial infection have greater increases in the percentage of neutrophils. Unlike the adult the CD4/CD8 ratio in children has been found to be lower. The predominance of eosinophils in BAL suggests eosinophilic pneumonia or drug toxicity.

Although LBA prolongs the duration of bronchoscopy, because the bronchoscope stays longer in the airways, there is an increased risk of complications when compared with bronchoscopy simple. The main complications of the procedure are temporary, such as tachypnea without cardiac decompensation, and fever spikes 4 to 6 hours after the procedure. Other possible complications include hypoxemia that is most often minimized by concomitant administration of oxygen during the procedure and transient bronchospasm.

BAL has become a valuable procedure because, unlike lung biopsy is less invasive, well tolerated by patients, insurance and low percentage of complications, even in infants.

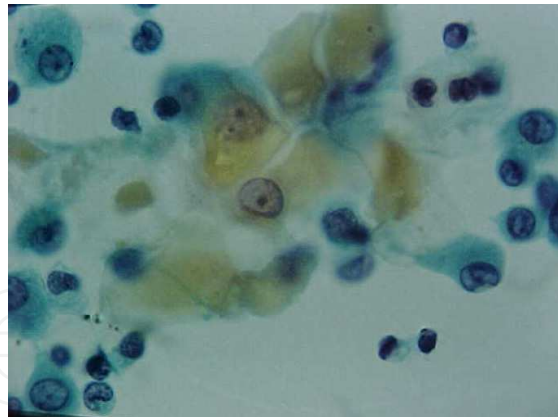


Fig. 11. BAL with large amounts of PAS-positive material in and out of cells (PAS 100 x).

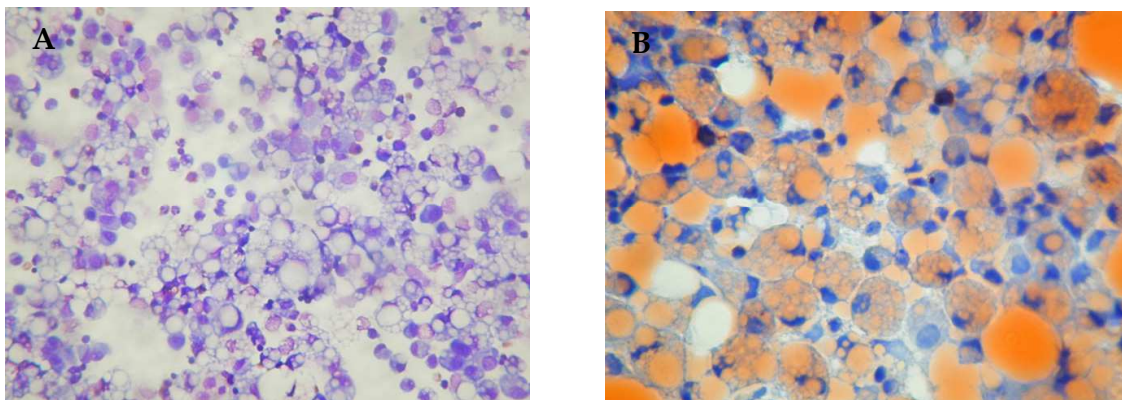


Fig. 12. BAL with large number of cells with predominance of foamy cytoplasm macrophages (A) (Giemsa 400X) and numerous macrophages with foamy cytoplasm stained orange (B) (Sudan 400X).

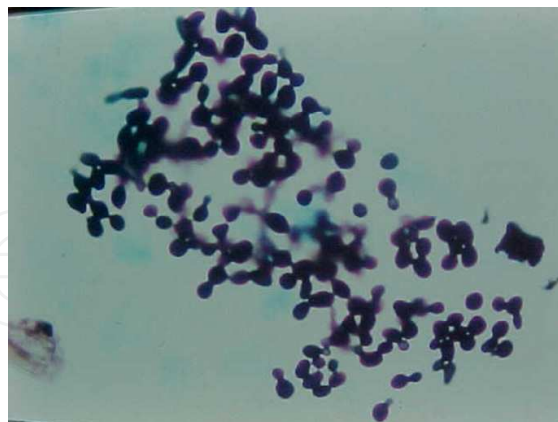


Fig. 13. BAL of immunocompromised child with chronic pneumonia shows a group of fungi (Gomori-Grocott 400x).

The presence of microorganisms in BAL fluid does not necessarily indicate they are the causative agents of pneumonia due to the possibility of contamination with the flora of the nasal or oropharynx. However, the growth of bacteria in the BAL should be enhanced through the use of protected a catheter or protected or by the quantitative bacteriological culture.

	Clement et al 1987	Ratjen et al 1995	Riedler et al 1995	Midulla et al 1995	Tessier et al 1996
No. of children	11	48	18	16	11
Age range	1-15	3-5	1#-10	2#-3	4-16
Sedation	LA	GA	GA	LA	LA
No. of aliquots	6	3	3	2	6
Vol.saline	10% FRC	3ml.Kg <sup>-1</sup>	3ml <sup>-1</sup>	20ml	10% FRC
BAL fluid recovered %	NR	58±15	NR	43.1±12.2	69.7±9.6
mean ± SD	NR	NR	62.5	42.5	68
median	NR	NR	42.5-71.5	20-65	52-87
range	NR	NR	NR	NR	NR
X 10 <sup>4</sup> cells.mL <sup>-1</sup>					
mean±SD	25.5 ± 13.6	10.3 ± 11.1	ND	59.9 ± 32.9	35.1 ± 18.4
median	24	7.3	15.5	51	30.5
range	7.0±50	0.5±57.1	7.5±25.8*	0 20±130	9±68
Alveolar Macrophage %					
media±SD	89.7±5.2	81.2±12.7	NR	86±7.8	89.9±5.5
mediana	89	84	91	87	92.5
range	85-97	34.6-94	84.2-94*	71-98	77-98
Lymphocyte %					
media±SD	8.7±4.6	16.2±12.4	NR	8.7±5.8	8.9±5.6
median	10	12.5	7.5	7	8
range	1-17	2-61	4.7-12.8*	2-22	2-22
Neutrophil %					
media±SD	1.3±0.9	1.9±2.9	NR	5.5±4.8	1.2±1.2
median	1	0.9	1.7	3.5	1
range	0-3	0-17	0.6-3.5*	0-17	0-3
Eosinophil %					
media±SD	NR	0.4±0.6	NR	0.2±0.3	0
median	NR	0.2	0.2	0	0
range	NR	0-3.6	0-0.3*	0-1	0

Age range is given in years, except where indicated by #; \*: First interquartile to third interquartile. LA: local anaesthesia; GA: general anaesthesia; FRC: functional residual capacity; ND: not done.

Table 9. Normal BAL cell count parameters in healthy children

## 5. Other special procedures in pediatric bronchoscopy

### 5.1 Bronchial biopsy

Bronchial biopsy is performed in the mucosa or in an endobronchial lesion allowing the assessment of the epithelium, the basal membrane and even the smooth muscle.

This procedure is safely used in research studies of respiratory disorders including asthma, recurrent wheezing, and cystic fibrosis, and has already revealed its usefulness for the diagnosis of either infectious or non-infectious granulomatous diseases (tuberculosis, sarcoidosis), endobronchial tumors, chronic fungal diseases, and for the management of difficult-to-control asthma. Although bronchial biopsy is appropriate for harvesting ciliated cells for the diagnosis of primary ciliary dyskinesia, nasal brushing remains the recommendable technique to be performed in this disorder due to its simplicity, with equal results.

Bronchial biopsies can be performed under direct vision although some endoscopists has been preferred to use flexible bronchoscope. Adult flexible bronchoscope (4.9 mm OD) is also used for biopsies because a 2.0mm instrumentation channel is needed for most biopsy forceps. Standard 1.8 mm diameter forceps are also used to obtain bronchial samples, although the 1,1 forceps has been successfully used, too. We have to keep in mind that the size of the samples obtained with the 1,1 forceps are obviously smaller, and the successful rate of the technique could decrease because of that. An adequate sample for analysis must show at least 1mm of basal membrane, sufficient subepithelial stroma for inflammation assessment, areas of smooth muscle and submucosal glands. In general the number of biopsies performed for a trustworthy analysis varies from a minimum of 1 up to 6.

In general the technique is well tolerated and no important bleeding or pneumothorax has been reported. Different from transbronchial biopsy, routine chest radiography is not necessary as we don't go through bronchial wall during the procedure. The risk of major bleeding increases in biopsies of very vascularized lesions. In these cases, 1-2 ml of adrenalin at 1 / 20.000 should be instilled previous to the procedure. General anesthesia or deep sedation is usually used to avoid patient movement during the procedure and to increase safety, specially in children.

## 5.2 Transbronchial biopsy

Transbronchial biopsy (TB) is a procedure performed to obtain lung fragments, using an appropriate flexible biopsy forceps, which is inserted through the bronchoscope. The aim of this procedure is to collect material from the lung parenchyma using a minimally invasive procedure. Although, TB is routinely used in adult patients with a good diagnostic yield in many situations since the 70s, its role in children took longer to be established. Issues related to the techniques used, the yield results and the safety of the procedure possibly contributed to this fact.

Currently, TB has a well-defined role for the monitoring of pediatric patients who underwent a lung or a heart-lung transplantation, when it is performed with well-established protocols during the first year after transplantation to assess the presence of rejection or infection.

Transbronchial biopsy in this setting was able to detect asymptomatic rejection in up to 24% of cases (Faro et al., 2004). It must also be performed when there is any abnormality of the heart's transplant patient presented with cough, dyspnea or fever associated with radiological findings or in the presence of decline in lung function. Although the diagnostic yield of TB in patients with other medical conditions, with or without immunodeficiency, may reach 67%, ERS Task Force considers the role of TB in non-transplanted patients are still controversial. Some studies also demonstrate the use of TB for the diagnosis of other diseases such as lung disease in immunosuppressed patients, sarcoidosis, eosinophilic granuloma and lymphoma.

Transbronchial biopsy can be performed either through a flexible or rigid bronchoscope. For the flexible bronchoscope, it is generally used the adult model with an outer diameter of 4.9 mm and a 2.2 mm working-channel diameter, which is not often a problem for older children (figure 14). For the younger children, smaller diameter bronchoscopes may be used with working-channels as narrow as 1.2 mm, which also involves the usage of smaller forceps, which could lessen the chances of obtaining adequate samples for analysis,



potentially decreasing the diagnostic yield. The rigid bronchoscope could also be used for these younger children, thus allowing the use of larger forceps with no significant differences in technique.



Fig. 14. Flexible bronchoscope with biopsy forceps on its distal end.

The technique for obtaining fragments from distal airways is the same as described by the ERS Task Force. In the absence of localized disease, at least two lobes should be approached. However, only one lung should be sampled to minimize the risk of bilateral pneumothorax. The minimum number of fragments to be harvested is still uncertain, ranging from 3 to 4, depending on the experience of each service. The use of fluoroscopy can be a great value for the procedure, since it allows a more accurate location of the biopsy forceps, and also the assessment off its operation during the procedure, despite the limitations of the two-dimensional image generated. ERS Task Force considers the use of fluoroscopy mandatory to perform TB.

Overall, TB is a safe procedure when performed by experienced professional. Less serious complications include transient hypoxemia, fever and dyspnea. Serious complications include bleeding and pneumothorax, and occur in around 5% of the patients submitted to TB, although series of patients reported the incidence of pneumothorax up to 12%. Recent publications reported the incidence of pneumothorax and bleeding around 2%. The complications rate appears to be higher than that observed in adult patients. The use of positive pressure ventilation can theoretically contribute to a higher incidence of pneumothorax. Therefore, TB should be performed during spontaneous ventilation whenever it's possible. TB seems to be a technique that deserves better use, still being underused in clinical pediatrics.

## 6. Foreign body aspiration

Accidents in childhood are important causes of morbidity and mortality worldwide, requiring prompt recognition and early treatment to minimize the risk of serious fatal consequences. Among the accidents, there is a foreign body aspiration (FBA) of the airway. United States of America statistics show that 5% of deaths from accidents with children under 4 years are due to FBA, which is also the main cause of accidental death at home in children under 6 years. In Brazil, the FBA is the third leading cause of accidents with death.

Currently, the foreign body aspiration remains an emergency, presents itself the same way as in earlier times, but with diminishing considerable morbidity and mortality.

The majority victims are infants and children, early in life, with the predominant age of 4 years. The male over female prevails in most published works, probably the most curious and impulsive nature of the boys. According to Reilly et al, children younger than 4 years are more susceptible to FBA injuries due to their lack of molar teeth, oral exploration, and poor swallowing coordination. Usually the coordination between chewing and swallowing is completed around 5 years old. The caregiver was present at the time of injury in 48.9% of cases (82.3% while the children were eating, and 33.8% while playing).

Foreign body aspiration in children is associated with a failure of the laryngeal closure reflex, poor control of swallowing and habit of putting objects in the mouth. The negligence of some parents with certain objects might can be aspirated, as small toys and some foods are predisposing factors.

Foreign bodies may be organic or inorganic material. The origin of organic vegetables are more common: peanuts, beans, corn, fruits and seeds. Beans and peanuts are the most frequently aspirated. However the type of foreign body aspiration varies according to regional food habits. Dried vegetables stimulates an inflammatory reaction within a few hours, making the extraction extremely hard. Foreign bodies can be found from animal sources like chicken bone, and teeth fragments. The non-organic may be metal or plastic. The most frequent non-organic FBA are plastic pen cap, earring, pin, plastic toy, nib, nail, hair clip, earring tuners, small plastic parts. In recent years, children have been increasingly exposed to the electronic technologies containing buttons and batteries (Figure 15).

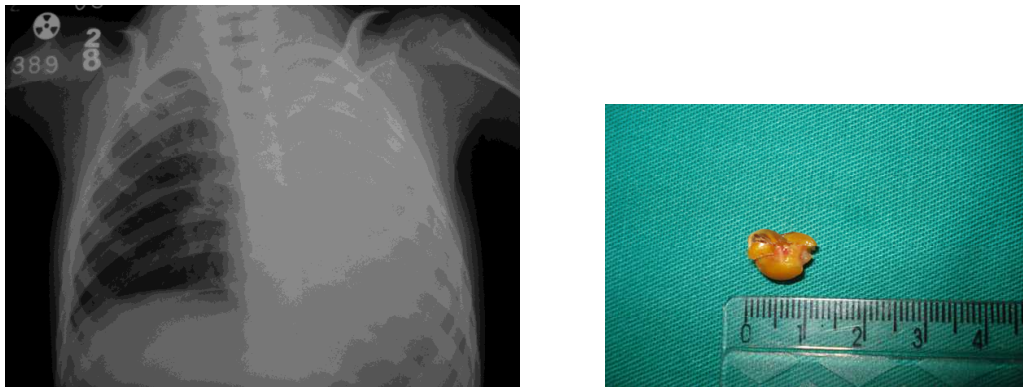


Fig. 15. Total atelectasis caused by corn removed from the left main bronchus.

Clinically, FBA manifests as a coughing, followed by choking, which may or may not be valued by parents. Most often, this is currently not seen by parents or guardians, a fact that delays the diagnosis, unless the aspiration is followed by complete obstruction of the airway.

Clinical findings depend on the type, size and location of foreign body and including persistent cough, located air intake, localized or diffuse, wheezing and breathing difficulties. Approximately 40% of the patients are asymptomatic and no changes in physical examination. The FBA can also be suspected in the first sudden onset of wheezing.

Foreign bodies may be located in the larynx, trachea and bronchi. The most commonly found is in the right main bronchus, due to anatomical position of this bronchus.

The symptoms will depend on the location:

Larynx: supraglottic (cough, dysphagia or difficulty to swallow food or saliva swallowing, inspiratory stridor); glottal (dysphonia, inspiratory stridor) (Figure 16) and subglottic (dyspnea or shortness of breath accompanied by chest indrawing, supraclavicular, suprasternal or universal).

Trachea: wheezing audible sound from the shock of the foreign body against the subglottis during expiration or coughing, cyanosis, retractions suprasternal, supraclavicular, intercostal, biphasic stridor, dysphagia, suffocation and sudden death.

Bronchi: clinical manifestations depend on the caliber that the foreign body occupies within the bronchial lumen. When there is atelectasis and a significant portion of the lung is involved can occur tachypnea, retractions, dullness to percussion and decreased breath sounds. Crackles may be present if there is infection.



Fig. 16. Fish bone in 2-year-old boy presenting dysphonia and inspiratory dyspnea.

Although the radiographic study should be performed in almost all cases, it is reiterated that the decision for endoscopic investigation is always warranted before a history and physical examination suggestive of aspiration.

Radiological study using the technical inspiration and forced expiration, is altered in most cases. The main radiological abnormalities are lung hyperinflation and atelectasis. Normal chest radiograph, consolidations, and radiopaque foreign bodies are reported less frequently.

Chest X-ray should remain the initial imaging modality for patients with clinically suspected of FBA. Nevertheless, in cases with normal chest X-ray and clinical suspicion of FBA, multi-slice computed tomography possibly integrated with virtual bronchoscopy should be considered to avoid unnecessary bronchoscopy.

The early diagnosis of FBA is essential. Large number of patients are treated for weeks and months due to recurrent respiratory diseases before the suspicion of FBA. Late diagnosis or wrong results in respiratory complications such as recurrent pneumonia, lung abscess, and obstruction of the airway which can be fatal.

Bronchoscopy is the procedure of choice for foreign body removal. The authors prefer the rigid bronchoscope because it has less risk of complications.

Patients are submitted to rigid bronchoscopy under general inhalation anesthesia and assisted ventilation. The foreign body extraction is performed by special clamps for each

type of foreign body, aided by optical rigid. In some cases fragments of foreign bodies are removed through small size bronchial lavage with saline solution and suction aspiration cannulas. Subsequently should be performed the review of tracheobronchial tree.

A radiological control should be done. Antibiotics and steroids are necessary in some patients due to inflammatory reaction triggered by plant and animal aspiration.

In cases of foreign body be larger than the opening of the glottis tracheostomy will be necessary. Thoracotomy is indicated when it is not possible to extract the foreign body by bronchoscopy after several attempts. The review of the tracheobronchial tree should be done in 2 to 4 weeks depending on the case.

Peri-operative complications, such as bronchospasm, bleeding, pneumotorax and desaturation can occur.

FBA are a life-threatening event in children that require early diagnosis and prompt successful management. Prevention is the most critical element in reducing morbidity and is considered the most effective treatment of FBA injuries. Changes in product design, campaigns of prevention of accidents in childhood, education of parents and carers are strategies that have been used to reduce morbidity and mortality caused by foreign body aspiration.

## **7. Stridor and congenital airway anomalies**

Stridor is acute respiratory noise that results of a turbulent airflow due to blockage of airway. It is the most frequent indication for bronchoscopy.

The incidence of stridor ranging from 13.5% to 96% of endoscopies. It is higher in newborns and infants, with an average age of 4 months. In newborns and infants, the caliber of the airway is more narrow, and any obstruction can result in a blockage to the passage of air, resulting in a turbulent airflow. The preponderance of males over females is not clear. The most common is the inspiratory stridor, with origins in the larynx, upper trachea or hypopharynx.

The child with stridor should be examined carefully, starting with detailed history, followed by physical examination, radiological and endoscopic examination. Is very important to a good history, emphasizing a history of intubation, its duration and size of the endotracheal tube, history of trauma during intubation and the number of times that the child was intubated. Information such as age of onset of stridor, the duration of the stridor, the association with triggering agents, such as tears and pain, the association with the position (prone, supine, or sitting), the quality or nature of crying, the presence of other symptoms such as paroxysmal cough, cyanosis and aspiration are important and should be investigated.

If symptoms worsen in the supine position and improve in prone, may be caused by laryngomalacia, or tracheal compression by the innominate artery. In the prone position, the structures obstruct the airway and stridor increases. It is important to evaluate the morphology of the skull in relation to malformations, the presence of micrognathia or retrognathia, cyanosis, signs of infection in the oral cavity, the presence of excessive salivation or oral secretions, use of accessory respiratory muscles, throbbing of the nose, chest wall retraction and the child's level of consciousness.

Chest X-ray should be mandatory in all patients. Images of the neck and upper airway are useful for evaluating the air columns above and below the larynx and the lung parenchyma, allowing us to follow the evolution of local collapse and obstruction. High kilovoltage techniques are useful to observe the larynx, vocal cords and subglottic region. Fluoroscopy, barium swallow, computed tomography, and electromagnetic resonance may be useful in the diagnosis of structural and / or dynamic changes of the tracheobronchial tree, such as tracheomalacia, tracheal or bronchial compression by anomalous vessel, patients with swallowing disorders, laryngeal cleft, vascular ring, tracheoesophageal fistula and radiolucent esophageal foreign bodies. Although these tests can contribute to the differential diagnosis of stridor, bronchoscopy is establishing a definitive diagnosis.

The main causes of stridor are congenital and occur more frequently in the larynx, followed by the trachea and bronchi. Table 10 shows the causes of stridor by anatomical location.

<b>Upper airway</b>	Choanal atresia Tumors, cysts and masses Craniofacial anomalies
<b>Larynx</b>	Laryngomalacia Paralysis of vocal cords (congenital and acquired) Infections conditions (croup and epiglottitis) Subglottic stenosis (congenital and acquired) Hemangioma Saccular cysts e laryngoceles Webs, atresia Cleft larynx Laryngeal pappilomatosis Trauma Foreign body
<b>Lower airway</b>	Tracheomalacia, Bronchomalacia Tracheoesophageal fistula Vascular anomalies (aberrant innominate artery, double aortic arch, pulmonary artery sling) Tracheal web, cysts and stenosis Accessory bronchi and lobes Infections conditions Pulmonary sequestration Asthma, bronchiolitis, bronchitis Foreign body

Table 10. Most common causes of stridor in children

Laryngomalacia is the most common congenital anomaly of the larynx and the most important cause of stridor, predominantly in males in the ratio 1.6 / 1 (Figure 17). May be isolated or associated with other abnormalities of the airways such as tracheomalacia, bronchomalacia, vocal cord paralysis, subglottic stenosis, hypertrophy of adenoids.

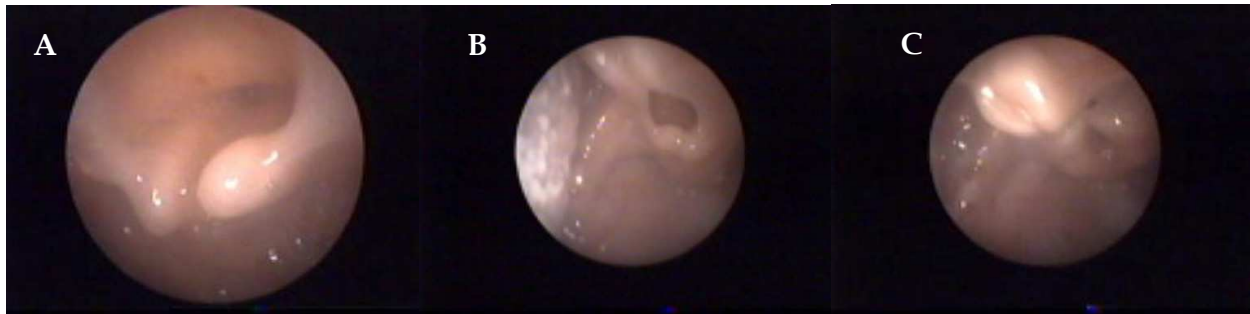


Fig. 17. Inspiratory collapse of cuneiform cartilages (A), anterior collapse of the cuneiform cartilages (B) and long tubular epiglottis (C).

The vocal cord paralysis is another frequent cause of stridor (Figure 18). Vocal cord paralysis secondary to congenital disorders of the central nervous system is common and often is associated with multiple anomalies, as Arnold-Chiari syndrome. The vocal cord paralysis can be acquired as a result of iatrogenic repair of cardiovascular disorders, most common cause of unilateral paralysis of vocal cords. Paralysis of vocal cords acquired from trauma and infections, is rare.



Fig. 18. Left vocal cord paralysis.

Acquired subglottic stenosis is also a frequent cause of stridor, usually secondary to intubation (Figure 19). The incidence of acquired subglottic stenosis is increasing due to improved care of premature.

Differential diagnosis of base of tongue mass includes lingual thyroid, thyroglossal duct cyst, lymphoid hyperplasia, hemangioma, teratoma, adenoma, salivary gland tumor, fibroma, dermoid cyst, and carcinoma.



Fig. 19. Acquired subglottis stenosis.

The ectopic thyroid may be present in the tongue, although it is a rare injury, can occur in infants. The hygroma generally affects the hypopharynx and the supraglottic region, causing sometimes very important obstructions to breathing. Hemangiomas are the most common tumors of childhood, the incidence ranged from 1% to 3%. Papilloma is the most common laryngeal tumor.

The most patients affected by laryngeal trauma are those undergoing mechanical ventilation. The severity of the injury is related to the number and duration of endotracheal intubation.

The craniofacial anomalies may have severe impairment of the airways. The cause of airway obstruction in micrognathia is ptosis of the tongue. The children in prone position improved significantly. In more severe cases the tracheostomy is indicated.

In general the stridor caused by extrinsic compression of the trachea and bronchi is expiratory. The endoscopic examination can show pulsatile compression of the anterior wall of the trachea caused by double aortic arch, pulmonary sling and aberrant innominate artery. Symptoms such as dysphagia, recurrent vomiting, and chronic respiratory failure may be associated with stridor.

Respiratory infections also can cause stridor. They are most often of viral etiology. The most common are croup, epiglottitis and tracheitis. In general in cases of bacterial etiology there are high fever associated with toxemia. Endoscopy is indicated when the child does not respond to medical therapy, has prolonged or recurrent seizures and low age.

Congenital laryngeal membrane is unusual. The majority is glottic and is extending into the subglottis.

Atresia and stenosis are common congenital abnormalities in the nose, with an incidence of 1 in 7000 newborns, predominantly in males. Unilateral atresia is twice as common than bilateral and is associated with other craniofacial abnormalities facias.

Bronchial abnormalities most common are additional, stenosed and collapsed bronchus. Generally, bronchial abnormalities may be associated with other visceral anomalies, including inversus situs, intestinal malrotation and cardiac malformations.

Congenital tracheal stenosis is rare. The diagnosis is made by bronchoscopy that is the best procedure to define the extent of the stenosis.

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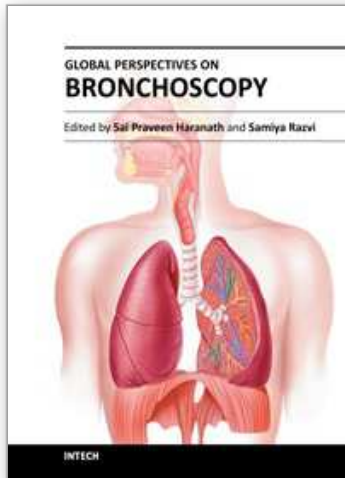
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## **Global Perspectives on Bronchoscopy**

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Bronchoscopy has become an essential part of modern medicine . Recent advances in technology have allowed integration of ultrasound with this tool. The use of lasers along with bronchoscopes has increased the therapeutic utility of this device. Globally an increasing number of pulmonary specialists, anaesthesiologists and thoracic surgeons are using the bronchoscope to expedite diagnosis and treatment. The current volume on bronchoscopy adds to the vast body of knowledge on this topic. The democratic online access to this body of knowledge will greatly increase the ease with which both trainees and expert bronchoscopists can learn more .The contributions from around the world cover the breadth of this field and includes cutting edge uses as well as a section on pediatric bronchoscopy . The book has been an effort by excellent authors and editors and will surely be a often reviewed addition to your digital bookshelf. . In summary, this book is a great testament to the power of collaboration and is a superb resource for doctors in training, ancillary team members as well as practicing healthcare providers who have to perform or arrange for bronchoscopy or the associated procedures.

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