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REVIEW

Indications and complications of rigid bronchoscopy

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ABSTRACT

Introduction: Rigid bronchoscopy is an invaluable tool for the management of airway disorders and an essential skill for an interventional pulmonologist. Since its introduction in the late 19th century, it has remained an important technique for the management of central airway obstruction, foreign body aspiration and massive hemoptysis.

Areas covered: This article will review the history, indications, contraindication, technique and complications of rigid bronchoscopy. We will also briefly discuss the methods of anesthesia and ventilation and finally our perspective on the future of rigid bronchoscopy.

Expert commentary: Although the rise of flexible bronchoscopy in the 1960s led to a decline in the use of rigid bronchoscopy, the last two decades have witnessed resurgence in its popularity. We anticipate that it will remain an important tool used by interventional pulmonologists for decades to come. We suggest that interventional pulmonologists must have training and develop expertise in this technique.

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Rigid bronchoscopy; central airway obstruction; massive hemoptysis; rigid intubation; endobronchial tumor; therapeutic bronchoscopy; foreign body removal

1. Introduction

Rigid bronchoscopy has been an immensely useful tool for over a century in the diagnosis and management of airway diseases. Its first use in the late nineteenth century by Dr Gustav Killian sparked the growth of pulmonary medicine by giving physicians new insights into airway anatomy [1]. Central airway obstruction (CAO) by tumor and foreign body (FB) aspiration are common problems faced by the interventional pulmonologist. An episode of mechanical airway obstruction occurs in up to 20–40% of patients with lung cancer [2]. Rigid bronchoscopy continues to be indispensable for the management of CAO and other airway diseases.

Over the past 120 years, the use of rigid bronchoscopy has waxed and waned. However, despite the remarkable advancements in flexible bronchoscopy, rigid bronchoscopy has proven itself to stand the test of time and remains the therapeutic instrument of choice for the management of complex airway diseases [2].

Large volume suction capability, better airway control, more therapeutic options, and ability to accurately place a wide variety of airway stents make rigid bronchoscope technically superior to the flexible bronchoscope in the management of airway obstruction. It is essential to realize that flexible bronchoscopy complements the rigid bronchoscope and should not replace it for therapeutic interventions in the airway [2]. In this review, we will discuss the history of rigid bronchoscopy, the technique, its indications and contraindications, and our perspective on the future of rigid bronchoscopy.

2. History

As early as the fourth century BC, Hippocrates suggested the introduction of a pipe into the larynx of a suffocating patient. Desault (1744–1795) suggested nasotracheal intubation as a treatment for suffocation and FB aspiration [3]. However, it was not until 1894 when Kirstein in Berlin started to intentionally intubate the larynx with the esophagoscope. He suggested that his experience needed further study, but warned that the lower trachea was a very dangerous place. Rhinolaryngologist, Gustav Killian of Freiburg University attended Kirstein's lecture in 1895 at the second Congress of the Southern German Laryngologists in Heidelberg; and began his experiments with the new method [3]. In 1897, Gustav Killian removed a pork bone from the right main stem bronchus of a farmer who had aspirated while eating soup. Dr Killian used a head mirror as an external light source and a 33.5-cm esophagoscope to remove the 11 × 3-mm bone fragment while performing the first documented FB retrieval utilizing bronchoscopy [4]. He made some very early observations of the bronchial anatomy and sparked the growth of bronchoscopy [5]. To grasp the true significance of his achievements, one must consider the fact that at that time most patients fell chronically ill after aspiration of a FB. Many of them developed chronic pneumonia and hemorrhage, which had over a 50% mortality. Even surgical procedures like lobectomy and pneumonectomy were introduced after 1910 [3].

In 1904, Chevalier Jackson, the 'father of American bronchoesophagology' equipped his bronchoscope with a light bulb and suction channel, and modified the scope to

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match the tracheal length [4]. In 1922, Dr Albricht reported a success rate of 98.3% in the 703 patients that underwent rigid bronchoscopy for FB aspiration between 1911 and 1921[5]. Broyles and Hopkins introduced the telescope optic, optical forceps and improved lighting and imaging in 1940s and 1950s [3].

The rigid bronchoscope rapidly became very popular across the world and remained the only tool that allowed direct examination of the airways until the introduction of the flexible bronchoscope in 1966 by Shigeto Ikeda from the National Cancer Center in Tokyo, Japan [4]. Over the next few decades, as the flexible bronchoscope saw rapid technological advancements, it became widely popular and the use of rigid bronchoscopy rapidly declined. A 1991 American College of Chest Physicians (ACCP) survey showed that only 8% of responders at that time were routinely performing rigid bronchoscopy [5]. By 1999, this number had dropped to only 4% [3].

Since the 1980s, the rise in lung cancer incidence has led to an associated increase in CAO. This has subsequently led to a resurgence of rigid bronchoscopy as a very valuable tool for the interventional pulmonologist [6]. Cavaliere in Italy, Diaz-Jimenez in Spain, and Dumon in France became the forerunners of rigid bronchoscopy in the late twentieth century and contributed significantly to the field. Dumon developed a dedicated therapeutic rigid bronchoscope and the first widely applied stent application device [7].

Rigid bronchoscopy has several advantages over flexible bronchoscopy such as better control of the airway and ventilation, and the ability to simultaneously use large forceps and suction catheters. These technical advantages that make rigid bronchoscopy invaluable for the management of CAO have led to the increase in the number of rigid bronchoscopies being performed today [3].

3. Equipment

3.1. Rigid bronchoscope

There have been few changes to the design of the rigid bronchoscope since it was first used by Killian in 1897. It is a stainless steel, straight and hollow cylindrical tube available in various sizes. The external diameter varies from 9 to 14 mm, the wall thickness ranges from 2 to 3 mm, and the length of the adult rigid bronchoscope is usually 40 cm, while the tracheoscopes are shorter (30 cm). Rigid bronchoscopes with extra large diameter (up to 16 mm) have been developed for exceptional cases, but they are not readily available.

Most rigid bronchoscopes have a uniform diameter from proximal to distal end. There is typically a beveled end that serves many purposes. It allows for lifting of the epiglottis, safer intubation through the vocal cords, dilation of airway strictures, and allows one to 'core' though an airway lesion to achieve airway patency [8–10]. Most bronchoscopes are round when viewed in cross section while some are oval. Most bronchoscopes are an empty metallic tube while some have a small internal channel through which the rigid telescope can be passed. Rigid bronchoscopes typically have fenestrations at the distal one third of the bronchoscope to allow for contralateral lung ventilation when the bronchoscope is inserted into a main stem bronchus (Figure 1). On the other hand, the shorter tracheoscopes do not allow for main stem bronchus intubation and therefore, do not have the distal fenestrations seen on the bronchoscope (Figure 2). The proximal end of the bronchoscope varies by manufacturer but typically have several ports to allow passage of the telescope, suction catheters as well as a variety of instruments used for tumor destruction, tumor excision, dilation, and FB removal [11].

The past few decades have seen several new modifications of the standard rigid bronchoscope giving the interventional

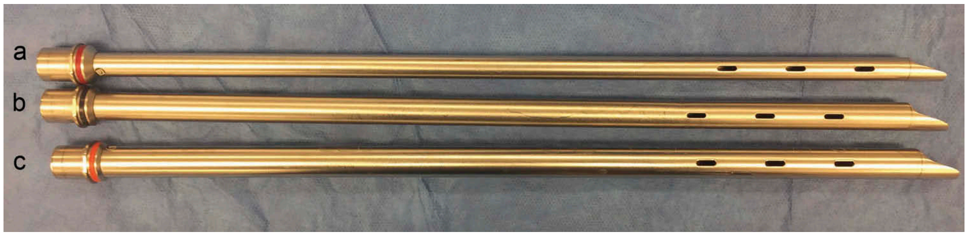

Figure 1. Bronchial tubes (ventilating) of the three most commonly used sizes in adults: (Outer Diameter/Inner Diameter mm color) (a) 10/9.2 mm Red, (b) 12/11 mm (Black) and (c) 13.2/12.2 mm (Orange). Full color available online.

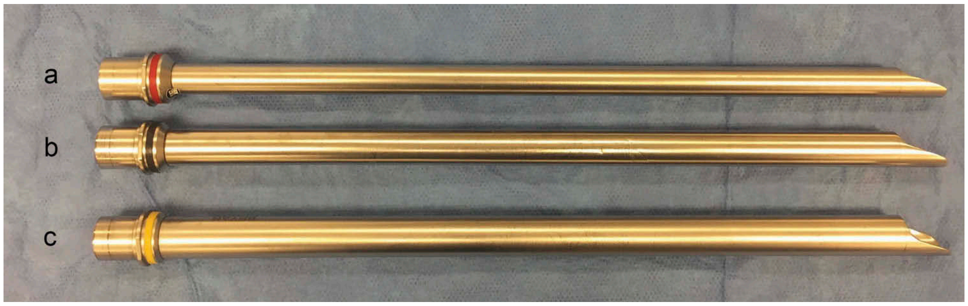

Figure 2. Tracheal tubes (non-ventilating) of the three most commonly used sizes in adults (Outer Diameter/Inner Diameter mm color): (a) 10/9.2 mm Red, (b) 12/11 mm (Black) and (c) 13.2/12.2 mm (Yellow). Full color available online

pulmonologist new tools to advance the field. The Bryan-Dumon™ series II Rigid Bronchoscope was the first major modification to the rigid bronchoscope since the time of Gustav Killian. It has an operator head with a universal instrumentation barrel that can be placed on the proximal end of bronchial or tracheal tube of any size. It also has three side ports for instruments, ventilation, and anesthesia. This innovative design allows the operator to use various endoscopic tools, suction catheters, and laser fibers simultaneously, without losing visualization. The Bryan-Dumon stent placement kit is available for the placement of silicone tracheobronchial stents. The stent placement kits have steel stent introducers and pushers that allow for loading of the Y stent in a musket-barrel type fashion. These kits are color-coded corresponding to the color-coded bronchial and tracheal tubes of the Series II Rigid Bronchoscope (Figure 3).

The Wolff Texas Rigid Integrated Bronchoscope was designed by Dr Garrett Walsh at the MD Anderson Hospital in Houston, TX, USA. This system has a separate channel for optics allowing for a larger channel for instruments while maintaining continuous visualization. This unique design that combines the operator head with the camera minimizes the loss of working space taken up by larger optics. Besides more space, this system also improves efficiency because the telescope does not need to be removed before insertion of other tools. The irrigation port at the operator end can help keep the distal lens clean to maintain optimal visualization. Additional fenestrations at the distal end of the bronchoscope provide a 360-degree view. This bronchoscope is compatible with all stent systems.

3.2. Optics

Generally, a rigid telescope and light source are inserted through the rigid bronchoscope to allow visualization of airways. Direct visualization through the rigid bronchoscope is possible in a few systems that use light conducted through a tube extending through the length of the bronchoscope. Alternatively, a flexible bronchoscope can be used.

3.2.1. Rigid telescope

Rigid telescopes can provide visualization at angles of 0°, 30°, 40°, 50°, 90°, 135°, and 180°. However, 0-degree telescopes are commonly used for rigid bronchoscopy and are adequate for visualization of trachea, main stem bronchi, and bronchus intermedius (Figure 4). A flexible bronchoscope can be inserted through the rigid bronchoscope to allow easy visualization of lobar bronchi.

Figure 3. Stent Placement Kits – color-coded to use with the same colored bronchial or tracheal tubes. (a) Red, (b) Black, (c) Yellow, (d) Orange. Full color available online.

Figure 4. (a) Rigid telescope, (b) Light source, (c) Camera head, (d) Assembled telescope with attached light source and camera head.

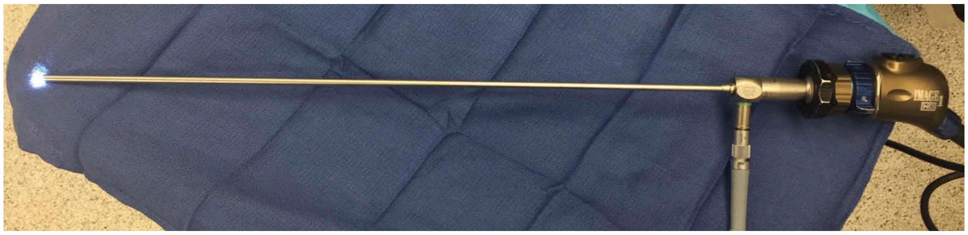

Figure 4. Continued.

3.2.2. Light source

A good light source attached to the telescope is essential for optimal visualization during rigid bronchoscopy (Figure 4). Most frequently used is a cold light source, e.g. xenon and halogen lamps. Intensity of light is typically adjusted manually.

3.2.3. Video equipment

Video imaging is achieved by attaching a single-chip or three chip video camera head to the telescope (Figure 4). A flexible bronchoscope is a good alternative.

3.3. Accessory instruments

Tools that may be used during rigid bronchoscopy are rigid forceps for biopsy, rigid or flexible suction tube, forceps to remove FBs, optical forceps for biopsy, and stent kits (Figure 5). Rigid grasping forceps are probably the most useful accessory to the rigid bronchoscope. They are used for multiple interventions such as placement, repositioning and removal of stents, tumor excision, and for FB extraction. Wolff offers an optical holding forceps 3XL 'Cyclops Forceps' that has a centrally positioned 5.5-mm telescope which ensures optimum visualization while providing great mechanical stability for the use of forceps.

4. Rigid bronchoscopy procedure

Rigid bronchoscopy is typically performed in an operating room or a bronchoscopy room equipped with the necessary bronchoscopy equipment, and with the ability to provide general anesthesia, conventional closed circuit ventilation and jet ventilation.

4.1. Patient preparation

After preoperative evaluation is complete, the patient is brought to the operating room. Patients are oxygenated with 100% FiO_2 via face mask. Dentures should be removed and teeth and gums carefully inspected. Teeth and gums should be protected with plastic mouth guards, foam rubber, or gauze pads. Cervical spine extension is often necessary and can be achieved by either placing a rolled blanked or towel between shoulder blades or by suspending the head and neck of the patient over the edge of the operating table or more commonly, by simply lowering the hinged head end of the operating table. However, caution should be used in patients with cervical spine disease or instability.

4.2. Anesthesia

The most frequently used anesthesia technique is total intravenous general anesthesia with propofol and jet ventilation [12]. This technique is usually well tolerated and is well suited for rigid bronchoscopy; however, caution must be used in patients with poor functional or cardiovascular status [13]. Complete muscle relaxation is helpful to allow easy intubation and also when work is being performed in the lower airways. Inhaled gases can be used when closed circuit positive pressure ventilation is employed but not when using jet ventilation, which is an open system.

4.3. Technique

4.3.1. Direct intubation

Direct intubation is the most common technique used for rigid intubation. The rigid telescope is placed within the distal end of the rigid bronchoscope. While maintaining complete visualization of the distal end of the rigid bronchoscope, it is inserted into the oral cavity. The beveled end is kept anteriorly as the bronchoscope is advanced

Figure 5. Accessory Instruments – (a) Rigid forceps, (b) Optical forceps, (c) Rigid suction tube.

along the tongue. The epiglottis is then visualized and lifted up by the rigid bronchoscope. As the vocal cords are approached, the bronchoscope is rotated 90° clockwise such that the beveled end lies between the cords as it is passed through them. The bronchoscope is advanced in a rotating motion to beyond the level of the cricoid cartilage. The beveled tip is allowed to rest on the posterior wall of the trachea.

4.3.2. Intubation with laryngoscopy

Rigid intubation can also be done with the use of direct laryngoscopy. A curved or straight laryngoscope is used to lift the epiglottis and visualize the larynx. A rigid bronchoscope is then passed through the cords in a similar fashion as described earlier while maintaining direct visualization of the vocal cords either directly through the rigid bronchoscope or with the use of a telescope.

4.3.3. Intubation via tracheostomy

Intubation through a tracheostomy is fairly straightforward. After topical anesthesia and neck rotation, a rigid bronchoscope can be easily inserted via a tracheostomy while maintaining visualization with a telescope. Caution should be used to avoid injury to the posterior tracheal wall during intubation.

4.4. Ventilation

Ventilation strategies for rigid bronchoscopy have evolved considerably over the past few decades. The various methods of ventilation include apneic oxygenation, spontaneous assisted ventilation, controlled ventilation (closed system), manual jet ventilation and high-frequency jet ventilation [14]. The most common technique in the 1990s was the use of spontaneous assisted ventilation with intravenous anesthesia. However, the high-risk patient population suffering from CAO suffered frequent episodes of hypoxemia with this strategy. This has led to a paradigm shift away from this mode over the past two decades [15]. Even in pediatric populations, the use of spontaneous ventilation has been shown to increase the risk of hypoxemia and other complications during rigid bronchoscopy [8].

The need for a mode of ventilation that could provide continuous oxygenation and ventilation; while allowing adequate airway control led to the reemergence of jet venturi ventilation. Sanders originally described this method in 1967 [3]. Low-frequency jet ventilation has been shown to effectively ventilate and oxygenate the patient while keeping the proximal end of the bronchoscope open and free to allow passage of instruments [16,17]. To achieve jet ventilation through an open system, 100% oxygen is injected at 50 psi through one of the operator ports at the proximal end of the bronchoscope. The anesthesiologist manually achieves this by providing jets at a rate of 8–15 breaths/min, while observing chest rise with each breath to ensure adequate ventilation (Figure 6). Since the jet ventilation system is open to the atmosphere, room air is also entrained into the bronchoscope resulting in a variable FiO_2 delivered to the distal airways [18]. Although adequate oxygenation can usually be obtained easily, a limitation of this system is the limited ability to assess minute ventilation and airway pressures, potentially leading to an increased risk of iatrogenic pneumothorax due to dynamic hyperinflation distal to a stenotic airway [18,19].

The Hemer bronchoscope produced by Wolff has a measuring port that can allow for measurement of partial pressures of oxygen and carbon dioxide as well as pressure fluctuations during the procedure. The pressure on inspiration resulting from the jet nozzle and room air entrainment reaches a plateau in the working channel at a distance of approximately 10 cm from the proximal end of the bronchoscope. As a result, the inspiratory pressure distal to this point can be taken as being representative of the mean inspiratory pressure. The Hemer bronchoscope has an internal port at 14 cm from the proximal end of the bronchoscope and can be connected to pressure transducers and gas-sensors to monitor end-tidal CO_2 [20]. The measuring devices for pressure and breath gas and the jet pressure control are connected via a three-way stopcock and connecting tubes to the luer connector of the measuring tube. When used with the Monsoon high-frequency jet ventilator, ventilation is discontinued if a set pressure limit is exceeded [21].

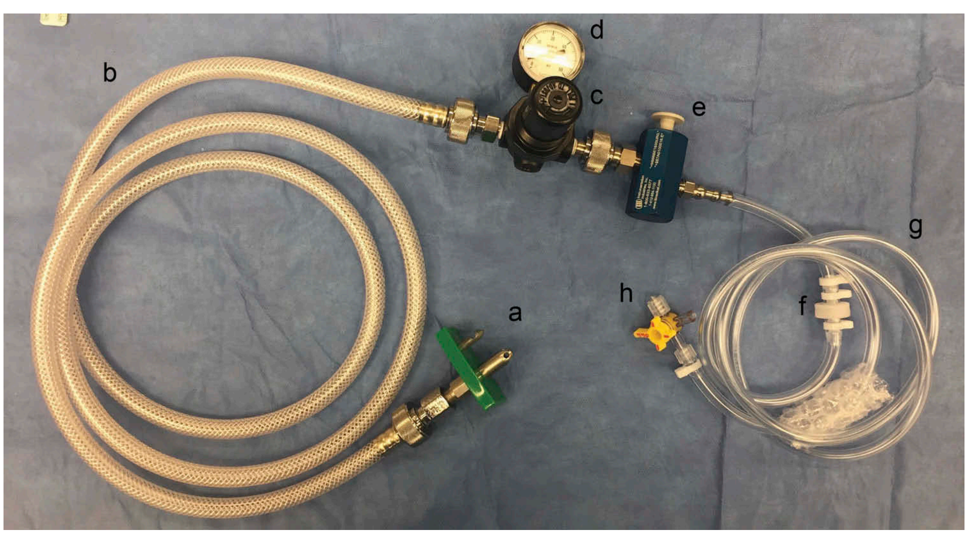

Figure 6. Manual jet ventilator (a) Oxygen source wall adapter, (b) 6 ft. high-pressure hose assembly, (c) Pressure regulator, (d) Pressure gauge, (e) On/Off valve, (f) In-line filter, (g) 6 ft. small bore tubing assembly, (h) Luer lock connector with a 3-way stop-cock to allow connection of end-tidal CO2 monitor.

5. Indications

The principle indications for rigid bronchoscopy include diagnostic indications such as obtaining large tissue biopsies or therapeutic indications such as removal of complex FBs, management of massive hemoptysis, and treatment of CAO due to malignant or nonmalignant etiologies (Table 1) [22]. The large working channel of the rigid bronchoscope that allows for simultaneous ventilation and introduction of various tools in the airway is extremely valuable in management of CAO [21]. Rigid bronchoscopy is particularly useful for management of most endobronchial pathologies including endobronchial tumor, tracheal or bronchial stenosis, airway obstruction due to FB aspiration, and massive hemoptysis [23]. Rigid bronchoscopy is often also used as an adjunctive technique to allow the use of other endobronchial tools such as laser, photodynamic therapy, and tracheobronchial stents [24]. As malignant airway diseases have become more common, both diagnostic and therapeutic interventions are often done in the same procedure.

5.1. Central airway obstruction

CAO of the trachea or main stem bronchi has become more common due to the lung cancer epidemic [18]. Approximately 30% of lung cancer patients will develop complications associated with airway obstruction during their disease course [25]. Pulmonary metastases from other malignancies, including breast, colon, and renal cell cancer, also commonly result in malignant airway obstruction [26]. However, the incidence of benign causes of CAO is increasing as well [18]. CAO can be caused by many benign diseases such as autoimmune diseases (such has granulomatosis with polyangitis, sarcoidosis, etc.), lung transplantation, post-endotracheal intubation, thermal injury, chemical injury, and idiopathic tracheal stenosis to name a few [27]. We favor the use of the term 'nonmalignant' to describe CAO caused by these diseases, as they are just as much a threat to life as malignant causes of CAO and their course is often not 'benign' [2,4]. The malignant and nonmalignant causes of CAO are listed in Table 2.

Table 1. Indications of rigid bronchoscopy.

Diagnostic	Obtain large biopsies	Forceps biopsies of endobronchial tumor
		Cryobiopsy of lung parenchyma
	Airway examination	Limited distally to lobar bronchi
Therapeutic	Foreign body extraction	
	Massive hemoptysis	Laterlization/localization of bleeding
		Control of bleeding in case of central airway tumors
		Protection and ventilation of the non-bleeding lung
	Central airway obstruction	Mechanical tumor debulking with forceps or microdebrider
		Tumor excision/resection
		Tumor ablation with laser, electrocautery, argon plasma coagulation, cryotherapy, photodynamic therapy
		Balloon dilation
		Stent placement

Table 2. Etiologies of central airway obstruction (CAO).

Malignant	Nonmalignant
Primary airway tumors • Bronchogenic carcinoma • Carcinoid tumor • Mucoepidermoid carcinoma • Adenoid cystic carcinoma	Lymphadenopathy • Sarcoidosis • Infectious (e.g. tuberculosis)
Tumors with direct extension into the airway • Esophageal carcinoma • Laryngeal carcinoma • Mediastinal tumors (thyroid, thymus, germ cell) • Malignant lymphadenopathy	Granulation tissue formation due to • Endotracheal tubes • Tracheostomy tubes • Surgical anastomosis • Airway stents • Foreign bodies • Wegner's granulomatosis
Metastatic tumors • Bronchogenic carcinoma • Breast carcinoma • Renal cell carcinoma • Colon carcinoma • Malignant melanoma • Metastatic sarcoma	Pseudotumors • Hamartoma • Amyloidosis • Papillomatosis
Lymphoma	Webs • Idiopathic • Tuberculosis • Sarcoidosis Hyperdynamic • Tracheobronchomalacia • Excessive dynamic airway collapse Relapsing polychondritis Goiter Foreign body aspiration Mucus plug Blood clots

There are three types of CAO: endobronchial obstruction, extrinsic compression, and a mixed pattern. To relieve endobronchial obstruction, mechanical debulking with forceps or microdebrider or tools such as laser, electocautery, argon plasma coagulation, cryotherapy, or photodynamic therapy are used. For extrinsic compression, balloon dilation and/or stenting are used to keep the airway open. For mixed patterns, ablation followed by stenting if often necessary. Significant differences exist in how physicians approach CAO at various institutions [28].

Patients with CAO typically presents with dyspnea, cough, or hemoptysis. Many patients present with wheezing or stridor. Location of wheezing over the trachea does not necessarily mean tracheal obstruction; however, unilateral wheezing usually suggests airway obstruction distal to the carina [29–31]. It should be noted that dyspnea on exertion in the setting of tracheal obstruction is a sign of significant narrowing of trachea (<8 mm). Luminal narrowing to less than 5 mm leads to symptoms at rest or stridor [32–35]. More than half of the patients with tracheal stenosis can present with respiratory distress [8].

Rigid bronchoscopy is a safe, reliable, and effective method of relieving CAO. Urgent therapeutic rigid bronchoscopy in patients who present with acute respiratory distress due to CAO can relieve symptoms, allow successful withdrawal from mechanical ventilation, and prolong survival in critically ill patients [36]. The British Thoracic Society guidelines for advanced diagnostic and therapeutic flexible bronchoscopy recommend the use of flexible bronchoscopy with a endotracheal tube or laryngeal mask airway for the management of malignant airway obstruction [37]. However, due to the many advantages of rigid bronchoscopy as discussed later, we suggest rigid bronchoscopy be used along with flexible bronchoscopy, when available.

5.1.1. Tumor debulking and ablation

Endobronchial debulking of tumors can be achieved mechanically or with the use of ablative techniques such as laser, argon plasma coagulation (APC), electrocautery, etc. Mechanical debulking can be done by 'coring' out a tumor with the use of the rigid bronchoscope. The beveled edge of the rigid bronchoscope is placed against the base of the tumor, which is then dissected away from the airway wall by gentle forward rotating motion of the rigid bronchoscope. Fragments of excised tumor can then be removed with forceps, cryoprobe, or suction catheter [31]. The rigid bronchoscope can provide immediate tamponade at the base of the tumor minimizing the bleeding, while maintaining adequate ventilation to the contralateral lung (in case of tumor distal to the carina) via side ports. The large channel of the bronchoscope allows for rapid suction of tumor fragments or blood and also adequate space for adjunctive instruments such as laser or APC. A microdebrider can also be used for mechanical debulking of central airway tumors, in particular, tracheal tumors. Although these techniques are easy and effective for endobronchial tumor excision, careful attention must be paid during 'coring' out a tumor or application of microdebrider to ensure that a correct axis and course is taken. Potential complications are airway wall perforation or vascular injury and these can be life-threatening. When a patient can tolerate lower levels of oxygen, thermal ablation techniques such as laser, electrocautery, and APC can be applied. Complete bronchoscopic resection is feasible in certain airway tumors (e.g. endobronchial hamartoma) without invasion through the airway wall, and bronchoscopy in such cases can often be curative (Figure 7).

5.1.2. Bronchoplasty

A rigid bronchoscope or tracheoscope can help effectively dilate airways in a safe manner [38–40]. This can be done by dilation using the barrel of the rigid bronchoscope itself, or with a dilation balloon or by combining modalities. Besides malignant CAO, balloon dilation has been shown to be effective in the management of nonmalignant airway stenosis as with lung transplantation or post-intubation tracheal stenosis [31]. One big advantage of using rigid bronchoscopy for dilation is the ability to maintain a safe airway with continued ventilation that is not possible when using a balloon or bougie for dilation. The rigid bronchoscope or tracheoscope is particularly useful for management of subglottic or tracheal stenosis. The beveled end of the rigid bronchoscope can help support the floppy posterior membrane while using the balloon for dilation such that adequate radial force from the balloon is directed toward the stiffer anterolateral walls of the trachea. Moreover, the rigid tracheoscope allows for optimal ventilation, repeated access, and quick dilation in this difficult location.

5.1.3. Airway stenting

Rigid bronchoscopy is an essential tool when an airway stent is necessary. In our experience, we almost always use rigid bronchoscopy for airway stent placement and use flexible bronchoscopy alone only when rigid bronchoscopy is unsafe, contraindicated, or technically difficult. A recent survey of the European Association of Bronchology and Interventional Pulmonology showed that rigid bronchoscopy is the predominant technique used for placement of airway stents in 20 of the 26 European countries that were surveyed [41,42]. The most common reasons for placement of airway stents are extrinsic compression of the airway from tumor or lymph nodes, to stabilize of airway wall after intraluminal removal of tumor, to restore patency in benign recurrent strictures, to support a symptomatic malacic airway, and to cover and potentially treat a fistula [38].

Rigid bronchoscopy offers many advantages over flexible bronchoscopy for stent placement, repositioning, maintenance, and removal [43]. These include a large working channel, improved airway patency during stent placement by supporting the airway walls with the rigid bronchoscope, improved ventilation during stent placement or removal, ability to directly visualize stent deployment during placement of a self-expanding metal stent, and ability to use large forceps to grasp the stent for repositioning or removal. In critically ill patients with malignant airway stenosis requiring urgent intubation, rigid bronchoscopy with stent placement can facilitate

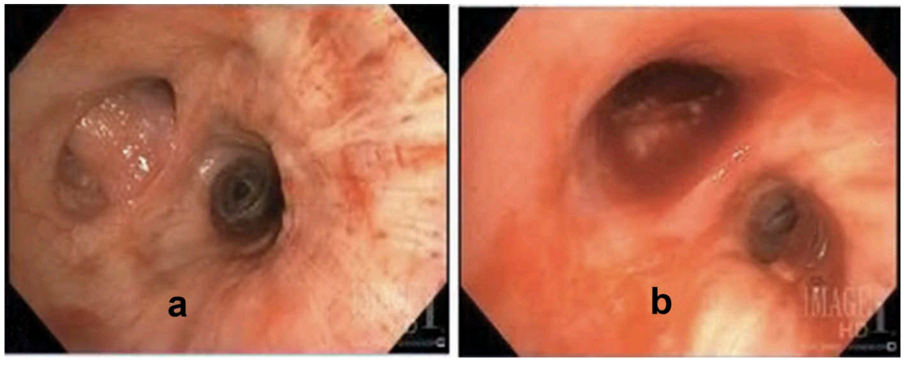

Figure 7. (a) Right middle lobe (RML) endobronchial tumor, (b) Patent RML after resection of tumor with electro-cautery snare. This tumor was confirmed to be a endobronchial hamartoma.

earlier extubation and act as a bridge to additional tumor-specific therapies, especially in chemoradiotherapy-naïve patients [44]. Silicone stents typically require rigid bronchoscopy for placement (Figure 8) [45]. In cases of benign airway disease requiring stenting, particularly in cases of tracheal stenosis, silicone stents should be considered first [46]. Rigid bronchoscopy is also particularly useful during T-tube placement in subglottic or tracheal stenosis [4].

5.2. FB removal

FB aspiration is fairly common in children [47–49]. It is less common in adults, but certainly not rare. The most common symptoms are choking followed by cough [50]. Physical exam findings include fever, stridor, retractions, and decreased breath sounds. Imaging is helpful but not necessary to establish a diagnosis of FB aspiration. Radiographic imaging should not be used to rule out the diagnosis of FB aspiration [42]. FBs can be retrieved using either flexible bronchoscopy or rigid bronchoscopy. As with the management of other conditions, the main benefits of rigid bronchoscopy are maintenance of airway and ventilation during the procedure, large working channel, and availability of large forceps that can be used for easy retrieval of FBs. Also, multiple instruments can be used at the same time through the large working channel of the rigid bronchoscope. Moreover, rigid bronchoscope can help prevent injury to airway walls during FB removal.

Although flexible bronchoscopy has been shown to be safe and successful in FB removal [51], many experts still consider rigid bronchoscopy the gold standard for diagnosis and management of FB aspiration [28,52]. If FB removal is attempted via flexible bronchoscopy, it is important that the bronchoscopist be familiar with rigid bronchoscopy and has the equipment readily available [53]. There are no prospective randomized trials to show which method is superior. In practice, however, rigid bronchoscopy is typically used in conjunction with flexible bronchoscopy and both are complementary. The ideal method used for FB removal depends on the location, size, and type of FB. Besides flexible/rigid forceps, many other tools can be used for FB removal such as snares, baskets, and cryotherapy.

5.3. Massive hemoptysis

Massive hemoptysis is often life-threatening. When bronchoscopy is indicated, rigid bronchoscopy is often necessary for management of massive hemoptysis. A rigid bronchoscope allows for large volume suction, maintenance of adequate ventilation, and isolation of the bleeding lung by selective intubation of the main stem bronchus [54,55]. In cases of proximal hemorrhage, rigid bronchoscopy can help directly tamponade the site of bleeding. The large working channel of a rigid bronchoscope allows for use of other instruments alongside a suction catheter for large volume suctioning. Measures that have been shown to control the source of bleeding include application of ice-cold saline or epinephrine and use of thermal techniques to ablate the source of bleeding, e.g. a central airway tumor [56]. Other techniques such as the use of rigid bronchoscopy with topical hemostatic tamponade therapy using oxidized regenerated cellulose mesh, tranexamic acid, thrombin, balloon tamponade, endobronchial stent placement, and airway blockage with biocompatible glue have been shown to be effective in the management of life-threatening hemoptysis [57].

Due to the advantages of rigid bronchoscopy in management of bleeding, many experts prefer it over flexible bronchoscopy for transbronchial cryobiopsies, which can occasionally result in severe bleeding [58]. However, it can potentially be done with the use of an endotracheal tube [59] or even under conscious sedation without airway intubation [59,60]. The recently published expert statement from the cryobiopsy working group on the safety and utility of transbronchial cryobiopsies suggests the use of either a flexible endotracheal tube or a rigid bronchoscope [61].

6. Contraindications

Rigid bronchoscopy is generally very well tolerated and absolute contraindications to this procedure are few (Table 3). Concern for complications generally arise from the need for general anesthesia. Although rigid bronchoscopy can be done successfully in the absence of general anesthesia, it is typically used for most cases [62]. Patients with comorbid diseases

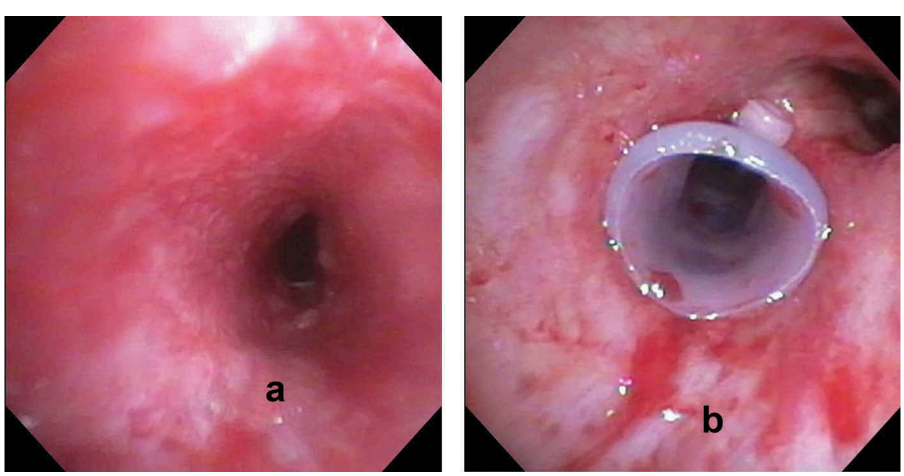

Figure 8. (a) Severe stenosis of bronchus intermedius in a patient with cystic fibrosis status post lung transplantation. (b) Restored patency of bronchus intermedius after balloon dilation and placement of silicone stent.

Table 3. Contraindications of rigid bronchoscopy.

Absolute	Relative
Cervical spine instability	Cervical spine fusion Hemodynamic instability Severe hypoxemia Severe coagulopathy Severe thrombocytopenia Operator inexperience

should be thoroughly assessed preoperatively just like before any other procedure requiring general anesthesia. Similarly, just like other invasive procedures, risks and benefits of rigid bronchoscopy should be carefully weighed in patients with coagulopathy or thrombocytopenia. In patients with facial injuries or cervical spine disorders, rigid bronchoscopy can be difficult (cervical spine fusion, facial injuries) or unsafe (cervical spine instability).

7. Complications

In well-trained hands, complications with rigid bronchoscopy are uncommon [60]. The most common complaint after rigid bronchoscopy is a sore throat, which typically subsides in 24–48 h. Serious complications are uncommon (<2%) and are either due to anesthesia or the procedure itself [63,64]. To safely perform rigid bronchoscopy and avoid serious complications, it is essential to perform proper preoperative assessment, appropriate instrument preparation and maintain adequate communication with the anesthesiologist [65].

In one retrospective study of 775 rigid bronchoscopies performed in a tertiary-care university hospital, the overall complication rate was 13.4%. The majority of complications were mild and major complications were rare (mortality rate, 0.4%) [65–67]. In another large series, only two deaths were recorded in 11,000 rigid bronchoscopies [68,69]. The overall complication rate with rigid bronchoscopy is low and comparable to flexible bronchoscopy. A recent study of the AQuIRE registry found the overall complication rate of therapeutic bronchoscopy done with rigid bronchoscopy to be 3.4% [69,70]. Risk factors for occurence of complications were urgent and emergent procedures, American Society of Anesthesiologists score > 3, redo therapeutic bronchoscopy, and use of moderate sedation.

7.1. Injury to the oropharyngeal structures

Careful inspection of the mouth and oral cavity prior to the procedure is essential to avoid dislodging a loose tooth during rigid intubation. Caution should also be used to avoid injury to lips, teeth, gums, and tongue.

7.2. Laryngeal edema

Laryngeal edema may occur during or immediately following rigid bronchoscopy. The utility of inhaled beta agonists or intravenous steroids in preventing laryngeal edema is unclear.

7.3. Spinal cord injury

Patients with cervical spine disease can suffer spinal cord injury during rigid intubation. Severe cervical spine disease is a relative contraindication to rigid bronchoscopy.

7.4. Injury to vocal cords and arytenoids

These injuries can be serious and are often a result of faulty intubation technique, and are therefore avoidable.

7.5. Airway laceration and perforation

Perforation of the posterior tracheal wall, particularly in the subglottis can be a result of traumatic intubation and must be avoided. Balloon dilation can also lead to tracheobronchial laceration, but it rarely progresses to transmural laceration and in fact, may improve patency outcomes [71].

7.6. Hypoxemia-induced cardiac ischemia and arrhythmias

This is a very serious complication that can occur during rigid bronchoscopy. Adequate communication with the anesthesiologist, proper preoperative assessment, and appropriate planning and preparation can help minimize the risk of severe hypoxemia.

8. Conclusion

Rigid bronchoscopy has stood the test of time and remains one of the most important tools used by the interventional pulmonologist to treat disorders of the airways. Despite advancements in flexible bronchoscopy, rigid bronchoscopy is an essential procedure for the management of CAO, FB aspiration, and massive hemoptysis. A well-trained interventional pulmonologist must have expertise in the use of rigid bronchoscopy. In well-trained and experienced hands, rigid bronchoscopy is safe and has a low risk of complications that is similar to that of flexible bronchoscopy.

9. Expert commentary

Since its introduction in late ninettenth century, rigid bronchoscopy has remained an essential tool for the management of airway diseases. Although its use declined in the later half of twentieth century after the introduction of flexible bronchoscopy in 1966, rigid bronchoscopy has made a comeback over the past two decades. This rapid increase in its use has been due in part to the increase in incidence of malignant airway disease. With the rising incidence of malignant CAO, there is growing recognition of the role of rigid therapeutic bronchoscopy for palliation of symptoms in these patients. Over the past two decades, training and expertise in rigid bronchoscopy has become more common and its use more widespread. Besides CAO, rigid bronchoscopy remains an invaluable tool for management of FB aspiration and massive hemoptysis. However, it must be pointed out that the basic technique for the procedure has witnessed little change over the past century. Some limitations of the procedure include difficulty in intubation in patients with cervical spine disease, a small range of available bronchoscope sizes, limited space within the bronchoscope, large size of telescopes and certain instruments such as optical forceps, limited reach of rigid optics to proximal airways, need to remove telescope often to clean the lens and to allow introduction of other tools, etc. There is certainly room for more research on the procedural technique and accessory tools to develop innovative methods, which can overcome these limitations.

Bronchoscopy, in general, can be diagnostic or therapeutic. Often it is both. It is for therapeutic bronchoscopy where using the rigid technique is particularly important and often necessary. Use of rigid bronchoscopy for CAO makes the procedure not only safer but also more effective and efficient. In fact, in a subset of this population, rigid therapeutic bronchoscopy has been shown to improve survival. FB removal is often done with rigid bronchoscopy and certain FBs can be impossible to remove without it. We believe that every interventional pulmonology fellowship program must provide sufficient training in rigid bronchoscopy such that every interventional pulmonologist has adequate expertise in this procedure. The number of interventional fellowship training programs in the US is rising rapidly. A multi-society interventional pulmonology fellowship accreditation standard has been developed with input and approval of the American Association for Bronchology and Interventional Pulmonology, Association of Interventional Pulmonology Program Directors, American Thoracic Society, ACCP/CHEST, and the Association of Pulmonary and Critical Care Medicine Program Directors [72]. This will ensure that accredited interventional fellowship programs provide training in rigid bronchoscopy and other procedures that is at par with the established standards.

Rigid bronchoscopy will likely remain relevant and an important procedure performed by interventional pulmonologists for decades to come. The basic technique, instruments, and indications of rigid bronchoscopy have been largely unchanged over the past few decades and we anticipate few changes in the near future. With the rapid rise in the number of interventional pulmonology fellowship training programs over the past decade, the number of interventional pulmonologists trained in the use of rigid bronchoscopy is rising rapidly. We anticipate that the incidence of malignant CAO will continue to rise due in part to improving survival of patients with lung cancer and other malignancies metastatic to the airway [73]. It appears that the number of rigid bronchoscopies performed will continue to rise over the next 5 years, in particular, for the management of malignant CAO.

Key issues

- Rigid bronchoscopy was introduced in the late 19th century and remains an important tool used by interventional pulmonologists
- Despite significant advances in flexible bronchoscopy over the past 5 decades, rigid bronchoscopy remains indispensable for management of central airway obstruction, foreign body aspiration and massive hemoptysis
- Rigid bronchoscope is essentially a hollow metal tube of varying sizes
- Rigid bronchial tubes are typically 40cm in length and have side ports to allow for ventilation during main stem intubation, while tracheal tubes are shorter (30cm) and lack ventilating side ports
- Visualization during rigid bronchoscopy is achieved by use of a rigid telescope attached to a light source and camera head. Alternatively, a flexible video bronchoscope can be used
- Rigid bronchoscope allows for use of many accessory instruments such as rigid forceps, optical forceps, rigid suction tube, laser, electrocautery/argon plasma coagulation catheter, cryoprobe, etc.
- The most frequently used anesthesia technique is total intravenous general anesthesia and jet ventilation
- Rigid bronchoscopy is generally very well tolerated and contraindications to this procedure are relative
- In well-trained hands, the overall rate of complications with rigid bronchoscopy is low (3.4%) and serious complications are rare.

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