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Review Article

Airway Stenting

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Abstract
Interventional pulmonology, otherwise known as "airway stenting," has developed in the field of pulmonary medicine focused on using advanced bronchoscopic techniques to treat airway disorders. Tracheobronchial disorders can be caused by malignant or benign tumors, extrinsic compression, postintubation tracheal injuries, tracheobronchomalacia, or sequelae after tracheostomy. Tracheobronchial prostheses, known as airway stents, are used to palliate the effects of large airway obstruction. Specially designed stents are being used increasingly, not only in the airways, but also in the biliary tree, esophagus, urinary tract, and vascular system. There are two main types of airway stents currently available; tube stents made of silicone, and expandable metallic stents. Silicone stents are usually placed with the aid of a rigid bronchoscope while the patient is under general anesthesia. Unlike silicone stents, metal stents can be placed with a flexible bronchoscope. We examine the advantages and disadvantages of currently available stents and present our thoughts on the future development of airway stenting.

Key words Airway stent · Silicone · Metal · Bioabsorbable

Introduction

Advances in bronchoscopic techniques have led to the development of interventional pulmonology, in the form of airway stenting, for the treatment of endotracheo-bronchial disorders. The medical term "stent" was introduced by Charles R. Stent, a British dentist who developed a device that supported the healing of gingival grafts. The term has since been used to refer to any device designed to maintain the integrity of hollow tubular structures.

The first clinical application of a T-shaped endotracheal silicone tube for airway stenting was reported by Montogomery.[1] The current generation of airway silicone stents was introduced by Duvall and Bauer[2] and Cooper et al.,[3] who modified the Montgomery T-tube design so that it could be inserted by bronchoscopy. In 1989, Cooper et al.[4] reported using a modified silastic T-Y tube for airway problems in 47 patients, including 11 with malignant obstruction. In 1990. Dumon[5] published excellent results of using an originally designed stent made of silicone in 66 patients. In the late 1980s, airway stents made of metal were developed, such as the Gianturco stent, which consists of a continuous loop of stainless-steel zigzag wire.[6,7]

Management of the patient with a major airway problem requires many surgical and endoscopic considerations and, usually, a multidisciplinary approach. Interventional broncoscopy provides important stabilization of the diseased airway. Temporary or permanent relief of airway obstruction provides important palliation, with remarkably improved quality of life and potentially prolonged survival. A variety of techniques are currently used for the palliation of malignant obstruction, such as dilatation, mechanical coring-out of the tumor, laser vaporization, photodynamic therapy, cryotherapy, brachytherapy, and stenting. Good results from airway stenting largely depend on patient selection, but satisfactory or excellent results are generally achieved in most patients undergoing airway stenting. Results also depend on the site and distal extent of tumor invasion and on the style of stent chosen.

The indications for airway stenting include[8]:

1. Malignant tracheobronchial obstruction with extrinsic compression of large airways in patients

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for whom curative therapeutic options have been exhausted
2. Malignant tracheobronchial obstruction despite bronchoscopic resection and dilatation
3. Malignant tracheobronchial obstruction in patients undergoing external beam radiation
4. Postintubation subglottic stenosis after failure of bronchoscopic resection or dilatation
5. Benign, complex tracheal stenosis in patients who are not surgical candidates
6. Benign tracheal stenosis after failure of bronchoscopic resection or dilatation
7. Benign tracheal or bronchial stenosis from inflammatory or infectious processes while waiting for a response to systemic therapy or pending open surgical resection
8. Localized or extensive tracheobronchomalacia regardless of cause
9. Anastomotic strictures after lung and heart-lung transplantation
10. Tracheo- or bronchoesophageal fistula

Airway Stents

There are two main types of airway stents in use today: tubular stents made of silicone, and expandable metallic stents. The Dumon stent, a silicone tube, is well established, especially for the treatment of stenoses resulting from the intraluminal ingrowth of tumors or granulation tissue. Expandable metallic airway stents are most often used in patients with airway stenosis caused by extrinsic tumoral compression. Silicone and expandable metallic stents have different advantages and disadvantages, which should be considered when the physician chooses the most appropriate stent for an individual patient (Table 1).[9]

Table 1. Advantages and disadvantages of silicone and expandable metallic stents

Silicone	Expandable metal
Removable	Permanent
Able to be dislodged	Stable placement
Adjustable	Difficult adjustment
Difficult placement	Easy delivery
Rigid bronchoscopy	Flexible bronchoscopy
General anesthesia	Local anesthesia
No tissue ingrowth	Tissue (tumor) ingrowth
Unreactive	Granulation formation
Decreased inner diameter	High internal/external diameter ratio
No epithelialization	Epithelialization
Can disturb mucociliary clearance	Preserves mucociliary function

Silicone Stents

The Montgomery T-tube is still used for the relief of subglottic stenosis. The T-tube design has been modified by several pulmonologists and surgeons. In 1982, Westaby et al.[10] designed a T-tube in which the distal branch was lengthened and bifurcated to straddle the carina and preserve patency of the airways in a patient who had suffered a severe scalding injury resulting in tracheomalacia and granulation tissue obstruction of the distal trachea and main bronchi. This stent was inserted through a tracheostomy stoma.

Cooper et al.[4] also used a modified Silastic stent in patients with malignant tracheobronchial obstruction. They described a technique for the endoscopic placement of this T-tube in which the horizontal limb is pulled out through a tracheostomy stoma.

Dumon experimented with a modified Montgomery T-tube throughout the 1980s. The Dumon stent is made of molded silicone with external studs placed at regular intervals to prevent dislodgment. Stent implantation in the lower trachea and bronchi did not become standard medical practice until Dumon published excellent clinical outcomes of using silicone stents in patients with several types of airway disease.[5,11]

Freitag et al.[12] designed the Dynamic stent, a silicone Y-stent with a long tracheal and left main bronchial limb, a short right main bronchial limb, and anterolateral walls reinforced with metal hoops. The nonreinforced silicone posterior wall is collapsible and mimics the dynamics of the membranous trachea during inspiration and expiration. Silicone stents have the advantages of being removable after placement, being impermeable to tumor ingrowth, and inducing minimal tissue reaction. However, one of their major disadvantages is that they disturb the physiological mucociliary function of the tracheobronchial epithelium under the stent. Therefore, secretions tend to accumulate in their lumen, which can cause obstruction. Another common criticism of silicone stents is their need for rigid bronchoscopy and general anesthetic for insertion. Silicone stents also have the potential to dislodge and become distorted, which can make them more difficult to seat, or result in migration and the need for replacement or revision.

Metallic Stents

The Gianturco stent was developed in the 1980s and is made up of a continuous zigzag loop of stainless-steel wire compressed into a cylinder, allowing delivery into a vascular or airway stenosis.[7,13] The successful use of expandable metallic stents in the vascular system and biliary tree has led to expansion of their use in the treatment of benign and malignant airway stenoses.[14–21]

The Palmaz stent is a balloon-expandable wire mesh tubular stent. Unlike the Gianturco stent, this stent does not exhibit any intrinsic radial force and is positioned and seated by balloon expansion.[22–24] The stent diameter is determined by inflation of a balloon after insertion. Theoretically, this feature limits hyperexpansion and the risk of perforation. These first-generation metallic stents are now rarely used in adult clinical practice in the United States because of their inflexibility and reports of complications.

The second generation of metallic expandable stents was led by the Wallstent, a self-expandable tubular mesh stent that is delivered in a constrained form and, once released, expands to a preset diameter.[23,25] The Wallstent, also known as the Schneider prosthesis (Schneider, Zurich, Switzerland), is commonly used in Europe to treat airway stenoses.[26] This stent is made of filaments of a cobalt-based super alloy braided in the form of a tubular mesh. It is loaded into a delivery catheter. Once released, the prosthesis expands. The stent is available in a variety of diameters and lengths and can be inserted through a flexible fiberoptic bronchoscope under fluoroscopic guidance.

The next and current generation of Wallstent is the Ultraflex stent, a self-expanding prosthesis woven from a single strand of nitinol. This nickel–titanium alloy stent exhibits properties of "shape memory," meaning that at low temperatures the alloy deforms plastically into a martensitic state, whereas at higher temperatures it regains its original shape, being the austenitic state. Positioning is controlled fluoroscopically. Usually, a guidewire is inserted through the bronchoscope. The scope is then removed, and the loaded delivery catheter is advanced over the guidewire until a radiographically visible plot on the edges of the prosthesis is aligned with previously placed skin markers specifying the limits of the lesion.[27–29]

Metallic stents have the following advantages over silicon stents: insertion and fixation is simpler: they provide better clearance of secretions; they can accommodate varying tracheal dimensions; and they have a high internal-to-external diameter ratio. However, metallic stents are not without problems. Tumor or granulation tissue can grow through stent interstices and once covered by epithelium, metallic stents are not easily removed by conventional bronchoscopic procedures alone; open surgery may be required. Covered and uncovered versions of some metallic stents are available. Covered stents should be deployed in patients with proliferating tracheal tumors or granulation tissue, or in patients with tracheal defects.[28,30]

Properties and Problems

Silicone stents can be removed, but they have the disadvantage of potential dislodgment or distortion, which may make them more difficult to seat or result in migration and the need for replacement or revision.[31] Silicone stents have several other problems, such as disturbance of the physiologic mucociliary function of the tracheobronchial epithelium under the stent. Siliicone stents are relatively thick and cause mucociliary function to be lost in the stented area. Secretions tent to accumulate in the lumen, which can cause obstruction. After stent placement, the patient should stay well hydrated in an effort to prevent the secretions becoming too thick. The most common criticism of silicone stents is the need for rigid bronchoscopy and general anesthetic for delivery. Silicone stents are also criticized for their reduced inner-to-outer diameter ratio compared with that of metallic stents.

In patients with airway obstruction caused by advanced malignant disease, airway stenting can produce a gratifying improvement in quality of life and prevent death from airway obstruction. Thus, the results of short-term palliation are satisfactory. However, airway stenting is associated with complications such as airway inflammation, stent migration, airway erosion, and stent fracture, which can be life-threatening.[31–41] Susanto et al.[24] reported using the Palmaz stent for bronchial stenosis and malacia after lung transplantation, the complications of which included suboptimal positioning, migration and collapse of the stent. Caution should be exercised in recommending metallic stents for benign strictures because the protrusion of granulation tissue through the wire mesh of the stent may occlude the lumen.[41] Spatenka et al.[40] described recurrent airway stenosis after stent placement, caused by the growth of granulation tissue within the stent, and Nashef et al.[33] reported a case of fatal massive hemoptysis from erosion of a stent into the pulmonary artery. Minor hemoptysis resulting from the extramural migration of a broken wire fragment was also reported.[35] The major disadvantage of metallic stents is that once placed, they are extremely difficult to reposition. Stents are usually assimilated into the bronchial epithelium and incorporated into the tracheobronchial wall. The radial force exerted by expandable stents creates the potential for erosion into surrounding structures with a possible bronchovascular fistula.

Granulation tissue formation probably occurs more frequently after the insertion of metallic stents than silicone stents. When tumor ingrowth or granulation tissue through stent interstices produces recurrent obstruction inside the stent, repeated debridement is required.[42] Covered stents have less tumor and granulation tissue ingrowth, although such problems may occur at the bare metal ends of these stents.

In children, the reported complications include collapse and migration of the Palmaz stent and granulation tissue formation.[22,31,43–45] Stent migration can be prevented by epithelialization, which also allows the restoration of mucociliary function; however, it complicates stent removal, especially in pediatric patients. Filler et al.[44] reported the case of a child who died of airway obstruction at the time of metallic stent extraction because the stent was incorporated into the tracheal wall.

The Wallstent (Schneider, Minneapolis, MN/ Schneider [Europe], Bulach, Switzerland) is a self-expanding stent made of woven stainless-steel filaments. Granulation tissue ingrowth at the end of these stents necessitating laser resection has been reported in the literature.[46–48] The lack of long-term follow-up, difficulty with removal, and airway injury at the time of removal all make the Wallstent unsatisfactory for use in benign airway obstruction. The Ultraflex stent is a self-expanding stent made of a single strand of woven nitinol.[29,38] Although it can be easily placed with a flexible bronchoscope under local anesthesia, removal requires general anesthesia and rigid bronchoscopy.

The benefits of stent placement are evident in patients who survive for at least several months after implantation; however, long-term follow-up data are limited to benign diseases.[26,49–54] Benign tracheobronchial stenosis is caused by a variety of non-neoplastic conditions resulting from known and unknown causes. The management of these patients can be challenging. Material fatigue may limit the long-term use of metal stents in the airway.[38] Thus, if these devices are used in benign disease, they may be exposed to great mechanical stress for many years. The absence of this information for these devices should preclude their use for most patients with benign obstruction.

Silicone stents have been used extensively and their long-term sequelae are well documented. These devices also have complications, but their removal and management are relatively easy in properly trained hands. More controversy exists over patients who have benign disease.[13,31] According to some reports, the similar complication rate of silicone stents and expandable metallic stents support the use of expandable stents in patients with benign disease.[38]

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 metallic stents. The primary advantages of silicone stents are that they can be repositioned and removed easily, and they have little tissue reactivity and no tumor ingrowth. The most common criticisms are their need for rigid bronchoscopy for delivery, and their reduced inner-to-outer diameter ratio compared with that of metallic stents. Conversely, the primary advantages of expandable metallic stents are their ease of delivery by flexible bronchoscope with fluoroscopy, and their stability with minimal potential for stent migration. These stents are usually used when there is difficulty seating a silicone stent, if extreme extrinsic compression results in silicone stent distortion, or if it is impossible to place a large enough silicone stent into the airway. However, their use is specifically avoided in patients with benign disease because they may become impossible to reposition or remove.

We expect that the next generation of stents will improve on the excellent qualities offered by silicone and metal stents, and eliminate their downfalls. The ideal stent should be simple to insert, easily removable, rigid enough to resist external compression, allow clearance of secretions, and easy to secure to avoid proximal or distal migration. Stents that are biodegradable[55–57] may offer an alternative for treating airway stenosis in the near future.

Stenting in the Future

The ideal airway stent that combines the advantages of silicone and metallic stents has not yet been developed. Silicone stents tend to disturb airway mucociliary clearance and migrate, and metallic stents cannot be removed by bronchoscopic procedure once covered by epithelium. Therefore, metallic stents should not be used in children because it may be necessary to exchange existing stents for larger ones as they grow.

Bioabsorbable knitted tubular stents made of poly-L-lactic acid (PLLA) may be useful to treat major airway stenosis in the child who is growing up year by year, because extraction of the device is unnecessary. Furthermore, mucociliary clearance function is better maintained, because the normal airway is preserved after stent resorption. Experimental studies have shown that PLLA stents are mechanically strong enough to retain their tubular shape against extrinsic forces.[56] Although further investigations of their long-term results and adjustability to various airway conditions are needed before clinical application, PLLA seems to be a promising material for use in airway stents.

Advances in interventional bronchology, including the bioabsorbable airway stent, may provide definitive alternatives to standard surgical intervention for both malignant and benign airway stenosis in the future.

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