CHEST

Metallic Endobronchial Stents
A Contemporary Resurrection

Sameer K. Avasarala, MD; Lutz Freitag, MD; and Atul C. Mehta, MD

Airway stenting has been practiced for several decades. It is one of the most common procedures performed by interventional pulmonologists. Typically, these stents are implanted to maintain the tubular patency of the tracheobronchial tree. They are only considered as a temporizing measure, or when a surgical option cannot be pursued. Through the past few decades, a number of metallic airway stents have been introduced into the market. First generation stents were comparatively simplistic and crafted from stainless steel. The latest generation of metallic airway stents are hybrid in nature and constructed with complex alloys. As airway stenting become more widely practiced, concerns arose regarding their safety. However, with improved understanding of stent-airway interactions, advancements in biomedical engineering, and a larger emphasis on post procedural care, the use of metallic endobronchial stents has been resurrected. We present the history, technological advancement, and contemporary indications of metallic airway stents.

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Metallic stents are designed to maintain patency of the airway.[1] Deployment of these stents is a common procedure performed by interventional pulmonologists and thoracic surgeons. Metallic stents are considered when no other therapeutic options of acceptable risk are available. These stents gained popularity due to their relative ease of deployment with a flexible bronchoscope, a favorable internal-to-external diameter ratio, identifiable nature on plain chest radiograph, and a relatively lower incidence of migration.

However, over the past several decades, the practice pattern of metallic stent deployment has fluctuated greatly. Initially, as use of these stents increased, their availability increased accordingly. The number of unique long-term complications related to the use of metallic stents also increased proportionally. Well-known complications from metallic stent implantation include granuloma formation (obstructive or nonobstructive), infection, migration, hemoptysis, stent fracture, and in-stent tissue growth. Partly due to unfamiliarity with the prevention and management of these unusual complications, the US Food and Drug Administration (FDA) advised caution in July 2005 regarding the use of metallic stents for benign airway disease.[2] This statement affected practice patterns and resulted in a sharp decline in the use of these stents. Some centers completely abandoned the use of certain types of metallic stents for benign airway diseases.[3]

ABBREVIATIONS: EDAC = excessive dynamic airway collapse; FDA = US Food and Drug Administration; RP = relapsing polychondritis; TBM = tracheobronchomalacia; TEF = tracheobronchoesophageal fistula

AFFILIATIONS: From the Respiratory Institute (Drs Avasarala and Mehta), Cleveland Clinic, Cleveland, OH; and the Department of Pulmonology (Dr Freitag), St. Anna Hospital, Lucerne, Switzerland.

CORRESPONDENCE TO: Atul C. Mehta, MD, Respiratory Institute, Cleveland Clinic, 9500 Euclid Ave, Cleveland, OH 44195; e-mail: mehtaa1@ccf.org

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TABLE 1] Variety of Important Factors That Can Have an Impact on the Likelihood of the Development of Metallic Stent-Related Complications

Stent sizing
Oversized
Undersized
Stent location
Subglottic trachea
Stent factors
Exposed metal of distal ends
Degree of stent covering
Expansile mechanics
Postimplantation management
Lack of standardized management protocol
Lack of adequate clinical and bronchoscopic follow-up
Failure of timely removal of implanted stent

Nevertheless, clinicians and researchers attempted to achieve a better understanding of the basis for these complications, their prevention, and management. Eventually, the result was major advancements in metallic stent technology and appropriate use. Today, a variety of metallic stents are available in the proceduralists' armamentarium. The present review addresses the basis for complications, technological advancements, indications, and outcomes related to metallic stents.

Basis for Complications and Their Management

Akin to the aspiration of a foreign body, complications can arise with metallic stents. The proposed bases for metallic stent-related complications are listed in Table 1.

The obstacles of the early years of metallic stent implantation involved the limitations of models and sizes. In addition, the tools to gauge the size of the required stent were relatively imprecise, and the practice relied heavily on guesswork. Often the accuracy of the stent size (diameter and length) and the design were ill-matched based on the availability of a specific device. An undersized stent may cause undue friction, whereas an oversized stent can exert undue pressure on the airway wall, both of which result in excessive granulation tissue formation.[4] However, advancements in radiology have significantly reduced the incidence of these complications. With the advent of high-resolution imaging, multiplanar reconstruction, three-dimensional reconstruction, and thin section cuts, chest CT scans are more accurate in their assessment of airway dimensions.[5-8] The sizing of bronchial stents must be based on measurements from the coronal cuts of a chest CT image. Axial cuts image in an oblique plane and may overestimate the diameter. Devices are now available (Alveolus Stent-Sizing Device; Merit Medical Endotek) that improve congruency between the size of the stent and the selected airway.[9] Although not designed or marketed to do so, CREBalloon Dilatation Catheters (Boston Scientific Co.) can also be used to assist with airway-stent size matching. Neither device has been well studied or proven to change outcomes.

Poor understanding of biophysical interactions, such as foreshortening, pressure distribution, and stent-tissue interactions, also contributed to the higher complication rates with the early metallic stents. Older metallic stents promoted the formation of granulation tissue through a phenomenon known as foreshortening. Their lengths changed under compression; coughing leads to compression and mucosal trauma from the movement of the wire edges[10] (Fig 1A). Suboptimal pressure distribution also plagued older uncovered metallic stents. The hoop strength generated by the stent apparatus exceeded that of the perfusion pressure of the mucosa, generating perturbations in microcirculation and fibroblast proliferation.[11] Stent-tissue interaction is the complex interplay between the viscoelastic factors between a stent and tissue.[12] Tumor and scar tissues demonstrate different time constants when a dilatational force is applied. A gentle expansile force will re-open stenosis but cannot resist the compression secondary to tumor growth (Fig 1B).

Nitinol (an equiatomic metal alloy of nickel and titanium) has emerged as the metallic stent alloy of choice. Its super elasticity and shape memory impart more favorable fatigue behavior compared with that of traditional metal alloys.[13] To avoid undue trauma, metallic stents with sharp ends are avoided. The choice of metallic stent (fully covered, partially covered, or uncovered) is largely predicated by the clinical scenario for which it is being used. Stent-related granulomas are typically treated with bronchoscopic techniques such as cryotherapy or electrocautery. Over the years, proceduralists have become cognizant of the need to avoid metallic stents in the subglottic trachea because the risk of granulation tissue formation is high.[14] The value of poststent management has also become more widely recognized. Literature prior to 2005 seldom addressed poststent management. Assistance with

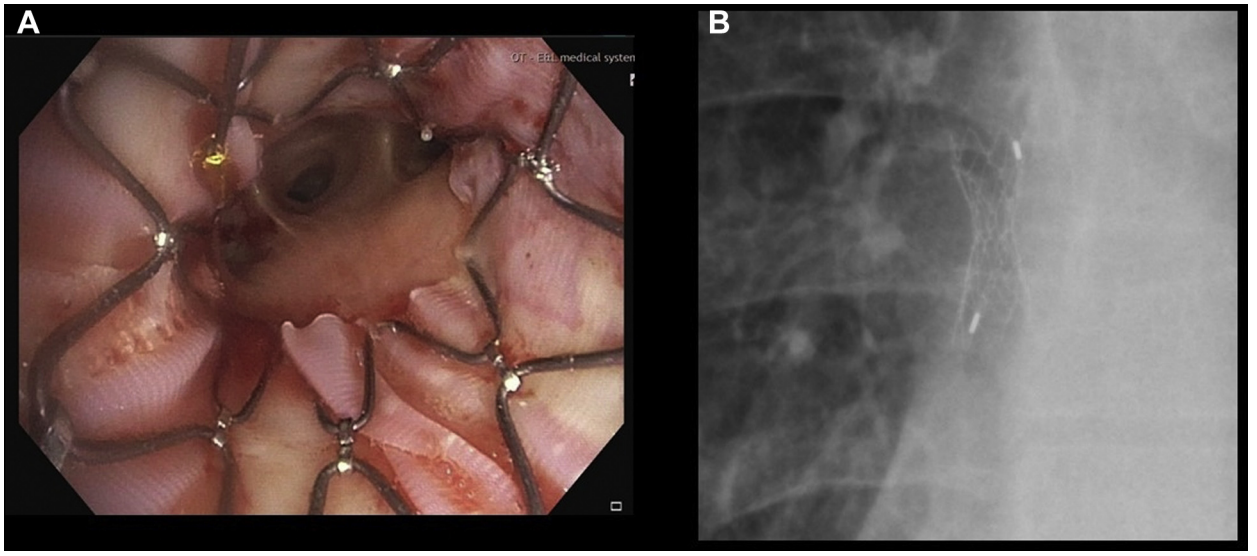

Figure 1 – *The covering of a modern metallic endo-tracheobronchial stent (Silmet stent is pictured in this example) distributes the expansion force over the mucosa. A, Theoretically, this biophysical profile avoids high pinpoint pressures that promote the development of granulation tissue formation. A self-expanding metallic endo-tracheobronchial stent (Silmet stent in this picture) will act as a long-term dilator, gradually opening a stricture within several days. B, The expansion can be observed under fluoroscopy or on controlled plain radiography.*

airway clearance (with nebulized saline and bronchodilators) to reduce the burden of biocolonization, judicious use of antibiotics, frequent follow-up bronchoscopies, and early removal of stents before they become fully granulated are now common practices (Fig 2). Data show that surveillance bronchoscopy within 4 to 6 weeks of stent placement may be useful in detecting early complications and initiating prompt management.[15] However, most other practices are not evidence based; their true effectiveness is currently unknown.

Technological Advancement

As technology and manufacturing advanced, so did metallic stent development. Metallic stents can be grouped into chronologic generations. Although later generations may be more advanced from an engineering standpoint, there have been no head-to-head clinical trials to state that any given stent is better than another. Many of the metallic stents discussed in this article have only been described in retrospective studies or small-sized prospective studies.

First-Generation Stents: Gianturco Z-Stent and Wallstent

Implantation of stents into the airway was first reported in the late 19th century. Trendelenberg and Bond are credited with the initial descriptions of implanting an airway prosthesis.[16] Almost a century later, Montgomery[17] described his experience with his T-tube tracheal stent.

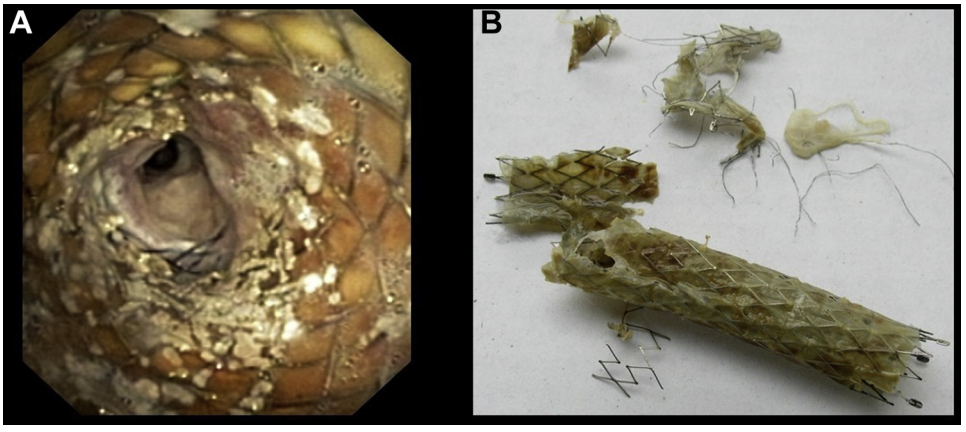

Figure 2 – *A metallic endo-tracheobronchial stent with evidence of biocolonization. A, This can serve as a nidus for an infection or airway obstruction. B, Remnants of a metallic endo-tracheobronchial stent that became fully granulated and fractured.*

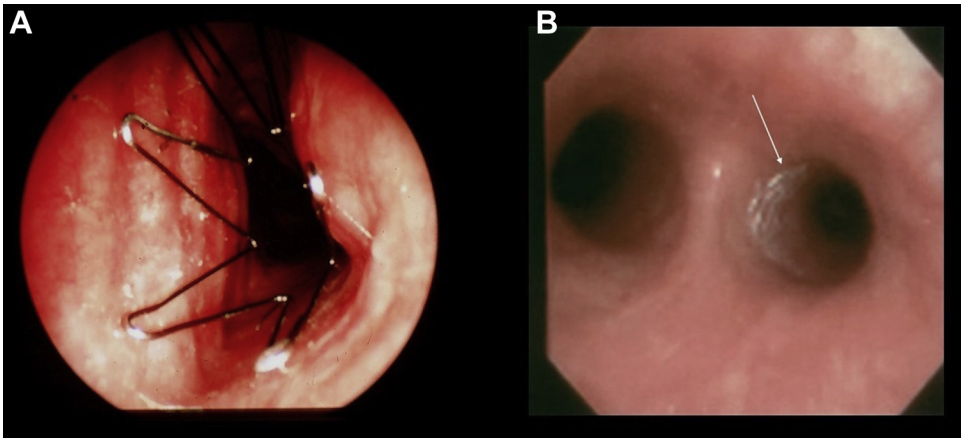

Figure 3 – *A, Implanted Gianturco Z-stent. B, Wallstent implanted (white arrow) into the airway of a patient with relapsing polychondritis. (Panel B was adapted with permission from Sarodia et al[19]).*

Two decades later, early metallic stents were introduced. Their designs were simplistic compared with current metallic stents. The self-expanding Gianturco Z-stent (Cook Europe) (Fig 3A) was originally reported in 1985.[18] It was an endovascular stent and developed by the famed interventional radiologist Cesare Gianturco. Another early metallic stent was the Wallstent (Schneider) (Fig 3B)[19]; it too was initially developed as an endovascular stent. It was first described in radiology literature in 1987.[20] Both the Wallstent and the Gianturco stent were composed of stainless steel. They were delivered into the airway via catheters that ranged from 7F to 12F in diameter. In the original report, the Gianturco Z-stent and the Wallstent were deployed in 55 patients. In this study, 30% of patients who had a Gianturco stent implanted had complications, such as migration, perforation, and/or rupture of the metallic mesh; one fatality was reported.[21] One theory behind these outcomes with the Gianturco stent is the excessive pressure exerted at the Z band, which can result in airway perforation. The complications of stent fracture and migration of the Gianturco stent were not limited to a single case series.[22] In early studies, the Wallstent was also noted to have a high rate of late complications: migration (12%), inflammatory granulation or tumor ingrowth at the tip of the prosthesis (36%), and symptomatic retention of secretions (38%).[23] The ends of the stainless steel wires of the Wallstent caused trauma to the airway mucosa and resulted in the formation of granulation tissue, bleeding, and, in extreme cases, perforation of the airway.

Second-Generation Stents: Palmaz, Strecker, AERO, Ultraflex, and Dynamic (Y)

The second generation of metallic stents included balloon-expandable (Palmaz and Strecker) and self-expanding (Ultraflex and AERO) stents. At that time, balloon-expandable metallic stents were used primarily for the treatment of pediatric tracheobronchomalacia (TBM). However, an airway that was re-captured by a balloon-expandable metallic stent, which has no inherent expansile force, could potentially re-collapse. In pediatric patients, migration of the stent due to natural growth of the airway was also a concern.

The Strecker Bronchial Stent (Boston Scientific Co.) is a balloon-expandable metallic stent of tubular mesh design with a braided tantalum alloy filament.[24] The first case series using Strecker metallic stents was reported in 1991.[25] A large study showed that stent distortion occurred in approximately 25% of the 51 patients who received a Strecker stent.[26]

The Palmaz stent is a balloon-expandable metallic stent with a stainless-steel framework[27] (Fig 4). Dr Julio Palmaz developed these stents to be used within vasculature. They feature a closed-cell design, which confers high radial strength but limited flexibility. In 1998, one of the first series describing the use of the Palmaz stent (Johnson & Johnson Interventional Systems) within the airway was reported. The stents were implanted in the airways of 12 patients, mainly with benign airway pathology (10 of 12). Technical success was achieved in all patients. Ten patients experienced clinical improvement; however, five patients died.[28] All of the patient deaths were reported to be unrelated to the stent.

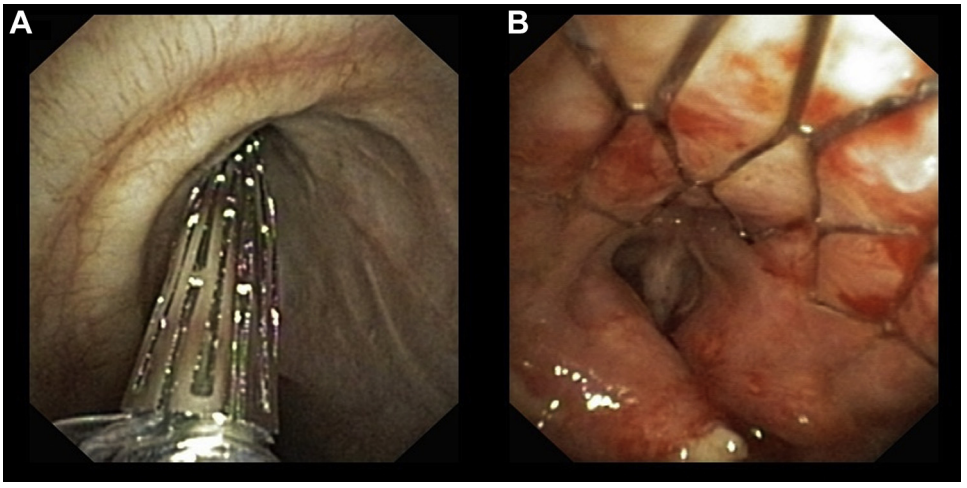

Figure 4 – *Palmaz stent (A) loaded onto a balloon and (B) postimplantation.*

The AERO Tracheobronchial stent (Merit Medical Endotek) is a commonly used self-expanding metallic stent (Fig 5). It is a hybrid stent composed of a laser-cut nitinol frame and a polyurethane cover.[29] A unique feature of the AERO stent is the antimigration fins that embed into the mucosa. Although these fins may help prevent migration, they can be counterproductive when stent removal is required. The hybrid design combines the advantages of a pure metallic stent and a silicone stent; however, the disadvantages (eg, stent migration) still existed. In an early case series of six AERO stents placed in three lung transplant recipients, five stents migrated (83%), six stents (100%) caused thick mucus build-up, and strictures recurred in all patients (100%).[30] A larger study (31 AERO stents among 195 stent procedures) found that the AERO stent had a higher rate of infection and granulation tissue formation compared with the cohort of stents that were studied.[31]

The Ultraflex stent (Boston Scientific) (Fig 5) is another well-known self-expanding metallic stent. It comes in both fully uncovered and partially covered (hybrid) versions.[32] The base of the stent is crafted from knitted nitinol. The central portion of the covered variety is coated with silicone; the ends are uncovered. In both variations, the distal ends of the stent are uncovered, which promotes epithelization and mitigates migration. A large case series (62 Ultraflex stents among 60 patients) reported 100% technical success and a low complication rate (8% mucus plugging, 5% stenosing granulation tissue, 5% stent migration, and 5% tumor ingrowth).[33]

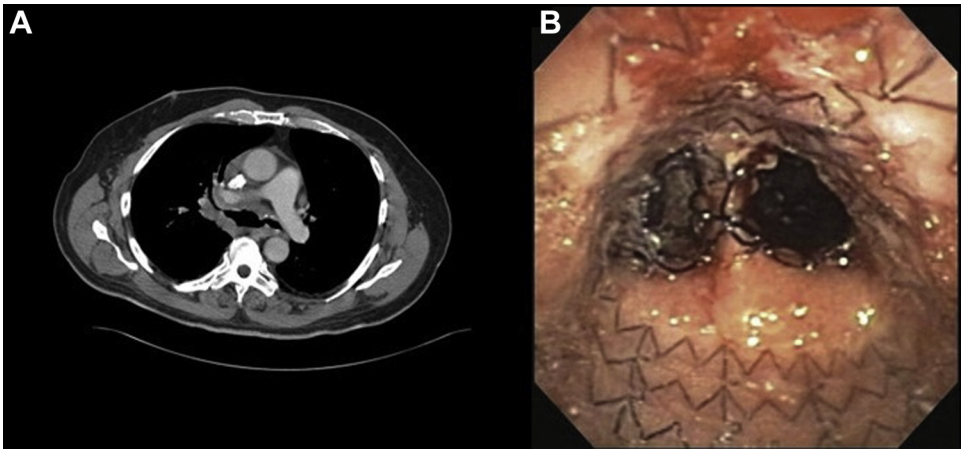

Figure 5 – *A, Chest CT scan demonstrating a tracheomediastinal fistula. B, Multiple metallic stents implanted for the management of the same fistula. An AERO stent has been implanted in the distal tracheal. Ultraflex stents have been implanted in the main bronchi. Figures in Panel A and B were reproduced with permission from Choudhary et al.*[62]

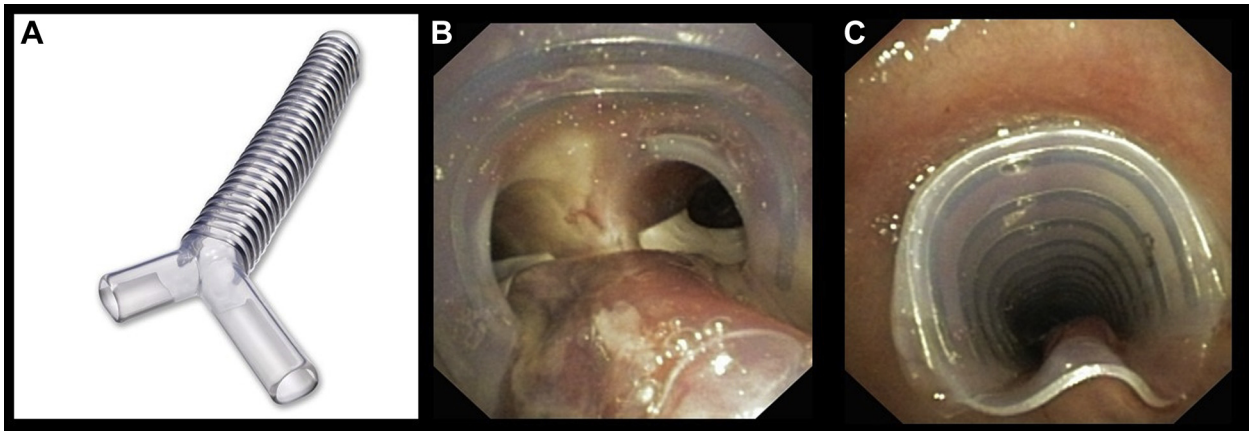

Figure 6 – *Dynamic Y stent (A) prior to and (B-C) postimplantation. Panel A image reproduced with permission from Boston Scientific.*[33]

The Dynamic (Y) tracheobronchial stent (Boston Scientific) is a widely used non-self-expanding metallic stent (Fig 6).[34] It was designed to maintain patency in central airways.[35] The frame is composed of stainless steel struts covered with silicone. The largest trial with this stent included 135 patients with central airway stenosis (malignant or benign) or tracheobronchoesophageal fistulas (TEFs). A follow-up period of 3 months demonstrated a low incidence of stent-associated complications: two patients died of hemoptysis secondary to erosion into vascular structure, and cephalad migration occurred in four patients.[36] Smaller studies with this metallic stent have also noted low rates of stent-related complications.[37] As with most stents, long-term follow-up data are not available. The initial implantation of this stent is done via direct, video, or suspension laryngoscopy. Rigid and flexibly bronchoscopy can be useful with further positioning after it has already been implanted within the proximal trachea.[38-41]

Third-Generation Stents: Bonastent, Silmet, Hanarostent, Carina-Y-Stent, COMVI, and iCAST

A majority of the third-generation metallic stents are hybrid in design, have a nitinol framework and are self-expanding. Table 2 summarizes their salient features. These stents were presented for consideration following publication of the FDA report in 2005.[2] The availability of multiple sizes of these stents improved stent-to-airway size matching.[40]

The most contemporary example of a self-expanding metallic stent is the Bonastent tracheal/bronchial stent (EndoChoice, Inc.) (Fig 7A). The Bonastent has a hook and cross-wire framework primarily composed of nitinol wire. It is covered by a silicone membrane, which mitigates luminal compromise from granulation tissue.[42] It can be deployed via flexible bronchoscope with wire-guided fluoroscopy or via a rigid bronchoscope with direct visualization. The Bonastent remains in place due to direct pressure upon the adjacent airway.[40] There are limited clinical data on this stent. Thus far, one small case series presented by Holden et al[43] described their experience with five Bonastent deployments among four patients. In this single study, no early complications (within 30 days of placement) were reported. No case series or reports describing the Bonastent have been published.

The Silmet stent (Novatech) (Fig 1) is a self-expanding metallic stent that is similar to the Bonastent.[44] Its nitinol metallic frame is fully covered with polyester. This stent is offered in straight, conical, and customized (direct from the manufacturer) versions. The largest case series describes the implantation of 52 Silmet stents among 52 patients. Technical success was achieved in 51 patients (98%), and radiographic improvement was noted in 25 patients (48%). A 15% tumor overgrowth and 7.6% migration rate were also reported.[45]

The Hanarostent (M.I. Tech) (Fig 7B) is a fully covered self-expanding metallic stent.[46] It is not frequently used in the United States and is more frequently used in Asia. Outcome data have not yet been published for this stent.

The Carina-Y-Stent (MICRO-TECH) (Fig 7C) is a metallic stent with a Y design to allow placement into the main carina. It is constructed from nitinol mesh and has atraumatic ends. Although it is a Y-shaped stent, it can be placed without the use of a rigid bronchoscope. In addition to the Y configuration, this stent is also available in straight and J configurations for use in patients following a pneumonectomy.[47] Data are limited

TABLE 2] Multiple Third-Generation Metallic Stents That Are Currently on the Market. Each of Them Has a Unique Profile.

Model	Mechanics	Framework	Covering	Available Sizes (Diameter × Length)	Advantages	Disadvantages
Bonastent[a]	Self-expanding	Nitinol	Silicone	10-20 mm × 20-80 mm	Can be placed with FB	Stent migration Stent fracture
Silmet	Self-expanding	Nitinol	Polyester	10-20 mm × 20-60 mm (straight, fully covered)	Multiple shapes (straight, conical, or customized from the manufacturer)	Stent migration Stent fracture
Hanarostent	Self-expanding	Nitinol	Silicone	10-22 mm × 30-80 mm	Can be placed with FB Antimigration flares at both ends	Stent migration Stent fracture
Carina-Y-Stent	Self-expanding	Nitinol	Elastic	Tracheal limb, 16-20 mm × 40-50 mm Main bronchi limb diameter range, 12-14 mm	Comes in Y, J, and straight configurations Atraumatic ends Varied coverage options	Stent migration Stent fracture
COMVI	Self-expanding	Nitinol	Polytetrafluoroethylene	10-24 mm[b] × 30-100 mm	Triple layered construction	Stent migration Stent fracture
iCAST[a]	Balloon expandable	Stainless steel	Polytetrafluoroethylene	5-12 mm × 16-59 mm	Low crossing profile Can be used for lobar stenting	Stent migration is common
Dynamic[a]	Rigid stent	Stainless steel	Silicone	Tracheal limb, 11-15 mm × 110 mm Main bronchi limbs, 8-12 mm × 25/40 (right/left) mm	Maintains airway patency well due to rigid profile	Requires laryngoscopy during the initial stages of implantation

FB = flexible bronchoscope.
[a]Manufactured and marketed in the United States.
[b]When fully expanded, the size diameters of the distal side flares may be larger.

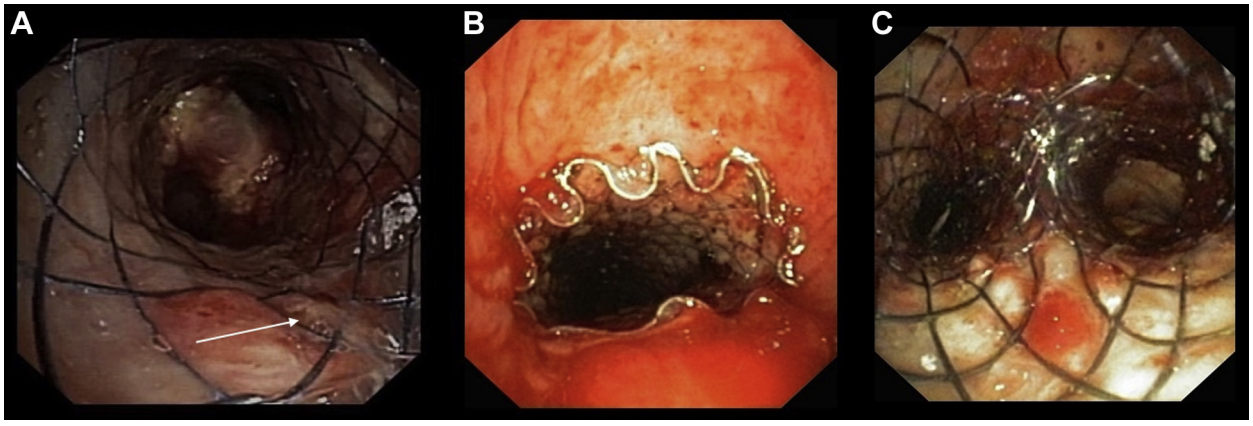

Figure 7 – *Newer generation metallic stents: A, Bonastent; B, Hanarostent; and C, Carina-Y-Stent. The white arrow indicates tissue in-growth through the Bonastent.*

with regard to this particular stent; the published case series do not exclusively assess this model of a self-expanding Y-shaped metallic stent.[48,49]

The COMVI tracheobronchial stent (Taewoong Medical) is another self-expandable metallic stent that has a nitinol wire structure with a polytetrafluoroethylene membrane. Its structure is unique in that it is triple layered (wire-membrane-wire).[50] These stents are not commonly used in the United States but have been tested and are used in some parts of Asia.[51,52] In the larger of two studies, 30 stents were placed among 24 patients. The incidence of granulation tissue formation (36.7%) and of stent migration (13.3%) was relatively high.[51]

The most widely used balloon-expandable tracheobronchial stent is the iCAST (Atrium) (Fig 8).[53] It was initially designed as an endovascular stent. Its frame is composed of stainless steel covered in two layers of polytetrafluoroethylene.[40] It can be deployed via the 2.8-mm working channel of a standard adult flexible bronchoscope. The iCAST stents come in sizes as small as 5 mm × 16 mm, making them the stent of choice for a lobar airway. Sethi et al[54] reported a < 10% complication rate with 120 iCAST stents deployed in patients with lobar bronchial stenosis. Although the complication rates were low, it remains unclear if there is symptomatic improvement or physiologic benefit from lobar stenting.[54,55]

Contemporary Indications

A variety of indications for the deployment of a metallic stent are accepted in current clinical practice.

Tracheoesophageal Fistula

A tracheoesophageal fistula (or TEF) is defined as an abnormal communication between the main airways (trachea or main bronchi) and the esophagus. It has a significant morbidity and mortality burden. It can lead to recurrent chemical pneumonitis or pneumonia from

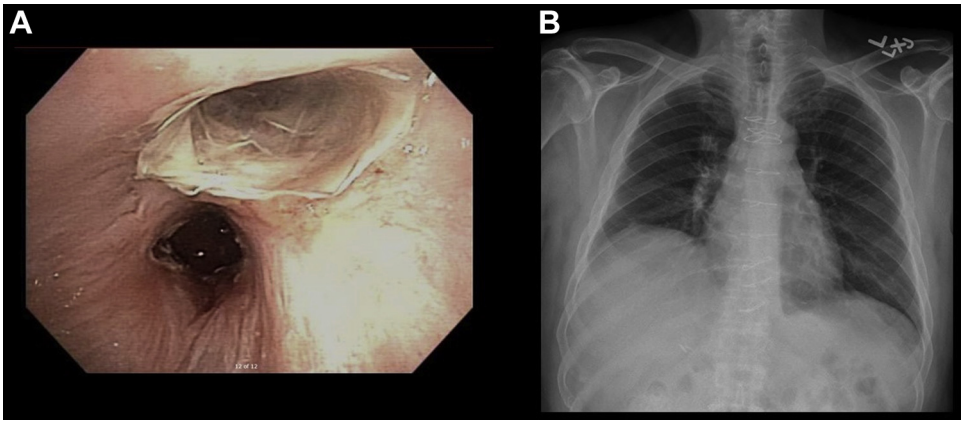

Figure 8 – *A, iCAST implanted into the right upper lobe. B, The same iCAST stent is well visualized on plain chest radiography.*

airway soiling.[56] Benign and malignant TEF are two distinct entities. The latter portends a poor prognosis, typically in the range of weeks to months.[57] Because most patients with TEF have major medical comorbidities, the strategy of airway and/or esophageal stenting is more commonly used than surgery.

Self-expanding metallic stents are preferred in TEF. They can be deployed rapidly and accurately with the use of a guidewire or under direct visualization. Unlike a semi-rigid silicone stent, self-expanding metallic stents can be quickly repositioned following implantation if needed. This capability is extremely advantageous in TEF because a malpositioned stent can worsen the fistula, obstruct the airway, or damage the esophagus, trachea, or surrounding structures. Compared with silicone stents, improved secretion clearance, more precise accommodation to tracheal dimensions, and lower incidence of migration are advantages of metallic stents in the management of TEF.[58]

In a study of 63 patients with malignant TEF, complete closure was achieved in 45 patients (71%).[59] One technical recommendation is that the stent should be 4 cm longer than the fistula to effect a 2-cm overlap on each end of the TEF.[57] This practice is theorized to provide adequate coverage for the TEF and offer protection when the malignant TEF naturally increases in size. No strategy is universally accepted with regard to which metallic stent to use to treat a TEF. Several of the metallic stents described in the preceding section could potentially be used; the Dynamic (Y) and Hanarostent are specifically marketed for this purpose.[34,46] Although combined (esophageal and airway stenting) can be performed, it carries a high risk of fistula enlargement.[60,61]

Tracheomediastinal Fistula

Tracheomediastinal fistulas, which involve an abnormal communication between the trachea and the mediastinum, are rare and commonly fatal. They usually occur due to underlying malignancies, lymphoma being the most common type. Case reports describe these fistulas being treated with a variety of metallic stents, including the Ultraflex[62,63] (Fig 5).

Relapsing Polychondritis

Relapsing polychondritis (RP) is rare immune-meditated inflammatory disorder of cartilaginous structures. More than one-half of all patients with RP have large airway (larynx, trachea, or main bronchi) involvement.[64] Inflammation, contractures, and loss of cartilaginous support can cause fatal airway narrowing. Typical treatment strategies, such as use of nonsteroidal antiinflammatory drugs and systemic glucocorticoids, are usually recommended for milder disease. However, they have not been proven effective in stabilizing the airways.[65] CPAP may provide assistance in severe forms of the disorder,[66] and carefully selected patients may benefit from invasive interventions such as balloon dilation, airway stenting, and/or tracheostomy.[67] It should be noted that no single medical or surgical treatment has been found to be uniformly effective for treatment.[68]

The Montgomery T-tube, placed as an endotracheal prosthesis, was initially used to treat RP.[69] Subsequently, metallic stents were used. Expandable metallic stents are now commonly used to stabilize the airway in these patients. Faul et al[70] reported the use of multiple types of metallic stents in a patient with RP. A few years prior, Dunne and Sabanathan[71] reported the implantation of multiple Gianturco self-expandable stainless-steel Z-stents for RP. In 1999, Sarodia et al[19] reported the first case series of patients with RP who were managed with self-expanding metallic stents (Fig 3B). Seventeen self-expanding metallic stents were implanted among five patients with RP. Four patients (80%) were receiving concurrent immunosuppression that included prednisone, which could have prevented formation of granulation tissue. Three patients (60%) survived at least 16 months after the first metallic stent was placed.

Excessive Dynamic Airway Collapse

Both excessive dynamic airway collapse (EDAC) and TBM exhibit an expiratory collapse of the central airways. It is heralded by a decrease in the cross-sectional area of the tracheobronchial lumen.[72] The true prevalence of the disorder is unknown because there is no consensus regarding the diagnostic criteria for the percentage of narrowing of the airway's cross-sectional lumen.[73] Pathologically, EDAC and TBM are distinct entities. TBM is due to softening of cartilage rings, whereas EDAC is due to laxity of the posterior membrane of the airway walls.[74] Functional bronchoscopy and dynamic imaging are useful for diagnosis and monitoring of these conditions.[75]

Pharmacologic treatment options are limited to targeting concurrent excessive secretions. Nonpharmacologic treatments include positive pressure ventilation, stenting, and surgical repair of the airways.[76] Historically, the placement of silicone stents has been the mainstay of therapy. They served to reduce dyspnea

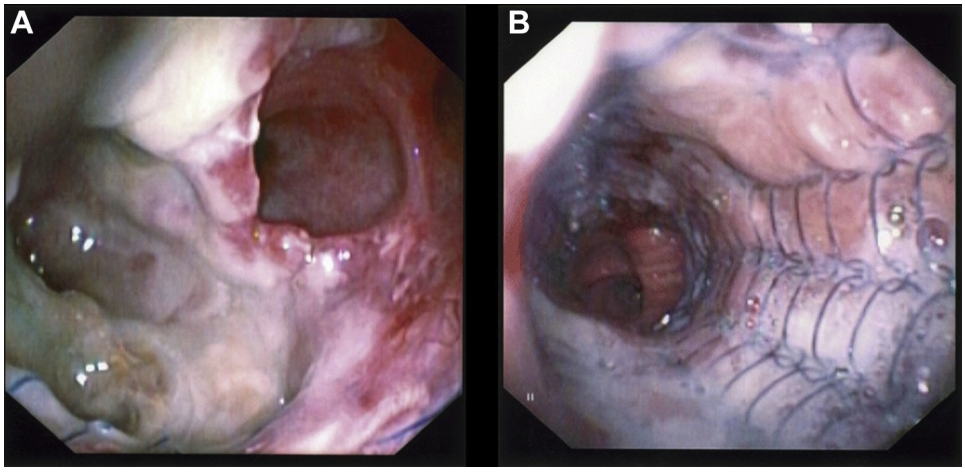

Figure 9 – *A, Bronchial dehiscence in a lung transplant recipient. B, The implantation of the uncovered Ultraflex stent promotes granulation tissue formation and healing. Figures in Panel A and B were reproduced with permission from Mughal et al.*[83]

and improve quality of life, as well as assess candidacy for tracheal surgery.[77]

In a trial with a self-expanding metallic stent, Majid et al[78] showed that use of the Ultraflex stent in EDAC resulted in decreased dyspnea, cough, and secretions. Because the intent of this study was to assess stenting solely as a trial (not a definitive therapy), the mean duration of a stent in situ was 7 days. The Dynamic (Y) stent is also exclusively marketed for the treatment of EDAC.[34]

Lung Transplantation

Airway: Patients who undergo lung transplantation are susceptible to airway complications. Airway complications occur in 10% to 15% of lung transplant recipients[79] and are associated with a mortality of 2% to 4%.[80] To augment awareness and promote standardization, the International Society of Heart and Lung Transplantation recently published a consensus statement regarding the identification, classification, and management of these complications.[81] One of the most serious airway complications that can occur is dehiscence; without treatment, severe cases can be fatal.

Anastomotic dehiscence can be managed in a variety of ways: prevention, endobronchial stenting, or surgical repair.[82] The intrinsic process of granulation tissue formation favors the use of metallic stents in dehiscence, providing a distinct advantage (Fig 9). The stents can be removed after peri-bronchial soft tissue has covered the defect.[83] One study reported that 15 self-expanding metallic stents were implanted among 12 patients who developed airway complications following lung transplantation. Both patency and symptomatic improvement were achieved in 11 patients (92%).[84] Although stent implantation is commonly performed, late survival in patients with treated anastomotic airway complications remains poor.[85]

Lobar Stenting: Airway stenting is most commonly performed in the trachea, main stem bronchi, or the bronchus intermedius. A collapse of lobar airways can occur; however, stenting is controversial if the collapse occurs in isolation.[86] It is not a novel practice; the American College of Chest Physicians Quality Improvement Registry, Evaluation, and Education Registry reported that 329 (29% of all patients) had lobar stenting performed.[87] The presence of lobar obstruction was associated with smaller improvements in dyspnea.[88] The most common argument against it is that recapturing a single lobe does not provide a benefit due to the relatively low volume of its ventilatory surface area as a ratio to that supplied by the entire tracheal bronchial tree. However, in carefully selected patients, it can provide improvement in symptoms.[89] For these smaller airways, the small size of the iCAST stent makes them an ideal choice (Fig 8). The largest series (122 iCAST stents deployed in 38 patients with lobar bronchial stenosis) resulted in 100% of patients having either a symptomatic or radiographic improvement.[54] Complication rates were not excessive, the highest being migration (10%). Lobar stenting is not limited exclusively to iCAST stents. A smaller study by Fruchter et al[90] (14 patients) used S.M.A.R.T. stents (Cordis) and Palmaz stents in the lobar airways. Ten patients in this cohort reported significant improvement in their functional capacity measure via a 6-min walk test.

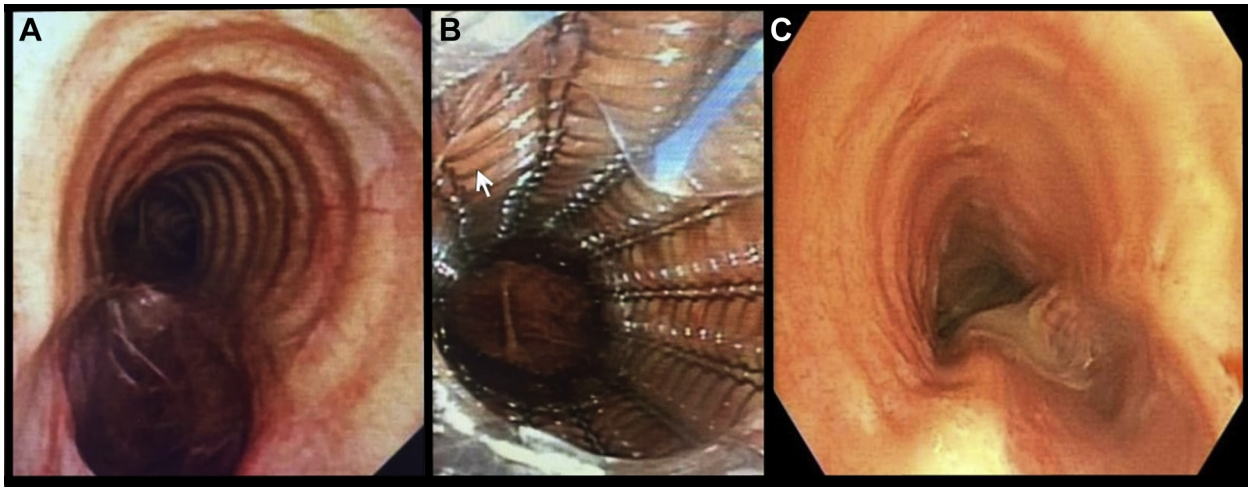

Figure 10 – *A, A large iatrogenic tracheal injury. B, Implantation of an uncovered Ultraflex stent to assist with granulation tissue formation, and subsequent healing. The white arrow highlights the direct contact between the stent's frame and the tracheal mucosa. C, The deficit has fully healed and the stent has been removed. Figures in Panels A-C have been reproduced with permission from Grewal at al.*[92]

Benign Airway Stenosis

Fortin et al[91] reported that newer, third-generation self-expanding metallic stents (Silmet) can be considered as a treatment option for benign airway stenosis. The study reviewed 40 self-expanding metallic stent insertions; no cases of stent-related mortality were reported. The clinical success rate of stent treatment was 40.7%. The complication and stent removal rates were high; all complications were successfully managed endoscopically. Thirty-six of the stents had to be removed. The report concluded that further study to compare the performance of these newer stents with that of silicone stents is needed. A study of 82 patients showed that self-expandable metallic stents are a safe and effective treatment modality for carefully selected patients with either malignant or benign airway obstruction.[4] In summary, use of metallic stents in benign airway stenosis should only be considered when surgery is not possible, airway splinting is needed, and a silicone stent cannot be used.

Figure 11 – *Customized three-dimensional printed stents. Printing technology allows the prosthesis to be shaped to better conform to an individual's airway.*

Tracheobronchial Injury

Metallic stents can be rapidly deployed with a flexible bronchoscope in a variety of airway emergencies, including a tracheobronchial injury. These injuries can be iatrogenic or accidental.[92] It is important that the management of such injuries is coordinated across a multidisciplinary team: thoracic surgery, interventional pulmonology, and intensive care medicine. Depending on the level of injury and clinical status of the patient, metallic stent deployment may be an appropriate treatment option (Fig 10).

Conclusions and Future Directions

Proceduralists support the current resurgence in metallic stent use. Studies published following the 2005 FDA report[2] have proven their safety. Despite historically cited disadvantages and for a variety of reasons, the newer metallic stents have gained favor in the management of certain pathologies compared with silicone stents. However, discrete Level 1A evidence for stent comparison has yet to be developed due to the

heterogeneity of clinical conditions, stent types, and practice patterns worldwide.[93]

The notions that metallic stents are potentially harmful or permanent are no longer accurate. Metallic stents should not be considered absolutely permanent in a well-selected patient. A small study by Shah et al[94] described the removal of 19 metallic stents among 14 patients over 16 procedures. Stents were removed at a median of 35 days; one patient had a metallic stent in place for 595 days prior to removal. Complications were noted in six patients. Larger studies by Noppen et al[95] and Alazemi et al[96] have also shown that metallic stents can be removed safely and effectively, but complications requiring hospitalization and associated increases in health-care costs are not uncommon. The current body of literature suggests that complications with metallic stents occur more frequently when implanted in patients with nonmalignant airway disease or have been in situ for > 3 months.[97]

As in most facets of medicine, progression is the rule. The intense research currently advancing stent technology will invariably lead to the production and mass availability of the next generation of endo-tracheobronchial stents: biodegradable, drug-eluting, and custom-printed three-dimensional stents[98-100] (Fig 11). However, at present, the ideal metallic or silicone stent does not yet exist.

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