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Rigid Bronchoscopy

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Abstract

Rigid bronchoscopy is one of the oldest medical techniques used in the respiratory and thoracic fields. Even though its use declined after the development of flexible bronchoscopy, it has again gained importance with the growth of interventional pulmonology, becoming a critical technique taught as part of the training in this subspecialty. The therapeutic advantages compared to other approaches of thoracic pathologies makes rigid bronchoscopy a primary component in the present and future of interventional pulmonary medicine.

Keywords
- rigid bronchoscopy
- flexible bronchoscopy
- airway stents
- tracheal stenosis
- cryotherapy
- laser
- electrocautery

Rigid Bronchoscopy: History

The evaluation of the airways in bodies has been described throughout medical history since before Hippocrates. However, it was not until 1855 that a Spanish singer and music teacher, Manuel Patricio Rodríguez García, performed the first "in vivo" visualization of the airways by studying his own larynx. After publication of his article "Observations of the Human Voice," the use of his technique began to grow. Due to his accomplishments, he is often considered the "father of laryngoscopy."

In America, Horace Green is considered the father of laryngology and tracheobronchology and not only introduced but continued to make advancements to the techniques of laryngology. In 1859, he reported the use of indirect laryngoscopy for the first time to perform a laryngeal silver nitrate application. It was not until after his death in 1867 that he was recognized for many of his accomplishments to the New York Academy of Medicine.

In 1873, Johann Nepomuk Czermak further perfected the technique of indirect laryngoscopy with the invention of the concave headlamp. He also made other advancement to this technique during his work in Austria, Poland, and Germany. In 1895, Alfred Kirstein from Germany performed the first direct examination of the larynx by using a rubber tube with an electric bulb attached to it.

Also, in Germany, Gustav Killian began looking beyond the larynx and further in the airways. He performed the first rigid bronchoscopy to remove a foreign body from a patient who had aspirated a bone into his right mainstem bronchus, using a rigid scope that he designed. He further went on to describe that the airways were mobile. Killian published his first case series in 1898.[1] Killian is known as the "father of bronchoscopy."

During the same time, Chevalier Jackson, an American laryngologist from Pennsylvania, developed his own endoscopes with distal illumination, which he used first on dogs and inanimate models. He published his experience in 1907 on his book "*Tracheobronchoscopy, Esophagoscopy and Bronchoscopy*."[2] He was named then "father of American bronchoesophagology." E. Broyles introduced the telescope optic for bronchoscopy in Baltimore in 1940, which were followed by the addition of optical forceps (1948). In England in 1954, Hopkins developed a rod-lens telescope system that improved the lighting and imaging, improving further the access to the airways. This technology was adopted by Karl Storz as a cold light illumination source for his rigid bronchoscopes in 1963.

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Fig. 1 Rigid bronchoscope (Lymol rigid barrel, with Storz telescope).

Advancements in rigid bronchoscopy continued through the 1960s, but with Shigeto Ikeda's invention of the flexible bronchoscope, for the next several decades not much occurred with rigid bronchoscopy except in a few centers around the world, that still use it for therapeutic applications.

Rigid Bronchoscopy: Equipment

Although there have been significant improvements in optics, there have only been minor changes to the equipment used in the days of Chevalier Jackson. Currently, there are several manufacturers of rigid bronchoscopes and accessory equipment: Novatech SA (La Ciotat, France), Karl Storz Endoscopy-America, Inc. (El Segundo, CA), Richard Wolf Medical Instruments Corporation (Vernon Hills, IL), and Lymol Medical (Woburn, MA). Despite this, the rigid bronchoscope remains relatively similar to the original instrument, a stainless steel tapered tube with a flared and beveled distal tip (►**Figs. 1** and **2**). Some of the bronchoscopes have different capabilities for light delivery, end-tidal CO_2 monitoring, interchangeable introduction tubes, sizes, and accessory introduction, but the basic tool is very similar.

The diameter of rigid bronchoscopes ranges from 3 (pediatric) to 18 mm. The size chosen is dependent on the airway it is to be introduced into and the procedure, which is proposed. Rigid bronchoscope lengths range from 33 to 43 cm. The length varies by the choice of a bronchial and tracheal rigid bronchoscope (or with different manufacturers, the length of the instrumentation tubes uses for tracheal or bronchial procedures). As would be expected, bronchial tubes are longer and have fenestrations to allow ventilation of the contralateral airway while the tube tip is inserted into either the right or left mainstem bronchus. Tracheal tubes, on the other hand, are shorter and have no fenestrations (►**Fig. 3**).

The proximal end of rigid bronchoscopes has a central opening and several side ports that can be used for ventilation, light and imaging, end-tidal CO_2 monitoring, and instrumentation. The most common technique for illumination and visualization is often provided by a thin glass rod (telescope) connected to a proximal light source through a fiberoptic cable. Other systems of delivering light to the distal end of the scope include prism systems as well as light channels with distal illumination ports. The bronchoscope can be used with direct visualization down the tube, directly through a telescope, or the telescope can be connected to a camera head to provide visualization on a monitor.

Rubber caps are used on the different proximal ports in order to minimize air leak when volume ventilation is used or to help hold instruments when open channel jet ventilation is used.

Multiple accessory instruments can be used through a rigid bronchoscope. They include large optical biopsy or grasping forceps (►**Fig. 4**), suction catheters, and stents through stent delivery systems. Others include laser and argon plasma fibers, cryotherapy probes, electrocautery systems as well as

Fig. 2 Hopkins telescope (Storz).

Fig. 3 Bronchial and tracheal rigid barrels (Lymol).

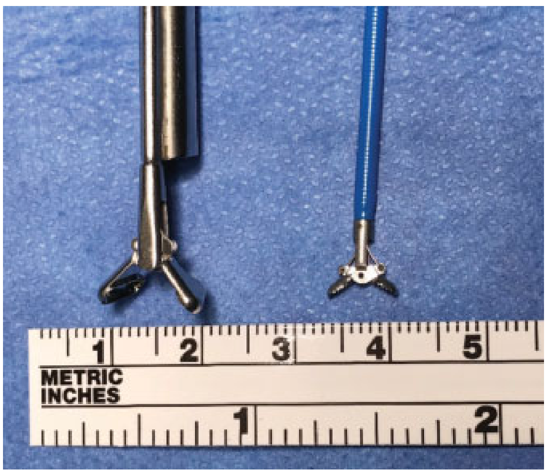

Fig. 4 Rigid forceps versus flexible forceps.

Table 1 Differences between rigid and flexible bronchoscopes

	Rigid bronchoscope	Flexible bronchoscope
Outer diameter (mm)	3–18	2.2–6
Inner (working) diameter (mm)	2–16	1–2.2
Suction capability	++ + +	++
Simultaneous control of ventilation/airway	Yes	No
Bronchoscopy tools use	Multiple at same time	One at a time
Moderate sedation	No	Yes
General anesthesia	Yes	Yes
Placement of self-expanding stents	Yes	Yes
Placement of silicone stents	Yes	No
Use of ablative techniques	Yes	Yes

microdebriders, and dilatation balloons, many of which are sold by manufacturers other than the rigid bronchoscope manufacturers. It is often common to use flexible bronchoscopes through the working channel of the rigid bronchoscope to access more distal airways or to assist with performing other endobronchial procedures.

Rigid Bronchoscopy: Indications

The rigid bronchoscope can and has been used for many of the same indications as flexible bronchoscopy. There are some centers in the world that use a rigid bronchoscope in nearly every case of bronchoscopy that they perform, introducing instruments for all procedures via the rigid bronchoscope. This said many institutions view the rigid bronchoscope as more significantly a therapeutic tool, while the flexible bronchoscope continues to be a primary diagnostic tool (►**Table 1**).

The indications for rigid versus flexible bronchoscopy are often characterized as diagnostic and therapeutic. Diagnostic indications for rigid bronchoscopy include obtaining endobronchial biopsies (larger specimens can be acquired to evaluate tissue deeper into the airway wall, ciliary function, or more difficult tissues to assess the diagnostic evaluation and control of the airway in massive hemoptysis, as well as for the performance of transbronchial lung biopsies (including cryobiopsies). The most common therapeutic indications include management of central airway obstruction (CAO) (malignant and benign), placement of airway silicone stents, extraction of foreign bodies, and use of ablative technique modalities (e.g. electrocautery, argon plasma coagulation, laser, cryotherapy, balloon, microdebrider, among others). The following sections will elaborate on many of these therapeutic indications in more detail.

Massive Hemoptysis

Massive hemoptysis is a life-threatening condition that includes not only a large amount of blood loss (definition based on volume of blood is still controversial) but also the presence of hypoxia and hemodynamic instability, which most often leads to the patient's death. The most common causes of massive hemoptysis include bronchiectasis, lung cancer, and infections such as tuberculosis or due to aspergillomas.[3]

Rigid bronchoscopy is often recommended as the preferred method for evaluation and management of massive hemoptysis. During the assessment, the control of the airway can be maintained directly through the rigid bronchoscope, in addition to airway protection of the alternative airway when needed, large-volume suction through catheters and/or flexible bronchoscopes through the rigid, as well as the simultaneous use of different tools to control bleeding.[4]

As in flexible bronchoscopy, techniques such as the use of large-volume cold saline can be used with rigid bronchoscopy to control lung parenchymal bleeding.[4] Additionally, rigid bronchoscopy with balloon occlusion of the airway can achieve isolation of the bleeding allowing simultaneous removal of blood clots from the contralateral airways to improve ventilation and oxygenation. Once bleeding is controlled, blood clot removal can be done with the use of large-bore suction catheters as well as cryotherapy probes, sometimes simultaneously through a rigid bronchoscope.[5]

It is imperative to mention that despite the benefits of rigid bronchoscopy in the management of massive hemoptysis, the success of it will depend directly on the expertise of the operator, the assisting team, and the time frame to perform it.[6]

Airway Foreign Bodies

The first use of rigid bronchoscopy was the removal of foreign body (pork bone) from the airways, described by Killian in 1898.[1] Historically as well as in some countries around the world, removal of aspirated foreign bodies still remains the principle indication for rigid bronchoscopy. Collections of these removed foreign bodies can be found in some museums yet today, for instance, in the Mutter Museum (Philadelphia, PA), Chevalier Jackson's collection remains on permanent display. Even though aspiration of foreign bodies is more common in children than in adults, the elderly and those with some of the neurologic limitations of age (e.g., Alzheimer's disease) can be equally at risk.[7]

Despite the preference in the use of rigid bronchoscopy for removal of foreign bodies by physicians with that capability, as it allows a large diameter platform for the foreign body to be extracted and multiple tools to be used, there are no data that demonstrate that the use of rigid bronchoscopy is better than flexible bronchoscopy. Furthermore, the specific tools used for extraction of foreign bodies by rigid bronchoscopy are as expected, larger, and can only access central airways, compared with flexible bronchoscopy tools that can reach several generations of airways further.

The techniques used for removal of foreign bodies most frequently include the use of forceps, retrieval baskets, or loops. The use of cryoprobes to extract foreign bodies (organic, with fluid content) has also proven to be safe and effective.[8]

Central Airway Obstruction

CAO is probably the most common indication for therapeutic rigid bronchoscopy, constituting approximately 70% of its use in adults.[9] Malignant etiology of CAO (by primary or metastatic cancer) is seen in 30% of cases.[10] Among benign etiologies that can cause CAO, the most common are posttraumatic intubation, posttracheostomy stenosis, benign tumors, and inflammatory conditions of the airways.[11] Post-lung transplantation stenosis of anastomosis is a growing issue and should also be considered in this list.

The main goals for relieving malignant CAO include improvement of a patient's performance status in order to receive oncologic treatment, clinical improvement of complications related to CAO (i.e., postobstructive pneumonia, hemoptysis), and palliation of symptoms (i.e., dyspnea, cough). For the latter, relieving malignant CAO showed a significant effect in dyspnea and quality of life in more than 40% of patients.[12] Even though management of malignant CAO can be performed with flexible bronchoscopy also, the results of the AQuIRE (Quality Improvement Registry, Evaluation and Education) data revealed that rigid bronchoscopy was the preferred choice in more than 65% of malignant CAO.[13] The main disadvantage reported for flexible bronchoscopy compared with rigid bronchoscopy is its limitation with controlling ventilation and securing the airway.[14] A comparison between flexible and rigid bronchoscopies is shown in ►**Table 1**.

Different techniques have been described in the management of malignant CAO with rigid bronchoscopy, depending on the type of obstruction: intrinsic (endoluminal involvement), extrinsic (extraluminal tumor with airway compression), and mixed (combination of intrinsic and extrinsic).[10] For intrinsic and mixed CAO, one of the techniques used is mechanical debulking, which can be performed with large debulking optical forceps or using the bronchoscope as a cutting tool with an "apple-coring" technique.[9] Additionally, different ablative techniques of tissue destruction (i.e., laser, argon plasma coagulation, electrocautery) are used in conjunction with the debulking techniques to most effectively relieve airway obstruction. With extrinsic and sometimes mixed disease, balloon bronchoplasty and the placement of tracheal or bronchial stents are used to further assist in the relief of stenosis (►**Fig. 5**).

The most common causes of benign CAO are postintubation and posttracheostomy tracheal stenosis.[11] Rigid bronchoscopy has been very well described in the management of benign disease, either as a bridge for surgical resection (primary treatment when possible) or more with greater frequency for curative relief of the airways disease.[15]

Among the techniques used in benign CAO, the most common include balloon dilation and placement of silicone stents.[16] Ablative techniques (i.e., laser, electrocautery, cryotherapy) are used only when there is tissue formation in the airway lumen (cicatricial scar tissue or granulation tissue) that, when removed, assists in relief of the stenosis. In addition to sequential balloon dilation of the airway, the rigid bronchoscope itself can also be used to further dilate areas of stenosis. The use of topical mitomycin C has been described in combination with laser and balloon dilation for the management of tracheal stenosis. The additive effects of mitomycin C are reported by operators; however, when evaluated more objectively, the practice has debatable results.[17]

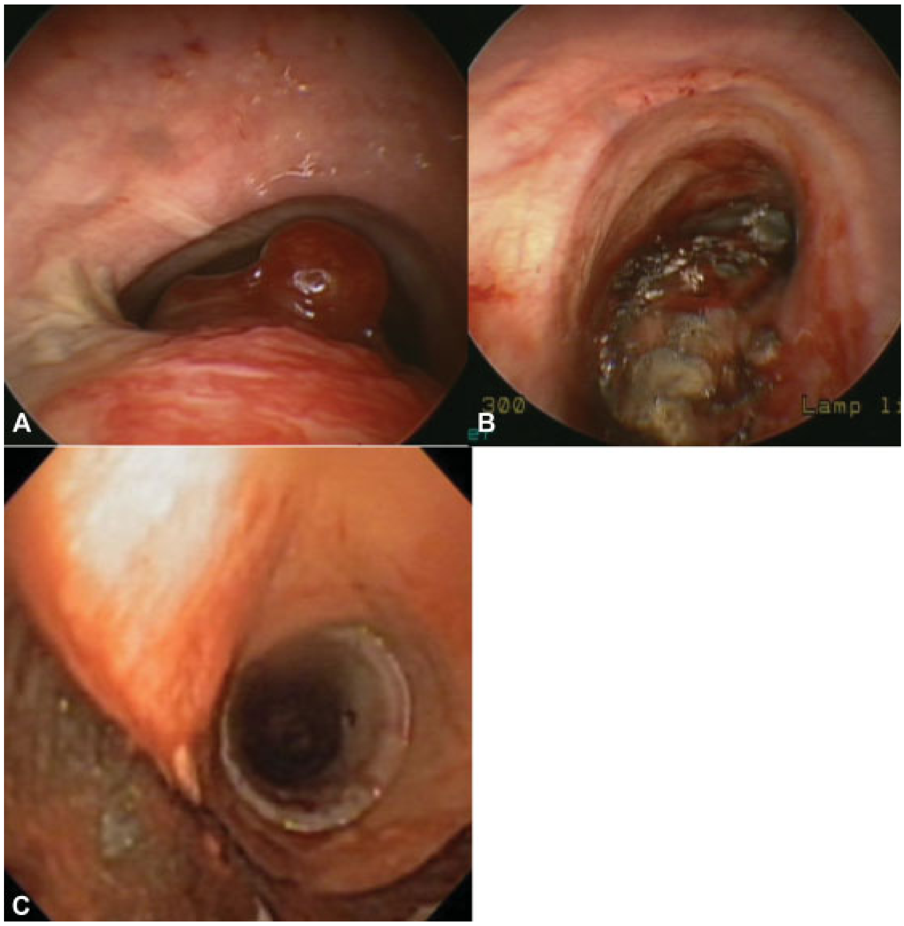

Fig. 5 Endotracheal tumor (A), treated via rigid bronchoscope with laser (B), followed by placement of silicone tracheal stent (C).

As with any other procedure, choosing the most correct techniques maximizes the opportunity for success. Subcategorizing the diagnosis of tracheal stenosis takes into account conditions beyond the fact that an airway is obstructed. Identifying the key characteristics can ensure that the best opportunity for success has been chosen with the interventional management of disease, for example, the management of simple postintubation stenosis (presence of endoluminal tissue only) versus complex tracheal stenosis (involvement of the tracheal cartilage/length/location). Brichet et al described a dramatic improvement of respiratory symptoms in 31 out of 32 patients, when managed with a combination of laser and bronchoscopic dilatation (for simple stenosis) versus dilation with stent placement (for complex stenosis).[18]

Placement of Airway Stents

Rigid bronchoscopy is the method of choice to deploy silicone stents in the airways.[19] The main indications for the use of silicone stents are malignant or benign CAO, treatment of fistulas (i.e., stump dehiscence, tracheoesophageal fistulas), management of tracheal lacerations,[20] and stabilization of airways in the management of severe tracheobronchomalacia.[11]

Rigid bronchoscopy allows stabilization of the airway and continuous ventilation during the deployment of stents. Also, the use of specially design silicone stent deploying systems (adapted to the rigid bronchoscopes) makes the procedure more efficient and safer (►**Fig. 6**). Silicone stents are in general safe and although complications such as stent migration (9.5%), granulation tissue formation (8%), and mucous plugging (4%) have been described,[21] their use in the management of airways disease is a very important component of the treatment of complex airways disease (►**Fig. 7**).

Even though other types of airway stents (i.e., self-expanding metallic stents) can be placed without rigid bronchoscopy, most experts in the field agree that rigid bronchoscopy provides a more secure and controlled environment for stent deployment and use. Additionally, the choice and placement of an airway stent with rigid bronchoscopy ensure that all stent options are considered prior to choosing the best tool.

Rigid Bronchoscopy: Anesthesia

Preprocedural Assessment

Rigid bronchoscopy necessitates a thorough preprocedural assessment. This begins with a careful evaluation of the neck stability and mobility. Rigid bronchoscopy requires the position of the head to be extended to create a direct path from the oral introitus through the larynx and into the trachea. Those patients with a history of rheumatoid arthritis (RA), cervical spine fusion, radiation therapy to the neck, or a history of head and neck reconstructive surgery can be either

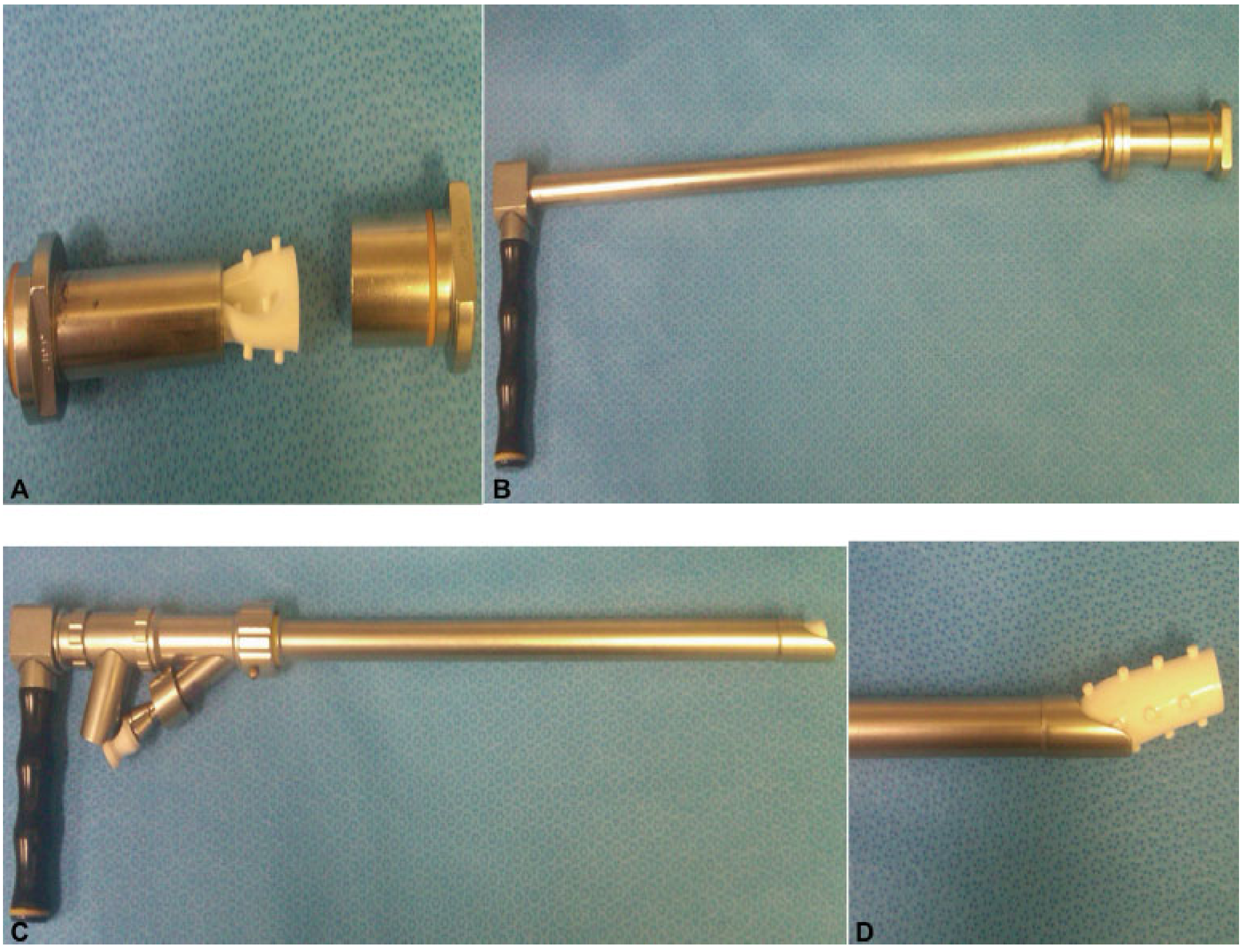

Fig. 6 Silastic stent placed in stent loader (A), then connected to stent deployer (B). Once stent is passed into the deployer, the deployer is inserted through the rigid bronchoscope (C) which is already in position in the airways. The stent is pushed with the deployer plunger from its proximal end into the airway (D).

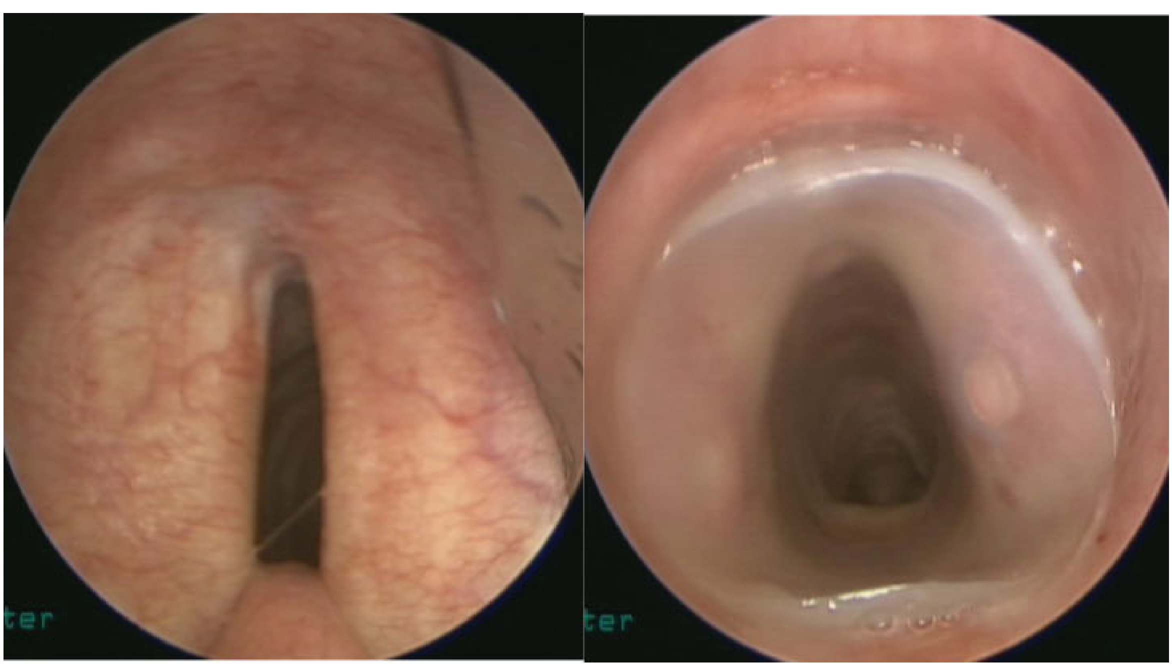

Fig. 7 Tracheal stenosis (posttracheostomy), managed with silicone tracheal stent.

at increased risk of injury as in RA patients with the danger of atlantoaxial subluxation or the intubation can be made difficult due to limitations in motion. An assessment of the degree of mouth opening must be conducted, paying careful attention to the presence of preexisting loose teeth, micrognathia, or jaw disorders from temporomandibular joint conditions. From a cardiovascular standpoint, an assessment for orthostatic hemodynamic changes is important. Additionally, careful attention should be paid to history of vagal events leading to syncope. With the rigid bronchoscope placed into either of the mainstem bronchi, for more distal work, compression of the carotid can lead to vagal events during the procedure.

Patients undergoing therapeutic rigid bronchoscopy for CAO from surrounding mediastinal masses may develop intraprocedural hemodynamic changes from a direct mass effect on the heart and central vascular structures (e.g., superior vena cava syndrome). Planning with the anesthesia team is very important to ensure procedures without complications. The use of invasive hemodynamic monitoring is recommended (such as arterial line placement) in these and similar cases with consideration of preprocedural fluid resuscitation in some cases.

In situations where electrocautery or other electric energy is to be used, consideration has to be made for patients who are pacemaker dependent. Monopolar systems can cause electromagnetic interference with pacemakers inhibiting pacing, causing inappropriate tachycardias or leading to reprograming to name some of the complications. Alternative thermal ablative therapies and tumor debulking techniques need to be considered. Also, the team should assure the availability of temporary pacing and defibrillation equipment in the procedure room.[22] Depending on the proposed procedure, special conditions must be considered. For instance, patients require special eye protection when laser ablative therapy is planned. Appropriately placed grounding pads must be placed when anticipating the use of electrocautery.

From a pulmonary standpoint, the team should evaluate the baseline oxygenation and ventilation requirements; patients may often need to tolerate being on a low fraction of inspired oxygen (FiO_2), particularly in those situations when thermal ablative therapy is needed. In the case of jet ventilation, the tolerance for increased levels of end-tidal CO_2 needs to be considered as in volume ventilation, some degree of air leakage around the rigid bronchoscope that could potentially compromise effective intraprocedural ventilation must be considered. These variables help illustrate the close communication needed between the operator and anesthesiology team. Planning requires consideration of the optimal mode of ventilation for the intended procedure, instituting a backup plan for gaining airway control, particularly in patients with severe tracheal narrowing, and a plan for postprocedural airway complications including laryngospasm. When the risk of massive hemoptysis exists, additional measures need to be taken such as keeping a bronchial balloon blocker readily available in the procedure room and having blood available.

Type of Anesthesia

Anesthesia for rigid bronchoscopy cases requires anesthesiologists not only familiar with the procedure but additionally fully aware of the oxygenation and ventilation issues often encountered during rigid bronchoscopy cases. These cases are some of the very few that the anesthesiologist does not have control of the airway, similar to some laryngeal procedures. The control of the airway while performing complex procedures changes with obstructions, holding of ventilation, and limitations of FiO_2. In short, the anesthesiologist does not have all of the tools they are accustomed to available, so it is very important that good communication be used at all times to minimize the risk to the patient and maximize the efficiency of the procedure.

Total intravenous anesthesia (TIVA) is the preferred and recommended technique for the delivery of anesthesia during rigid bronchoscopy cases. Rigid bronchoscopy is either performed using volume ventilation or jet ventilation. In either situation, the airway is in direct communication with the room air, and therefore, the surgeon will be directly exposed to the inhaled anesthetics and their effects. This is dangerous to both, the surgeon as it is to the patient. Additionally, reliable delivery of inhaled anesthetics can be affected by fluctuations in the airflow commonly encountered during rigid bronchoscopy as seen with the recurrent buildup of secretions and blood clots in the airways and with the repeated episodes of apnea during balloon dilation for relief of CAO. Finally, proper delivery of inhaled anesthetics can also be compromised by air leakage through, and around, the rigid bronchoscope and by different ventilation techniques, such as jet ventilation.[23] TIVA is therefore the recommended anesthetic for rigid bronchoscopy. TIVA allows for rapid titration and thus adapts better to the constant changes in the depth of sedation that are faced during rigid bronchoscopy. The choice of anesthetic agent should take into consideration patient-related, disease-related, and procedure-related factors. In general, anesthetic agents with short duration of action and rapid elimination (such as remifentanil and propofol) and those with minimal effect on the respiratory drive are desired.[24]

In addition to end-tidal CO_2 monitoring, there is evidence to suggest that the use of more complex intraprocedural monitoring can improve the safety and postprocedure recovery. Studies suggest that bispectral index can help reduce the risk of awareness during rigid bronchoscopy[25] and improve recovery time[26] with general anesthesia.

Paralytic agents are often used to facilitate rigid bronchoscopy intubation. Limitation of vocal cord motion can minimize laryngeal injury and expedite the time of intubation. Further use of paralytics during the procedure are often administered as needed depending of the patient's condition, the length of the procedure, and the endobronchial intervention being performed.

Ventilation Strategies

Various modes of ventilation can be used during rigid bronchoscopy and include spontaneous-assisted ventilation, controlled ventilation, and jet ventilation. In general, there is no evidence at the present time to support the use of one mode over the other. A recent meta-analysis looked particularly at foreign body removal in children and found no difference between controlled and spontaneous ventilation.[27] Today, the choice of a given ventilation mode relies mainly on the experience and preferences of both the anesthesiologist and the bronchoscopist.

Spontaneous-assisted ventilation is typically done with TIVA and assistance is provided during deeper periods of sedation or during apnea.[28] With controlled ventilation, neuromuscular blockade is commonly needed. To minimize air leakage and ensure effective ventilation, a semiclosed circuit can be achieved by capping all portals of the rigid bronchoscope and by packing the oropharynx with wet gauze. Manual assistance with ventilation may prove necessary with severe airway stenosis where minimization of turbulent flow during ventilation is key to maximize ventilation. Jet ventilation requires an open system to avoid barotrauma. It can be of two types: manual or high-frequency jet ventilation (HFJV). The high respiratory rate and small tidal volumes that characterize HFJV minimize airway motion making it suitable for delicate and precise endobronchial interventions. Jet ventilation is associated with minor complications (hypoxemia, hypercapnia, and hemodynamic instability). More severe complications, such as barotrauma, are rare.[29]

Rigid Bronchoscopy: Intubation Techniques

Following preoxygenation with a face mask, a mouth guard is placed to cover the upper teeth. If the patient has dentures, they are typically removed and a wet gauze is placed to cover and protect the gingiva. In order to optimize the view of the glottis, the head and neck need to be properly positioned. Classically, the patient is placed in a sniffing position; some bronchoscopists would elevate the head using a pillow. Others would place the head of the surgical table in a downward incline position allowing the head of the patient to slightly suspend below the level of the torso and achieving extension of the atlanto-occipital joint.

During direct intubation, the rigid bronchoscope is held with the dominant hand while the fingers of the other hand are protecting the upper teeth/gum and controlling the head position. After adjusting the white balance and the image focus, the rigid telescope is positioned inside the bronchoscope in such a way to allow full visualization of the beveled tip. The rigid bronchoscope is advanced with its beveled tip facing up. The uvula is identified first then the bronchoscope is advanced along the base of the tongue until the epiglottis comes in view. At this point, the rigid bronchoscope is passed gently underneath the epiglottis, lifting it to expose the arytenoids and the vocal cords. As the beveled tip approaches the vocal cords, the tip is rotated 90 degrees in one direction and is used to gently push the ipsilateral vocal cord sideways making room for the rigid scope. At that point, the rigid bronchoscope is advanced in a rotational movement turning the bevel to the 6 o'clock position while moving it into the trachea. This motion uses the smooth edge of the bevel to gently push the contralateral vocal cord to the side, maximizing the size of the laryngeal introits. Once in the trachea, the beveled tip is typically positioned in a way to be lying against the posterior membranous wall of the trachea.

Intubation is also performed with direct visualization through the rigid bronchoscope, using an internal light system. Other interventional pulmonologists expose the larynx with a laryngoscope prior to intubating. No evidence exists on the benefit of one technique versus the other, and the technique used is specific to the training the interventionist received.

For patients with a preexisting endotracheal tube in place, the rigid bronchoscope is advanced alongside the tube until the vocal cords are visualized. The glottis is then cleared of all secretions. It is recommended that if using a telescope that it be pulled back further into the rigid bronchoscope, extending the suction catheter and beginning suction as the cuff of the tube is deflated. This is due to the fact that secretions are commonly just below the balloon and can be expressed with any airway pressure interfering with airway visualization. Suction is continued as the endotracheal tube is removed then the rigid bronchoscope is advanced as described in the direct intubation technique earlier.

Rigid intubation can also be performed through the tracheal stoma (as in postlaryngectomy patients). This can be achieved by standing behind the head of the patient but slightly to the side of the bed typically with the head rotated to the opposite side. The rigid bronchoscope is then carefully introduced and advanced obliquely and rotated into proper position.

Rigid Bronchoscopy: Contraindications

The most common contraindication for not performing a rigid bronchoscopy has to do with the comorbidities of the patient and the risk these impose to receiving general anesthesia. There are few absolute contraindications to the performance of rigid bronchoscopy, particularly in view of the fact that rigid bronchoscopy is sometimes the lifesaving modality needed. In most instances, patients with very high oxygen requirements and particularly those with high levels of positive end-expiratory pressure (PEEP) would not be taken to the operating room (OR) for a rigid bronchoscopy procedure. This stated, in the case of CAO, when the patient cannot be effectively oxygenated nor ventilated due to the malignant obstruction despite an FiO_2 of 100% with PEEP would, at experienced programs, be taken to the OR to relieve the malignant airway obstruction and thereby treat the etiology of the ventilation and oxygenation problem.

Similarly, coagulopathic states, recent cardiac or neurologic events, the presence of aortic aneurysms, must all be considered very seriously before taking patients for surgery. Neuromuscular conditions that could be worsened with paralysis have to be special consideration for anesthesia. Consultation with the anesthesia team, with the patient, and the patient's family must be completed prior to any high-risk procedure.

Other relative contraindications consist of physical changes that may prevent access to the airways with a rigid bronchoscope. These include limited mouth opening, unstable midline facial fractures, laryngeal obstruction, and limited neck hyperextension and rotation as seen in fused or unstable cervical spines. As previously mentioned, patients with RA and other conditions associated with atlantoaxial subluxation and instability should be evaluated for this prior to undergoing rigid bronchoscopy.

Certain tools used during rigid bronchoscopy have their own specific contraindications that are not necessarily attributed to the rigid bronchoscope but must be taken into consideration if they will be used. The use of "hot" ablative techniques: electrocautery, argon plasma coagulation, and laser, requires a FiO_2 of less than 0.40. On the contrary, "cold" ablative techniques: cryotherapy, mechanical debulking, and airway stenting can be used in the high oxygen environment and may lead to prompt recanalization and positive outcomes in similar scenarios. In clinical situations of pure extrinsic compression, airway stenting is the preferred and recommended intervention.[30]

Rigid Bronchoscopy: Complications

Rigid bronchoscopy is a safe procedure when the clinical evaluation and procedure are performed by an appropriately trained physician. Large multicenter databases have been used to analyze the outcomes of therapeutic bronchoscopy. In cases of malignant CAO, the reported complication rate and mortality are 3.9 and 0.5%, respectively. The factors most commonly associated with complications include: urgent or emergent cases, American Society of Anesthesiology score higher than 3, redo therapeutic bronchoscopy, and moderate sedation.[13] Previous data reported a complication rate for nonmalignant disease of 15%.[31]

Due to the nature of the procedure, sore throat and neck pain are the most commonly reported symptoms in the postoperative period. Injury to any of the upper airway structures may be seen during rigid intubation including: laceration of the hypopharynx, vocal cord injury, laryngocricoid edema, and vocal cord spasm. Additionally, the potential for damage to dentition, even loosing teeth is a risk of all cases and patients should be warned of this risk.

Cardiovascular complications, hypercarbia, and hypoxia can be associated with general anesthesia.[28,32] Preoperative cardiac risk factors or in some cases unknown risk factors can place patients at risk of these complications during airway procedures. The fact that intraoperative hypoxia and apneic periods are not uncommon in the management of central airways disease, underlying cardiac issues can manifest. Preoperative evaluation and optimization of clinical conditions when possible is vitally important to a safe busy program.

Intraoperative hypoxia and hypercarbia can occur during procedures: hypoxia—volume ventilation/hypercarbia—jet ventilation. These conditions can be complicated by underlying lung disease. Of similar significance is in those instances when a lobe or lung has been collapsed and it is opened as a result of the procedure. These patients can begin developing intraoperative hypoxia and even more significant postoperative hypoxia for a period of time due to the new ventilation-perfusion (VQ) mismatch created by the newly established ventilation to under perfused lung units.

Bleeding is a very real and intraoperatively very complex problem. Bleeding can come from complications of both malignant and benign diseases. Different types of tumors and/or the location of their invasion can influence the risk of bleeding. Vascular involvement of tumors or anatomically atypically positioned vessels can lead to airways disease and also complicate its management. Patients who had received previous radiation, surgery, and even chemotherapy with recurrent disease, or complications secondary to the treatments often have an increased risk of bleeding due to the changes in the surrounding tissue, more so than with the tumor itself. Overall, the planning necessary to ensure safe procedures requires a great understanding of airway and mediastinal anatomy, the different disease processes, and the effects of various interventions.

Airway perforation is another complication of rigid bronchoscopy. It may be superficial (not full thickness) or full thickness and lead to pneumomediastinum and/or pneumothorax. The rigid bronchoscope is a tool that requires expertise in its use particularly in situations when an apple-coring technique is used, maneuvering through very tight stenosis, or when working in the distal mainstem bronchi. The bevel of the rigid bronchoscope must be focused on when intubating, moving the scope throughout the airway, and using it as a cutting tool. Training and understanding the details of these procedures is truly the only way to prevent these types of complications.

Although not directly related to rigid bronchoscopy, airway fires are a potential complication of "hot" ablative techniques: laser, electrocautery, and argon plasma coagulation that are commonly used with rigid therapeutic cases. In the closed environment of the airway when there is a high fraction of oxygen combined with a thermal source, a flash fire can occur. In this instance, all flammable material (suction catheters, balloons, and the outside sheath of a flexible bronchoscope) will all also ignite. To manage the situation, the scope must be removed, the patient aloud to apneic, so the oxygen is used up with the burn. Only then is it safe to re-enter the airway. The best way to prevent this from occurring is to reduce the FiO_2 to less than 0.40. This is not a guarantee, but if managed this way, the risk of fire is reduced to nominal.

Gas embolism is another ancillary procedure-related complication that can occur during rigid bronchoscopy. It is rare but potentially fatal problem that can be seen with the use of laser, argon plasma coagulation, and cryotherapy. All of these tools can lead to local increases in airway pressure. Sudden intraoperative hemodynamic, respiratory, and neurological changes should alert the team of these potential dangers. Knowledge of anatomical landmarks, the physical properties of the tool being used, and proper training are critical to decrease the risk of these outcomes.[30,33,34]

Future

The future of rigid bronchoscopy rests on the dissemination and standardization of training; the furthering translational, applied, and clinical research; and the development of new tools and technological innovations that can be applied through a rigid bronchoscope. Rigid bronchoscopy itself is a tool, which gives the interventional pulmonologist the ability to access, control, and operate on the airways. Many of the future advancements, which will be created, will use the rigid bronchoscope as a tool for use of these technologies more than actual changes in the rigid bronchoscope itself.

Examples of this include the use of the rigid bronchoscope as a conduit to perform cryobiopsies for interstitial lung disease increases.[35] A great amount of work is being done in industry for better tools to perform lung interventions. If further studies validate the potential use of radiofrequency, microwave, and cryoablation techniques for inoperable lung cancer, the rigid bronchoscope may become the preferred conduit for such procedures, for control of the airways, and any potential risks that may subsequently occur.

Similarly, advances in airway stenting will hopefully decrease the complications seen with airway stents, and therefore, increase the use of rigid bronchoscopy for other conditions associated with airways disease. Drug-impregnated, biodegradable, and three-dimensional printed stents have been successfully develop and may be beneficial in the near future.[36–38]

Rigid Bronchoscopy: Conclusion

As of 2018, there were 35 training programs offering a dedicated interventional pulmonology fellowship in North America, this number has significantly increased in the last decade. We now have accreditation standards which recommend a minimum institutional case volume in order to provide trainees with sufficient hands-on experience in rigid bronchoscopy. Although this number does not assure procedural competency, it serves as a basic standard for training programs.[39] Simulation training in rigid bronchoscopy should be considered if available.[40] A written board examination is currently available for those who become eligible after successfully completing an interventional pulmonology fellowship. Although the board examination is not American Board of Internal Medicine affiliated, the societies invested in the future of interventional pulmonology; the American Association for Bronchology and Interventional Pulmonology and the Association of Interventional Pulmonary Program Directors have worked together to create and maintain academic standards in this new field.[41] Through these standardization and accreditation mechanisms, we continue to attempt to ensure the safety of patients undergoing rigid bronchoscopy as well as the quality of the services we can provide.

Rigid bronchoscopy is an old technique, actually the original technique for accessing and working in the airways. With the advent of flexible techniques, the use of the rigid bronchoscope fell out of favor and the skills for use were almost lost. With the continued evolution of patient care, the rigid bronchoscope has found a resurgence in its use and the potential ways it can be used to manage complex airways disease.

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