The Art of Rigid Bronchoscopy and Airway Stenting

Antoinette Flannery, MB, BA Bch, MRCPI[a,*],
Cyrus Daneshvar, MB, chB, MD[b], Hervé Dutau, MD[c],
David Breen, MB, BA, BCh, BAO, MRCPI, MRCP(UK)[a]

KEYWORDS

• Rigid bronchoscopy • Airway stents • Future advances in stent technology • Complications

KEY POINTS

- Interventional pulmonology, including the provision of rigid bronchoscopy and airway stenting, is an integral component of a modern lung cancer service.
- Rigid bronchoscopy offers important palliation to patients with central airway obstruction. This may be intrinsic, extrinsic or a mixed pattern of obstruction.
- Rigid bronchoscopy also has an important role in benign airway diseases; in particular post tracheostomy or post intubation tracheal stenosis.
- A wide range of airway stents are commercially available. Stent selection should be carefully made to ensure a low rate of stent complications.
- Rigid bronchoscopy and airway stenting are advanced endoscopic skills that require additional training. However, there is a wide variability in access to training as shown by a recent European survey.

INTRODUCTION

For more than a century, rigid bronchoscopy has been used as both a diagnostic and therapeutic tool in complex airways disease. With the emergence of interventional pulmonology (IP) as a specific subspecialty within respiratory medicine, there has been renaissance in its use and, for many interventional pulmonologists, it occupies a central position in the management of both malignant and benign complex airway disorders. Indeed, despite the development of new techniques, for both diagnostic and therapeutic applications, many physicians still use the rigid bronchoscope as a mainstay of the procedure. In the hands of experienced proceduralists, patients can be offered definitive disease management in a safe, controlled environment using minimally invasive techniques. Its use allows direct access to the airway in a controlled manner and facilitates several treatment modalities, not exclusively including stent placement, endobronchial laser therapy, cryotherapy, electrocautery, argon plasma coagulation, and photodynamic therapy. Despite the development of new technologies, rigid bronchoscopy remains an invaluable skill. However, adequate training and knowledge of the procedure is vital in safely addressing central airway disease complications. A full discussion on all aspects of IP is beyond the scope of

[a] Interventional Respiratory Unit, Department of Respiratory Medicine, Galway University Hospitals, Galway 91 YR71, Ireland; [b] Department of Respiratory Medicine, Level 6, Derriford Hospital, Derriford Road, Plymouth, PL6 8DH, UK; [c] Department of Thoracic Oncology, Pleural Diseases and Interventional Pulmonology, North Hospital of Marseille, Aix-Marseille University, Marseille 13015, France
* Corresponding author.
E-mail address: Antoinette.flannery@hse.ie

Clin Chest Med 39 (2018) 149–167
https://doi.org/10.1016/j.ccm.2017.11.011
0272-5231/18/

chestmed.theclinics.com

this article, which focuses specifically on rigid bronchoscopy and airway stenting.

BACKGROUND

Father of modern bronchoscopy is the title given to Gustav Killian, an otolaryngologist from Freiberg, Germany. Killian is credited with the invention of the rigid bronchoscope and with describing the potential therapeutic indications. The first reported procedure was the removal of a pork bone from the right main bronchus of a farmer using a rigid esophagoscope in 1876. He then went on to describe the successful removal of foreign bodies from the airways in 3 separate cases.[1,2] In the paper "Direckte Endoskope der Luft-und Speisewege," published in 1915, Brünings and colleagues[3] reported a success rate for foreign body removal of 98.3%, with failure to extract the aspirated material in only 12 out of 701 cases. This was a significant advance in the management of a condition with a known 50% mortality before the rigid bronchoscopy era.

During this new era of "direct bronkoscopie," as coined by Killian, Chevalier Jackson,[4] based in America, was gaining recognition for his use of rigid bronchoscopy to remove foreign bodies from both children and adults.[5] The Mutter museum in Philadelphia displays 2374 objects recovered by Dr Jackson during his nearly 75-years-long career.[4] Jackson also began to expand the role of rigid bronchoscopy and pioneered endobronchial treatment of tuberculosis complications. He was also the first to report endoluminal mechanical resection of endobronchial tumors.

Advances in technology in the latter decades of the twentieth century, especially with the emergence of fiberoptic imaging and bronchoscopy, significantly affected the way physicians undertook airway inspection. This ultimately resulted in the introduction of the flexible bronchoscope; with a thoracic surgeon from Japan, Shigeto Ikeda, credited with its development in 1962. The first commercially useful instrument was presented at Copenhagen in 1966[6] and, with some additional modifications and adoption of the working channel, the Machida flexible bronchoscope became commercially available in 1968.[5] With an increase in the popularity of the flexible bronchoscope due in part to the obvious advantages (minimally invasive, absence of need for general anesthesia, and superiority in visualizing smaller peripheral airways), there was a notable decrease in the use of rigid bronchoscopy over the 2 decades that followed. Training availability in this method became a rarity and its use became almost obsolete except for several dedicated physicians, particularly in Europe.

These physicians continued to explore its role in airway disease. Airway laser via a rigid bronchoscope was first described in 1981 by Lucien Toty and colleagues.[7] However, its refinement and central role in accepted standards of practice was attributed to Dr Jean Francois Dumon who is seen as the father of modern day rigid bronchoscopy and stenting. The term stent is credited to Charles Stent who developed the first custom-made mold of teeth in the nineteenth century. However, he was not to know that his name would become synonymous with this cornerstone of modern day medicine.[5] Over the last 30 years, stents have evolved from experimental interventions to essential components in many fields of medicine and surgery, including cardiology, vascular medicine, urology, otolaryngology, and pulmonology. Literature case reports of stent deployment go back as far as 1915. However, it was not until the development of the Montgomery T-tube in the sixties[8] and, more importantly, the major breakthrough that occurred with Dumon's[9] development of a dedicated silicone stent for the trachea and bronchi in the mid-1980s, that stent use became standard. The first airway stent was placed in Marseille, France, in 1985. With these 2 developments, stenting became an integral part of the management of airway compromise caused by benign and malignant conditions.

With these advances in central airway management, treatment options became available for patients with both benign and malignant airway conditions. Tumor debulking with laser and stent placement in selected patients became standards in practice, offering immediate and lasting symptomatic relief and palliation of central airway obstruction in malignant disease. Rigid bronchoscopy had regained its vital role in IP, offering options to both surgical and nonsurgical candidates. However, current practices are once again changing, particularly those related to stent placement.

CURRENT ROLE OF RIGID BRONCHOSCOPY

Rigid bronchoscopy maintains a central role in advanced airway management. It serves both malignant and benign diseases. The rigid bronchoscope allows stabilization of compromised airways, treatment of palliative endobronchial disease, and treatment of nonsurgical candidates with benign conditions. More recently, it supports newer endobronchial techniques. This has resulted in the growth of IP as a specific subspecialty in respiratory medicine.[10]

The rigid bronchoscope is an invaluable tool in interventional bronchoscopy.[11–13] It allows, with maximal safety and under general anesthesia, adequate ventilation of the patient through a side port; efficient suctioning of blood, secretions, pus, and smoke via large suction catheters; and the use of accessory instruments (eg, laser probes, cryoprobes, rigid forceps).[14] These features were clearly documented in the recent British Thoracic Society guideline for advanced diagnostic and therapeutic flexible bronchoscopy in adults, which described that "Rigid bronchoscopic procedures under general anaesthesia combine the ability to maintain adequate ventilation, to remove large volume tumour and safely control large volume haemorrhage."[15]

It also allows therapeutic interventions, such as dilatation of stenoses or extrinsic compression, and mechanical coring and debulking of endoluminal tumors, using the distal bevel to rapidly recanalize the airway.[16] In addition, a foreign body can safely be removed using the rigid forceps. The rigid bronchoscope is the instrument of choice in cases of acute respiratory failure secondary to endoluminal obstruction because it allows for a rapid procedure while maintaining airway patency and adequate ventilation. A rigid bronchoscope is required for silicone stent placement using a dedicated rigid loading system.

The procedure has many advantages compared with the flexible scope. Treatment of central airway obstruction with a flexible bronchoscope alone is not generally recommended, particularly in the case of tracheal lesions. Its small working channel may not be sufficient to prevent airway flooding in case of massive bleeding. The flexible biopsy forceps have a small diameter and can only sample or debulk small tumoral fragments, leading to long and fastidious procedures.[5] In an attempt to overcome this, metallic snares or baskets have been developed to remove larger pieces of tumors or foreign bodies.[14]

SPECIFIC INDICATIONS

Malignant Airway Obstruction

Malignant central airways disease with obstruction is the main indication for endobronchial intervention, with bronchogenic carcinoma accounting for between 74% and 100% of patients in large cases series.[17–24]Classic literature reports obstruction occurring in up to 20% of patients with bronchogenic carcinoma, with up to 40% developing complications over the course of their disease. Brewer's[25] 1977 case series of 359 subjects (defined by chest radiograph), reported 20.3% (16.3%–24.9%) having central airways involvement at presentation and a further 49.1% (43.7%–54.3%) having lobar bronchial involvement. A recent review of index computed tomography scans in patients presenting consecutively with a new diagnosis of lung cancer to a UK hospital found that endobronchial disease was reported in 29% (95% CI 24.4–33.5), with a total of 7.6% (95% CI 4.9–10.2) of patients having involvement of a central airway.[26] This differs considerably from the historical literature but still represents a significant burden of disease, which may go neglected in centers without access to interventional pulmonologists. Such patients are recognized as having a poor outcome,[27] whereas intervention can lead to improvements in performance status, quality of life, and physiologic measures.[28–30] Chhajed and colleagues[31] demonstrated no difference in survival between those with malignancy receiving chemotherapy but without central airway obstruction (median survival 8.4 months) compared with the subjects who underwent successful airway recanalization by means of laser (25%), stent (25%), or both (50%), followed by adjuvant chemotherapy (median survival 8.2 months $P = .395$).

Cavaliere and colleagues[17,18] reported on more than 3000 cases over 15 years, and consistently found most benefit in airway debulking is obtained in the larger airways, rather than lobar regions. These larger airways (trachea, main bronchi, and bronchus intermedius) were successfully treated in 85% to 97% of cases, whereas good outcomes in patients with lobar involvement were recorded in approximately 60%. Rigid bronchoscopy has been the preference over the past 30 years, which is reflected in the recent AQuIRE registry (American College of Chest Physicians Quality Improvement Registry, Evaluation, and Education) in which rigid bronchoscopes were used in 65.7% of cases.[24] Flexible bronchoscopy has been a universal skill among pulmonologists who benefit from its ease of use in awake to moderately sedated patients, obviating an anesthetist. In the AQuIRE registry, flexible bronchoscopy was performed in the context of a general anesthetic and moderate sedation was recognized as a risk factor for complications. The rigid scope is most suited to larger airways, and success is likely related to the scale of debulking that can be achieved, whereas combination with a flexible scope allows the full spectrum of treatment modalities.

To support this kind of treatment, the literature is understandably restricted to case series from large centers where skill sets have evolved, patient selection refined, and cohorts are nonrepresentative of the wider populations that suffer with such endobronchial disease. Given that oncologic treatments do not generally result in prompt improvement in patients' symptoms, endoscopic treatments are necessary adjuncts to the tailored management of patients at all stages of disease (neoadjuvant, adjuvant, and palliative). In addition, bronchial obstruction-related complications (atelectasis, respiratory insufficiency or distress, or repeated infections) are likely to interfere with optimal oncologic treatments, such as chemotherapy or radiotherapy.

Airway involvement can be intrinsic, limited to endoluminal involvement, an extrinsic compression, or a mixed condition with both tumor within the airway (ie, intrinsic) and external compression of the airway (ie, extrinsic).

In principle, purely intrinsic involvement can often be managed with debulking techniques to remove the endoluminal tumor. The rigid bronchoscope is then the instrument of choice. Three steps can be described. The first is coagulation and devascularization of the tumor, the second is mechanical coring, and the third is coagulation of the tumoral base. This technique is called laser-assisted mechanical debulking (or electrocautery, or argon plasma) (**Fig. 1**). On occasion, a stent may be placed as a bridge to chemoradiotherapy or alternatively may be considered as a permanent solution when the risk of local recurrence is high. Extrinsic compression without intraluminal disease is readily treated with dilation followed by stenting. Mixed (intrinsic and extrinsic) obstruction is usually managed with both debulking and stent insertion. Usually, the benefits noted after successful bronchoscopic treatment of obstruction last for 2 to 3 months.[32] Benefit duration after stent placement is generally reported to be around 4 months before tumoral stent overgrowth,[33] but this duration can be increased with the use of effective oncologic treatments (ie, chemotherapy and/or radiotherapy).

Other indications for endobronchial treatment include endobronchial metastases (eg, esophageal,

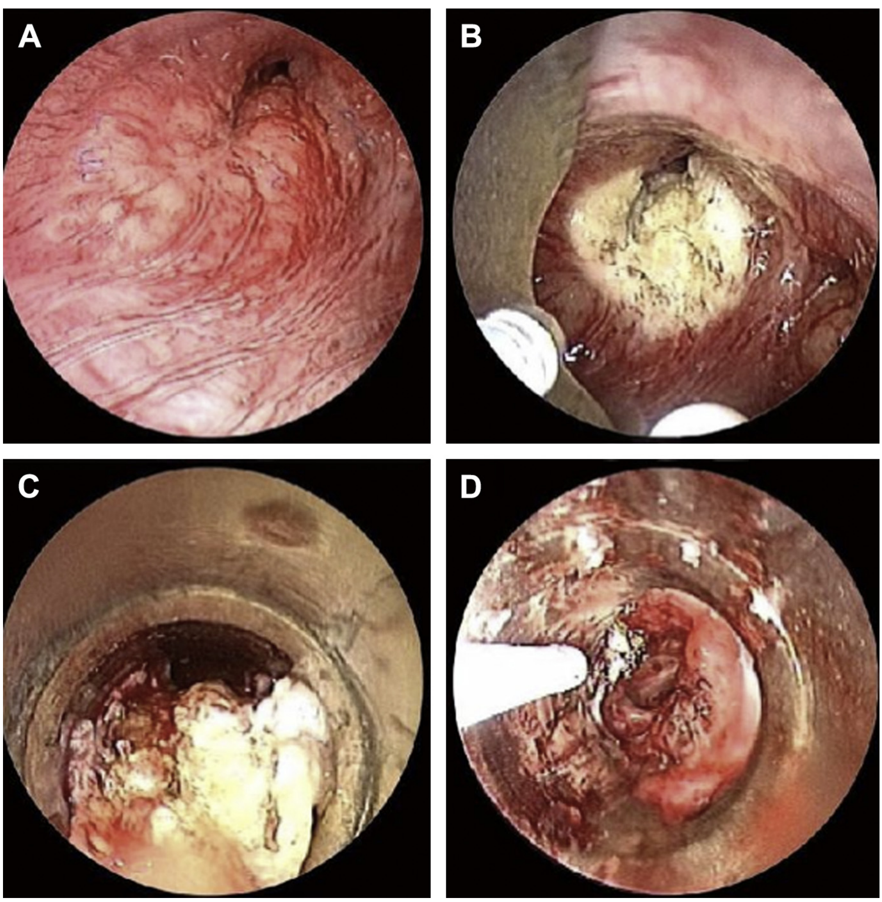

Fig. 1. Laser-assisted mechanical debulking of a mixed malignant tumor of the central airway. (*A*) Mixed lesion pre-treatment. (*B*) Laser coagulation of the lesion. (*C*) Mechanical debulking with the rigid bronchoscope. (*D*) Haemostasis obtained by laser coagulation of tumor bed.

thyroid, renal cell carcinoma, colon, and melanoma) or, alternatively, low-grade primary tumors (eg, adenoid cystic carcinomas, typical or atypical carcinoids).

In most cases, rigid bronchoscopy results in rapid recanalization of the airway and maintenance of patency, often in combination with other techniques such as stent placement. In turn, this results in rapid relief of symptoms and improved quality of life for patients. A retrospective study has shown that rigid bronchoscopy and mechanical debulking as a sole therapy is safe and successful in up to 83% of cases of central airway tumors.[34]

Removal of Foreign Bodies

Eighty percent of foreign body aspirations occur in children and is frequently accidental due to developing children putting objects in the mouth. In contrast, aspiration in the adult population is often associated with impairment of consciousness or swallowing.[11,12] The use of rigid bronchoscopy versus flexible bronchoscopy has been debated for years.[13,16,35] Flexible bronchoscopy can be used for the diagnosis and extraction of foreign bodies, which may be removed using forceps, snares, or baskets. It is more accessible and less expensive, and a general anesthetic is not required. However, rigid bronchoscopy remains the procedure of choice for asphyxiating foreign bodies because it offers superior airway control, suction, and extraction capabilities.[36] The risks of large-volume bleeding and flexible bronchoscope migration are real and need to be considered before attempting removal. As highlighted previously, this often involves using a combination of rigid and flexible bronchoscopes to ensure a safer and more complete single procedure.

In cases in which the foreign body is rounded, a smooth forceps is preferred. This allows for grasping of the largest volume of the flexible bronchoscope under direct visualization, taking care not to further advance the flexible bronchoscope down the airway. An important practice point in these cases is to remove the rigid bronchoscope and the forceps along with the extracted flexible bronchoscope en bloc (**Fig. 2**). In comparison, for sharp or irregular objects, a flexible bronchoscope and an alligator forceps are preferred. Depending on the clinical scenario, different techniques may be adopted by the proceduralist; often these are locally developed techniques. An example of this is using the Trendelenburg position while extracting heavy metallic flexible bronchoscopes. Finally, if the flexible bronchoscope is lost on removal, it is important to closely inspect the oral cavity and larynx before reintubation with a rigid bronchoscope.[14]

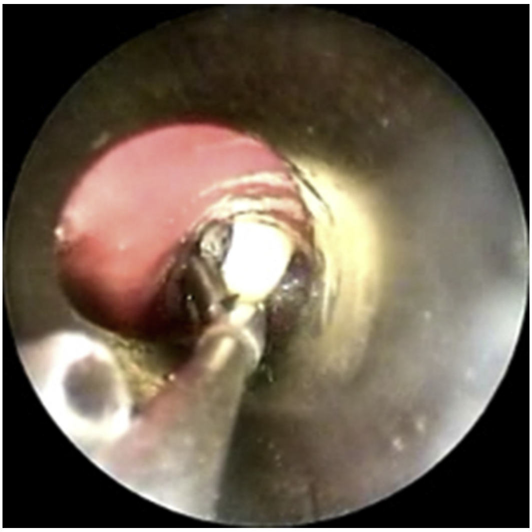

Fig. 2. Foreign body removal using a rigid bronchoscope. The foreign has body been removed en bloc with the rigid bronchoscope.

Hemoptysis

Airway hemorrhage can be a rapidly fatal condition. The risk of mortality depends on several factors, including the volume and rate of hemoptysis, underlying respiratory status, and associated comorbidities. Regardless of the treatment modality, there are high rates of morbidity and mortality. In stable patients who have minimal hemoptysis, bronchoscopy can diagnose the cause specifically and be used as the primary treatment modality.[37] The main disadvantages of using a fiberoptic bronchoscope include the small aspiration channel, which is easily obstructed with blood and clots; difficult endoscopic observation due to the lens being frequently obscured by blood; and inadequate pulmonary ventilation.[38] In the event of large-volume or life-threatening hemoptysis, it is imperative to use a rigid bronchoscope. The broad internal diameter allows good endoscopic vision throughout the procedure, controlled ventilation, and access of equipment for timely aspiration of blood and clots, along with selective lung intubation if necessary.[38] A further advantage to using the rigid bronchoscope is that the scope itself can be used to effectively tamponade a visible bleeding vessel and control further blood loss. Once the rigid bronchoscope is in situ with the contralateral protected lung, there are several methods available to the physician to control the bleeding, including cold saline lavage, argon plasma coagulation, laser photocoagulation, electrocautery, which are all safe and easily applied via rigid bronchoscopy. Overall, the rigid bronchoscope is a safe and effective tool in the management of hemoptysis and, on review of the literature, boasts an 85% to 100% success rate in identifying the site of hemorrhage.[38–43] Unfortunately, bronchoscopists are not always present in the event of these cases; moreover, if present, may not be adequately trained in the skill of rigid bronchoscopy.

Benign Airway Stenosis

There are many causes of acquired benign tracheal stenosis; the most common are tracheal intubation and posttracheostomy.[44,45] Other rarer causes include previous upper airway surgery, inhalational injury, and autoimmune conditions; for example, sarcoid, granulomatosis with polyangiitis, previously known as Wegener granulomatosis or systemic lupus erythematous.[46] In this small cohort of patients, multidisciplinary team involvement is essential to determine the choice of therapy.

In many patients, the obstruction will be amenable to surgical resection; however, this may not always lead to superior outcomes. Important considerations include the available radiological imaging, patient lung function and comorbidities, rates of recurrence, and scarring at surgical sites. Endoscopic resection with rigid bronchoscopy can lead to immediate symptom resolution along with excellent local control of stenosis using a host of techniques, including balloon bronchoplasty, stent placement, argon plasma coagulation, cryotherapy, and so forth.[47] The choice of technique is often made based on physician preference, available techniques, and equipment. In addition, the type of stenosis is important (**Fig. 3**).

A tracheal stenosis may be classified as simple or complex. A simple stenosis involves the mucosa alone, whereas a complex stenosis is associated with cartilage instability. In the setting of a simple stenosis, the stenosis should be radially incised in 3 locations before serial dilatation with the rigid bronchoscope. In the scenario of a simple stenosis, a tracheal stent may not be required; however, a complex stenosis frequently requires stenting to stabilize the airway. Benign stenoses at the level of the main bronchi (eg, after sleeve lobectomy, transplantation) can be more difficult to dilate. The stenosis is often extremely tight and may require the use of a balloon or pediatric rigid scopes for the first dilatation. For example, simple

Fig. 3. Endobronchial management of a tracheal stenosis using a laser to make radial incisions followed by serial dilatation and stent insertion. *Arrows* represents the rotation action that is performed to dilate a stenosis.

stenosis without cartilage damage will often resolve after 2 to 3 dilatations without stent insertion. This is less likely in cases with a complex stenosis in which stents may be needed to maintain patency. Kajiwara and colleagues[48] demonstrated complete symptomatic resolution after bronchoscopic intervention using a combination of up to 3 modalities in 4 subjects. This effect was maintained for a period ranging from 51 to 112 months. In selecting appropriate patients, treatment of benign airway stenosis can be minimally invasive, reproducible, and highly effective.

In addition, benign endobronchial tumors can be managed with good effect using rigid bronchoscopy.[49–51] Good indications for endoscopic treatment include tumors in which the distal margins can be endoscopically evaluated and in which the tumor is located within the tracheobronchial tree (as far as subsegmental bronchi). In addition, pedunculated lesions are probably best treated because the endoscopist can clearly see removal of the lesion and can treat the bed of the tumor at the end of the procedure. Finally, complete treatment is not possible if there is extramural tumor invasion. It is also important to stress that, in rare cases, recurrence or malignant transformation can occur even after resection. Therefore, careful periodic observation of the resection stump with the flexible bronchoscope is mandated.

Tracheoesophageal Fistula

Fistula formation between the esophagus and main airways (trachea or main bronchi) can be a devastating complication of esophageal disease and results in significant morbidity and mortality for patients, including chemical pneumonitis from airway spillage and pulmonary infections. It is generally agreed that a fistula should be closed but the optimal method for performing this intervention remains under debate. It is unclear if this should be done with an esophageal stent, a tracheal stent, or both.[52]

Physicians must be aware and assess for possible respiratory compromise by extrinsic airway compression from an exophytic esophageal lesion. A patient with respiratory symptoms before esophageal stent insertion should have an airway stent inserted before esophageal stenting. In addition, in cases in which a residual fistula remains despite an optimally placed esophageal stent, patients may require double stenting with a second airway stent. In all other cases, the authors advocate commencing with a single esophageal stent and assessing for persistence of fistula or development of respiratory symptoms secondary to ongoing airway spillage.

Surgical dehiscence and airway lacerations in patients unfit to undergo surgical repair may also be treated with airway stenting. Airway lacerations in patients not requiring positive pressure ventilation will heal spontaneously and do not require stenting.[53]

EQUIPMENT, TECHNIQUE, AND ANESTHESIA

Although the rigid bronchoscope is available in various types and sizes, the basic concept is the same: a solid tube that is open at each end with side holes along the distal end of the scope. The various lengths and diameters range from 5 mm to 13.5 mm. The barrel wall is 2 to 3 mm thick and the internal diameter is uniform throughout. The latter enables ventilation to the contralateral lung when working on an obstructing lesion in the ipsilateral main bronchus.[54] The tracheoscope is shorter in length compared with the bronchoscope and has no ventilation slits. Fig. 4 is a typical diagrammatic representation of a rigid bronchoscope and its components. Multiple ports on the proximal end of the bronchoscope allows for the attachment of various ventilation devices and ancillary tools, such as suctioning tubes to aspirate blood, secretions, pus, and smoke, and easy introduction of ancillary instruments; for example, laser probes, cryoprobes, and rigid forceps.[14,55] In addition, the design of the rigid bronchoscope itself allows for rapid recanalization of obstructed airways using its distal bevel to core and debulk tumors, the so-called core-out or corkscrew technique.

Current indications for rigid bronchoscopy include removal of a foreign body, hemostasis and clot removal in hemoptysis, relief of central airway obstruction from benign or malignant conditions, stent placement, and endoluminal therapies.[54] In addition, the procedure can play a central role in modern airway procedures, such

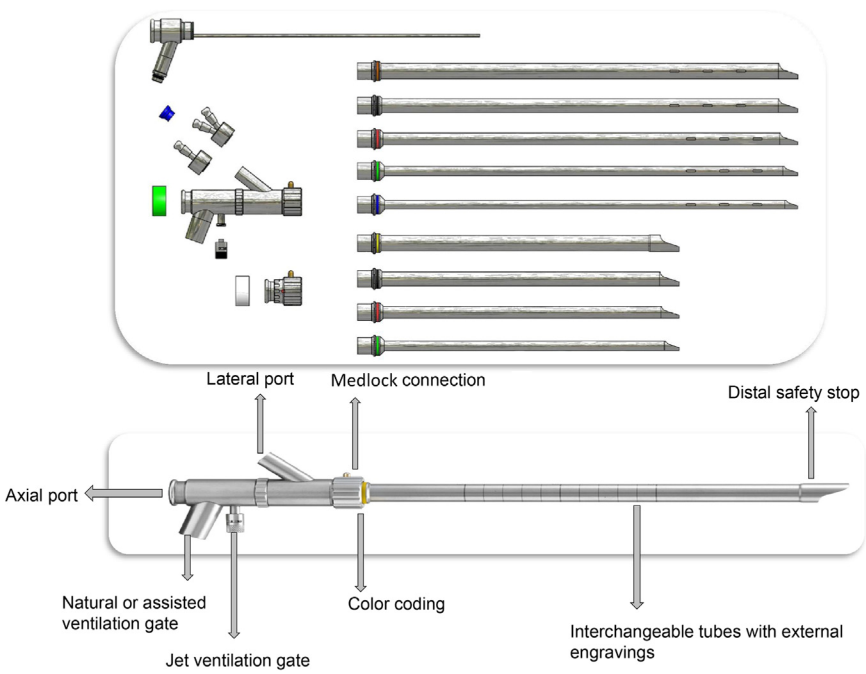

Fig. 4. Components of series III EFER-DUMON® rigid bronchoscope. (*Courtesy of* Efer Endoscopy, La Ciotat, France; with permission.)

as valve or coil placement, and controlled assessment of collateral ventilation. Treatment of many of these conditions is not considered safe nor feasible using flexible bronchoscopy alone and, currently, the therapeutic capabilities of the flexible bronchoscope are deemed to be inferior to those of rigid bronchoscopy.[56] However, rigid bronchoscopy and flexible bronchoscopy work as complementary techniques with many bronchoscopists using the flexible scope via the rigid tube. It is an important tool with easy maneuverability that allows exploration and clearing of peripheral airways, examination of more distal airways, and inspection of segments lateral to the central airways. In addition, it is the only tool available for the management of upper lobe obstruction owing to the inherent flexible characteristics of the scope.[14]

Rigid bronchoscopy, unlike the flexible procedure, requires general anesthesia. This may have an impact on the availability and growth of the procedure despite the many inherent advantages of the rigid procedure (see later discussion). There are various options for providing general anesthesia, although, in principle, most units have developed their own protocols that are acceptable to the anesthetist and physician alike. The procedure brings a unique set of issues, particularly the sharing of the airway between the 2 specialities.[57,58]

In general, anesthesia can be administered intravenously or by inhalation. Intravenous options are usually preferred and, in particular, target-controlled total intravenous anesthesia is often selected in many units. Inhalational techniques are less commonly used because the rigid tube is an open system and this can lead to operating room pollution. Ventilation techniques that can be used include spontaneous ventilation, spontaneous assisted ventilation, jet ventilation, high-frequency ventilation, or rarely used (although described) closed-circuit positive-pressure ventilation.

After the induction of anesthesia, the patient's head is partially extended and the bronchoscope is inserted in the midline, with the bevel anterior. The operator's finger or a plastic tooth protector protects the upper teeth. The bronchoscope is advanced to and passed under the epiglottis and then rotated 90° so that it can be passed through the vocal cords without injury and into the upper trachea (**Figs. 5, 6**).

To enter 1 side of the bronchial tree, the patient's head is rotated toward the contralateral shoulder. When using a tracheoscope, the physician can initially intubate with the largest caliber tube, thus allowing thinner diameter bronchoscope barrels, which can be inserted through the lumen of the tracheoscope. There is, therefore, no need to remove the latter or to reintubate the patient. A flexible bronchoscope can also be passed through the lumen of the rigid bronchoscope to allow inspection of distal airways. As mentioned previously, IP physicians who favor the rigid scope do not use this technique exclusively and recognize the importance of ancillary techniques and the central role of the flexible scope during a procedure. The flexible scope is essential for airway toileting and specimen collection.

Fig. 5. Typical positioning of a rigid bronchoscope during a procedure as seen externally.

Rigid Bronchoscopy Equipment

There are several commercially available rigid instruments available on the market.

The Efer-Dumon rigid bronchoscope (EFER Endoscopy, La Ciotat, France), has a universal proximal head that can be connected to all the bronchoscope barrels. In addition, the various sized barrels are color-coded. Other manufacturers of rigid bronchoscopy equipment include the TEXAS Rigid Integrated Bronchoscope (Richard Wolf, Knittlingen, Germany), the Karl Storz rigid bronchoscope (Tuttlingen, Germany), and the Dutau-Novatech rigid bronchoscope (Novatech, La Ciotat, France). Illumination in modern rigid bronchoscopes is provided by a xenon light source with a prismatic light deflector that is attached proximally to allow full use of the bronchoscope lumen. A rigid telescope is passed through the central opening of the bronchoscope barrel. The bronchoscopist can either look down the eyepiece of the telescope, or a charge-coupled chip video camera can be connected to the eyepiece for visualization on a monitor. This also allows the physician to record procedures.

Most physicians only need to use a direct view rigid telescope because the flexible bronchoscope

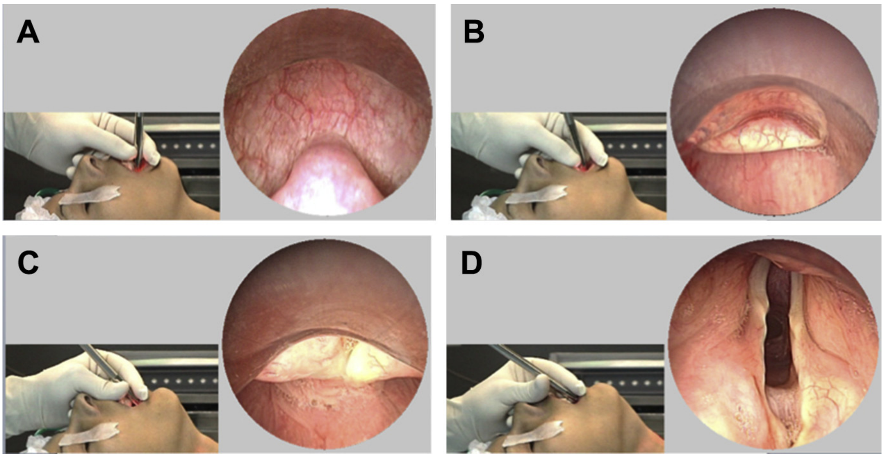

Fig. 6. Standard tracheal intubation with a rigid scope with important landmarks: (*A*) uvula, (*B*) epiglottis, (*C*) bevel of rigid tube passing under epiglottis, (*D*) vocal cords.

negates the use of angled telescopes to assess lateral to the central airways or view and treat lesions in the upper lobes. The Texas rigid bronchoscope is the first fully integrated rigid bronchoscope with a semiflexible endoscope inside. The benefit of the Texas system is the full inner lumen of the rigid bronchoscope. The semiflexible endoscope is attachable to a separate channel inside the tube.

Airway Stents

Despite major developments from various companies over the last 40 years, there remain 2 major groups of stents in current use: silicone and metallic stents. **Box 1** lists current indications for stent insertion.[59–61]

The range of metallic stents includes fully uncovered, partially covered, and fully covered metallic stents. In addition, stents can be grouped into straight, bifurcating (Y-stents), and T-tubes. Silicone stents require rigid bronchoscopy for deployment, whereas metallic stents can be placed with either a rigid or flexible bronchoscope, according to the physician's preference.

The main purpose of tracheal and bronchial stents is to restore patency of the airway. Any symptomatic endoluminal pathological complication associated with a significant reduction in airway luminal diameter (greater than 50%) may be an indication for an airway stent if the patient is symptomatic secondary to the obstruction.

Five major indications have been established:

1. Extrinsic compression from tumors or lymph nodes
2. Stabilization of airway patency after endoscopic resection of intraluminal cancer
3. Treatment of benign strictures
4. Stabilization of collapsing airways (malacia and polychondritis)
5. Treatment of fistulas (eg, stump dehiscences, tracheoesophageal fistulas).

Box 1
Indications for stent placement

Airway stenosis

Malignant

- Primary lung cancer
- Direct involvement from thoracic malignancies
- Thyroid
- Esophagus

Benign

- Postintubation (PITS)
- Posttracheostomy (PTTS)
- Stenosis at site of airway anastomosis
- Posttransplant
- Postresection
- Sarcoidosis
- Tuberculosis
- Granulomatosis with polyangiitis
- Idiopathic tracheal stenosis

Airway fistula

- Benign
- Malignant

Tracheomalacia

Indications for stent placement.
Abbreviations: PITS, postintubation tracheal stenosis; PTTS, posttracheostomy tracheal stenosis.

In life-threatening situations, there are no absolute contraindications. However, other techniques should be considered before stent placement. It is the authors' opinion that stents should be placed as a final option if adequate airway patency cannot be achieved by other techniques. A stent is, by definition, a foreign body and can result in a range of complications for the patient. The treatment of benign lesions requires particular caution because stents may be harmful in the long term, even if early benefit is often noted. In general, only removable stents should be used for these indications unless a multidisciplinary team has determined inoperability.[62]

Silicone Stents

Silicone stents are available in all designs: straight, Y-stent, and T-tube varieties. The gold standard stent remains the Dumon stent (Tracheobronxane, Novatech, La Ciotat, France). These prostheses are the most widely used stents worldwide. They are made from silicone with studs on the external surface. These studs prevent migration and reduce mucosal ischemia by limiting contact with the airway wall. The stents are available in a wide range of sizes and diameters (up to 18 mm in external diameter and 60 mm in length). This ensures that the stent can be sized to the required length to encompass the stenosis and 0.5 cm of normal mucosa above and below the stenosis. This minimizes the length of the stent and assists clearance of secretions and patient tolerance. The rims of each stent are polished to reduce the risk of granuloma formation. In addition, recent advances include radiopaque studs. The Dumon Gold Studded Stent (Novatech, La Ciotat, France) improves radiographic visualization. The Dumon silicone stent is also available in a Y-design for disease at the level of the carina. Unlike the straight stent, the Y-stent is more difficult to place correctly and requires a significant amount of time to position across the carina using rigid grasping forceps. In addition, hourglass stents are available that are particularly suitable for benign stenosis. Another commercially available silicone stent is the Polyflex stent (Boston Scientific, Natick, MA, USA). This stent is made from polyethylene threads built into the silicone. The stent may adapt better to an hourglass stenosis when compared with the Dumon silicone stent; however, it has a higher migration rate because it is more easily compressed than the Dumon stent. Other silicone stents, such as the Hood stent (Hood Laboratories, Pembroke, MA, USA) and the Noppen stent (MTW, Essen, Germany), are no longer commercially available. All silicone stents require rigid bronchoscopy for placement. Finally, dynamic stents are also available. These have a flexible posterior wall, which mimics the posterior wall of the trachea. This may improve secretion clearance.

Self-Expandable Metallic Stents

In contrast to silicone, metallic stents can be placed with flexible bronchoscopy. The self-expandable metallic stent (SEMS) is available as fully covered, partially covered, or uncovered stents. These include the Silmet stent (Novatech, La Ciotat, France), Aero Tracheobronchial Stent (Merit Medical Systems, Inc, UT, USA), and the Ultraflex stent (Boston Scientific, Natick, MA, USA). Although the SEMS has the advantage of not requiring rigid bronchoscopy, it is the authors' standard practice to use rigid bronchoscopy for placement because it allows greater airway manipulation and management. Metallic stents should not be used in benign disease because their removal can be difficult and result in major airway trauma and complications.

Customized Stents

A further advantage of silicone stents is the ability to customize them at the time of the procedure. The Marseille group has described several customizations to improve the functionality of the stent for an individual's airway. This includes cutting the stent to minimize its impact on the airway and the addition of windows in the stent using the Dutau Forceps (Novatech, La Ciotat, France). This improves ventilation of subsegmental bronchi, which would otherwise be covered.[63] Finally, industry customized stents are available. Two scenarios in which customized stents were necessary have been described: the conical SEMS for postpneumonectomy fistula and a 28 mm customized metallic stent to manage severe malacia in a patient with tracheomegaly associated with Marfan syndrome.[64,65]

T-Tube

The Montgomery T-tube was first designed by W Montgomery in 1965 and has undergone minimal change since then. The T-tube is now manufactured from silicone and comes in a range of lengths and diameters (Boston Medical Products, Inc, Westborough, MA, USA). It consists of 3 limbs and is used to treat a high tracheal and glottic stenosis. It requires a tracheostomy for placement. The 3-limb design allows recanalization of the airway without risk of migration because the stent is anchored via the limb exiting the stoma. This limb can be closed to allow speaking. Alternatively, it can be left open when a high tracheal stenosis still compromises the airway or opened intermittently to allow suctioning of the airway in patients with secretion retention.

Procedure Planning and Stent Placement

A decision to stent the airway should be made by a multidisciplinary team. As previously discussed, stenting should be viewed as a palliative procedure and, in most cases, should be the last therapeutic option. For example, in the setting of benign tracheal stenosis, surgical resection is the preferred treatment. However, this may not be possible and an airway stent should be assessed as a treatment choice. It is preferable that these procedures are planned and that the patient is reviewed in clinic before undertaking the intervention. This allows optimization of the medical condition and review of all available imaging. In addition, the anesthetist can assess the patient and optimize any reversible conditions. However, these procedures often occur in an emergent setting and are, therefore, often performed with minimal preassessment. It is the opinion of the authors that all therapeutic airway procedures should be performed with a rigid scope passed into the airway to ensure patency with adequate ventilation. If procedures are performed with a flexible bronchoscope, we strongly advise that an adult bronchoscope with a large working channel (minimum 2.8–3.2 mm) is used to allow adequate suctioning, delivery of laser probes, balloon dilators, and optimal aspiration. Larger stent delivery catheters should be introduced under fluoroscopy after placing external radiopaque markers.

Stent Choice

The stent of choice will depend on several factors that include the disease state and patient characteristics, airway anatomy, physician or surgeon expertise, and available equipment. Our preference is for a silicone stent and rigid bronchoscopy (Fig. 7). As stated in the British Thoracic Society (BTS) guideline, this allows airway stability, adequate ventilation, and rapid control of hemorrhage and clot removal.[15]

In addition, the silicone stent is easily customized and its position can be adjusted with ease after deployment. Finally, a silicone stent can be removed with ease if the clinical situation dictates (Fig. 8). In the authors' units, a SEMS is used when there is a distorted airway with excessive tortuosity. In these situations, the silicone stent does not

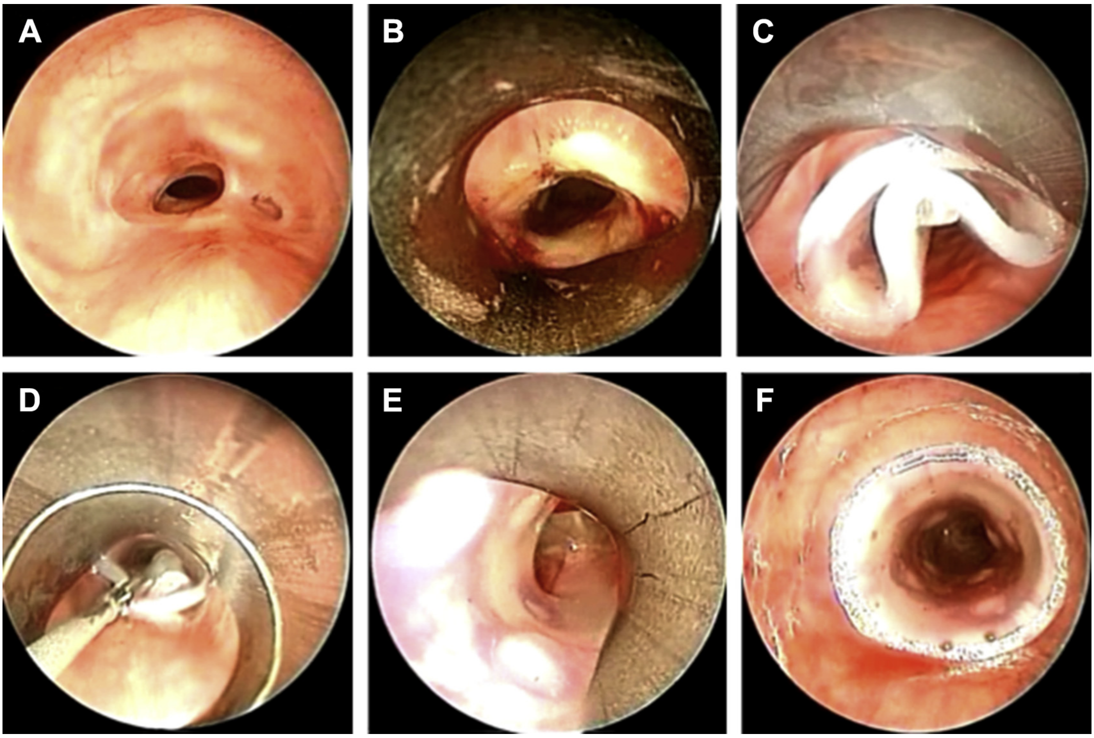

Fig. 7. Silicone stent placement for a benign tracheal stenosis. (*A*) Benign stenosis as seen from the rigid bronchoscope placed proximally in the trachea. (*B*) Dilatation of the stenosis using the rigid tube. (*C*) Stent delivery distal to the stenosis. (*D*) Stent positioning using a rigid forceps to grasp and position proximally. (*E*) Stent positioned over the stenosis and unfolded using the rigid scope. (*F*) Stent fully unfolded and well positioned at site of previous stenosis.

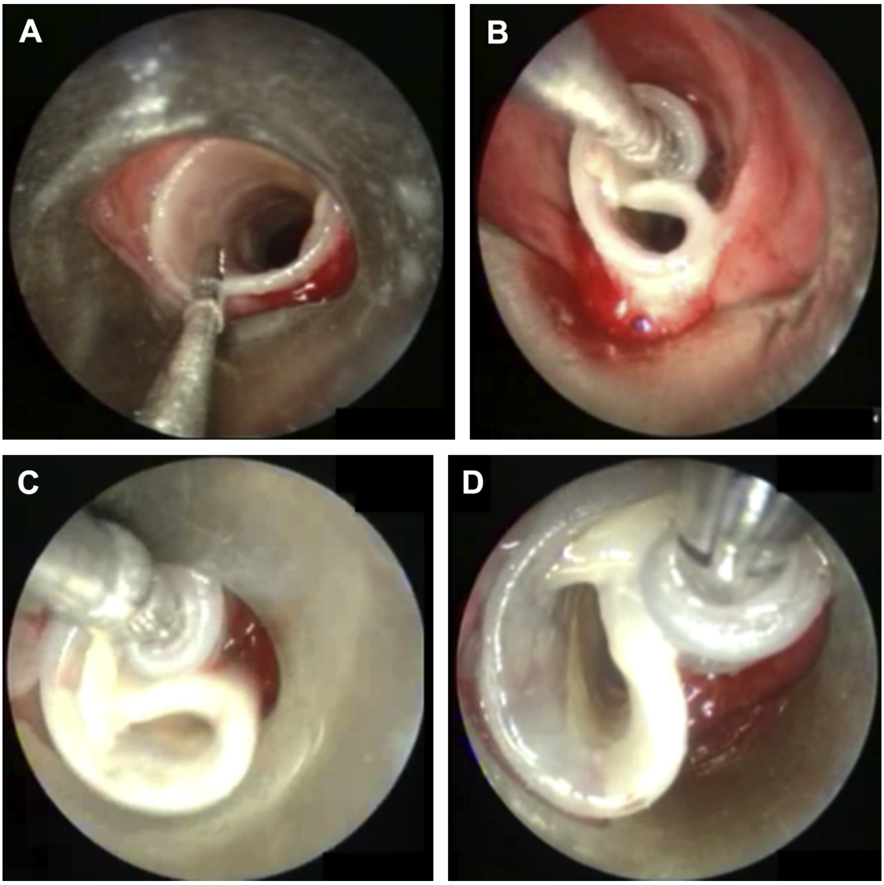

Fig. 8. Silicone stent removal using a rigid bronchoscope. (*A*) Stent grasped with rigid forceps. (*B*) Stent unfolded and pulled back into mouth of the rigid bronchoscope. (*C*) Proximal end of stent within rigid scope to ensure no damage occurs to cords on extraction. (*D*) Stent and rigid bronchoscope removed en bloc.

conform to the airway anatomy and, if placed, often results in kinking with ongoing airway stenosis and a high risk of complications. The SEMS more easily conforms to this type of airway. In addition, a conical SEMS is particularly useful in cases in which the diameter of the airway varies from distal to the proximal extremity (Fig. 9). However, unlike the recommendation of the BTS

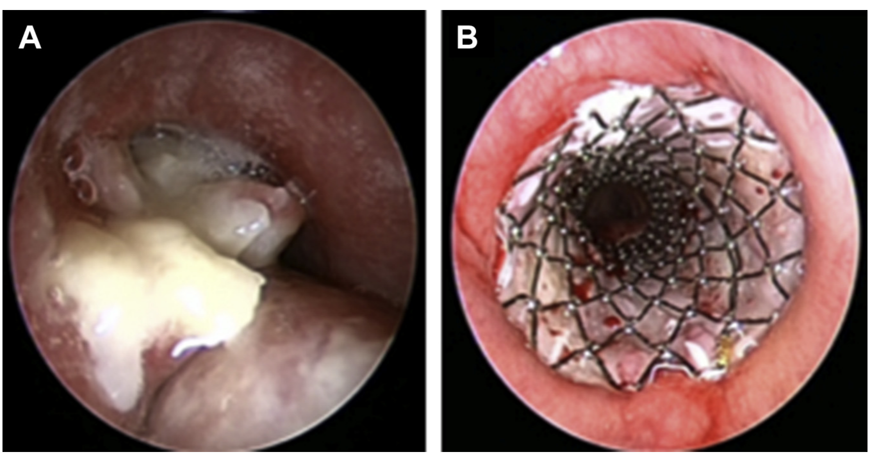

Fig. 9. SEMS insertion – pre (*A*) and post (*B*) malignant obstruction, debulking and SEMS insertion. SEMS, Silmet stent.

guideline, when placing a SEMS, our preference is to use rigid bronchoscopy and intubation. Once a decision is made to place a stent, the length of stenosis and required diameter needs to be measured. This can be performed with dedicated measuring forceps. The required stent size is estimated from the diameter of the rigid tube and the length can be measured using a flexible bronchoscope. The size of the stent should exceed the size of the stenosis by 1 cm, which allows 0.5 cm of clearance at the distal and proximal margin (**Fig. 10**). The stent should be larger than the stenosis so that there is adequate radial force to keep the prosthesis in position. Only experienced bronchoscopists who can respond and manage both the early and late complications of advanced airway disease should place stents.

CURRENT STENTING LANDSCAPE

In the early years of stent placement there was probably an overuse of this technique and, like all technologies, indications have become more defined over the last 2 decades. In addition, lung cancer presentation has changed with a decrease in central diseases and an increase in peripheral cancers. Moreover, physicians have become more aware of stent complications and most centers will follow the premise that stents should only be placed as a last resort when all other therapeutic options have been explored. In the scenario in which the lumen caliber is adequate after debulking, a stent should not be placed (**Fig. 11**). The Marseille group[66] has recently published their experience and highlighted the overall decrease in stent deployment over the last 3 decades. Examples of the changing landscape for stenting can be seen in all aspects of airway disease.

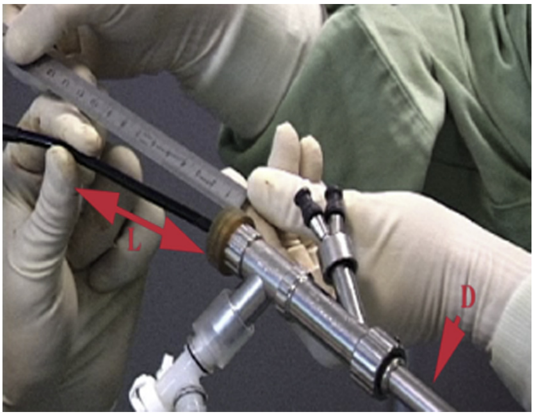

Fig. 10. Length (L) and diameter (D) calculations based on the diameter of the rigid tube (*arrowhead*) and proximal pullback (*double arrow*) of a flexible bronchoscope.

In benign tracheal stenosis, the initial practice as performed in most centers was to initially treat most cases by stent placement. Evidence does support that stenting tracheal stenosis can result in a high rate of success but it is also associated with complications and requires ongoing long-term management. In current practice, stenting in benign stenosis is reserved for patients in whom surgical or anesthetic contraindications preclude surgical intervention, which represents a small percentage of patients. As far as malignant obstruction is concerned, the Silicone Prosthesis in Obstructive lung Cancer (SPOC) trial has redefined the role of stenting.[67] This study concluded that a stent is only required as a palliative treatment when initial primary oncology treatments have proven insufficient. Historically, the management of a trachea-esophageal fistula was with double stenting (esophageal and tracheal or bronchial stents). This practice has also changed in recent years with a significant decrease in double stenting, which is reserved for cases of persisting aspiration or symptomatic secondary compression of the airway after esophageal stenting.

FUTURE OF STENTING

The future of stenting will include biodegradable, drug-eluting, and 3-dimensional printed stents. These advances have potential advantages for airway management, including stent placement without the requirement of later extraction, drug delivery directed to the underlying stented lesion, and individualized customized stents designed specifically for airway anatomy. Work is already underway in all these technologies and reports are beginning to appear in the medical literature.[68–75]

Training

Training and access to adequate training remains an ongoing issue and may hamper the growth of IP services in Europe. In the United States, a large number of centers now offer dedicated IP fellowships but surveys performed in the past have demonstrated that it is difficult to obtain adequate numbers of procedures to ensure competence in the rigid bronchoscopy technique. In the United States, 31.3% of pulmonary programs have an IP service; however, rigid bronchoscopy training is offered in only 4.4% of these practices.[76]

A recently completed survey by the European Association of Bronchology and Interventional Pulmonology (EABIP),[77] submitted for publication has demonstrated a significant heterogeneity of IP services around Europe. Dedicated programs need to be developed to allow for further growth and sharing of knowledge in Europe. The National Institute of

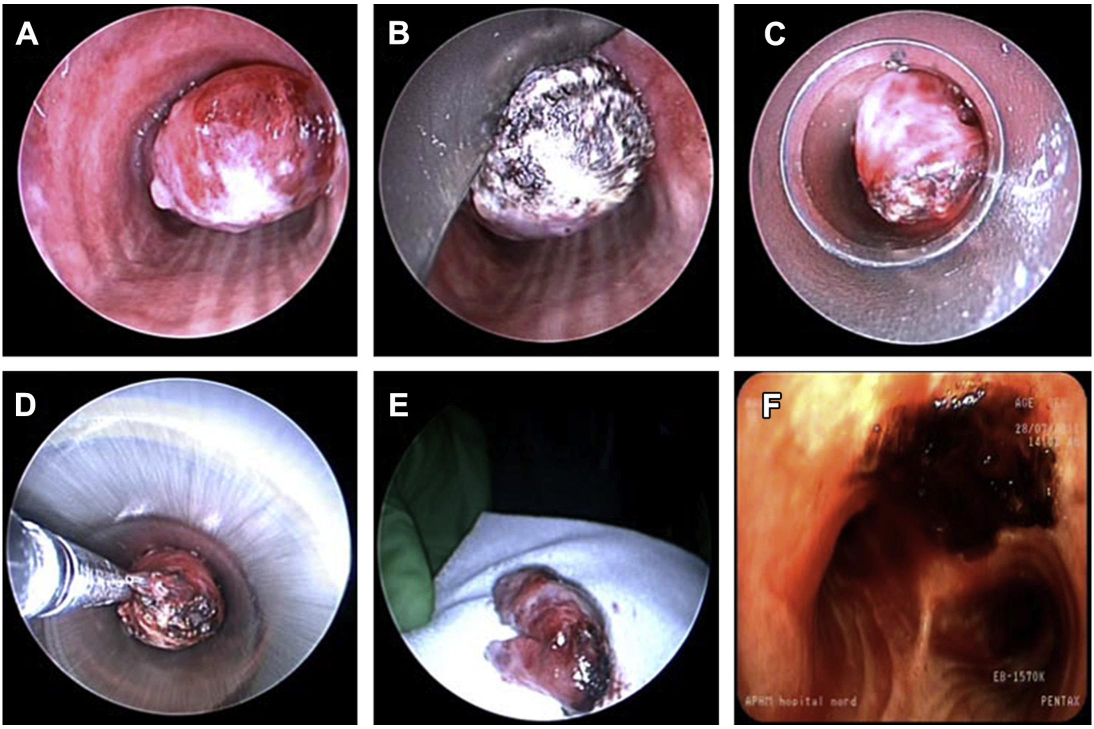

Fig. 11. Laser-assisted mechanical debulking of a distal tracheal tumor. (*A*) Large tumor at distal trachea with near complete obstruction of the lumen. (*B*) After initial devascularization the tumor surface using laser. (*C*) The tumor is mechanically debulked using the tip of the rigid bronchoscope. (*D*) The debulked tumor is removed via the lumen of the scope using a rigid forceps. (*E*) The large tumor specimen is seen immediately after debulking. (*F*) After debulking, the distal tracheal lumen is of normal caliber and the laser is applied to residual tumor and bed of the lesion.

Clinical Excellence (NICE) guideline CG121 recommended that all cancer centers should ensure that patients have rapid access to a team capable of providing interventional endobronchial treatments, and the advantages of the rigid bronchoscopy procedure were documented in the BTS guideline on therapeutic procedures.[15,77]

The guideline recommended that patients with central airway obstruction due to intraluminal tumor should have endobronchial tumor debulking considered. However, despite documenting the advantages of the rigid bronchoscopy procedure, as described previously, they recommended that a laryngeal mask or uncuffed endotracheal tube be used to achieve airway control. This will have a major impact on the growth of the procedure within the United Kingdom and, indeed, our recent survey[78] seems to support this conclusion.

Finally, a recent American College of Chest Physicians publication has suggested standards for accreditation of IP fellowships in the United States.[79] It recommends a curriculum for a standard IP program. The program should be set over a 12-month curriculum with at least 9 months devoted to direct IP training. In addition, there should be ample exposure to associated specialties, including but not limited to thoracic surgery and otolaryngology. Appropriate research should also be undertaken. Finally, they set out guidelines for the minimum institutional volumes necessary for accreditation of an IP fellowship program. Ongoing standardization of practice within Europe and the United States will further cement the position of IP as a subspecialty in respiratory medicine.

COMPLICATIONS

Overall complications can be related to the underlying patient state, anesthesia, rigid bronchoscope, or ancillary tools. In addition, stent-related complications can be divided into early and late. However, despite the patient population, complications directly related to the rigid bronchoscope are relatively uncommon. Few data exist regarding the incidence of complications; however, severe complications are rare in experienced hands.

The most common complication is sore throat or neck after the procedure. Other complications include injury to the teeth or gums, tracheal or bronchial tears, and severe bleeding.

Table 1
Summary from large case series of reported complications following interventional bronchoscopy

Study	Number	Indications	Therapies	Rigid Bronchoscope	General Anesthetic	Any Complication	Death	Bleeding	Respiratory Failure	Pneumothorax or Mediastinum	Cardiac
Ost et al,[24] 2015	1115	Mixed indications	All[a]	66%	86%	44 (3.9)	6 (0.5)	6 (0.5)	37 (3.3)	NA	NA
Perin et al,[22] 2012	464	Malignant CAO	Nd:YAG	NA	100%	39 (8.4)	10 (0.2)	12 (2.6)	11(2.4)	5 (1.1)	0 (0)
Schumann et al,[23] 2010	225	CAO (any)	Cryotherapy	14%	NA	13 (5.7)	0	12 (5.3)	0 (0)	0 (0)	2 (0.9)
Maiwand et al,[21] 2004	476	Lung cancer CAO	Cryotherapy	NA	100%	17 (3.6)	0	3 (0.6)	4 (0.8)	5 (1.1)	8 (1.7)
Reichle et al,[20] 2000	364	Mixed indications	APC	87%	NA	18 (4.9)	2 (0.5)	0 (0)	0 (0)	0 (0)	4 (1.1)
Cavaliere et al,[17] 1996	2008	Mixed indications	Nd:YAG	96%	94%	60 (3.0)	12 (0.6)	19 (0.9)	15 (0.7)	8 (0.3)	17 (0.8)
Cavaliere et al,[18] 1988	1000	Mixed indications	Nd:YAG	95%	78%	27 (2.7)	5 (0.5)	10 (1.0)	6 (0.6)	6 (0.6)	3 (0.3)
Total	5652	—	—	—	—	218 (3.9)	26 (0.4)	62 (1.1)	73 (1.3)	24 (0.5)	34 (0.7)

Data are number (%) unless stated.

Abbreviations: APC, argon plasma coagulation; CAO, central airway obstruction; NA, not available; Nd:YAG, neodymium: yttrium aluminum garnet.

[a] Combined modalities frequently, any: APC 30%, laser 23%, electrocautery 20%; cryotherapy 8%, dilation 40%.

Hypoxemia-induced cardiac ischemia and arrhythmias are the most dangerous complications. From large cases series, the overall serious complications are observed in approximately 3.9% of patients with a procedure mortality of 0.4% (**Table 1**).[17,18,20–24]

The AQuIRE registry, a multicenter registry, found a complication and mortality rate of 3.9% and 0.5%, respectively.[24] Refractory hypoxemia was associated with moderate sedation, redo therapeutic bronchoscopy, and tracheoesophageal fistulae. Procedural complications were associated with emergent, urgent-first therapeutic bronchoscopy, and an American Society of Anesthesiologists (ASA) score greater than 3. The 30-day mortality was 14.8%, with risk factors identified as a Zubrod score greater than 1 (World Health Organization performance status), an ASA score greater than 3, any intrinsic or mixed obstruction, and stent placement. The placement of Y-stent had the higher risk of death (odds ratio 4.92).

Stent-related complications can be seen in **Box 2**. A systematic review including 501 patients with airway stents, found that infection occurred in 16% and 19% of patients with malignant disease and nontransplant benign disease, respectively.[80] Pneumonia (47%) was the most frequent infection, whereas *Staphylococcus aureus* (39%) and *Pseudomonas aeruginosa* (28%) were the most common pathogens. The authors think that good technique, including selection of stent size and type, can assist in reducing complications. In addition, poststent care is essential to prevent longer term complications, including the use of saline nebulization at various concentrations and mucolytics to reduce rate of mucoid impaction, halitosis, and stent infection. Finally, stents placed for benign indications or stents in situ for a long duration will require periodic replacement.

Box 2
Stent-specific related complications

Halitosis

Infection

Stent biofilms

Obstruction

- Mucoid impaction
- Granulation tissue
- Tumor ingrowth

Migration

Fracture

SUMMARY

Rigid bronchoscopy and stenting is an additional skillset that should be obtained outside normal respiratory training. This is particularly seen in the United States where it is a separate fellowship and requires an additional year of dedicated training. However, in Europe, there is significant heterogeneity between health care systems and this needs addressing. Guidelines for lung cancer management recognize the central role of these techniques for a subgroup of patients who present with central airway compromise and associated symptoms.

However, these techniques performed by skilled operators in the correct setting can significantly reduce symptoms and improve a patient's quality of life. The techniques are well-established within thoracic oncology but future efforts need to focus on standardization of techniques and ongoing training.

REFERENCES

1. Becker HD, Marsh BR. History of the rigid bronchoscope. Interventional bronchoscopy, vol. 30. Basel (Switzerland): Karger Publishers; 2000. p. 2–15.
2. Kollofrath O. Entfernung eines Knochenstücks aus dem rechten Bronchus auf natürlichem Wege und unter Anwendung der directen Laryngoscopie. Münchener Medizinische Wochenschrift 1897;38:1038–9.
3. Brünings W, Albrecht W. Direkte Endoskopie der Luft-und Speisewege, bearbeitet von Prof. Dr. W. Brünings und Prof. Dr. W. Albrecht. Stuttgart (Germany): F. Enke; 1915.
4. Jackson C. Foreign bodies in the air and food passages: charted experience in cases from no. 631 to no. 1155 at the Bronchoscopic Clinic. New Bedford (MA): Reynolds; 1924.
5. Panchabhai TS, Mehta AC. Historical perspectives of bronchoscopy. Connecting the dots. Ann Am Thorac Soc 2015;12(5):631–41.
6. Miyazawa T. History of the flexible bronchoscope. Interventional bronchoscopy, vol. 30. Basel (Switzerland): Karger Publishers; 2000. p. 16–21.
7. Toty L, Riquet M, Personne C, et al. Pulmonary perforation of mediastinal caseous lymph nodes in children. Thirty-two cases (author's transl). Ann Chir 1981;35(3):220–3 [in French].
8. Montgomery WW. T-tube tracheal stent. Arch Otolaryngol 1965;82:320–1.
9. Dumon JF. A specific tracheobronchial endoprosthesis. Presse Med 1989;18(42):2055–8 [in French].
10. Ayers ML, Beamis JF Jr. Rigid bronchoscopy in the twenty-first century. Clin Chest Med 2001;22(2):355–64.
11. Limper AH, Prakash UB. Tracheobronchial foreign bodies in adults. Ann Intern Med 1990;112(8):604–9.

12. Chen CH, Lai CL, Tsai TT, et al. Foreign body aspiration into the lower airway in Chinese adults. Chest 1997;112(1):129–33.
13. Delage A, Marquette C. Airway foreign bodies: clinical presentation, diagnosis and treatment. In: Strausz J, Bollinger CT, editors. Interventional Pulmonoloy (ERS Monograph). Sheffield (England): European Respiratory Society; 2010. p. 135–48.
14. Dutau H, Vandemoortele T, Breen DP. Rigid bronchoscopy. Clin Chest Med 2013;34(3):427–35.
15. Du Rand I, Barber P, Goldring J, et al. British Thoracic Society guideline for advanced diagnostic and therapeutic flexible bronchoscopy in adults. Thorax 2011;66(Suppl 3):iii1–21.
16. Martinot A, Closset M, Marquette CH, et al. Indications for flexible versus rigid bronchoscopy in children with suspected foreign-body aspiration. Am J Respir Crit Care Med 1997;155(5):1676–9.
17. Cavaliere S, Venuta F, Foccoli P, et al. Endoscopic treatment of malignant airway obstructions in 2,008 patients. Chest 1996;110(6):1536–42.
18. Cavaliere S, Foccoli P, Farina PL. Nd:YAG laser bronchoscopy. A five-year experience with 1,396 applications in 1,000 patients. Chest 1988;94(1):15–21.
19. Hespanhol V, Magalhaes A, Marques A. Neoplastic severe central airways obstruction, interventional bronchoscopy: a decision-making analysis. J Thorac Cardiovasc Surg 2013;145(4):926–32.
20. Reichle G, Freitag L, Kullmann HJ, et al. Argon plasma coagulation in bronchology: a new method–alternative or complementary? Pneumologie 2000;54(11):508–16 [in German].
21. Maiwand MO, Evans JM, Beeson JE. The application of cryosurgery in the treatment of lung cancer. Cryobiology 2004;48(1):55–61.
22. Perin B, Zaric B, Jovanovic S, et al. Patient-related independent clinical risk factors for early complications following Nd: YAG laser resection of lung cancer. Ann Thorac Med 2012;7(4):233–7.
23. Schumann C, Hetzel M, Babiak AJ, et al. Endobronchial tumor debulking with a flexible cryoprobe for immediate treatment of malignant stenosis. J Thorac Cardiovasc Surg 2010;139(4):997–1000.
24. Ost DE, Ernst A, Grosu HB, et al. Complications following therapeutic bronchoscopy for malignant central airway obstruction: results of the AQuIRE registry. Chest 2015;148(2):450–71.
25. Brewer LA. Patterns of survival in lung cancer. Chest 1977;71(5):644–50.
26. Hindle M, Sibly A, Aldik M, et al. P19 Central airway obstruction in bronchogenic carcinoma. Thorax 2016;71:A93.
27. Vonk-Noordegraaf A, Postmus PE, Sutedja TG. Tracheobronchial stenting in the terminal care of cancer patients with central airways obstruction. Chest 2001;120(6):1811–4.
28. Monnier P, Mudry A, Stanzel F, et al. The use of the covered Wallstent for the palliative treatment of inoperable tracheobronchial cancers. A prospective, multicenter study. Chest 1996;110(5):1161–8.
29. Gilmartin JJ, Veale D, Cooper BG, et al. Effects of laser treatment on respiratory function in malignant narrowing of the central airways. Thorax 1987;42(8):578–82.
30. Zaric B, Kovacevic T, Stojsic V, et al. Neodymium yttrium-aluminium-garnet laser resection significantly improves quality of life in patients with malignant central airway obstruction due to lung cancer. Eur J Cancer Care (Engl) 2015;24(4):560–6.
31. Chhajed PN, Baty F, Pless M, et al. Outcome of treated advanced non-small cell lung cancer with and without central airway obstruction. Chest 2006;130(6):1803–7.
32. Mohsenifar Z, Jasper AC, Koerner SK. Physiologic assessment of lung function in patients undergoing laser photoresection of tracheobronchial tumors. Chest 1988;93(1):65–9.
33. Vergnon JM, Costes F, Bayon MC, et al. Efficacy of tracheal and bronchial stent placement on respiratory functional tests. Chest 1995;107(3):741–6.
34. Vishwanath G, Madan K, Bal A, et al. Rigid bronchoscopy and mechanical debulking in the management of central airway tumors: an Indian experience. J Bronchology Interv Pulmonol 2013;20(2):127–33.
35. Prakash UB, Midthun DE, Edell ES. Indications for flexible versus rigid bronchoscopy in children with suspected foreign-body aspiration. Am J Respir Crit Care Med 1997;156(3 Pt 1):1017–9.
36. Rafanan AL, Mehta AC. Adult airway foreign body removal. What's new? Clin Chest Med 2001;22(2):319–30.
37. Karmy-Jones R, Cuschieri J, Vallieres E. Role of bronchoscopy in massive hemoptysis. Chest Surg Clin N Am 2001;11(4):873–906.
38. Marsico G, Guimares C, Montesi J. Management of massive hemoptysis with rigid bronchoscopy and cold saline solution. Jornal de Pneumologia 2003;29:1590–600.
39. McCollun WB, Mattox KL, Guinn GA, et al. Immediate operative treatment for massive hemoptysis. Chest 1975;67(2):152–5.
40. Gourin A, Garzon AA. Operative treatment of massive hemoptysis. Ann Thorac Surg 1974;18(1):52–60.
41. Garzon AA, Cerruti M, Gourin A, et al. Pulmonary resection for massive hemoptysis. Surgery 1970;67(4):633–8.
42. Dweik RA, Stoller JK. Role of bronchoscopy in massive hemoptysis. Clin Chest Med 1999;20(1):89–105.
43. Bobrowitz ID, Ramakrishna S, Shim YS. Comparison of medical v surgical treatment of major hemoptysis. Arch Intern Med 1983;143(7):1343–6.

44. Grillo HC, Donahue DM. Post intubation tracheal stenosis. Semin Thorac Cardiovasc Surg 1996;8(4):370–80.
45. Wain JC. Postintubation tracheal stenosis. Chest Surg Clin N Am 2003;13(2):231–46.
46. Petrou M, Goldstraw P. The management of tracheobronchial obstruction: a review of endoscopic techniques. Eur J Cardiothorac Surg 1994;8(8):436–41.
47. Juarez MM, Albertson TE, Chan AL. Interventional bronchoscopy for obstructing benign airway tumors: which modality is ideal? J Thorac Dis 2011;3(4):217–8.
48. Kajiwara N, Kakihana M, Usuda J, et al. Interventional management for benign airway tumors in relation to location, size, character and morphology. J Thorac Dis 2011;3(4):221–30.
49. Sutedja G, Schramel F, van Kralingen K, et al. Stent placement is justifiable in end-stage patients with malignant airway tumours. Respiration 1995;62(3):148–50.
50. van Boxem TJ, Venmans BJ, van Mourik JC, et al. Bronchoscopic treatment of intraluminal typical carcinoid: a pilot study. J Thorac Cardiovasc Surg 1998;116(3):402–6.
51. Cavaliere S, Foccoli P, Toninelli C. Curative bronchoscopic laser therapy for surgically resectable tracheobronchial tumors: personal experience. J Bronchology Interv Pulmonol 2002;9(2):90–5.
52. Freitag L, Tekolf E, Steveling H, et al. Management of malignant esophagotracheal fistulas with airway stenting and double stenting. Chest 1996;110(5):1155–60.
53. Tazi-Mezalek R, Musani AI, Laroumagne S, et al. Airway stenting in the management of iatrogenic tracheal injuries: 10-year experience. Respirology 2016;21(8):1452–8.
54. Nicastri DG, Weiser TS. Rigid bronchoscopy: indications and techniques. Oper Tech Thorac Cardiovasc Surg 2012;17(1):44–51.
55. Plekker D, Koegelenberg CF, Bolliger CT. Different techniques of bronchoscopy. In: Strausz J, Bollinger CT, editors. Interventional pulmonology (ERS Monograph). Sheffield (England): European Respiratory Society; 2010. p. 1–17.
56. Lukomsky GI, Ovchinnikov AA, Bilal A. Complications of bronchoscopy: comparison of rigid bronchoscopy under general anesthesia and flexible fiberoptic bronchoscopy under topical anesthesia. Chest 1981;79(3):316–21.
57. Lorx A, Valko L, Penzes I. Anaesthesia for interventional bronchoscopy. In: Strausz J, Bollinger CT, editors. Interventional pulmonology (ERS Monograph). Sheffield (England): European Respiratory Society; 2010. p. 18–32.
58. Sarkiss M. Anesthesia for bronchoscopy and interventional pulmonology: from moderate sedation to jet ventilation. Curr Opin Pulm Med 2011;17(4):274–8.
59. Casal RF. Update in airway stents. Curr Opin Pulm Med 2010;16(4):321–8.
60. Lee P, Kupeli E, Mehta AC. Airway stents. Clin Chest Med 2010;31(1):141–50.
61. Ranu H, Madden B. Endobronchial stenting in the management of large airway pathology. Postgrad Med J 2009;85(1010):682–7.
62. FDA public health notification: complications from metallic tracheal stents in patients with benign airway disorders. Available at: www.fda.gov/MedicalDevices/Safety/AlertsandNotices/PublicHealthNotifications/ucm062115.htm. Accessed January 13, 2018.
63. Breen DP, Dutau H. On-site customization of silicone stents: towards optimal palliation of complex airway conditions. Respiration 2009;77(4):447–53.
64. Dutau H, Cavailles A, Fernandez-Navamuel I, et al. Tracheal compression in a patient with Marfan's syndrome-associated tracheomegaly treated by an XXL stent: the largest diameter airway stent ever placed in a previously undescribed airway condition. Respiration 2009;77(1):97–101.
65. Dutau H, Breen DP, Gomez C, et al. The integrated place of tracheobronchial stents in the multidisciplinary management of large post-pneumonectomy fistulas: our experience using a novel customised conical self-expandable metallic stent. Eur J Cardiothorac Surg 2011;39(2):185–9.
66. Airway stenting revisited: 30 Years, the Age of Reason? Dutau H, Dumon J-F. Journal of Bronchology & Interventional Pulmonology 2017;24(4):257–9.
67. Vergnon J-M, Thibout Y, Dutau H, et al. Is a stent required after the initial resection of an obstructive lung cancer? The lessons of the SPOC trial, the first randomized study in interventional bronchoscopy. Eur Respir J 2013;42(Suppl 57):P3752.
68. Dutau H, Musani AI, Laroumagne S, et al. Biodegradable airway stents - Bench to bedside: a comprehensive review. Respiration 2015;90(6):512–21.
69. Lischke R, Pozniak J, Vondrys D, et al. Novel biodegradable stents in the treatment of bronchial stenosis after lung transplantation. Eur J Cardiothorac Surg 2011;40(3):619–24.
70. Vondrys D, Elliott MJ, McLaren CA, et al. First experience with biodegradable airway stents in children. Ann Thorac Surg 2011;92(5):1870–4.
71. Zhu G, Ng AH, Venkatraman SS, et al. A novel bioabsorbable drug-eluting tracheal stent. Laryngoscope 2011;121(10):2234–9.
72. Chao Y-K, Liu K-S, Wang Y-C, et al. Biodegradable cisplatin-eluting tracheal stent for malignant airway obstruction: in vivo and in vitro studies. Chest 2013;144(1):193–9.
73. Huvenne W, Zhang N, Tijsma E, et al. Pilot study using doxycycline-releasing stents to ameliorate

postoperative healing quality after sinus surgery. Wound Repair Regen 2008;16(6):757–67.
74. Tam MD, Laycock SD, Jayne D, et al. 3-D printouts of the tracheobronchial tree generated from CT images as an aid to management in a case of tracheobronchial chondromalacia caused by relapsing polychondritis. J Radiol Case Rep 2013;7(8):34.
75. Cheng GZ, Estepar RSJ, Folch E, et al. Three-dimensional printing and 3D slicer: powerful tools in understanding and treating structural lung disease. Chest 2016;149(5):1136–42.
76. Pastis NJ, Nietert PJ, Silvestri GA, American College of Chest Physicians Interventional Chest/Diagnostic Procedures Network Steering Committee. Variation in training for interventional pulmonary procedures among US pulmonary/critical care fellowships: a survey of fellowship directors. Chest 2005;127(5):1614–21.
77. BTS recommendations to respiratory physicians for organising the care of patients with lung cancer. The lung cancer working party of the British Thoracic Society Standards of Care Committee. Thorax 1998;53(Suppl 1):S1–8.
78. Dutau H, Breen D, Bugalho A, et al. Current practice of airway stenting in the adult population in Europe: a survey of the European Association of Bronchology and Interventional Pulmonology (EABIP). Respiration 2018;95:44–54.
79. Mullon JJ, Burkart KM, Silvestri G, et al. Interventional pulmonology fellowship accreditation standards: executive summary of the multisociety interventional pulmonology fellowship accreditation committee. Chest 2017;151(5):1114–21.
80. Agrafiotis M, Siempos II, Falagas ME. Infections related to airway stenting: a systematic review. Respiration 2009;78(1):69–74.