Self-expanding metallic stents (SEMS) have gained wide-spread acceptance as a treatment for palliation of malignant airway obstruction (MAO) in the terminally ill patient. Ease of deployment and excellent efficacy have allowed for rapid dissemination of SEMS. However, an unintended consequence has been the use SEMS as definitive treatment for benign tracheal stenosis, which also includes a unique cohort of patients with tracheomalacia and dynamic airway collapse. Unfortunately, patients with benign airway obstruction (BAO) often have lengthier projected lifespans than MAO patients, and consequently, live long enough to develop significant complications from SEMS. Complications from SEMS are frequently more difficult to treat than the index benign stenosis/malacia for which the patient was originally stented, and this has recently prompted government warnings about use of SEMS for BAO.

Complications associated with SEMS placement for BAO include in-stent stenosis, migration, stent fracture, biofilm formation, and rarely, airway fistulae. Of these, SEMS-related stenosis is most often encountered and presents a formidable change to palliate. Currently, 2 general types of SEMS exist, covered and uncovered. Although covered SEMS fracture, migrate, induce a biofilm, and fistulize, they are less likely to stenose simply because the interstices between stent wires are covered with a nonabsorbable sheath that invests much, if not all, of the SEMS. This synthetic covering prevents ingrowth of granulation tissue and subsequent in-stent stenosis (although the ends of the stent can still become incorporated and granulate). Uncovered SEMS, although less likely to be plagued with biofilm and migration, have a much greater association with airway stenosis. Uncovered wires stimulate a vigorous inflammatory response, resulting in granulation tissue growth through the stent and incorporation of the stent wires into the airway wall (Fig. 1).

Once incorporated, extrication of SEMS using the built-in collapsing mechanism is not effective and attempting to persist along this avenue can lead to a high-grade, acute airway. Instead, 2 options exist to manage incorporated, uncovered SEMS where in-stent stenosis has become clinically relevant. A variety of endobronchial ablative therapies can be used to treat obstructing granulation tissue. Argon-plasma-coagulation (APC), cryotherapy, and microdebridement are slightly favored over laser ablation for stent disimpaction because they are less likely to fracture the stent, whereas the laser will melt nitinol struts. Mitomycin C and steroids can be applied as antiproliferative/antiinflammatory adjuncts in hopes of reducing granulation tissue regrowth, but are of questionable utility. The goal of this type of intervention is to restore stent patency, without SEMS removal. However, recurrent stent-related granulation tissue may mandate reintervention every 3-6 months and eventually will become refractory to ablative interventions. Moreover, these treatments themselves induce inflammation and stimulate granulation tissue and ultimately extend the airway injury.

The second, and preferred, option to manage granulation tissue in-growth and stent incorporation is endobronchial (or open) extraction. The decision to proceed along this treatment pathway should be made in the context of multidisciplinary collaboration (general thoracic surgery, interventional pulmonology, medical, thoracic anesthesia). Every component of the team is critical, and it is unlikely that a successful outcome can be achieved without each. Tracheal resection (and removal of SEMS) has been performed in rare circumstances. However, because most tracheal SEMS are >4 cm long, the length of trachea involved usually exceeds that which can safely be reconstructed, particularly because the area of disease always extends beyond both proximal and distal ends of the stent.

General indications for SEMS extraction are recurrent in-stent stenosis, stent fracture, and stent-related fistula (tracheoesophageal). There should be a clear plan for airway reconstruction after SEMS removal, and this most commonly involves replacement with a Silastic prosthesis (T-tube or Dumon-type indwell- ing stent). Patients should always be counseled about the possibility of tracheostomy as well. Highlighted here is an endobronchial technique for extraction of an incorporated SEMS.

Two videos have been provided to help demonstrate both the pathology and advanced techniques for extraction of incorporate SEMS. Video 1 was created from a patient with an uncovered SEMS placed for long-segment tracheomalacia secondary to radiation injury. The patient was referred at 1 year following placement with intractable cough, wheeze and dyspnea. The video demonstrates SEMS failure and 3 differ-
ent late complications: stent fracture, granulation tissue overgrowth, and unfortunately, development of tracheo-esophageal fistula (noted along the left side of the patients’ airway and likely induced by stent fracture).

Video 2 shows the bronchoscopic and surgical approach to extraction of a densely incorporated covered-SEMS. The indications for SEMS removal in this case were granulation tissue in-growth, dense incorporation and, gram-negative rod bacterial biofilm development. Because the stent was so deeply incorporated into the airway wall, open extraction through multilevel tracheotomy was required. In addition, real-time airway reconstruction with silastic prosthesis was necessary. Video 2 demonstrates rigid control of the airway (including pneumatic dilatation) followed by surgical exposure of the cervical tracheal, piece-meal SEMS extraction, and finally, T-Tube reconstruction.

**Operative Technique**

![Bronchoscopic photo of an incorporated SEMS with a granulation tissue bridge spanning the stent interior.](image)

Uncovered SEMS are not subject to biofilm formation (as are covered SEMS) but unfortunately can promote granulation tissue in-growth. Use for benign tracheal stenosis is contraindicated for most patients. The main advantages of SEMS over Silastic stents are much lower rates of migration and less mucus impaction; however, Silastic stents are not plagued by in-stent stenosis. Options for management of SEMS-related granulation tissue include endobronchial ablation/debridement or extraction (and, rarely, tracheal resection). Ablation is a reasonable strategy initially, however, may ultimately result in the SEMS becoming more densely incorporated and more difficult to remove. Mucosal application of antiproliferative/antiinflammatory medications to maintain SEMS patency has been attempted with variable success.
Figure 2  SEMS being deployed for a high-grade, benign tracheal stenosis. Ease of deployment has facilitated widespread use of SEMS, including for benign tracheal stenosis. SEMS are typically deployed over a guide-wire with fluoroscopic and flexible bronchoscopic guidance. Rigid bronchoscopy is not necessarily required for SEMS placement, as a laryngeal mask airway or large endotracheal tube (ETT) will suffice to control the proximal airway. The illustration depicts an uncovered nitinol SEMS being deployed with a proximal-to-distal release across a tracheal lesion. The radial stent force is sufficient to dilate short, high-grade stenoses and longer segment tracheomalacia. Although most benign stenotic airway processes are now considered relative contraindications, SEMS are clearly a preferred treatment for patients with malignant airway obstruction. Similar SEMS-related complications occur regardless of placement for MAO or BAO. Because development of complications is a time-related phenomenon, patients stented for MAO often expire before SEMS-related problems arise.
Figure 3  Fully deployed SEMS in the proximal trachea with palliation of stenotic/malacic segment. Once deployed in the airway, there is a built-in collapsing mechanism at both the proximal and the distal ends of the SEMS. Bronchoscopic extraction, before full tissue incorporation, is easily facilitated by collapsing the SEMS (cinching down on 1 of 2 encircling threads) and delivery through the vocal cords. Even uncovered SEMS (placed for BAO) can be removed in this manner for several weeks after initial deployment. It is recommended that uncovered SEMS be bronchoscopically interrogated between 4 and 6 weeks after placement. In contrast to most other BAO, anastomotic airway stenoses and partial dehiscence (without bronchopleural fistula) following pulmonary transplantation are increasingly managed with uncovered SEMS, but patients require frequent surveillance and stent exchange. If deployed for benign indications, any evidence of SEMS incorporation should prompt removal (and possible replacement, before full incorporation occurs).
Figure 4  SEMS incorporation and in-stent granulation tissue stenosis. The radial force of SEMS, in combination with foreign body reaction, contaminated field, and constant airway movement, leads to granulation tissue in-growth as well as granulation build-up at proximal and distal ends of the stent. A stenotic or malacic segment, perhaps 1-2 cm in length initially, can extend considerably. Once an uncovered stent has become fully incorporated, it is impossible to remove the stent by simply using the standard built-in collapsing mechanism. In fact, persisting to extricate the stent in this fashion can lead to collapse of both stent and airway and, if the stent has become deformed or fractured by this maneuver, a critical airway obstruction can result. There is no easy solution to control the airway in this circumstance, as it is very difficult to reexpand a deformed SEMS. Moreover, tracheostomy through inflamed trachea and fractured stent is a challenge even in the elective setting, let alone when trying to reestablish airway control urgently. If a patient presents with impending airway loss from SEMS stenosis and limited experience exists for management, endobronchial balloon dilatation (pneumatic tracheoplasty) is a reasonable palliative maneuver to stabilize a patient before transfer to an experienced center. This intervention can be performed with a flexible bronchoscope passed through a laryngeal mask airway or subglottic ETT.

Stent involved & entangled with stenotic tissue
Control of the airway with rigid bronchoscope. If an incorporated and stenotic SEMS is to be removed, appropriate preoperative planning is essential. Likelihood of open removal should be assessed. In addition, the specters of associated esophageal fistula should be considered. Finally, a definitive strategy for airway reconstruction should be ready and necessary equipment should be organized. Standard “exit plans” for reconstruction include Silastic airway stent, T-tube, covered SEMS, tracheostomy, and, rarely, tracheal resection. Control of the airway is almost always facilitated through rigid instrumentation. This illustration demonstrates the placement of a ventilating rigid bronchoscope into the airway. The patient is placed in a standard “sniff” position with neck extended and jaw thrust. This position lines up the oropharynx, glottis, and proximal airway. The upper incisors should be protected, and coexisting cervical spine disease needs to be assessed before proceeding. Intravenous paralytics are required for rigid bronchoscope placement. Inhalational anesthetics are usually avoided because there will be significant leak of delivered tidal volume through the scope. A larger rigid ventilating bronchoscope (~13-mm-diameter) is preferred, and the mouth is packed with moistened gauze to reduce ineffective ventilation. A radial arterial line is placed to monitor carbon dioxide retention and assess adequacy of ventilation. Long tracheal catheters should be available should the need for jet ventilation arise. Rigid or flexible optical scopes, passed through the rigid bronchoscope, are used for visualization. Depending on the degree of airway stenosis, the neck and chest may need to be prepared steriley and a tracheostomy table set up in the operating room. Sterile wire-cutters should also be available. Rarely, groins may need to be included in the sterile drape for extracorporeal support access.
Figure 6  Control of the airway with suspension laryngoscope. For extraction of SEMS with distal subglottic or proximal tracheal involvement, suspension laryngoscopy may need to be used. As illustrated above, an adult laryngoscope (eg, Jako, Dedo, etc) with a minimal internal diameter of >11 mm can be positioned at the level of the anterior commissure of the vocal cords and suspended. A standard suspension rod (eg, Lewy) is fastened to the laryngoscope, which allows for control of the airway and hands-free passage of instrumentation through the scope. The patient can be managed with intermittent apnea, interrupting the procedure every 2-3 minutes to place a small ETT through the laryngoscope into the airway. Alternatively, jet ventilation can be used through the laryngoscope. Regardless, a permissive hypercapnea strategy is employed, although once the procedure is completed, several minutes of normal ventilation will be required to allow for CO₂ normalization before waking the patient. Portable fluoroscopy (shown above) is often necessary to identify the precise location of a fully incorporated SEMS. Larger laryngoscopes can obstruct venous return at the base of tongue and should be relaxed at 10- to 15-minute intervals, or sooner, if venous congestion is noted. Tooth guards are also required. (Color version of figure is available online at http://www.optechtics.com.)
Figure 7 Ablation of SEMS-related granulation tissue. A variety of techniques can be employed to debride stent-associated granulation tissue and uncover incorporated stent struts and wires. It is seldom possible to remove an incorporated stent in 1 procedure. Instead, serial interventions are frequently necessary. Every planned extraction begins with ablation of the investing granulation tissue. Instrumentation is passed through the rigid bronchoscopy or laryngoscope. In addition, a standard flexible bronchoscope can be passed through the rigid instrumentation. The working channel of this scope can then be used for various thermal probe placements and synchronizes debridement with visualization. APC is illustrated and is often preferred first because of properties that allow ionized gas to bend toward tissues unlike laser light (linear). APC superficially chars tissue, and eschars are then endoscopically evacuated. Endobronchial laser (ie, Nd-YAG or CO₂) can actually vaporize tissue and preclude the debridement step but penetrates more deeply through tissues. Because APC only treats tissues superficially, there is less chance of deep tissue injury. These thermal technologies (in addition to monopolar electrocautery) are hemostatic and coagulate blood on contact. Other effective ablative therapies are cryotreatment (via probe) and mechanical debridement (microdebrider). Some densely incorporated SEMS will ultimately need to be removed piecemeal (Fig. 13): Nitinol stent wires, unless fractured from metal fatigue, are not easily disrupted or cut. Endobronchial laser is an effective tool to melt wires and can be used if intact removal of the entire SEMS is not possible, facilitating piecemeal extraction. Finally, for thermal endobronchial therapies, concentration of inspired oxygen should be below 40% and all ventilation held during the treatment bursts to avoid airway ignition. Airway lasering should not be done through a standard ETT, as the tube can combust. Treatment should be performed in short bursts with frequent interval assessment—the endpoint being complete wire exposure.
Figure 8  SEMS dislocation from tracheal wall. Once the SEMS scaffold is exposed, gradual circumferential dissociation of the stent from the tracheal wall can be performed. Endoscopic forceps can be used to develop the plane, although care must be taken to avoid airway perforation at this juncture. Pneumatic airway dilators, commonly used to dilate strictures, provide controlled pressures to separate stent from the airway. Although they are available in a variety of sizes, the smallest balloon dilator, 8-10 mm, is preferred. Real-time visualization should be possible, and the balloon tip can be easily seen if it is being advanced in the correct plane (between wires and airway) and if the SEMS is fully exposed. Mobilization of the stent off the airway wall is quite tedious, and after each inflation of the dilator, rigid forceps can be used to distract the SEMS further from the tracheal wall.
Once a significant portion of the stent has been mobilized, the balloon can be advanced along the length of the SEMS and inflated while rigid forceps are providing counternitension. It should be kept in mind that the weakest part of the airway is the posterior membranous portion. If stent wires are unable to be mobilized off this portion of the airway, leaving these wires attached should be considered. Persisting in complete removal at this point might result in evulsion of the posterior wall and/or tracheoesophageal fistula. If a tracheal SEMS cannot be sufficiently mobilized bronchoscopically, cervical tracheotomy and open exploration are indicated.
Figure 10  Removal of mobilized SEMS. Once fully mobilized from the airway wall, removal is straightforward. The illustration demonstrates removal of SEMS in 1 piece and, importantly, shows that after all treatments, manipulations, and distortions, extracted SEMS are surprisingly deformed when ultimately removed. A standard tracheal SEMS (20 mm × 6 cm), even when collapsed, can become lodged within a 13-mm rigid bronchoscope or direct laryngoscope, and often, the scope will have to be removed with the foreign body. The anesthesia team should be made aware of this eventuality and be prepared to mask ventilate or reintubate. If additional bleeding needs to be controlled, rigid airway control should be reestablished and hemostasis achieved.
Conclusions

Bronchoscopic extraction of incorporated SEMS is a formidable task. A multidisciplinary team is required and experience with bronchoscopic and open airway procedures is essential. The most common indication for SEMS removal is recurrent high-grade in-stent stenosis from granulation tissue ingrowth through uncovered stents placed in patients with BAO. Bronchoscopic removal is the procedure of choice, although the limitations of the procedure should be understood. Tracheal resection for SEMS extraction is less often indicated and reserved for circumstances, such as fistula, and for the reconstruction phase. Advances in bronchoscopic techniques and instrumentation have now allowed for SEMS to be extracted with far less morbidity, and bronchoscopic extraction should be the new standard.

Supplementary Data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1053/j.optechstcvs.2012.03.004.

References