Respiratory Medicine
Series Editors: Sharon I.S. Rounds · Anne Dixon · Lynn M. Schnapp

Samuel Goldfarb
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Diagnostic and Interventional Bronchoscopy in Children

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Preface

Over the past century, the role of bronchoscopy has evolved from removal of airway foreign bodies by Chevalier Jackson to image-guided precision lung tissue sampling by robotic techniques. This book serves as a comprehensive review of pediatric flexible bronchoscopy fundamentals and as an introduction to the full spectrum of advanced diagnostic and interventional techniques. It represents the collective experience of international experts sharing their insight with the next generation of pediatric bronchologists.

Flexible bronchoscopy has become an indispensable tool used by pediatric pulmonologists to evaluate airway pathology and for select therapeutic interventions. It is exciting to think about where the field will be in the next 5–10 years and beyond. The indications for flexible bronchoscopy in adults have expanded due to major advances in technology. Minimally invasive techniques for targeting lesions in the lung and mediastinum using endobronchial ultrasound (EBUS), computed tomography and electromagnetic navigation have become standard in adult interventional pulmonology programs. As these techniques improve, they have the potential to eliminate the need for surgical biopsy of lung and mediastinal tissue.

Pediatric pulmonologists are now tasked with determining how these tools can be applied to the care of children. Early reports have demonstrated safety and feasibility, but there will be limited opportunity for training and maintenance of skills in the pediatric setting until indications have expanded to provide suitable procedure volumes. Children who could benefit from these procedures include those with thoracic malignancy, immunocompromised pneumonia and radiographic changes of unknown etiology. The greatest potential for increasing the number of children who can benefit from these minimally invasive approaches comes not from advances in the bronchoscopy tools themselves, but from innovation in laboratory analyses. Identification of disease-specific biomarkers and use of genomic technology for microbial detection and cancer diagnostics will maximize the yield of increasingly smaller specimens obtained through image-guided tissue sampling. Only then will the field be ready to make its next leap forward. As we stand on the shoulders of the giants who came before us and who impart their wisdom through this textbook, we can see a bright future and look to the next generation to deliver us there.

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Part I

History and Fundamentals of Flexible Bronchoscopy

1 Pediatric Bronchoscopy: A Personal Odyssey Through 5 Decades

Robert E. Wood

Bronchoscopy – the direct, visual examination of the airways – had its beginning around the turn of the nineteenth and twentieth centuries. Over the next several decades, great advances were made in the understanding of airway pathology and therapeutics, despite the relatively primitive optical characteristics of the available instruments. Pediatric applications, however, were limited almost entirely to the removal of aspirated foreign bodies, and a large variety of very ingenious forceps were designed for specific types of foreign bodies.

The development of the class rod telescope in the late 1960s brought a quantum leap to bronchoscopic technology, enabling detailed visualization and photography. The era of diagnostic bronchoscopy in pediatric patients had begun [1, 2]. However, bronchoscopy was almost exclusively the domain of surgical specialists (and pediatric pulmonology was not yet a defined specialty).

In 1968, Ikeda introduced a flexible fiberoptic bronchoscope, which was initially intended to be used as a flexible telescope passed through a rigid bronchoscope. Soon, however, an intrepid pulmonary fellow described the use of this new instrument by transnasal passage [3], obviating the need for both general anesthesia and the rigid bronchoscope, and the use of flexible bronchoscopes exploded. This generated considerable controversy between the adult pulmonologists and their surgical colleagues [4], but this controversy slowly died out, and flexible bronchoscopy became an integral part of adult pulmonary practice.

I saw my first pediatric bronchoscopy in 1970 – for foreign body extraction – and was not impressed. In 1972, while at the NIH, I saw my first flexible bronchoscopy (in an adult CF patient), and was stunned by the potential of this instrument for research. Shortly thereafter, I discovered that the Radiology department had purchased a flexible bronchoscope, intending to use it for bronchograms, but after using it a couple times had decided not to use it again. I asked, and soon found myself the proud owner of a flexible bronchoscope (6 mm in diameter). With naïve enthusiasm, I learned to use the flexible bronchoscope, essentially having to teach myself. At that time, there was some interest in "therapeutic lung lavage" with a bronchoscope in CF patients [5]. Thinking I could do it better, I performed vigorous procedures with saline mixed with antibiotics in a number of adolescent and young adult CF patients. After several years, I concluded that there was no significant clinical benefit to warrant the procedure.

A more significant event, however, was the seminar by Dr. Marvin Sackner, who described the measurement of tracheal mucociliary transport (and its stimulation by administration of terbuta-

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line) by observations through a flexible bronchoscope. I asked him to help me do such a study in CF patients. He sent his colleague, Dr. Adam Wanner, and together we studied 20 patients. The publication of that study [6] enabled me to start my subsequent fellowship at Rainbow Babies and Children's Hospital as the PI of an NIH grant. Although I could show that beta agonists did indeed stimulate mucociliary transport in CF patients, I could not show significant clinical benefit.

Shortly after I began my fellowship, I discovered that the Olympus Corp had marketed a flexible bronchoscope that was only 3.7 mm OD, and obtained one. Without a suction channel, this instrument had limited utility. After some thought, and experimentation, I attached Teflon tubing to the outside of the bronchoscope, and was able to do clinically useful bronchoscopy in children as young as 18 months [7]. With this experience in hand, I approached the Olympus Corp, and asked them to make a flexible bronchoscope suitable for use in children. They were incredulous (at that time, flexible bronchoscopes were primarily used in the management of adults with lung cancer, and they could not imagine why anyone would want to do flexible bronchoscopy in children). Despite their trepidation, in late 1978, I was provided with a prototype, the Olympus BF3C4, based on the specifications I had provided. Overnight, my life changed, and suddenly, I was performing several hundred diagnostic and therapeutic bronchoscopies in infants and children each year.

The advent of pediatric flexible bronchoscopy, like that in adult practice, was not without controversy. In the spring of 1980, I presented my experience in children younger than 6 years at a national meeting (at that time the conventional wisdom was that flexible bronchoscopes could not be used in children younger than 13 years). Despite the obvious diagnostic and therapeutic benefit, with no significant complications [8], I was promptly accused of "medical voyeurism" and "the grossest of medical malpractice for doing this in children." Fortunately, I was not intimidated.

When the first pediatric flexible bronchoscope was marketed, in 1980, a good friend, Bettina Hillman, invited herself to come to Cleveland and be trained by me. She brought a friend, Michelle Cloutier, and I gave those two very nice ladies two weeks of my life. They promptly went home and called all their friends, and I soon realized I could very easily be overwhelmed. I conjured up the idea that if I could get "everyone" to come at the same time, I could give some formal lectures, do some hands-on labs, and then I would never have to do it again – as everyone who needed training would have been trained. Heh, heh, heh… The first course was in 1981 – this year (2020) will mark the 40th year of the course – much expanded in scope and detail, with the addition of rigid instruments. I plan for the course to continue well into the future, in the capable hands of my younger colleagues. The course has been the source of enormous personal satisfaction to me, enabling several thousand physicians to gain a comprehensive introduction to pediatric bronchology and bronchoscopy and to begin to develop their skills.

During the next several decades, the use of flexible bronchoscopy spread widely, and has become an indispensable aspect of pediatric pulmonary practice [9], as well as a useful research tool. Bronchoscopy had a unifying influence on pulmonary practice, enabling practitioners to visualize, sample, and treat the airways of children in ways never before possible. I believe (without evidence, however) that it played a role in the crystallization of the specialty of pediatric pulmonology itself, which became a recognized specialty in 1986. Several important developments occurred along the way to the present day: the introduction of new instruments (smaller diameters, better optics, etc.), more widespread acceptance and "legitimacy" in the eyes of our surgical colleagues, and awareness that in many pediatric patients, the use of *both* rigid and flexible instruments in the same session is extremely valuable.

No sooner had the BF3C4 gone on the market, than I began to press the Olympus Corp to build smaller instruments. The tracheal diameter of a full-term newborn infant is approximately 5 mm, so the 3.7 mm instrument obstructs most of the airway. While it is quite feasible to use this size instrument in premature infants, it must be done the way porcupines make love: extremely carefully, and very rapidly. I assisted Olympus in the development of smaller instruments, without suction channels, which are essential to pediatric practice, but much less useful due to lack of suction, eventually leading to the now standard 2.8 mm instrument with 1.2 mm channel. Smaller channels, we discovered, were useless. I believe that we have now reached the practical limits of physics, and that instruments smaller than 2.8 with 1.2 mm suction channel would not add to clinical utility. Unfortunately for me, all my assistance to Olympus has been given *gratis*.

Pediatric flexible bronchoscopy developed essentially independently from advances in rigid instrumentation and practice. Most pediatric flexible bronchoscopists viewed their surgical colleagues as adjuncts, to be called in for special occasions, such as foreign body extraction. Until 1989, I had no access to a pediatric otolaryngologist, and when I did, we did not do concurrent bronchoscopic procedures. It was only when I came to Cincinnati Children's Hospital (CCHMC), in late 1999, to help establish the Aerodigestive Program, that I began to have first-hand exposure to rigid bronchoscopy in real time. It was an eye-opening experience for me as well as for my surgical colleagues. We had each thought that our instruments were "superior" for most applications (although I had always insisted that foreign body extraction was the near-total domain of rigid instruments). We were shocked to begin to discover our own limitations, and the advantages of the other. At CCHMC, rigid bronchoscopy is performed with light anesthesia, spontaneous breathing, and in almost all cases with the glass rod telescope alone, instead of with deep anesthesia and a ventilating bronchoscope. My surgical colleagues, led by Dr. Robin Cotton, thought that they were seeing the upper airway with great fidelity. The very first procedure I did with Dr. Cotton was in a 13-year-old girl with OSA (obstructive sleep apnea). He examined the child first, and saw marked arytenoid prolapse. As he and his fellow were discussing a supraglottoplasty, I discovered that the child also had massive adenoidal hypertrophy, and severe glossoptosis. Both these lesions, each of which could have caused the OSA, had been missed by the rigid laryngoscopy. To Dr. Cotton's everlasting credit, it took him about 5 seconds to change his viewpoint 180°. And I had thought that a laryngoesophageal (LE) cleft was the rarest of pediatric airway anomalies. I did not realize that it is almost impossible to define many LE clefts with a flexible instrument; at CCHMC we make this diagnosis several times each week, in children with histories of recurrent pneumonia, etc. I learned that the posterior glottis and subglottis is the most difficult part of the pediatric airway to evaluate with flexible instruments. In the evaluation of any child with suspected aspiration, examination with *both* rigid and flexible instruments is indispensable.

As a result of our working together, watching each other performing the procedures, my surgical and pulmonary colleagues have established a practice in which at least 2/3 of the more than 2000 flexible bronchoscopies performed each year by the pulmonary group are done in conjunction with ENT as a combined rigid/flexible examination. This is of course very heavily influenced by our patient population, which is dominated by children with complex airway issues. With the flexible bronchoscope, we can observe airway dynamics, unaltered by the mechanical distortion introduced by the laryngoscope and by the rigid bronchoscope itself, and examine and sample the distal airways. With rigid instruments, we can see the fine details of the structure of the larynx and trachea, and manipulate the tissues under direct visualization. In our patient population, 1 + 1 = 3. There are, of course, many patients in whom one or the other type of instrument is most suitable for the immediate need, and in these patients, dual procedures are not performed. In general, *airway dynamics* are best evaluated with a flexible instrument, while the *anatomy* of the larynx, especially the posterior aspect of the larynx, and the cervical trachea, are best evaluated with rigid instruments. It is, for example, very easy to fail to discern posterior glottic stenosis with a flexible instrument, and attribute the endoscopic findings to vocal cord paralysis.

Over the years, I have performed bronchoscopy for many different indications, and have come to recognize that it is useless to make a list of "indications for bronchoscopy" and instead can boil my list down to a single point: Diagnostic bronchoscopy is indicated when there is information in the lungs or airways of the child, necessary for the care of the child, and best obtained with the bronchoscope. Likewise, therapeutic bronchoscopy is indicated when bronchoscopy is the most effective way to achieve the therapeutic goal. Bronchoscopy should not be performed if the risk exceeds the potential benefit, but it is important to recognize that many times the most important finding is the definitive exclusion of serious pathology. A normal examination, performed carefully, can yield enormous parental comfort and eliminate other, often more invasive, evaluations.

During my career, I have learned much about the pediatric airways, and about bronchoscopy. For the first half of my career, I had no (or little) access to the services of an anesthesiologist, and performed my procedures with topical anesthesia alone (in teenagers and young adults) or with sedation I administered. I believed that proceduralist administered sedation was superior to anesthesia, and I was wrong. For many reasons. First of all, bronchoscopist's hypnosis is a real phenomenon – it is easy to focus on the procedure and forget about the patient's status. An anesthesiologist's sole responsibility is to maintain the patient in a safe condition, while facilitating the task of the bronchoscopist, who in turn is free to focus exclusively on the airways and the procedure. The drugs available to the anesthesiologist are vastly superior to those available to the pulmonologist, enabling rapid induction and emergence, and safe and effective titration of the level of sedation appropriate to the needs of the bronchoscopist. The anesthesiologist's team takes responsibility for the preoperative management of the patient, and for recovery, freeing the bronchoscopist to do other tasks or to shorten turnover time between cases. The downsides of this approach, however, include higher cost and the fact that the anesthesiologist must recognize the special needs of the flexible bronchoscopist, and cooperate fully. There must be very effective and trusting communication and cooperation between the bronchoscopist and the anesthesiologist. In too many institutions today, the anesthesiologist insists that flexible bronchoscopy be performed with deep sedation/anesthesia, assisted ventilation, and via a laryngeal mask airway (LMA) or endotracheal tube (ETT) (both of which lead to many erroneous diagnoses, by masking/bypassing the upper airway and altering the lower airway dynamics). When I first came to CCHMC, it was the "rule" that all flexible bronchoscopies had to be done via LMA or ETT. Neither the anesthesiologists, nor the otolaryngologists understood the important role of the flexible bronchoscope in the native upper airway. Today, a relatively "new" procedure "Drug Induced Sleep Endoscopy," essentially does what pediatric pulmonologists have been doing for years in every patient – paying attention to the anatomy and dynamics of the upper airway. When I came to CCHMC, a transient desaturation was cause for termination of the procedure, regardless of whether the goals of the procedure had been achieved. There was period of education, demonstration, negotiation, and accommodation before we became a unified team; this is one of the larger challenges facing flexible bronchoscopists in many other institutions, even today, I believe.

I am often asked by a pediatric pulmonologist to provide training in "interventional bronchoscopy." I feel strongly that in the vast majority of cases, this is not indicated. Interventional bronchoscopy includes such procedures as the placement of stents (very rarely indicated in pediatric patients, despite the intuitive appeal in patients with severe dynamic airway collapse), balloon dilation, laser, cautery, cryotherapy, etc. Unless these procedures are done frequently enough to gain *and maintain* competence, they are dangerous. A fool with a tool is still a fool… My pulmonary colleagues and I together perform more than 2000 flexible bronchoscopies per year, and the number of procedures we do that would be classified as "interventional" is less than 25, spread among our six primary bronchoscopists. We have the world's largest pediatric airway surgery program, of which we are a part, and our ENT colleagues do the vast majority of the (still small numbers) "interventional" procedures. I feel strongly that while diagnostic flexible bronchoscopy should be a part of virtually every sizeable pediatric pulmonary program, there should be a greased chute to the most appropriate center of excellence with experience and qualifications to handle the patients who need "interventional" procedures. One skill that is absolutely critical, however, is the ability to perform a bronchoscopic intubation in patients with critical airways or in an emergency situation. In patients above the age of 10 years or so, an adult interventional bronchoscopist should be able to meet the needs of the patient, but for younger children, a specialized pediatric facility is best. The pediatric airways are (and should be) a frightening place for an adult bronchoscopist without special pediatric training and experience.

Training bronchoscopists has been a significant aspect of my career. I am often asked "how many flexible bronchoscopies must one do to gain competence?" There is no answer to this. I have had fellows who in their third year could not reliably get through the nasal airway and others who within a couple of weeks on the bronchoscopy service develop an amazing level of manual skill with the bronchoscope. At CCHMC, our pediatric pulmonary fellows perform 300–400 or more procedures during their training. But preparation for independent practice involves more than learning how to make the bronchoscope go from point A to point B… Of all the skills of the bronchoscopist, cognitive skills are probably the most important. There are many, many ways to get the wrong answer when doing a bronchoscopy, and experience is by far the best teacher. "What am I looking for," "what am I looking at," and "now, what do I do with it" are questions one is more likely to be able to answer after hundreds of procedures… At a minimum, the aspiring bronchoscopist must be able to know the anatomy (and its normal variants), be able to drive the bronchoscope effectively and safely, be able to recognize the common pathologic findings, and be capable of either dealing with them effectively or of enlisting appropriate consultants in a timely fashion. Bronchoscopy is *not* a "See one, Do one, Teach one" matter…

I do not anticipate that the near future will bring quantum changes in bronchoscopic technology for pediatric patients. The biggest change I anticipate is the development of smaller video chips to improve the optical quality of the images.

What I have learned over the past 5 decades can be summarized briefly:

1. "WNL" all too often *really* means "We Never Looked." The great grandfather of bronchoscopy Chevalier Jackson said, in 1915, "If in doubt as to whether to do a bronchoscopy, you should do the bronchoscopy." That advice is valid today.
2. You never know what you may find in the airways of a child. Even today, I am often very surprised by what I discover.
3. You must do enough procedures to develop and maintain skill. If you are not doing at least one a week, you are unlikely to develop and maintain skill (and you are likely depriving a number of your patients of the potential benefit).
4. Pediatric bronchoscopy is a Team Effort – you must have the proper venue, equipment, and support team for safe and effective bronchoscopy.
5. Wherever pediatric flexible bronchoscopy is done, there must be colleagues skilled and equipped for pediatric rigid bronchoscopy.
6. Effective and timely communication is crucial to safety and success.
7. In order to achieve the correct diagnostic impression, issues relating to sedation and airway management are paramount.

Robert Frost, in his poem "The Secret," said "We dance around in a circle and suppose. But the Secret sits in the middle and Knows." I like to paraphrase this: "We dance around the patient, and suppose. But the bronchoscope sees into the patient, and knows…."

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2 Organizing and Maintaining a Flexible Bronchoscopy Program

Robert E. Wood

A pediatric flexible bronchoscopy program is a complex operation, and requires a team, not merely one person. In order to justify the base costs to set up to do pediatric bronchoscopy, a certain volume of business is needed, and the bronchoscopist must pay attention to business matters.

The Team

A bronchoscopy team consists of (at least) the following:

- Bronchoscopist(s) – physician(s)
- Assistant(s) for procedures – nurse, respiratory therapist
- Anesthesiologist/sedation nurse – physician/nurse
- Scheduling/clerical/billing staff
- Cleaning staff

The composition of the team will be different in different institutions, but the tasks/roles above must be performed by someone with skill, training, and support to do the job properly. The bronchoscopist is the team leader, and must be aware of and should be personally competent to perform all the tasks of each of the team members. For example, the physician must be knowledgeable about how to clean the bronchoscopes after procedures, and be willing to perform this task when necessary. *The team leader will have a difficult time supervising what he does not know how to do.*

Bronchoscopy is rarely done in a vacuum, and flexible bronchoscopists need to have colleagues who are skilled (and equipped) to do rigid bronchoscopy when the situation demands. Flexible bronchoscopists need to develop and maintain close collegial relationships with their surgical colleagues. Depending on the specific indication for the procedure, it may be important that *both* rigid and flexible instruments are employed during the same procedure (this is especially true for laryngeal lesions, where rigid instruments give a superior image of the structure, but flexible instruments yield a superior evaluation of *dynamics*.

Assistants for bronchoscopy need to be trained and skilled for the task. To draft a willing but untrained nurse or medical student to assist at a procedure is an invitation to disaster, be it damage to the equipment, mishandling of a specimen, or something worse. The assistant's first responsibility is to the patient, although the precise roles played by the assistants before, during, and following the procedures will vary from institution to institution and from situation to situation.

Patients must be safe and comfortable during procedures, and for pediatric patients, this almost always means sedation/anesthesia.

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Someone other than the bronchoscopist must be responsible for the safe and effective sedation and monitoring of the patient. This can be a sedation nurse, working under the supervision of the bronchoscopist, or it can be an anesthesiologist. This person's sole responsibility is to monitor the patient and the response to sedation, as well as record keeping (charting medications given, vital signs, etc.). It is useful to note that not just any anesthesiologist will do, as pediatric bronchoscopy is particularly challenging to every basic concept held dear by anesthesiologists (control of the airway, etc.). *There must be clear and effective communication between the bronchoscopist and the anesthesiologist before, during, and after the procedure.* Use of the wrong type or level of sedation/anesthesia or the wrong technique for airway management during the procedure may well lead to an incorrect diagnosis.

Patients do not magically appear – they must be scheduled. The efficiency and style with which patients are scheduled can have a dramatic impact on the success or failure of a program. Procedures must be scheduled with care to take into account other procedures, needs, etc. When feasible, multiple procedures can be scheduled for the same anesthesia session; this requires skillful coordination among services.

Scheduling is more complex than merely picking a date and a time and telling the patient when and where to appear. The scheduler must take into account the availability of the venue, staff, coordination with other services, the urgency of the procedure, the wishes and schedule of the patient/family, etc. Someone must ensure that the patient will be properly prepared for the procedure. This task can be shared among the physician, who sees the patient in advance of the procedure and obtains the informed consent; the nurse, who makes sure that the family understands such matters as when to stop feeding the child, and where and when to appear; and the scheduler, who provides the family with written materials to help them prepare.

Nursing input into patient preparation is important. At CCHMC, families are contacted by phone in advance of the scheduled procedure, after the physician visit, if the nurse did not see the patient at the time of the physician visit. It is a fact of life that nurses, contacting the family after the patient has seen the physician, can often obtain important information that the physician did not. This may be because some parents feel less intimidated by a nurse than a physician, because they may later remember facts not recalled during the physician visit, or for other reasons. The nurse should review risk factors, including specific medical history, behavioral history, medication history, allergies, etc. My personal patients are prescreened by my nurses prior to the initial visit, which allows me to be more prepared for the visit. In patients in whom there are perceived risk factors for anesthesia, a formal anesthesia consult is obtained in advance of the procedure.

The work product of endoscopy is information – images, observations, and their interpretation, as well as test results on specimens obtained during the procedures. The physician must prepare a formal report of the procedure, which is then distributed to the appropriate caregivers (referring physicians, consultants, etc.) and to the medical record. If referring physicians do not receive timely and informative reports, they will have much less incentive or desire to refer patients in the future. While it is the responsibility of the physician to prepare the procedure note, the nursing and clerical staff play an important role in the distribution of the reports and other data. They may also help deliver information to the families.

Finally, bronchoscopy cannot be performed without appropriate instruments that are suitable for use in the patient. Someone, be it the physician, the nurse or RT assistant, or someone specially trained for the task, must be responsible for cleaning the instruments after each use. Another fact of life is that in most institutions, people hired for roles such as this are not college graduates, and may not be highly motivated by intellectual goals. It is important to carefully train, supervise, and encourage staff who care for the instruments. They can make or break the program. In their own way, the role (and the responsibility) of the instrument cleaners is as important as is the role of the physician.

The Venue

Bronchoscopy must be performed in an appropriate venue. The venue must be safe, and it must be effective for the purpose. Flexible bronchoscopy *could*, in theory, be performed almost anywhere (on a city bus, an airplane, an operating room), but what *can* be done is not necessarily what *should* be done. There are three basic venues for bronchoscopic procedures: operating rooms, endoscopy suites, and intensive care units.

An *operating room* is almost always an appropriate venue, especially when an anesthesiologist is employed to assist with the sedation of the patient. There may be challenges in scheduling, and one cannot be certain (without prior evaluation and arrangement) that the proper/necessary equipment and supplies are available in the OR. Depending on the acuity of the patient's problem, the complexity of the intended procedure, and the anticipated need for other services, the OR may be the only logical place for the procedure.

An *endoscopy suite* is an ideal venue for many bronchoscopic procedures. The suite must be fully equipped for any foreseeable emergency (hemorrhage, pneumothorax, cardiac arrest, etc.). Unless there is a "critical mass" of procedure numbers, staffing may be a problem. In many institutions, an endoscopy suite can be shared among several services (i.e., pediatric and adult pulmonology, or pediatric pulmonology and pediatric gastroenterology, etc). This will result in more efficient utilization of resources, including equipment (light sources, video processors, procedure tables, etc.), but may result in some difficulties due to scheduling conflicts. Properly administered and operated, however, an endoscopy suite that includes pediatric flexible bronchoscopy can be among the most cost-effective units in a hospital.

It is technically possible to perform flexible bronchoscopy at the patient's bedside. This makes it tempting to "have scope, will travel…" and to perform procedures just about anywhere. However, *this is unwise in the extreme*, and *it is rarely safe or effective to do bedside procedures outside an intensive care unit*. Even in an ICU, the bronchoscopist must ensure that appropriately trained staff are available to assist. Not any ICU nurse will be an effective bronchoscopy assistant, especially when the patient is unstable. On the other hand, for many patients, the ICU is an ideal venue, if moving the patient to another facility involves risk or very serious inconvenience. When procedures are done in the ICU, the bronchoscopist must ensure that everything that could possibly be needed comes along to the ICU. This includes such simple things as slip-tip syringes (not usually available in ICU's – the standard Luer-lock syringes will not work with flexible bronchoscopes).

Preoperative and Patient Recovery Facilities

Many pediatric flexible bronchoscopies are performed on an outpatient basis, and there must be an appropriate venue for the patient prior to the procedure. Sharing an outpatient surgery facility with surgical services can be very cost effective. Likewise, the patient must have a safe and effective venue for postoperative recovery from sedation, and it is very effective to share the post anesthesia recovery unit with surgical services. The most dangerous time for a patient undergoing bronchoscopy may be immediately after the procedure is completed; with no further stimulation, the patient may become apneic, and the staff tend to relax their vigilance once the procedure is completed.

Equipment

It has been said that the difference between men and boys is the price of their toys. Flexible bronchoscopists must be *real* men, because our toys are *very* expensive (with all due apologies to the women who are also very good flexible bronchoscopists). A pediatric flexible bronchoscope costs on the order of $25,000. It is difficult to operate a meaningful pediatric bronchoscopy program with only one instrument. At a *minimum*, I recommend the following:

- 2–2.8 mm flexible bronchoscopes
- 1 adult bronchoscope (available; possibly borrowed on an ad hoc basis from the adult services) with 2.0 mm suction channel
- 1–2.2 mm flexible bronchoscope (this instrument has no suction channel, and is therefore of relatively limited utility, but when it is needed, nothing else will do)
- 1 light source
- 1 video processor
- 1 monitor
- 1 video recording system

It can be cost effective (especially when sharing an endoscopy suite) to share the light sources, video processors, monitors, and video recording systems. I strongly recommend, however, that the 2.8 mm flexible bronchoscopes not be shared with other services, as they are not robust, and are very easily damaged by users not accustomed to these small instruments (no matter how otherwise skilled or well-meaning). The half-life of a flexible bronchoscope in the hands of a gorilla (i.e., anyone untrained or irresponsible) is approximately 17 milliseconds.

The light source, video processor, etc., should be mounted on a cart so it can be moved from site to site. There also needs to be a cart with all the supplies and ancillary equipment that would be needed at another venue (i.e., ICU); the video monitor can be mounted on this cart, which can then be positioned appropriately for best visibility during the procedure.

Equipment Cleaning

Next to performing the procedure, cleaning the equipment is the most important aspect of bronchoscopy. An improperly cleaned bronchoscope can be lethal. There is only one criterion for a clean bronchoscope – it is ready to be used on the bronchoscopist. After the procedure is completed, the soiled instrument must be carefully transported to the cleaning facility. This step is a critical one, for it is here that many instruments are physically damaged. Care must be taken to avoid contamination of the clean environment by a dirty instrument. A cleaning facility must be capable of maintaining effective separation between dirty and clean equipment, of properly cleaning and then disinfecting the instruments, and storing them appropriately.

Equipment Storage

It is important to have a secure place to store equipment. The cost of a flexible bronchoscope exceeds $25,000, and theft or vandalism (intentional or otherwise) can wreak havoc on a bronchoscopy program's operations (not to mention the budget). Storage should not only be secure, but should ensure that the equipment is kept clean and ready for use on short notice. The hospital's Infection Control staff should be involved in decisions about instrument storage.

Handling the Data Generated by the Procedures

The job is not done until the paperwork is done. A sad fact of life is that often what we write seems more important than what we've done. But *the work product of endoscopy is information* – images, observations and their interpretation, and data generated from specimens obtained during the procedure.

Image management – I believe that all procedures should be recorded whenever possible. I have had the miserable experience of reviewing a video recording of a procedure done as long as a year previously, and finding a very significant abnormality that I missed during the procedure itself. I have also been an expert witness in legal cases that I believe would never have become a legal case had the procedure been recorded.

Bronchoscopy generates large volumes of images, whether still images or video recordings, and it is important to have a systematic way to retrieve the images when they are needed. A computerized database of procedures, with information about the image storage (e.g., videotape number, DVD number) is virtually mandatory. There are systems now available for the central recording and archiving of video data, which make the results of endoscopic procedures readily available for review at multiple locations as needed. At CCHMC, all endoscopic procedures since 2006 are recorded in an online video archive, and can be accessed very quickly.

Images obtained during bronchoscopy are useful not only for the medical record, but for teaching medical professionals and for education of patients and families. Still images can be incorporated into procedure notes. It may be very helpful to show parts of the video record to parents or even the patient, to help them understand the findings and their significance.

Procedure reports are an important part of the medical record, and, sadly, in our current medicolegal atmosphere, are perhaps the most important aspect of the procedure. They are used for many purposes, including patient management, teaching, research, and as support documentation for reimbursement. The report needs to include the indications for the procedure in the context of a brief history, a description of the procedure and the findings, the complications, diagnostic impressions, and a discussion and plan for follow-up. It can be helpful to incorporate photos into the report, although this requires special editing and cannot readily be done through centralized hospital dictation systems. There are software packages available that can help generate a report and incorporate photos.

Procedure reports need to be distributed to the appropriate places, including the medical record, the referring physician and other physicians participating in the care of the patient, etc. While the report should, in general, be prepared as soon after the procedure as possible, in many cases it may be advantageous to defer preparation of the final version of the report until data from the BAL specimen (cultures, cytology) are available and can be incorporated into the final impressions and recommendations. If not, then care must be taken to ensure that the data do not disappear into the ether, and that appropriate action is taken in response to the findings.

Handling specimens – other than death of the patient, the most serious complication of bronchoscopy is to do the procedure and get the wrong (or no) answer. One of the most common mistakes that can lead to a wrong answer is mishandling of the specimens (BAL, biopsy, etc.). The bronchoscopist must be sure that the laboratory knows how to process the specimen in the most appropriate way, and that the laboratory understands what information is needed and how to report the data. It does the patient no good to entrust the BAL specimen to a courier who leaves it sitting on a desk while he takes a break, only to have the specimen (finally) arrive after the laboratory has closed for the night. What then happens to it? BAL specimens need to arrive in the microbiology laboratory within an hour after collection, and should be processed promptly. It does the patient no good if the biopsy specimen is placed into the wrong preservative, or if the wrong tests are requested on the requisition. The bronchoscopist should pay careful personal attention to the laboratory requisitions, making sure that all the important information is recorded properly*, and if necessary, carry the specimen to the laboratory himself.*

Communication

The name of the game is effective communication. The bronchoscopist must communicate with the team members in a timely and effective manner (and vice versa). It is very important to achieve effective communication with the patient/family prior to the procedure. Setting the proper expectations can be critically important to patient and family satisfaction, regardless of the diagnostic findings of the bronchoscopy. There needs to be effective and timely communication with the family afterwards, as well. If the family expects to receive the results of the BAL cultures but has no idea of the time frame, they may call the physician's office three times a day. If, however, they are told ahead of time that it will take 4–5 days for the information to become available, many unnecessary phone calls, wasted time, and considerable angst can be avoided.

Communication among professionals is also of critical importance. First of all, for proper patient care, the physician(s) responsible for the patient need to have the information gained by the procedure. Secondly, bronchoscopy is primarily a referral service, and without a steady flow of patient referrals, the bronchoscopy program will not support itself. Satisfied customers (aka referring physicians) will be repeat customers.

Business Matters

Business matters *matter*. Someone, if not the bronchoscopist, must pay careful attention to billing for procedures, setting appropriate charges, accounting for expenses and revenue, etc. While many patients' medical needs are covered by insurance, you can be certain that insurance companies will take every excuse not to pay for your services (this is another reason careful documentation is so important). The documentation must support the charges submitted, and the procedure coding must be appropriate. In the United States, CPT codes are required for billing. The current code for a diagnostic bronchoscopy is 31622; if bronchoalveolar lavage is also performed, the code is 31624. It is not appropriate to utilize *both* (and to charge for) 31622 and 31624 on the same procedure by the same physician. Likewise, it is usually (although not always) considered inappropriate to bill for both a diagnostic bronchoscopy 31622/4 *and* a laryngoscopy (31575). The rules for procedural coding can be complex, may change from year to year, and the bronchoscopist should learn to use them most effectively. In any case, the bronchoscopist must be prepared to back up the billing with a procedure note, which documents the indications, procedure, findings, and plan.

Reimbursement for procedures is always an unsettling process for physicians. No matter how we charge for our services, third-party payers will attempt to reduce the payments. It is important to track billings and receipts, to investigate and follow up on denials, and to adjust practices to ensure that the maximum fair payments are received. In general, there will be two components to the charges for a bronchoscopy: the professional fee, and the facility fee. Generally, the facility fee is managed by the institution, and should be structured to include the costs of the equipment, supplies, staff, procedure room, etc.

Capital equipment costs for flexible bronchoscopy can be significant. As noted above, sharing resources with other services that use the same light sources, video processors, etc., can be very cost-effective. At current prices, a flexible bronchoscope costs approximately $25,000, a light source $14,000, a video processor $24,000. Thus the cost to set up even a relatively modest program can exceed $75,000. This can seem like a major investment on the part of the institution. However, the global revenue to the institution generated by a flexible bronchoscopy program far exceeds the direct costs attributable to the procedures themselves. There are radiology studies, clinic visits, hospital admissions, OR charges, and laboratory fees, as well as additional services directly or indirectly resulting from the patient referral (i.e., other surgical procedures, ICU stays, etc.). These revenues constitute a hidden "multiplier factor," which hospital administrators use to evaluate the potential impact of a program. Only the administrators know the factor the institution uses in its considerations, but you can be assured that the numbers are larger than you might suspect. Be aware of this when you negotiate with the institution for support of your program.

Equipment repairs can be a major headache, especially if there is no service contract. The cost of a service contract will depend on a number of factors, including your track record with the equipment supplier, the number and type of instruments you have, etc. The cost to replace a fiberoptic bundle in a flexible bronchoscope is on the order of $10,000; it is easy to see why a contract is a good idea. Flexible bronchoscopes can last for years if they are cared for in a proper fashion, but can be broken in milliseconds if not. When an instrument must be sent for service, it is important to have a replacement instrument for patient care. While a "loaner" instrument may be available from the manufacturer, this is not always the case, and I strongly recommend that you have a minimum of two instruments. If you are not doing enough procedures to justify having two, you are probably not doing enough procedures to justify doing any. ☹

The economics of a flexible bronchoscopy program can be complex. However, it can be a source of significant revenue, not only from the procedures themselves, but also from cost savings (early diagnosis leading to decreased ICU stays, for example), and can lead to increased patient referrals to the institution. In building a business plan with your institution, consider all potential revenue, and plan for expansion. In my 20 years at Cincinnati Children's Hospital, the number of flexible bronchoscopies performed by pulmonologists increased from approximately 100/year to more than 2200 in 2019. A rather sizeable impact.

The road to success

1. Build, train, and nurture your team.
2. Ensure that you have a proper venue.
3. Obtain and maintain proper equipment.
4. Handle data (images, reports, specimens) properly.
5. Maintain good records – a database is essential.
6. Have a good business plan.
7. Work with your institution for mutual support.
8. Communicate.
9. Communicate.
10. Communicate.
11. Build and nurture collegial relations within your institution.
12. Build and nurture collegial relations with referring physicians and institutions.
13. Pay close attention to business matters.
14. Have fun!

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3 Upper Airway Anatomy and Physiology

Conor Devine and Karen Zur

Nasal Cavity

The nasal cavity extends from the anterior nasal aperture to the beginning of the nasopharynx posteriorly and is divided into two separate cavities by the nasal septum. Broadly speaking, the nasal cavity has three key functions: respiration, protection, and olfaction. An average adult human inhales 10,000 L of air daily [1]. The upper airway has evolved to allow for both oral and nasal breathing, but in the absence of nasal obstruction, humans preferentially rely on the nasal airway for respiration. The large surface area of the sinonasal cavity has superior heat and moisture exchange capabilities, and is adapted to trapping impurities in inhaled air. The nasal cavity accounts for approximately half of total airway resistance—significantly greater than that of the oral cavity [2]. The nasal cavity accounts for the largest and greatest fluctuation in resistance to airflow; however, these fluctuations are not made as quickly as in other segments of the upper airway, such as the pharynx, oral cavity, and larynx [2]. Unlike these other segments of the upper airway, the nasal cavity is largely immobile save the contribution of facial mimetic musculature to flare nostrils and dilate the nasal valve. Rather, changes in nasal airflow are largely mediated by the autonomic control of the robust mucoperiosteal lining of the nasal cavity.

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Anatomy

The external nose is pyramidal in shape, reflecting the paired nasal bones, paired upper lateral cartilages, and paired lower lateral cartilages supported in the midline by the nasal septum. The bony framework of the nasal cavity is comprised of several bones of the skull and midface. The lateral walls of the nasal cavity consist of the maxillary bones and lacrimal bones. The palatal processes of the maxilla and the horizontal processes of palatine bones form the floor, which is the nasal surface of the hard palate. And the roof of the nasal cavity has contributions from the cribriform plate, the ethmoid bones, the sphenoid bones, the nasal bones, and the frontal bones. The anterior bony entrance to the nasal cavity is called the pyriform aperture and is a heart-shaped opening formed by the nasal bones and maxillary bones. The external nasal opening or nostril is formed by the nasal ala, the nasal sill inferiorly, and the nasal columella medially. The columella is formed by the medial crura of the lower lateral cartilages. The nostril gives way to the nasal vestibule, which is lined with stratified squamous

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epithelium and houses hairs called vibrissae, which trap large particles in inspired air [3, 4]. From here, the nasal cavity extends posteriorly to the nasal choana or posterior nasal aperture. This space marks the boundary between the nasal cavity and the nasopharynx. It is bounded by the vomer, the sphenoid bones, the medial pterygoid plates, and the palatine bones (Figs. 3.1 and 3.2).

The midline nasal septum divides the nasal cavity into two separate cavities, thereby helping to increase surface area of the nasal cavity. In addition to dividing the airway, it provides structural support to the nasal dorsum and serves as one of the primary sources of nasal tip support. The nasal septum is divided into three segments: the membranous septum, the cartilaginous septum, and the bony septum. The membranous septum extends from the columella to the quadrangular cartilage where the cartilaginous septum begins. The quadrangular cartilage attaches superiorly to the perpendicular plate of the ethmoid bone, posteriorly to the vomer, and inferiorly to the maxillary crest of the maxilla. Here it is firmly adherent to the maxilla by way of decussating fibers which help to anchor it. Posterior to the quadrangular cartilage, the perpendicular plate of the ethmoid descends from the skull base to meet the vomer inferiorly and form the bony septum [4–6].

The septal perichondrium and periosteum carry rich vascularity to the overlying respiratory epithelium from the internal and external carotid artery systems via the ophthalmic, maxillary, and facial arteries. This robust vascularity has significant contributions to the physiology of the nasal airway, helping to regulate nasal airflow, heat exchange, and humidification. During endoscopic evaluation, one may notice the bilateral septal swell bodies on the anterior septum, just anterior to the level of the middle turbinate. While these may look like septal deviations, they are areas of thickened mucosa which are soft and compressible [7].

Along the lateral nasal wall are bony outcroppings called conchae. These form the bony scaffold for the respiratory epithelium-covered turbinates, which are fully developed by 24 weeks gestation [8]. The superior and middle turbinates stem from the ethmoid bone while the inferior turbinates originate from the maxilla. The primary purpose of the turbinates is to greatly increase the surface area of the nasal cavity to aid in humidification, heat exchange, and filtration. The inferior turbinate is the largest of the three with most robust

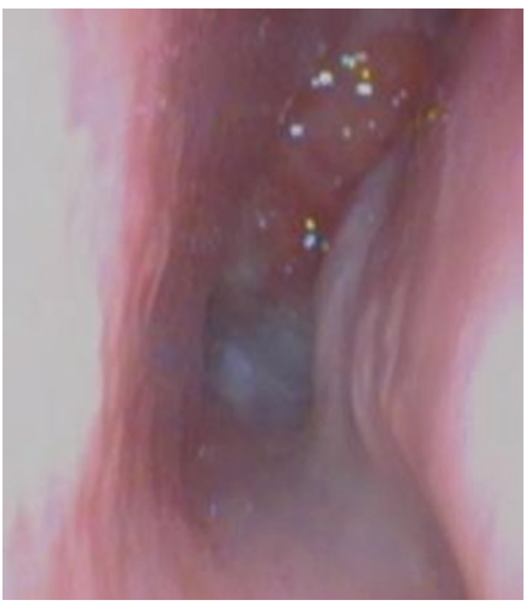

Fig. 3.1 Left choana showing partial obstruction by adenoid bed superiorly

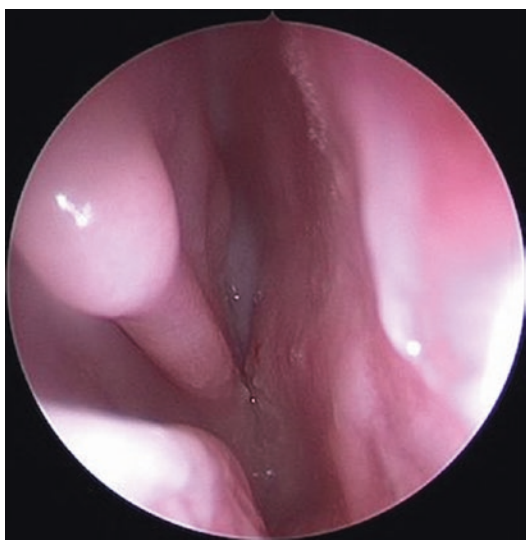

Fig. 3.2 Right choanal atresia. Notice the posterior septal deviation and blind-ended cavity