Airway stenting

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Central airway obstruction produces symptoms of dyspnea, stridor, and obstructive pneumonia and is frequently life threatening, with impending suffocation. In most cases, resection and surgical reconstruction provide the best opportunity for definitive management. Bronchoscopic management, however, is the first step in providing a diagnosis, stabilizing the obstructed airway, and evaluating resectability. In patients who are unresectable owing to anatomic limitations, metastatic disease, or overall medical condition, endoscopic techniques are minimally invasive and can provide significant palliation [1]. Although the long-term outlook in these cases is often dismal, the temporary or permanent relief of airway obstruction provides significant palliation, with significant improvement in quality of life and potential prolongation of life.

Multiple procedures now are used for the palliation of airway pathology. Laser resection, photodynamic therapy, endobronchial brachytherapy, and endobronchial débridement (core out) all are used for malignant airway lesions. Dilatation and laser resections are advocated as palliation for benign tracheobronchial stenosis. Flexible and creative application of each of these techniques, combined within an individual patient, provides the best chance for successful airway palliation [1]. Experience with interventional bronchoscopy, including stent placement, is an important part of any thoracic surgical program in which airway resection or lung transplantation is performed, providing for management of postoperative anastomotic complications.

In benign and malignant disease, tracheobronchial stents have been used to palliate the effects of large airway obstruction caused by extrinsic compression, intraluminal disease, or loss of cartilaginous support. Advances in airway prosthetics have produced various silicone stents and expandable metal stents, enabling the correction of increasingly complex anatomic problems. Although airway resection and reconstruction are the preferred therapy for benign and
malignant lesions, tracheobronchial stents provide an alternative to open surgical procedures that may be preferred by some patients or physicians. The surgeon or pulmonologist considering stenting for airway palliation should be experienced with the indications and techniques of airway resection or be part of a closely linked multidisciplinary team that allows a balanced consideration of airway resection versus therapeutic bronchoscopy.

The first modern treatment of major airway obstruction by placement of endotracheal stent was reported by Harkins [2] in 1952, who described the use of metal tubes for benign tracheal stenosis resulting from trauma. The current generation of endoluminal stents was introduced by Duvall and Bauer [3], who modified the Montgomery T-tube design so that it could be inserted by bronchoscopy. In 1989, Cooper and colleagues [4] reported on a modified Silastic stent used in 11 cases for malignant tracheobronchial obstruction. Dumon [5] published results of a newly designed stent used in 66 patients in the late 1980s.

Stents

Silicone stents

The solid tubular stents are manufactured out of molded silicone. The most commonly used silicone stents are the Dumon and Hood stents, which come in various diameters and lengths (Table 1). The Dumon stent (Bryan Corp, Woburn, Massachusetts) is made of molded silicone with external studs at regular intervals to prevent dislodgment. Also available from other manufacturers are silicone stents that may have proximal and distal flanges for stabilization or have external studs like the Dumon stent (Hood Laboratories, Pembroke, Massachusetts). Y modifications for stenting of the distal trachea, carina, and mainstem bronchi also have been introduced (Fig. 1A).

One of the most recent modifications has been designed by Freitag (Dynamic Stent, Rüsch, AG Kernan, Germany) and is a silicone Y stent with the anterolateral walls reinforced with metal hoops. The Dynamic stent has a long tracheal and left main bronchial limb and a short right main bronchial limb (Fig. 1B). The nonreinforced silicone posterior wall is collapsible and mimics the dynamics of the membranous trachea during inspiration and expiration [6].

Metal expandable stents

The successful use of expandable metal stents in the vascular and biliary trees has led to their use in benign and malignant tracheobronchial stenoses. The Gianturco stent (Cook, Bloomington, Indiana) was developed in the 1980s and is made up of a continuous zigzag loop of stainless-steel wire that is compressed into a cylinder, allowing delivery into a vascular or airway stenosis [7]. These stents come in fixed lengths (2 or 2.5 cm), but tandem stents also have been produced with double the length of the single stents.
### Table 1
Characteristics of major airway stents

<table>
<thead>
<tr>
<th>Stents</th>
<th>Manufacturer</th>
<th>Construction</th>
<th>Delivery</th>
<th>Sizes</th>
<th>Costs (approx US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hood</td>
<td>Hood Corp</td>
<td>Molded silicon rubber</td>
<td>Tube stent</td>
<td>6 × 13–18 × 70 plus Y stents</td>
<td>100–350</td>
</tr>
<tr>
<td>Dumon</td>
<td>Bryan Corp</td>
<td>Molded silicon rubber</td>
<td>Tube stent</td>
<td>9 × 20–16 × 60 plus Y stent</td>
<td>350</td>
</tr>
<tr>
<td>Dynamic</td>
<td>Rüsch</td>
<td>Silicone with anterolateral steel struts</td>
<td>Y stent</td>
<td>Y stents only 3 sizes, 13, 15, 17 mm tracheal diameter</td>
<td>1600</td>
</tr>
<tr>
<td>Wallstent</td>
<td>Boston Scientific</td>
<td>Woven cobalt/chrome alloy monofilaments coated with silicone</td>
<td>Self-expandable constrained within delivery catheter</td>
<td>8 × 20–24 × 60</td>
<td>1495</td>
</tr>
<tr>
<td>Ultraflex</td>
<td>Boston Scientific</td>
<td>Single-strand woven nitinol, with and without silicone coating</td>
<td>Self-expandable constrained within delivery catheter</td>
<td>8 × 20–20 × 80</td>
<td>1625</td>
</tr>
<tr>
<td>Strecker</td>
<td>Boston Scientific</td>
<td>Single-strand tantalum mesh</td>
<td>Balloon-expanded deployment</td>
<td>8 × 20–11 × 40</td>
<td>1000–2000</td>
</tr>
<tr>
<td>Palmaz</td>
<td>Johnson and Johnson</td>
<td>Expandable, slotted, stainless-steel tube</td>
<td>Balloon-expanded deployment</td>
<td>8 × 10–12 × 40</td>
<td>1950–2250</td>
</tr>
<tr>
<td>Wallgraft</td>
<td>Boston Scientific</td>
<td>Woven cobalt/chrome alloy monofilaments with polyethylene covering</td>
<td>Self-expandable constrained within delivery catheter</td>
<td>6 × 20–12 × 70</td>
<td>1300</td>
</tr>
<tr>
<td>Polyflex</td>
<td>Rüsch</td>
<td>Polyester mesh-coated with silicone</td>
<td>Self-expandable constrained within delivery catheter</td>
<td>6 × 20–22 × 80</td>
<td>150–450</td>
</tr>
<tr>
<td>Gianturco</td>
<td>William Cook Europe</td>
<td>Cylindric zigzag, stainless-steel monofilament</td>
<td>Self-expandable constrained delivery catheter</td>
<td>6 × 25–35 × 50</td>
<td></td>
</tr>
</tbody>
</table>

The Palmaz stent (Johnson and Johnson Interventional Systems, Warren, New Jersey) is an example of a fixed-diameter balloon expandable stent. In contrast to the Gianturco stent, the Palmaz stents do not exhibit any intrinsic radial force and are positioned and seated by balloon expansion. The Palmaz stents are made of stainless steel with staggered rows of rectangular slots around the entire circumference. Once expanded, the Palmaz stent does not exert a continual expanding pressure on the airway. Because of the small sizes available, the Palmaz stents frequently have been preferred for stenting of pediatric stenoses. These first-generation metal stents are now uncommonly used in adult clinical practice in the United States owing to their inflexibility and reports of complications.

The second generation of metal expandable stents was led by the Wallstent (Boston Scientific, Natick, Massachusetts), which is a self-expandable tubular mesh stent that is delivered in a constrained form and, once released, expands to a preset diameter. The Wallstent has excellent flexibility and conformance to the
airway anatomy, but has had problems with ingrowth of tumor or granulation through stent interstices. A newer version of the Wallstent has been developed (Permalume, Boston Scientific, Natick, Massachusetts). This new version covers all but the proximal and distal 5 mm of the stent with a thin layer of silicone rubber to prevent tissue ingrowth or granulation ingrowth. The next generation of Wallstent recently released is the Wallgraft (Boston Scientific, Maple Grove, Minnesota), which is made up of the same monofilament structure of the Wallstent and Permalume stent. Unlike the Permalume stent, the Wallgraft has a polyethylene covering that extends to the end of the cylindric mesh, producing a complete covering of the metal structure.

Another second-generation stent, the Ultraflex (Boston Scientific, Natick, Massachusetts) stent, is a self-expanding prosthesis woven from a single strand of nitinol. This nickel-titanium alloy stent exhibits properties of “shaped memory,” meaning that at low temperatures the alloy deforms plastically (martensitic state), whereas at higher temperatures, it regains its original shape (austenitic state) [8]. Covered and uncovered versions are available, and because of the single-strand nature of their construction, endoscopic retrieval is more feasible than with a Wallstent or a Gianturco stent.

These second-generation stents have improved conformation to the airway contours. Their ease of delivery with fiber-optic bronchoscopy and fluoroscopy also has led to their widespread use for tracheobronchial stenoses. Although refinements have continued to be made over the past two decades, the existing stent designs still are flawed. The ideal stent should possess the following characteristics:

1. Ease of insertion.
2. Ability to be adjusted or removed.
3. Ability to re-establish and maintain airway patency.
4. Stability to prevent migration.
5. Consistency firm enough to resist compressive forces, yet compliant enough to prevent airway erosion.
6. Ability to conform to airway contours.
7. Low incidence of infection or granulation tissue.
8. Normal mobilization of secretions and minimal interference with mucociliary clearance.

Although silicone and metal stents possess some of these characteristics, each also lacks other significant characteristics. Thus, the ideal stent is yet to be created.

**Indications for airway stenting**

The large variety of indications for airway stent placement is listed in Table 2. Most patients requiring tracheobronchial stents have malignant disease, most commonly bronchogenic carcinoma. Proximal endobronchial tumor without distal lobar obstruction is the situation most amenable to airway palliation.
These patients may receive rapid and satisfying palliation by laser or core out of the endobronchial disease (Fig. 2B) [1]. In these patients, airway stenting may prolong the period of palliation initially achieved by mechanical or laser reestablishment of the airway (Fig. 2C). Patients who have locally advanced lung cancer also may have significant extrinsic compression of the airway, with or without endoluminal tumor. Airway stenting is the only immediate treatment for unresectable extrinsic airway compression, and it can provide prompt stabilization of a threatened airway while the primary tumor is treated with chemotherapy or radiation. In advanced recurrent disease, airway stenting can produce a gratifying improvement in the quality of life and an avoidance of dying from airway obstruction.

Other primary tumors adjacent to the airway may produce airway obstruction by direct invasion or extrinsic compression (Fig. 3A–C). Esophageal cancer, head and neck tumors, and thyroid cancer all may result in tracheal obstruction that can be palliated by stent placement. Expandable endoesophageal stents have produced a significant improvement in the palliation of patients who have malignant esophageal obstruction. When these stents are placed in the upper esophagus, however, they may result in a secondary extrinsic compression of the trachea or main-stem bronchi. In these situations the airway can be palliated with a second stent placed in the airway to maintain airway patency [9].
Primary airway tumors are treated most commonly with definitive surgical resection unless the length or extent of tumor precludes operability. Radiation is the usual second-line therapy for patients who are not candidates for surgical resection; however, for airway stabilization during treatment or for persistent airway stenosis after definitive therapy, patients who have primary tumors and endobronchial obstruction are candidates for stent placement.

Renal cell carcinoma, breast cancer, and colon cancer lead the list of primary tumors that are prone to airway metastases. Central endoluminal tumor from metastatic disease has the same indications for palliation as elucidated above. When the paratracheal or subcarinal lymph nodes are involved, associated extrinsic compression might occur. With extrinsic compression or a rapid occurrence of endoluminal tumor, airway stenting provides immediate and reliable palliation of obstruction.

The most common etiology of benign tracheal stenosis is a postintubation injury resulting in a cuff or stomal stenosis. For definitive therapy with reliable results, most of these patients are best treated with a tracheal sleeve resection [10]. This recommendation is true even for patients who have a high surgical risk, because a tracheal resection and reconstruction is usually only a neck operation with a minor physiologic insult that is well tolerated by most patients. It is rare that benign stenoses are corrected permanently by endoscopic treatment with dilatation, laser resection, or stenting. Especially in patients who have significant comorbidities, the repeated interventions required for endoscopic
management may be poorly tolerated and are a further indication for primary surgical repair.

Occasionally, patients may refuse surgery and others may have a long segment stenosis that is not amenable for surgical reconstruction. These are the primary indications for airway stenting in benign tracheal stenosis. Rarely, patients who have an early postintubation stenosis may have the airway remodeled over an indwelling tracheal stent that ultimately could be removed with a narrow, but adequate, and stable airway [9]. Other patients may benefit from temporary endoluminal stenting while awaiting optimal conditions for a planned surgical correction.

For patients who have traumatic airway disruption, airway stenting is not indicated. These patients should have their tracheobronchial laceration corrected surgically. Patients that present later with a benign stricture from trauma also are best corrected by surgical resection and primary reconstruction if possible, with stenting being reserved for unreconstructable lesions or as temporary palliation.

Idiopathic tracheal stenosis involves the proximal trachea and often extends into the subglottic larynx. The initial management of these patients may be periodic dilatation, but in refractory stenoses, they usually are treated with tracheal or laryngotracheal resection and reconstruction. Generally, these lesions are not amenable to tracheal stenting because of their anatomic location extending proximally into and above the cricoid cartilage. It is difficult to seat an endoluminal stent proximal to the cricoid cartilage, and the stent in this location runs the risk for producing subglottic granulations that may extend or further

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Fig. 3. (A) Metastatic leiomyosarcoma of the neck with invasion and extrinsic compression of the cervical trachea producing severe respiratory distress. (B) Wallstent with Permalume is placed, and dilatation with an angioplasty balloon ensures complete expansion. (C) Bronchoscopy after stent deployment reveals a widely patent airway and the patient had immediate and durable palliation of her airway symptoms.
complicate the original stenosis. If these patients do require airway stenting, this probably is best accomplished with external stabilization with a tracheal T-tube.

Anastomotic stenosis after lung transplantation, airway resections, and bronchoplastic procedures now provide a common indication for endobronchial stenting. Anastomotic complications occur in 4% to 15% of lung transplant anastomoses [11]. Most of these patients are not good candidates for direct surgical reconstruction or anastomotic revision and so may be best palliated with temporary or prolonged endobronchial stenting. Anastomotic stricture after tracheal resection or bronchial sleeve resection is uncommon, occurring in approximately 5% of primary airway resections [12]. Many of these patients may be candidates for reoperative surgical resection and reconstruction but usually would benefit from a period of airway stenting to allow maturing of the fibrous scar so that reoperative surgery is facilitated [13].

Most benign stenoses caused by inflammatory or infectious conditions are not appropriate for definitive surgical correction and are best treated by dilatation and endobronchial stenting. This recommendation is also true for various miscellaneous causes of airway obstruction such as relapsing polychondritis, tracheopatthia osteoplastica, and tracheobronchomegaly.

Vascular compression of an adjacent airway may occur in the setting of postpneumonectomy syndrome, aortic aneurysm, or significant pulmonary artery dilatation. Vascular compression of the airway is a relative contraindication to stenting owing to the concern of stent erosion and the development of a fatal bronchovascular fistula. Therefore, in these patients every attempt should be made to correct the underlying problem rather than to use a stent to palliate the secondary consequences of airway compression.

Occasionally, tracheobronchial malacia may result in functional airway obstruction in the absence of a fixed stenosis. Long segment malacia or functional anteroposterior collapse of the airway in patients who have severe chronic obstructive pulmonary disease is another indication for stenting that may result in excellent palliation (Fig. 4A–C). Stenting is more difficult on these patients because of a lack of a malignant or benign stricture in which to seat the stent. These patients often require a more complex stent geometry, such as a carinal Y stent or a tracheal T-tube, to seat the stent adequately and prevent migration.

Generally, patients are candidates for endobronchial stenting when they have malignant or benign obstruction that is not amenable to definitive surgical correction (Table 3). Temporary stenting may be useful to stabilize the airway in preparation for surgical resection [14]. It is important that the ability to place an airway stent does not become the primary indication for its use. Most patients are best treated by definitive surgery, and many other patients benefit from other endobronchial therapeutics that provide reliable results without the disadvantages of an indwelling prosthesis [1].

Bronchoscopic evaluation

Bronchoscopy is essential in the evaluation of the patient who has central airway obstruction and who may be a candidate for stenting. Bronchoscopy
performs five critical functions in the evaluation and treatment of patients who have symptomatic central airway obstruction:

1. Definition of the existence and pathology of the airway abnormality.
2. Temporary stabilization of the critically narrowed airway.
3. Definition of the extent, severity, and complexity of the stenosis.
4. Assessment of the treatment modalities that may be successful given the pathology and anatomy.
5. Direct therapeutic intervention for temporary or long-term airway palliation [9].

<table>
<thead>
<tr>
<th>Surgically correctable lesions</th>
<th>Surgically uncorrectable lesions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient refuses surgery</td>
<td>Extrinsic compression</td>
</tr>
<tr>
<td>Short life-expectancy</td>
<td>Recurrent stricture (after dilation)</td>
</tr>
<tr>
<td>Planned delay of surgical intervention</td>
<td>Recurrent endoluminal tumor</td>
</tr>
<tr>
<td>High surgical risk</td>
<td>Stabilization during chemoradiation</td>
</tr>
<tr>
<td>Trial of airway remodeling</td>
<td>Malacia</td>
</tr>
</tbody>
</table>

The airway anatomy should be mapped carefully, thus defining the extent of the lesion and its relation to the normal anatomy and directly measuring the distance of the stenosis from the vocal cords, cricoid cartilage, carina, and in relation to the main-stem bronchi and bronchus intermedius. Although stents may be placed under fluoroscopic guidance without bronchoscopy, most pulmonary physicians and thoracic surgeons prefer bronchoscopy during the stent delivery to refine the accuracy of stent placement, to provide necessary stent revisions, and to assess the adequacy of the airway after stent placement.

The initial bronchoscopic assessment defines the pathology and anatomy, providing clues to choosing the optimum therapeutic approach. Numerous palliative modalities for unresectable airway lesions exist. Tumor or granulation tissue can be debulked by mechanical core out with the tip of a bronchoscope or with biopsy forceps. This procedure also can be augmented by laser vaporization. Benign or malignant strictures can be dilated with esophageal bougies, with serially sized rigid bronchoscopes, or with hydrostatic balloon dilatation. Patients who have significant extrinsic compression or malacia, however, usually do not have other endoscopic strategies other than airway stenting. Stenting also provides an adjunct to débridement of an endoluminal lesion if the initial therapy fails or has the appearance of likely early failure. The endoscopic techniques for airway palliation are not mutually exclusive. Each of these modalities, including definitive surgical correction, should be available and considered by the physician evaluating a patient who has symptomatic central airway obstruction. Stenting usually is performed only when other strategies have failed. An algorithm for the application of therapeutic bronchoscopy is depicted in Fig. 5.

The availability of rigid bronchoscopy is especially important for airway stenting, because rigid bronchoscopy allows delivery of silicone or expandable airway stents. This characteristic allows for choosing the best stent for the patient anatomy rather than for using a stent simply because a nonexpandable stent was unavailable. It is much easier to manipulate, adjust, and even remove stents by rigid bronchoscopy. In contrast, flexible bronchoscopy provides little ability to adjust expandable stents once they have become seated firmly within the airway. Flexible bronchoscopy is also important and often performed in concert with rigid bronchoscopy. The flexible bronchoscope is more adept at evaluating the distal airways and traversing a stent deployed to aspirate distal secretions and to ensure patency of distal lobar and segmental orifices.

Choice of stent

Silicone and expandable metal stents have advantages and disadvantages that should be considered when the physician chooses the best stent for an individual patient (Table 4). Because no stent is ideal for all clinical situations, to maximize positive outcomes in individual patients, physicians should consider the full assortment of silicone and expandable stents. The primary advantages of the silicone stent are that it can be repositioned and removed easily. The solid silicone rubber has little tissue reactivity, no tumor ingrowth, and minimal granulations.
These stents are inexpensive and easily customized to the airway anatomy. Silicone stents have a defined diameter that prevents uncontrolled expansion. The most common criticism of the silicone stents is their need for rigid bronchoscopy and general anesthetic for delivery. Silicone stents also are criticized for their reduced inner-to-outer diameter ratio compared with that of expandable stents. This reduced ratio, combined with loss of mucociliary clearance, may lead to inspissated secretions within the stent. Silicone stents also have the disadvan-

Table 4
Relative advantages and disadvantages of silicone versus expandable metal stents

<table>
<thead>
<tr>
<th>Silicone Advantages</th>
<th>Disadvantages</th>
<th>Metal Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjustable</td>
<td>Rigid bronchoscopy</td>
<td>Flexible bronchoscopy</td>
<td>Permanent</td>
</tr>
<tr>
<td>Removable</td>
<td>Difficult placement</td>
<td>Easy delivery</td>
<td>Difficult adjustment</td>
</tr>
<tr>
<td>No ingrowth</td>
<td>Dislodgment</td>
<td>Stable placement</td>
<td>Need fluoroscopy</td>
</tr>
<tr>
<td>Unreactive</td>
<td>Decreased inner diameter</td>
<td>Conformation</td>
<td>Granulations</td>
</tr>
<tr>
<td>Controlled expansion</td>
<td>Distortion</td>
<td>Epithelialization</td>
<td>Tumor ingrowth</td>
</tr>
<tr>
<td>Inexpensive</td>
<td>Distortion</td>
<td>Ventilation through interstices</td>
<td>Erosion</td>
</tr>
</tbody>
</table>

tage of potential dislodgment or distortion that may make them more difficult to seat or may result in migration and need for replacement or revision.

The primary advantage of the expandable metal stents is their ease of delivery, by means of flexible bronchoscopy with fluoroscopy under topical anesthesia. These stents are stable, with minimal potential for stent migration, and they conform well to the airway anatomy. Uncovered stents have the theoretic benefit of neoepithelialization with incorporation of the stent into the airway wall and resumption of mucociliary clearance. Because of the metal structure, these stents have less of a wall thickness than silicone rubber stents and therefore a better ratio of inner-to-outer luminal diameter.

The most serious disadvantage of metal stents is that they are essentially permanent and nearly impossible to reposition or remove. This characteristic is especially troubling when tumor ingrowth or granulation tissue produces recurrent obstruction inside the stent, requiring repeated débridement or repeat stenting within the preexisting stent. The covered stents have less difficulty with tumor and granulation ingrowth, making them easier to remove, although the bare metal ends of these stents still are incorporated into the airway wall with possible tumor ingrowth and granulation tissue. The radial force exerted by expandable stents creates the potential for erosion into surrounding structures with a possible bronchovascular fistula.

For patients who have advanced malignancy and airway obstruction, silicone stents and covered expandable stents offer reliable palliation. The optimum choice of a stent in this setting may be determined by the anatomy of the lesion and the experience and preference of the pulmonary physician or thoracic surgeon. More controversy exists, over patients who have benign disease. Some have pointed to the similar rate of complications reported for silicone stents and expandable metal stents as a rationale in supporting the use of expandable stents in benign disease [15]. Others feel that the severity and irreversibility of the complications from expandable stents are a strong relative contraindication to their use in benign disease [9,16]. The permanence of expandable stents, their inability to be repositioned, the possibility of extension of airway injury by stent-related granulations, and the concern about potential erosion of a long-standing stent all discourage consideration of metal stents for benign disease. For some settings, however, the anatomy or the position of the lesion may make adequate stenting with silicone stents impossible; thus, expandable stents may provide the only remedy.

**Stent placement**

Patients undergoing flexible bronchoscopy can be managed routinely with topical anesthesia, with or without intravenous sedation. When planning flexible bronchoscopy, however, the degree of airway compromise must be considered carefully. Extreme caution should be exercised in initiating endoscopy with minimal support in the endoscopy unit when one is evaluating a patient who has potentially critical central airway obstruction. In this setting, flexible bronchos-
copy, with the immediate availability of general anesthesia, and rigid bronchoscopy provide a safer environment for establishment of airway control.

Patients undergoing rigid bronchoscopy require a general anesthetic. Most patients can be managed with routine ventilation to the ventilating side limb of the rigid bronchoscope. Occasional catheter jet ventilation may be helpful, but this generally adds unnecessary complexity without added benefit over standard ventilation techniques. To facilitate adequate ventilation, the endoscopist may need to negotiate the stenosis and direct the ventilating bronchoscope into a mainstem bronchus. This necessity is facilitated by the immediate presence of small pediatric rigid bronchoscopes that can traverse the stenosis. With a closed telescope-guided system, it is possible to maintain ventilation, even during delivery and positioning of the endoluminal stent. Temporary cessation of ventilation, however, may be useful to minimize aerosolization of blood or secretions that may obscure the endoscopic field.

Bronchoscopy serves to define the proximal and distal extent of the stenosis, which can be marked with external radiopaque markers if stent deployment is aided with fluoroscopy. A core out or laser vaporization of endoluminal tumor or dilatation of a stricture prepares the airway for maximum stent deployment. The length of the airway to be stented can be measured directly and the diameter is estimated with the diameter of the rigid bronchoscope as a benchmark. Expandable stents have different delivery systems consisting of constraint within a sheath (Wall-stent, Ultraflex stent) or expansion over a balloon (Palmaz stent, Strecker stent). These stents are deployed with fluoroscopy and the radiopaque landmarks placed with the initial bronchoscopy. It is sometimes possible to provide some minimal revision of the proximal or distal ends of a Wallstent or Ultraflex stent before it becomes seated firmly against the airway wall. This revision is easier with the Ultraflex stent because of its woven construction. Significant manipulation of the Wallstent may result in unraveling of the wire mesh structure and loss of stent integrity.

Silicone stents are more difficult to deploy and four strategies have been described for the accurate placement of these stents by rigid bronchoscopy [9]. One technique places the stent on the outside of an appropriately sized rigid bronchoscope with an endotracheal tube inserted as a sheath over the proximal portion of the bronchoscope. The patient then is intubated with the rigid bronchoscope and the overlying stent and pusher tube. This pusher tube prevents the stent from riding up on the bronchoscope as it is inserted. After the tip of the bronchoscope is placed through the stenosis, the bronchoscope is rotated gradually and withdrawn, but with the external sheath held in place and pushing the stent off the tip of the bronchoscope at the desired location. Grasping forceps then can be used to modify and adjust the final stent position [4]. The main problem with this technique is the bulk of the bronchoscope-stent-pusher-tube apparatus in passing through the vocal cords and through the area of stenosis.

The second technique, popularized by Dumon [5], uses a specialized stent delivery system, the Dumon-Harrell Universal Bronchoscope (Efer la Ciotat, France, and Bryan Corporation, Woburn, Massachusetts). This system features
tubes of various sizes that can be used to calibrate and dilate the stenosis. These tubes also can be used as introducers for prostheses of all sizes. Once the stenosis has been dilated and a stent chosen, the stent is collapsed into the distal end of the delivery tube, which is passed through the bronchoscope to the site of stenosis. A plunger system then is used for pushing the stent out of the introducer. Fine-tuning of the stent positioning again is performed under direct visualization with forceps.

The third technique delivers the endoluminal stent through the lumen of the rigid bronchoscope without any specialized equipment [1]. Rigid bronchoscopy is performed with a Storz bronchoscope (“Shap-shay” laser bronchotracheoscope, Karl Storz Endoscopy America, Culver City, California) that has no internal light carrier and a smooth internal lumen, allowing placement of 14 mm or smaller silicone stents through the lumen of the bronchoscope. This placement is facilitated by lubricating the stent with a silicone lubricant that allows the stent to be pushed through the rigid bronchoscope with grasping forceps and directly positioned. This method has the benefit of requiring fewer manipulations with less airway trauma and without the need for specialized equipment.

The fourth technique involves direct laryngoscopy to place the stent through the vocal cords into the proximal airway with grasping forceps or Magill forceps. Rigid bronchoscopy then is performed, and the stent is manipulated into appropriate position. This technique is most useful for stents having a diameter greater than 14 mm or for carinal Y stents that cannot fit through the Storz bronchoscope. This technique has the advantage of allowing larger stents to be placed through the vocal cords with minimal trauma.

Carinal Y stents are especially difficult to place owing to their bulk and geometry. Some have introduced these stents over a rigid bronchoscope placed through the left main-stem limb, with a Fogarty catheter (Edwards Lifesciences, Irvine, California) placed through the right main-stem limb and into the right main-stem bronchus to guide proper placement [4]. Others have described placing carinal stents into the airway by means of direct laryngoscopy [17]. Rigid bronchoscopy through the tracheal limb of the Y stent then can be used to straighten and seat the main-stem bronchi stent limbs into their appropriate locations. Sometimes, it is easiest to invert the shorter right main-stem limb inside out into the tracheal limb. When the left main-stem limb is seated at the carina, the right main-stem limb then can be pushed out into the right main-stem with the grasping forceps or the tip of the telescope.

Careful endoscopic evaluation of stent position is necessary before completion of the procedure. Because of its short length, the right main-stem bronchus is the most difficult site for stenting. Here, the physician can modify the silicone stent by cutting it at an angle with a shorter lateral length than medial length. This action facilitates seating while maintaining patency to the right upper-lobe orifice. Inexact deployment of the silicone or expandable stent with partial obstruction of a lobar or segmental orifice or incomplete coverage of the tumor stenosis should not be accepted. In these cases, the stent should be repositioned endoscopically, or it should be removed and placement should be reattempted. A high degree of stent accuracy is necessary to achieve optimal palliation and minimal complications.
In some cases it may be necessary to place multiple stents to achieve complete palliation. Bilateral main-stem bronchial obstruction can be managed with a solitary carina stent or bilateral bronchial stents. Sometimes extrinsic compression of the subcarinal space produces simultaneous obstruction of the right main-stem bronchus and bronchus intermedius. Two separate stents can be placed to provide good airway palliation and to maintain unobstructed ventilation of the right upper lobe. If the right main-stem bronchus stent is modified by means of cutting the distal end at an angle as described above, the medial edge of the bronchus intermedius stent and right main-stem bronchus stent may intussuscept, while providing an unobstructed orifice to the right upper lobe [9].

The final endoscopic assessment should provide an estimate of the adequacy of airway palliation and the stability of the stent. It also should assist in anticipating potential complications. To maximize the diameter and minimize complications of migration, granulations, and secretion retention, expandable stents should be seated firmly in the full circumference of the airway. Silicone stents should be seated firmly to avoid dislodgment. A stent that is too big for the stenosis, however, may buckle and result in partial airway obstruction by the stent itself. Granulation tissue can develop at the proximal or distal end of stents, particularly in the bare metal portion of expandable stents. If possible, it is preferable to keep these areas away from lobar or segmental orifices; otherwise, granulation tissue may lead to recurrent obstruction.

Stent obstruction with encrusted secretions is a potential complication, particularly in silicone stents. After stent placement the patient should stay well hydrated in an effort to minimize the thickness of secretions. Mucomyst nebulizer treatments are reserved for those patients who develop stent obstruction from inspissated secretions. Postobstructive infection should be treated with appropriate antibiotics, but routine antibiotic therapy is unnecessary because of stent placement. Steroids are not employed routinely after stent placement, except for the potential treatment of glottic edema secondary to trauma during stent placement itself.

Patients who have an indwelling stent and who develop recurrent or worsening airway symptoms should have a bronchoscopy to exclude stent malposition or obstruction. Stents that have become obstructed with inspissated secretions usually can be cleaned adequately in vivo with the rigid or the flexible bronchoscope. With silicone stents it is also easy to remove the stent temporarily, cleaning them in a basin of hydrogen peroxide and reinserting the same stent. Granulations or tumor progression may infiltrate through the interstices of a metal stent. Tumor and granulation tissue can be debrided mechanically or laser vaporized to relieve stent obstruction.

Results

As with most other procedures, good results in airway stenting largely depend on proper patient selection. Satisfactory or excellent results can be achieved in
90% to 96% of patients undergoing therapeutic bronchoscopy, including stenting [1,18]. Results usually depend more on the site and distal extent of tumor infiltration rather than the histology or style of stent chosen. Distal lesions that extend into lobar or segmental orifices are much less likely to achieve successful palliation than those lesions consisting of focal tracheal, main-stem bronchial, or bronchus intermedius obstruction.

The major disadvantage of silicone stents includes stent migration and obstruction of the stent with inspissated secretions. Several series now have accumulated experience with patients after silicone stent placement and show a rate of stent migration of 5% to 10%, and a 4% to 8% rate of stent obstruction with inspissated secretions or granulations [9,18,19]. The University of Washington experience confirms the palliative nature of silicone stent placement, with 39% of patients requiring repeat procedures for stent revision or for clearing of obstructing secretions. Because of the lack of incorporation of silicone stents into the airway wall, however, these complications are fairly minor and easily managed by endoscopy and stent revision or débridement. Overall, it seems that in properly selected patients, good results can be achieved in more than 90% of patients receiving silicone stents, with 10% to 40% of patients requiring further endoscopies or stent revision [9,18,19].

The Wallstent has been the most frequently used expandable airway stent in the United States. Several small series of 12 to 50 patients have been reported, combining outcomes for benign and malignant lesions. These series also have shown a 90% to 95% success in achieving temporary palliation, with approximately 15% of patients developing stent obstruction owing to tumor or granulation ingrowth [20,21].

Few studies have been published regarding the use of the Ultraflex stent. Jantz and Silvestri [15] have inserted 49 Ultraflex stents into 34 patients having benign or malignant tracheobronchial obstruction. With a mean follow-up of nearly 20 months, none of the 16 patients who had benign tracheobronchial disease had suffered complications of granuloma formation or secretion retention. The only published comparison between the Wallstent and the Ultraflex stent has been in the palliative treatment of esophageal obstruction. In these patients, the Wallstent was associated with higher procedure-related mortality and early complication rate. Stent dysfunction and reintervention rate, however, was higher for patients receiving the Ultraflex stent [22]. In this series, the Wallstent was found to have a greater dynamic expansile force, and the Ultraflex stent was more flexible and easier to reposition or remove after deployment.

Summary

Various airway pathologies may result in central airway obstruction. For patients who have benign and malignant disease, definitive surgical correction by tracheobronchial resection and reconstruction is preferred. Numerous patients, however, have unresectable airway lesions owing to the extent of disease or to
medical or surgical contraindications. These patients can be palliated by several endoscopic strategies, including dilatation, core out of tumor, laser resection, endobronchial brachytherapy, or photodynamic therapy. Airway stenting with silicone or expandable metal stents provides reliable and durable palliation in 80% to 95% of properly selected patients. The major advantages of silicone stents are the ease of customization, repositioning, and removal, with the major drawbacks being stent migration or stent obstruction. Expandable metal stents have the advantage of ease of insertion, conformation to the airway, low inner-to-outer diameter ratio, and stent stability. These advantages, however, are offset by (1) the development of tumor ingrowth or of granulation at the end of the stent or through the interstices of the stent and (2) the difficulty or impossibility of stent repositioning or removal once it has been seated completely within the airway.

Management of the patient who has central airway obstruction requires a thorough knowledge and consideration of the surgical and endoscopic management options and, usually, a multidisciplinary approach, with experienced thoracic surgical consultation to evaluate the potential for definitive surgical correction. The interventional bronchoscopist must consider the spectrum of endoscopic therapeutics fully. Most patients benefit from combining strategies in a flexible algorithm directed at optimizing patient outcomes. The benefits and risks of airway stenting must be considered in comparison with the other options for airway palliation. In refractory strictures, rapidly recurrent tumor, or extrinsic compression, endobronchial stenting likely will be necessary to achieve durable palliation of airway obstruction. The short- and long-term implications of airway stenting, including the complications of silicone versus expandable metal stents, should be considered thoroughly, while the physician bases treatment or procedure decisions on individual patient anatomy and expected natural history.

References


