AMERICAN THORACIC SOCIETY DOCUMENTS

Official American Thoracic Society Technical Standards: Flexible Airway Endoscopy in Children

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These official Technical Standards of the American Thoracic Society (ATS) were approved by the ATS Board of Directors, January 2015

Background: Flexible airway endoscopy (FAE) is an accepted and frequently performed procedure in the evaluation of children with known or suspected airway and lung parenchymal disorders. However, published technical standards on how to perform FAE in children are lacking.

Methods: The American Thoracic Society (ATS) approved the formation of a multidisciplinary committee to delineate technical standards for performing FAE in children. The committee completed a pragmatic synthesis of the evidence and used the evidence synthesis to answer clinically relevant questions.

Results: There is a paucity of randomized controlled trials in pediatric FAE. The committee developed recommendations based predominantly on the collective clinical experience of our committee members highlighting the importance of FAE-specific airway management techniques and anesthesia, establishing suggested competencies for the bronchoscopist in training, and defining areas deserving further investigation.

Conclusions: These ATS-sponsored technical standards describe the equipment, personnel, competencies, and special procedures associated with FAE in children.

Contents

Overview

To update the American Thoracic Society (ATS) Official Statement on Flexible Endoscopy of the Pediatric Airway, the ATS sponsored the development of technical standards for the performance of pediatric flexible airway endoscopy (FAE). To complete this effort, an international, multidisciplinary committee comprehensively reviewed the literature and developed this report, including an online supplement in which we describe select topics in more detail.

Conclusions

- Equipment and setting
  - The number and type of bronchoscopes required at any individual institution is determined by each institution's understanding of the anticipated number of procedures.

These technical standards were endorsed by the American Academy of Pediatrics, February 2015.

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This is based on the characteristics of its patient population and typical indications for FAE. In addition, this number should reflect the facility's ability to clean and disinfect the equipment in a timely fashion.
    - The appropriate setting for FAE is determined by the patient's clinical condition, facilitates patient safety, allows completion of necessary procedures, and provides adequate space to accommodate equipment and all necessary personnel.
- Infection control
    - The minimal acceptable standard for reprocessing a flexible bronchoscope is meticulous manual cleaning followed by high-level disinfection.
    - Established guidelines and manufacturer's recommendations for inspection, maintenance, storage, cleaning, and manual or automated reprocessing of flexible bronchoscopes should be strictly followed.
    - Personnel responsible for reprocessing the flexible bronchoscope should receive appropriate training, including initial and annual competency testing.
    - Personal protective equipment should be used during the procedure, when handling used flexible bronchoscopes, and throughout the cleaning and disinfection process.
    - Institutional protocols should include the maintenance of a procedure log as well as a means for identifying appropriately disinfected bronchoscopes.
- Training
    - Definition of a core set of demonstrable competencies is recommended including subsequent monitoring and documentation of trainee progress.
- Situations where FAE is commonly performed
    - The primary reason for performing FAE is when, based on the available clinical data, the need for information from or intervention within the lungs or airways is most safely, effectively, and easily achieved by FAE.
- Preprocedure evaluation
    - A standardized preprocedural evaluation should include recognition of preexisting conditions that may affect the outcome of FAE.
    - All care providers involved in the procedure should review and agree upon the procedural plan, the equipment needed, and the appropriate infection control measures required before the procedure. This may be best accomplished in a formalized "Time Out" process, where individual patient information is also reviewed.
    - Informed consent procedures should be followed and appropriately documented in the medical record in accordance with local and/or national guidelines.
- Sedation and airway management
    - The goals of sedation for FAE depend on clinical considerations and should (*1*) provide patient comfort, (*2*) maintain hemodynamic stability, (*3*) maintain adequate gas exchange, and (*4*) provide satisfactory conditions for therapeutic or diagnostic FAE.
    - Collaboration between the endoscopist and the anesthesia or sedation provider is essential to optimize the interplay between anesthetic depth, airway management, and accurate diagnosis by FAE.
- Airway examination
    - Proximal airway anatomy and airway dynamics cannot always be accurately evaluated when FAE is performed via a laryngeal mask airway or via an endotracheal tube. Nasal passage of the flexible endoscope is preferred when upper airway dynamics are to be evaluated.
    - Rigid bronchoscopy serves a complementary role with FAE and, depending on the indication, may also need to be performed to adequately assess the pediatric airway.
- Bronchoalveolar lavage
    - Bronchoalveolar lavage (BAL) is an essential technique to identify microbiologic or cellular abnormalities of the airway that may establish a diagnosis and guide appropriate therapies.
    - The optimal manner of performing BAL has not been systematically studied and requires further investigation.
    - The interpretation of certain markers found in BAL fluid remains uncertain and is an area for future inquiry.
- Specialized procedures
    - Bronchoscopic intubation, biopsies, airway dilatation, airway stenting, and removal of plugs and clots can all be performed via FAE in children in the appropriate setting and for the appropriate indication.

Flexible airway endoscopy (FAE) in young children was first described in 1978 (1), and the technique is now widely used in the assessment and treatment of infants and children with a variety of pediatric respiratory disease. The flexible bronchoscope allows for functional and anatomical examination of the upper and lower airways. FAE and specialized procedures, including bronchoalveolar lavage (BAL), are particularly important in the diagnosis and treatment of specific respiratory problems, including congenital or acquired airway anomalies, persistent or recurrent pulmonary infiltrates, community-acquired or ventilator-associated pneumonia, pulmonary infections in immunocompromised hosts, and pulmonary hemorrhage.

The current American Thoracic Society (ATS) guidelines for FAE in children were published over 20 years ago (2), and advances in care have rendered these guidelines insufficient. The field has witnessed expansion in the number and types of procedures performed, and technological evolution in available instruments, increased use of general anesthesia with concomitant changes in airway management, and growth in associated applications of FAE have enhanced the diagnostic and therapeutic capability of the procedure.

Methods

The ATS Pediatric Planning Committee appointed a chair and formed a committee of international experts comprising multiple disciplines to write technical standards. Potential conflicts of interest of our committee members were disclosed, vetted, and strictly managed according to the policies of the ATS. The committee was charged with reviewing the existing literature on pediatric FAE and presenting recommendations for technology standardization or elucidating areas in need of further study. An ATS Technical Standards is a document that describes how to perform a procedure. It is not intended to be a systematic review of the literature.

These Technical Standards are not intended to impose a standard of care but rather to provide a reasonable approach to performing FAE in children. Variations, taking into account individual circumstances, may be appropriate. These recommendations should not be viewed as dictates by care providers, third-party payers, institutional review committees, the court system, or other potential stakeholders.

Topics were assigned, and subcommittees were formed. Each subcommittee performed a pragmatic evidence synthesis of the literature using PubMed to search Medline for relevant publications in the English language from 1970 to March 2013. Presentations were made to the committee during a full-day workshop held before the ATS conference in May 2012 in San Francisco, California. After discussion, determinations were made by the committee regarding specific topics to be addressed in the technical standards, and assignments were made to prepare drafts for each of the topics. These were submitted to the chair who then integrated each of the subsections into a uniform manuscript. The committee reviewed the draft, and further discussion occurred at a full-day workshop at the 2013 ATS International Conference in Philadelphia, Pennsylvania and during a subsequent teleconference.

Equipment and Procedural Setting

Currently available pediatric flexible bronchoscopes range in outer diameter (OD) sizes from 2.2 to 6.3 mm, and internal channel sizes range from 1.2 to 3.2 mm in diameter. The 2.2-mm bronchoscope lacks a suction channel and is therefore limited in its utility. The appropriately sized flexible bronchoscope must be available to optimize the examination of any specific patient. The vast majority of pediatric programs would benefit from possessing a 2.7- or 2.8-mm OD bronchoscope because they are the smallest with a suction channel. In addition, possession of a 4.4- or 4.9-mm OD bronchoscope provides the bronchoscopist with the benefit, when appropriate, of the larger 2.0-mm suction channel. It should be noted that the nominal outer diameter is not always accurate (3). Institutions must consider the age of their patient population, number and types of procedures performed, and the time needed for bronchoscope cleaning and high-level disinfection in determining the appropriate complement of instruments to have available.

A mobile bronchoscopy cart allows procedures to be done in multiple settings. In addition to equipment outlined in Table 1, a portable cart should be equipped to separately transport clean and contaminated flexible bronchoscopes and supplies appropriate for the procedure. The capability for recording and archiving still and video imaging of FAE should be available.

The appropriate setting for FAE is determined by the patient's clinical condition; it should optimize patient safety, provide adequate maintenance of infection prevention, and allow for timely completion of necessary procedures. The space should accommodate the equipment and necessary personnel, including individuals to administer anesthesia or sedation, monitor the patient, and allow for resuscitation if necessary. Patients should be monitored with continuous pulse oximetry, using appropriately sized probes, and continuous cardiac and intermittent blood pressure monitoring. Supplemental oxygen and suction should be available at the bedside to be used as needed. Resuscitation equipment should be readily available in case of emergency.

Infection Control

Dr. Earle H. Spaulding devised a classification system for medical devices consisting of three categories: critical, semicritical, and noncritical. The categorization is based on the risk of infection involved with the use of the instrument (4). Flexible bronchoscopes come into contact with intact mucous membranes but do not typically penetrate sterile tissue and therefore are considered semicritical medical devices. The minimal acceptable standard for reprocessing a flexible bronchoscope is meticulous manual cleaning followed by high-level disinfection between uses. Accessories such as biopsy forceps are critical medical devices that require sterilization between uses (5–8). Standard approaches for achieving high-level disinfection have been described elsewhere (5–7, 9–11). Established guidelines and manufacturer's recommendations for inspection, maintenance, storing, cleaning, and manual or automated reprocessing of flexible bronchoscopes should be strictly followed (5–7, 9–11). Personnel responsible for reprocessing flexible bronchoscopes should receive appropriate training and supervision, including initial and annual competency testing. Personal protective equipment should be used during the FAE, when handling used flexible bronchoscopes, and throughout the cleaning and disinfection process (5–8, 10–15). For highly contagious emerging infections such as severe acute respiratory syndrome or

Table 1. Equipment That May Be Used in Flexible Airway Endoscopy

Recommended basic supplies
Slip-tip syringes: 10–60 ml
Swivel adapters
Lubricant
Drape sheets
Specimen traps (e.g., 70 ml)
Gauze sponges, alcohol wipes, cotton-tipped applicators
Antifog solution
Suction tubing
Bite blocks
Institution-specific documentation forms
Bronchoscope and video equipment
Appropriately sized flexible bronchoscopes
Light source
Image processor
Monitor
Video recording and still image capture capability
Dedicated computer with high-capacity digital storage
Protective equipment
Face masks and eye protection
Gloves: assorted sizes, sterile and nonsterile
Gowns with water barrier
Enzymatic cleaning solution
Biohazard bags
Fluids and medications
500-ml bags of preservative-free normal saline solution
1% and 2% injectable lidocaine solution
Nasal decongestant, topical solution
2% lidocaine jelly to apply to the nares and not as a lubricant for flexible airway endoscopy through an endotracheal tube
Specialized supplies
Transbronchial aspiration needles
Biopsy forceps: 1.0 mm, 1.8 mm
Fixative-filled specimen containers
Pick-ups, 18-gauge needles for specimens transfer
Grasping forceps
Retrieval baskets
Cytology brushes: 1.0 mm, 1.8 mm
Snares
Fluoroscopy

avian influenza, a power air-purifying respirator hood should be used during the procedure (11).

Institutional protocols should be in place to identify appropriately disinfected flexible bronchoscopes. A record should be maintained for each procedure to assist in outbreak investigation. Such a log should include patient identification information, date of the procedure, and a unique identifier of the flexible bronchoscope used (13, 16). The log can also serve as documentation for regulatory bodies during their site visits. Infection-control professionals should ensure that institutional policies are consistent with national guidelines and advocate for policy compliance (8, 12, 15).

Random bacterial surveillance cultures of processed flexible bronchoscopes or rinse water have been proposed to ensure effective disinfection. However, a correlation between bacterial counts from a flexible bronchoscope and infection after a pediatric FAE has not been established (8, 17–20).

Training

No evidence-based method has been established to assess competency in pediatric FAE. In 2003, the American College of Chest Physicians published guidelines on interventional procedures based solely on expert opinion (21).

Eighty-six percent of United States pediatric pulmonology training directors surveyed agreed that a minimum number of FAEs could be used to define competency during training, with the median minimum being the completion of 50 supervised procedures (22).

In adult pulmonology, multisociety recommendations have identified and defined (23, 24) specific competencies in FAE. Although there are no universally accepted tools for assessment of competency in FAE, studies in adult pulmonology have shown that tools such as core knowledge, including online curriculum and structured simulation training with objective assessment instruments, may expedite and facilitate FAE training. Suggested core competencies for pediatric bronchoscopists are outlined in Table 2. Rather than using an arbitrary number of procedures to define competency, these suggested core competencies should form the basis to assess FAE skills.

Table 2. Core Competencies: Pediatric Flexible Airway Endoscopist

1. Understanding indications and contraindications for FAE
2. Obtaining appropriate informed consent
3. Safety
   a. Patient safety
      i. Monitoring and ability to respond to abnormalities
   b. Provider safety
4. Use the principles of infection control
5. Ability to perform FAE through the nasopharynx
6. Identify normal upper airway anatomy and function including the nasopharynx
7. Identify normal lower airway anatomy and function
   a. Identify and enter segmental bronchi
8. Ability to keep the flexible bronchoscope centered and avoid excessive airway wall trauma
   a. Ability to identify secretions (i.e., clear, frothy, mucoid, purulent, bloody)
9. The ability to recognize abnormalities, including
   a. Nasal polyps
   b. Laryngomalacia
   c. Laryngeal cleft
   d. Adenoid and/or tonsillar hypertrophy
   e. Pharyngeal collapse
   f. Tongue-base obstruction
   g. Vocal cord paralysis/paresis
   h. Subglottic stenosis
   i. Subglottic edema
   j. Subglottic or supraglottic hemangioma
   k. Laryngeal or tracheal web
   l. Laryngeal papilloma
   m. Laryngeal cyst
   n. Tracheal stenosis
   o. Complete tracheal rings
   p. Tracheomalacia
   q. Bronchomalacia
   r. Bronchial stenosis
   s. Airway compression
   t. Mass lesion
   u. Foreign body
   v. Mucus plug
   w. Airway granuloma
   x. Tracheoesophageal fistula
   y. Tracheal bronchus
10. Bronchoalveolar lavage
11. Supplementary skills (i.e., therapeutic lavage, bronchoscopic intubation)
12. FAE through a laryngeal mask airway and endotracheal tube
13. Complications and management
14. Anesthesia effects
   a. Lidocaine toxicity
15. Cleaning and disinfection

Definition of abbreviation: FAE = flexible airway endoscopy.

The roles assumed by pediatric FAE assistants may depend on their professional background; specialized education; clinical knowledge and experiences; institutional, state, and national scope of practice; and practice setting. Table 3 details the role of the FAE assistant.

Common Reasons for Performing Flexible Airway Endoscopy

The reasons for performing diagnostic or therapeutic FAE vary with clinical presentation (Table 4). The primary indication for FAE is when, based on the available clinical data, the information from or intervention within the lungs or airways is most safely, effectively, and easily obtained by FAE (9).

The only absolute contraindication to FAE is refusal of the parent or guardian to provide informed consent; even then, if the procedure is necessary, the healthcare provider can seek a court order. The risks and benefits must be considered individually for each patient. When performance of the study is necessary, despite coagulopathy, pulmonary hypertension, cardiovascular instability, and severe hypoxemia or respiratory failure, appropriate

Table 3. The Role of the Assistant(s) in Pediatric FAE

Patient care
• Systematically assessing the health status of patients and documenting related health data
• Assisting with patient preparation and positioning during sedation or anesthesia induction
• Administering medications, depending on the expertise and scope of practice of the individual assistant, and evaluating pharmacological and other therapies mandated by the particular situation and evidence-based practice
• Responding appropriately to emergency situations to promote optimal patient outcomes by recognizing changes in the patient's health status
• Documenting patient-related data to ensure continuity in the provision and coordination of patient care
• Collaborating with other health care professionals to ensure quality and continuity of care
Equipment/supplies
• Maintaining familiarity with operation of each FB and all equipment and supplies
• Assessing FAE equipment to maintain good working order, cleanliness, and safety
• Maintaining supplies at levels adequate to safely and effectively perform FAE
• Establishing effective communication with equipment manufacturers' trained technical personnel to facilitate rapid access when troubleshooting problems
• Using training and annual competency checklists to assess proficiency in FB reprocessing
• Using a log or tracking system to match the FB to the patient, bronchoscopist, and method (manual or automated system) used to reprocess the FB
Specimens
• Assisting with obtaining BAL, brush, and biopsy specimens as directed by the bronchoscopist
• Handling, labeling, and transferring specimens with appropriate documentation to designated laboratories to ensure appropriate diagnostic testing

Definition of abbreviations: BAL = bronchoalveolar lavage; FAE = flexible airway endoscopy; FB = flexible bronchoscope.
The role of the assistant(s) may include these items but is not limited to them.

interventions may be incorporated to allow for the procedure to be safely completed (25).

Preprocedure Evaluation

Before FAE, a systematic preoperative evaluation is essential to reduce the risk of procedural complications. Medical history taking should focus on the nature of the suspected underlying pathology. Comorbid conditions that may affect the administration of anesthesia or sedation, complicate the procedure, or prolong postoperative recovery should be identified and when possible optimized. Particularly in cases where dynamic airway abnormalities are suspected, the bronchoscopist should determine the state in which the pathology is most prominent. This information will determine patient positioning, depth of anesthesia, or even the need for an exercise-associated FAE. The history and physical examination performed by the bronchoscopist should be separate from that of the anesthesiologist or sedating physician. Implicit in this recommendation is that when performing FAE in children, the responsibilities of sedating and monitoring the patient should be separate from the responsibility of performing the endoscopy. This division of labor between two trained individuals increases the likelihood of a safe outcome that yields useful information.

Preexisting conditions essential to recognize include hemodynamic instability, severe or uncontrolled pulmonary hypertension, profound upper or central airway obstruction (26), immunodeficiency (27), infectious risk to the team (such as tuberculosis), severe bronchial hyperresponsiveness, and/or uncorrected bleeding diathesis (28).

Preoperative medications should be considered during the preprocedure evaluation. Oral, nasal, or intravenous sedation may be used as adjunctive therapy in select patients with significant anxiety. The bronchoscopist may consider suspending or withholding antibiotics before the procedure to maximize the diagnostic yield of BAL. Patients with a history of bronchial hyperresponsiveness may benefit from an inhaled short-acting β-agonist immediately before the FAE (28). According to American Heart Association guidelines, FAE (with or without BAL) does not require routine endocarditis prophylaxis (29). However, prophylaxis in at-risk patients may be considered when transbronchial or endobronchial biopsy is planned. In general, no routine preprocedure laboratory assessments are absolutely required before FAE unless biopsy is planned (30). However, review of available pertinent radiographic images is mandatory.

In accord with local and national guidelines, appropriate informed consent procedures should be followed and adequately documented in the medical record. Discussion of potential procedural risks should be tailored to the individual patient and setting (Table 5). Before FAE, all care providers involved in the procedure should review and agree upon the procedural plan, equipment required, and indicated infection control measures. This may be best accomplished in a formalized "Time Out" process where individual patient information, such as drug allergies, is also reviewed.

Sedation and Monitoring

The goals of sedation for FAE depend on clinical considerations and include methods that (*1*) provide patient comfort, (*2*) maintain hemodynamic stability, (*3*) maintain adequate gas exchange, and

Table 4. Common Reasons for Flexible Airway Endoscopy in Children

Indication
Diagnostic
Unexplained stridor
Unexplained wheeze
Chronic cough
Recurrent pneumonia
Microbiologic sampling
Suspected aspiration
Suspected structural anomalies
Suspected endobronchial lesion
Obstructive sleep apnea
Radiographic abnormality
Hemoptysis and pulmonary hemorrhage
Monitoring of lung allograft
Monitoring of the artificial airway
Therapeutic
Treatment of persistent atelectasis
Control hemorrhage
Bronchoscopic intubation
Dilation of a stenotic airway

Table 5. Potential Consequences* and Complications† Associated with Pediatric Flexible Airway Endoscopy and Bronchoalveolar Lavage

I. Consequences
A. Mechanical
a. Minor epistaxis
b. Partial airway obstruction
i. Transient minor hypoxemia and hypercapnea
ii. Minor edema
iii. Stridor
c. Pharyngeal discomfort
d. Minor dysphonia
e. Cough
f. Minor airway bleeding
g. Transient inadvertent positive end expiratory pressure
h. Transient increased intracranial pressure
i. Transient minor fever
B. Anesthesia
a. Transient minor hypoxemia and hypercapnea
b. Transient apnea
c. Cardiac arrhythmia (transient bradycardia and tachycardia)
d. Transient hypotension
e. Nausea and vomiting
II. Complications
A. Mechanical
b. Significant‡ epistaxis
c. Vocal cord
i. Laryngospasm
ii. Trauma (avulsion, tear)
d. Significant stridor
e. Significant airway hemorrhage
f. Lower airway obstruction
i. Significant hypoxemia and hypercapnea
ii. Significant increased intracranial pressure
iii. Air leak (pneumothorax, pneumomediastinum)
g. Significant bronchospasm
h. Significant atelectasis
i. Untoward displacement of a foreign body
B. Microbiological
a. Nosocomial infection from contaminated equipment
b. Intrapulmonary spread of infection
C. Anesthetic
a. Significant apnea
b. Significant hypoxemia, hypercapnea
c. Significant hypotension
d. Significant nausea and/or vomiting
e. Significant aspiration
f. Adverse drug reaction
D. Multifactorial§
a. Significant aspiration
b. Prolonged fever for more than 24 h
c. Significant cardiac arrhythmias
d. Death

*"Consequences" refers to minor events that occur associated with the procedure. These are considered clinically insignificant.
†Aberrant adverse medical responses to the procedure.
‡"Significant" indicates requiring intervention and/or prolonged observation.
§"Multifactorial" implies more than one cause relating to the procedure, anesthesia, high-risk patient condition, or comorbidity.

(*4*) provide satisfactory conditions for therapeutic or diagnostic FAE. The administration of anesthesia and sedation requires a thorough understanding of potential adverse events and the skill to avoid potentially life-threatening complications. In addition, the individual responsible for providing sedation must focus particular attention on the entire periprocedural period, including presedation evaluation, sedation/analgesia administration, the patient's physiological status during the procedure, and recovery. The American Academy of Pediatrics, Section on Anesthesiology has published *Guidelines for the Pediatric Perioperative Anesthesia Environment*, which includes suggestions for age categorization, the need for intensive care after sedation for recovery, and the presence of coexisting disease (31). Since these guidelines were published, sedation outside of the operating room continues to increase, along with the varied practitioner's disciplines that are delivering sedation. Despite several policy statements published by different professional societies (31, 32), there remain no defined core competency requirements to provide procedural anesthesia and sedation and none that focus on FAE.

The relatively short duration of action of drugs currently available enables alteration of the level of sedation during the procedure to demonstrate dynamic abnormalities or to minimize coughing or movement. The interplay between anesthetic depth, airway management, and accurate diagnosis with FAE makes collaboration between the bronchoscopist and the anesthesia or sedation provider essential. Even topical anesthesia of the larynx may result in an erroneous diagnosis of laryngomalacia (33). The bronchoscopist, understanding the indications for the procedure, helps to determine the required level of sedation. Consequently, it is most important that endoscopic findings be interpreted in the context of history and clinical findings.

Airway Management and Examination

There are six ways to enter the pediatric airway during FAE: (*1*) transnasally, (*2*) transorally, (*3*) via face mask, (*4*) via laryngeal mask airway (LMA), (*5*) via endotracheal tube, or (*6*) via tracheostomy tube (Table 6) (34). One of the main advantages of FAE is the potential to examine the entire airway, but this is limited when the procedure is done through an artificial airway. Using an LMA bypasses the upper airway from the nostril to the glottis and distorts the view of the laryngeal anatomy and dynamics (35). Endoscopy through an endotracheal tube has the same undesirable consequences extending into the trachea and may result in missed or erroneous diagnoses. Therefore, the mode of entry into the

Table 6. Advantages and Disadvantages of Different Airway Entry Techniques

Technique	Advantages	Disadvantages
Natural airway (transnasal or transoral approach): insufflation of oxygen ± anesthetic gas using nasal prongs, nasal airway, or oral airway	Inspect entire airway Assess airway dynamics/malacia May allow for the use of a larger FB compared with FAE via an artificial airway Allows for airway evaluation with rigid scope	More difficult to monitor ventilation, airway patency Laryngospasm Anesthetic waste gas into OR environment
Facemask	Inspect entire airway Assess airway dynamics/malacia Does not limit size of FB	More challenging for the anesthetist than LMA or endotracheal tube Laryngospasm May limit movement of scope
Laryngeal mask airway	Easy to place Relatively secure airway Can assist ventilation with positive pressure	Cannot assess upper airway Cannot accurately assess vocal cord movement May limit size of FB Aperture bars may limit/hinder passage of FB Requires deeper sedation/ anesthesia than natural airway or facemask approach Can mask lower airway dynamics
Endotracheal or tracheostomy tube	Easy, fast, stable access to lower airways Secure airway, even with deeper levels of anesthesia Easy and quick to reinsert FB if needed Enables positive pressure ventilation during the procedure (may be especially useful when extensive suctioning is required) Potentially avoids contamination of lower airway specimens by upper airway secretions	Cannot assess upper airway Cannot assess vocal cord motion Cannot assess airway dynamics/ malacia May limit size of FB Requires deeper level of anesthesia

Definition of abbreviations: FAE = flexible airway endoscopy; FB = flexible bronchoscope; LMA = laryngeal mask airway; OR = operating room.

airway should take into account the clinical context and the reason for the procedure. If the reason for FAE is to assess airway anatomy or dynamics, then it should be performed via the nasopharynx. On the other hand, if evaluation of airway dynamics and anatomy is not indicated for the procedure, performing FAE in a manner that provides a stable airway is appropriate. Other exceptions to proceeding through the nasopharynx include situations when (*1*) the patient is mechanically ventilated or (*2*) the upper airway should be avoided to minimize the potential for contamination of the BAL fluid.

Another advantage of FAE is that the characteristics of the flexible bronchoscope permit the procedure to be done with only minimal mechanical distortion of the airway anatomy and dynamics (36). Positional modifications or airway maneuvers, such as placement of an oral airway, nasopharyngeal airway, chin lift, positive pressure, or shoulder roll placement, may alter the appearance and dynamics of the airway. Therefore, if structural or functional anomalies are suspected, the patient should be allowed to breathe spontaneously with a natural airway at least for the initial part of the airway evaluation. Once the upper airway and lower airway dynamics are evaluated, an airway adjunct such as a LMA may be placed if desired. Alternatively, the examination of airway dynamics may be done after the diagnostic specimens have been obtained, reducing the level of sedation as necessary.

The Role of the Rigid Bronchoscope

The primary focus of airway endoscopy is often an accurate, comprehensive anatomic evaluation. There will be times when patients will benefit from both rigid and flexible bronchoscopy to more completely assess the airway or for therapeutic interventions (Table 7). Adequate evaluation of the posterior aspects of the larynx, and to a lesser degree the cervical trachea, may be difficult with flexible bronchoscopy. In general, rigid instruments are superior for detailed anatomic assessment of the larynx and cervical trachea and for operative manipulation, principally foreign body extraction (37). In general, flexible instruments are superior for evaluation of airway dynamics at all levels, for examination of smaller airways, for BAL, and for removal of mucus plugs in peripheral airways.

BAL

Performance

BAL can be performed either bronchoscopically or nonbronchoscopically. The latter is performed by blindly inserting an appropriately sized suction catheter (4–8 French) through an endotracheal tube

Table 7. Characteristics of Flexible and Rigid Bronchoscopes and Their Implications

Flexible bronchoscopes
1. Flexibility allowing for:
   a. More thorough examination of the distal airway
   b. More thorough examination of the upper lobe segments
   c. Directed sampling by bronchoalveolar lavage
   d. Better assessment of airway dynamics depending on level of sedation
   e. Introduction through the nasal passage
   f. Can be introduced through an endotracheal tube or tracheostomy allowing for:
      i. Evaluation of tube placement
      ii. Bronchoscopic intubation
2. Solid interior
   a. Patient must breathe around the bronchoscope
      i. Limiting the choice of size
3. One small suction channel limiting:
   a. The size and types of instruments that can be introduced
   b. The ability to suction material from the airway
   c. Safe removal of foreign bodies
4. Optical performance is relatively limited, especially in the pediatric-sized bronchoscopes

Rigid bronchoscopes
1. Rigid tube
   a. Requires placing the patient under general anesthesia
   b. Difficult to perform at the bedside
   c. Alters airway dynamics
2. Hollow interior
   a. Allows for the introduction of a variety of instruments through the bronchoscope
   b. Provides the ability to ventilate patient through the bronchoscope
   c. Best for removing foreign bodies
   d. May be best for evaluation and control of brisk airway hemorrhage
3. Glass rod telescope
   a. Superior optics
   b. Superior visualization, especially of posterior larynx and subglottic space
   c. Can be used without the rigid tube, facilitating/allowing examinations with a lighter level of sedation/anesthesia, and with spontaneous breathing

(38–41) and can be helpful in identifying infectious agents in intubated infants and children with diffuse lung disease (42, 43). The only published study comparing bronchoscopic and nonbronchoscopic BAL was performed in adults and found similar sensitivity, specificity, and predictive values, using a clinical pulmonary infection score as a reference standard (44).

Bronchoscopic BAL, however, allows for direct sampling of the area of interest and affords a visual examination as well, which often may reveal unsuspected pathology. For most clinical applications, the flexible bronchscope is gently wedged into the selected bronchus so that the instrument channel is not occluded by the airway wall. Maintaining this position throughout the procedure, nonbacteriostatic normal saline is instilled through the suction channel and then recovered. Neither the optimal total volume nor the number of aliquots to be instilled has been established (38, 45–47). Investigators have used fixed volumes of 10 to 50 ml per aliquot or weight-based volumes, typically 1 ml/kg per aliquot (38, 47). For small-volume BAL, 2 ml of air should follow the saline to clear the suction channel of the instillate. The optimal BAL dwell time is unknown. The minimum amount of BAL fluid necessary to perform the typical battery of laboratory tests varies by institution. For adults it is recommended that the minimal total volume retrieved is $\geqslant$30% of the instilled volume (48).

Only scant evidence exists regarding the optimal location or number of sites for BAL. The right middle lobe and lingula are the lung segments most frequently sampled because they provide maximal return; however, clinical, radiographic, or FAE findings should direct where the lavage is performed, and this may at times necessitate sampling more than one lobe. Studies examining the microbiological and inflammatory profiles of young children with cystic fibrosis (CF) show remarkable heterogeneity, indicating that the characteristics of lavage fluid from one site may not be generalizable to the whole lung (11, 49). In evaluating children for suspected aspiration, it may be optimal to sample segments that are normally dependent.

Two basic techniques are used for lavage fluid collection, either using suctioning with a syringe or wall suctioning with an inline trap to gently aspirate the instillate while avoiding airway collapse. Both are currently acceptable approaches.

It is unclear whether early or late BAL aliquots are superior for cellular or microbiological analyses. It has been reported that the first aliquot is enriched with ciliated epithelial cells, neutrophils, and immunoglobulins when compared with subsequent aliquots (50, 51). Therefore, the appropriateness of pooling all aliquots into a single container depends on the reasons for obtaining the lavage in the first place. There may be value comparing the appearance or cellularity of recovered fluid from serial BAL aliquots in children with suspected pulmonary hemorrhage or interstitial lung diseases, but clear evidence to support this view is lacking.

Processing

BAL fluid should be delivered to the laboratory and processed promptly. Although there are no comparative data, some centers advocate maintaining the BAL fluid at 4°C in an effort to maintain cell viability (45). Approaches attempting to correct for dilution of the epithelial lining fluid are not standard practice. Measurement of albumin, total protein, secretory component, or urea concentrations in the BAL fluid are compromised by serious methodological uncertainties as well as alterations of alveolar–capillary permeability in various inflammatory conditions and have undergone limited validation.

Diagnostic Utility of BAL

Infection

Specific tests performed on BAL fluid will vary based on the clinical context and overall index of suspicion. Studies in adults suggest that the use of quantitative bacterial cultures increases specificity in establishing the diagnosis of ventilator-associated pneumonia (VAP) (52). Although analogous investigations have not been performed in children, current Centers for Disease Control/National Health Safety

Network criteria for VAP with common bacterial organisms specifies diagnostic threshold values as $\geqslant 10^4$ colony-forming units (cfu)/ml from BAL and $\geqslant 10^3$ cfu/ml from protected specimen brushing (53). In immunocompromised children, the detection of fewer organisms on quantitative culture may suggest active infection. Additional testing may include viral cultures; polymerase chain reaction assays for viruses, *Chlamydia*, and *Mycoplasma*; antigen detection for viruses and other pathogens; or galactomannan testing for *Aspergillus*.

Although there are published reference data for normal total and differential cell counts (41, 51, 54–58), their derivation from children undergoing procedures for a variety of clinical indications may weaken applicability to other populations. Nonetheless, cellular differential counts can be useful (47, 51, 59, 60). Microbiological data should be correlated with cytologic data. The presence of bacteria without an inflammatory reaction is much less likely to represent infection than contamination. The finding of ⩾5% BAL-obtained cells containing intracellular bacteria on direct microscopic exam (e.g., Gram stain) is an additional Centers for Disease Control/ National Health Safety Network diagnostic criterion for VAP (53).

BAL in CF

Although the findings from culture of expectorated sputum in adults with CF seem to correlate well with findings from FAE with BAL or protected brush sampling, discordance between bacterial cultures taken from the oropharynx with those taken from the lower airway by BAL has long been recognized (61–63).

Surveillance BAL has proven to be useful in identifying new organisms in otherwise asymptomatic, newly diagnosed young children with CF (64, 65). However, the usefulness of BAL culture results to specifically direct antimicrobial treatment of CF lung disease remains controversial (66, 67).

Because of the inhomogeneity of CF lung disease, BAL sampling from a single lobe may not detect the presence and true diversity of the underlying pathogenic airway organisms. Even when BAL specimens are taken from two lobes, infections may be missed (49, 68). However,

Table 8. Summary of Studies Assessing the Utility of Measuring Lipid-Laden Macrophages in Bronchoalveolar Lavage Fluid

Reference	Year	n	Se	Sp	PPV	NPV	Gold Standard	Cutoff	Comments
Ding *et al.* (92)	2002	26	0.57	0.75	0.84	0.69	Clinical diagnosis		Poor interobserver reliability
Colombo and Hallberg (93)	1987	45	1.0	1.0	1.0	1.0	Clinical diagnosis	90	
Yang *et al.* (94)	2001	56	0.92	0.76	0.85	0.87	Clinical diagnosis	150	Also evaluated different modifications on scoring
			0.88	0.88	0.92	0.83		200	
Moran *et al.* (95)	1988	64	1.0	0.22	0.24	1.0	Simultaneous lactose assay	100	Evaluated different cutoffs
			0.73	0.84	0.53	0.93		150	
			0.73	0.91	0.67	0.93		175	
			0.36	0.98	0.80	0.86		200	
Ahrens *et al.* (96)	1999	66	0.50	0.88	0.80	0.65	Clinical diagnosis of GER	13	Examined 900 cells; reported score divided by 9
			0.38	1.0	1.0	0.64		22	
Furuya *et al.* (97)	2007	82	0.99	0.78	0.82	0.97	Clinical diagnosis	165	Compared patients with clinical aspiration vs. control subjects with no lung disease
		112	0.84	0.70	0.62	0.88		199	Compared patients with clinical aspiration vs. nonaspirators with or without lung disease
		71	0.90	0.47	0.70	0.78		195	Compared patients with clinical aspiration vs. patients with lung disease but no clinical aspiration
Bauer and Lyrene (98)	1999	113	0.69	0.86	0.60	0.90	Response to therapy	85	
Miller *et al.* (99)	2002	43	0.78	0.88	0.64	0.94	Clinical diagnosis	Any	
Farrell *et al.* (100)	2006	18	0.80	1.0	1.0	0.93	Milk suctioned from ET tube vs. no respiratory symptoms	Any	Immunoassay for pepsin
Krishnan *et al.* (101)	2002	63	0.84	1.0	1.0	0.81	Respiratory symptoms and clinical symptoms of GER	Any	Used enzymatic assay to compare patients with clinical GER and respiratory symptoms vs. those with no GER and no respiratory symptoms

Definition of abbreviations: ET = endotracheal tube; GER = gastroesophageal reflux; NPV = negative predictive value; PPV = positive predictive value; Se = sensitivity; Sp = specificity.

the sampling of multiple lobes may increase the risk for complications.

BAL has provided valuable outcome measurements in important CF research studies (69). Future identification and analysis of novel protein biomarkers in BAL fluid may provide new means to assess disease severity and/or response to therapy in patients with CF (70, 71). Additionally, more advanced culture-independent evaluations of BAL fluid using ribosomal RNA sequencing have revealed the potential to identify nontraditional bacterial species in the progression of CF lung disease (65).

BAL in the Diagnosis of Pulmonary Aspiration

Although there is no question that chronic aspiration can cause respiratory disease, there is disagreement regarding how commonly this is seen and in particular whether gastroesophageal reflux leads to aspiration. The controversy is exacerbated by the lack of a diagnostic "gold standard" for aspiration, significantly complicating comparison of various diagnostic tests that purport to ascertain the presence of aspiration.

No unequivocal marker for exogenous aspiration is available for clinical use; BAL findings are influenced by many variables, including what is aspirated, how much is aspirated, and when the lung is sampled after the aspiration event.

Lipid-laden alveolar macrophages may be found in the BAL of all children, especially those with lung disease, because the source of the lipid may be endogenous as well as exogenous. The utility of a quantitative scoring system such as the lipid-laden macrophage index is controversial because published studies have used different diagnostic cutoff scores and different gold standards to diagnose aspiration (Table 8) (72–77). The test result may be a useful adjunct to diagnosis as long as it is interpreted appropriately within the clinical context.

BAL in Other Disorders

Lymphocyte subpopulation and CD4:CD8 ratios may be useful in diagnosing some interstitial lung diseases, such as sarcoidosis and hypersensitivity pneumonitis (78). The role of BAL in diagnosing adult forms of interstitial lung disease has recently been reviewed (78). BAL findings in other conditions, such as alveolar proteinosis, pulmonary hemorrhage, pulmonary Langerhans cell histiocytosis, chronic lipoid pneumonia, and pulmonary alveolar microlithiasis (79), are outlined in Table 9.

Specialized Procedures

In the on-line supplement we discuss principles for performing the following procedures in children: bronchoscopic intubation, transbronchial and endobronchial biopsy, bronchoscopic dilatation, and airway stent placement.

Table 9. Potential Tests on Bronchoalveolar Lavage Fluid Based on Suspected Diagnosis or Underlying Condition

Aspiration	
Lipid-laden macrophages (quantitative score)	Variable reports of PPV and NPV, needs to be interpreted in clinical context (72–75, 92, 97, 102, 103)
Milk proteins (histologic stain)	Not available outside the research setting (104, 105)
Pepsin (enzymatic or immunologic assays)	Early reports of good NPV and excellent PPV, but further validation is needed (106)
Immunosuppressed and ventilator-associated pneumonia	
Culture	The identification of pathogens not normally found in the lung is diagnostic; sensitivity has not been studied. Quantitative cultures to confirm the significance of commonly recovered organisms are thought to be helpful but also not well studied (53, 107–109).
Cytology	Fair to good PPV and NPV for *Pneumocystis jirovecii* (110)
PCR	Good predictive value for *P. jirovecii*, *Aspergillus* (110–112)
Galactomannin	Good predictive value for *Aspergillus* (111–113)
Cell counts and differential	Utility not well characterized (46, 55, 114)
Cystic fibrosis	
Culture	Yield improved with sampling from multiple lobes (49, 68)
Nonculture techniques (e.g., genome sequencing)	Significantly greater yield of organisms than culture; primarily a research tool (65, 115)
Inflammatory biomarkers	Primarily a research tool (70, 71)
Alveolar proteinosis (79, 116)	
Gross appearance	Milky, sediment is often visible
Cytology	PAS-positive, diastase-resistant amorphic material
Electron microscopy	Abundant extracellular multilamellated bodies and tubular myelin structures; alveolar macrophages with enlarged foamy cytoplasm
Alveolar hemorrhage (79, 117)	
Gross appearance	Bloody, increasing with each sequential sample
Cytology	Hemosiderin stained macrophages
Langerhans cell histiocytosis	
Cytology	Immunostaining for S-100, CD1a, langerin (79, 117–119)
Chronic lipoid pneumonia	
Cytology	Oil Red O staining with scoring for lipid-laden macrophages (79, 120)
Pulmonary alveolar microlithiasis	
Cytology	Microlith staining with PAS or von Kossa stain (79, 121)

Definition of abbreviations: NPV = negative predictive value; PAS = periodic acid–Schiff; PCR = polymerase chain reaction; PPV = positive predictive value.

Atelectasis

FAE can safely be performed in infants and children with atelectasis in a variety of settings (80–84). When atelectasis is not resolving and is problematic, FAE should be considered. Reports suggest FAE utility in the diagnosis of the etiology of atelectasis in 62 to 100% of cases (80, 82, 83, 85). Therapeutically, FAE has been used to relieve atelectasis in a variety of diseases, including hyaline membrane disease, pneumonia, CF, and plastic bronchitis, with variable success (81, 86–89). The use of sterile saline washes is standard practice. Case reports using bronchoscopically instilled mucolytics (84, 90) as well as other agents (91) exist, but the efficacy of these techniques over standard approaches has not been demonstrated. Flexible bronchoscopy can be performed for atelectasis when it is persistent, recurrent, and physiologically important or when the etiology of the atelectasis is in question.

Documentation

The procedure note should systematically describe the FAE procedure to present the rationale for management, communicate findings to others, and provide tracking information for internal auditing and quality assurance as well as data for medical research. The document should contain patient and provider information, specific indication(s) for the procedure, sedation and anesthesia used, a detailed description of the procedure and all specimens collected, images, and all complications or adverse reactions. The note also serves as the basis of procedure coding, billing, and reimbursement. In addition, a summary of specific FAE findings and recommendations should be included in the document. Based on the committee's collective clinical observations, it is recommended that video images from FAE procedures be recorded and saved when the need for future review is a consideration. Still images of abnormal findings should be stored in the medical record for future comparison.

Conclusions and Future Directions

The technical standards described in this document are limited by the lack of controlled studies in the field and are therefore based mostly on observational studies and expert opinion. Despite these limitations, the document serves to highlight some of the dramatic changes in the technique that have occurred since the ATS guidelines for pediatric flexible bronchoscopy were published. Of particular relevance is the evolution of airway management techniques and anesthesia for FAE. However, the underlying purpose for performing FAE in a child must remain the priority and focus.

Establishing clear, documentable competencies for the bronchoscopist in training to achieve is a mandate that must be undertaken in a responsible, thoughtful manner. This manuscript underlines skills that trainees should acquire and demonstrate before performing FAE independently.

Although BAL is routinely performed, there remain many unanswered questions regarding the best manner to collect BAL fluid. The optimal number of aliquots to instill, the volume of each aliquot, the total volume instilled, the site to sample, the number of sites to sample, and many other technique-related matters have not been subjected to any controlled trial. In many institutions, other diagnostic or therapeutic procedures that can be performed with a flexible bronchoscope are mostly relegated to bronchoscopists caring for adult patients. This is often due to the small size of the pediatric airway, but in the future, as technology continues to improve, some of these techniques may become available to the pediatric bronchoscopist equipped with the appropriate training and skills.

It is our hope that this document, while providing a framework for how to perform FAE in children, will stimulate further discussion, development, and study in the field. ■

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