REVIEW

Update on airway stents

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Purpose of review

The current review describes the latest evidence regarding the use of stents for malignant airway obstruction.

Recent findings

Therapeutic bronchoscopy, including stenting, can restore patency in up to 93% of patients with malignant central airway obstruction. The patients that benefit the most are those with worse baseline dyspnea, higher American Society of Anesthesiology score, poorer functional status, and central obstruction (rather than lobar). Early complications are relatively rare with stent placement, whereas late complications are not. Stents are a risk factor for lower respiratory tract infection, which, in turn, is a negative prognostic factor in terms of survival. Recent research has seen the development of personalized stents via three-dimensional printing, mini stents for more distal airways, and stents with drug-eluting and biodegradable properties.

Summary

Airway stents must be judiciously used, but we now have data that help guide patient selection and that inform us of what potential complications may occur and when. Stents are under development with newer properties that may extend the therapeutic reach of these interventions.

Keywords

malignant airway obstruction, stent, therapeutic bronchoscopy

INTRODUCTION

Central airway obstruction (CAO) is defined as narrowing of the trachea, main stem bronchi, or the bronchus intermedius [1]. Some definitions have included the lobar bronchi as well [2]. Benign causes include postintubation or post-tracheostomy tracheal stenosis, lung transplant-related strictures, and autoimmune processes (e.g. granulomatosis with polyangiitis) [3■■]. Malignant causes include both primary lung cancers and disease metastatic to the lung.

Approximately 80 000 cases of malignant CAO occur in the United States each year, with one-third of nonsmall cell lung cancers initially presenting with CAO [1]. Airway metastasis from nonlung cancers is not uncommon either. Those cancers with the greatest predilection for the airways include cancers of the digestive tract, breast cancer, and renal cell carcinoma [1].

Various therapeutic modalities are available for CAO, including surgery, different ablative techniques, and tools for mechanical debulking. Airway stenting is usually reserved for cases in which these techniques alone are inadequate and requires careful patient and stent selection in addition to procedural expertise and awareness of potential complications. This article will review the recent literature on airway stents for malignant CAO. Stenting for CAO in benign disease has been covered elsewhere [3■■].

INDICATIONS AND PATIENT SELECTION

There are two broad categories of indications for stents. One is obstruction of the airway lumen. Masses outside of the airway can cause extrinsic compression. Masses can also reside inside the lumen, causing intrinsic obstruction. A mixed pattern of both can also occur. Additionally, loss of airway wall strength, such as in tracheobronchomalacia, can lead to airway collapse and obstruction of the lumen. Pure extrinsic compression and wall collapse are treated with stenting if severe enough. Pure intrinsic obstruction can often be dealt with by endoluminal ablative and debulking approaches

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Curr Opin Pulm Med 2018, 24:343–349

DOI:10.1097/MCP.0000000000000486

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KEY POINTS

- Airway stenting, among other therapeutic modalities, has the highest success rate for restoring airway patency in malignant central airway obstruction.
- Early complications of stenting are rare, but late complications are not. The most common late complications include infection, migration, and granulation tissue formation.
- Lower respiratory tract infection following airway stenting is associated with decreased survival.
- Stents under development are more versatile, with 3D printed stents able to fit more anatomically complex airways, mini stents able to reach smaller airways, and biodegradable and drug-eluting stents able to offer more therapeutic options to patients who may be poor candidates for more aggressive measures (such as repeat bronchoscopy or chemotherapy, respectively).

alone. Mixed patterns of disease often require multiple modalities of intervention.

A second indication is due to a defect in the airway wall. Broncho-esophageal fistulae or anastomotic dehiscence after lung transplantation can leave significant breaches in the airway wall. This can then lead to even more complications downstream. These disease states can potentially be treated with stenting.

A variety of airway stents are commercially available. They are broadly categorized based on their composition – silicone or metal. Within these categories, there are subtle but important differences that can have clinical implications (Fig. 1). No one stent is suitable for all conditions; each has its advantages and disadvantages.

Several factors must be considered together to determine if and when to proceed with stent placement. One is whether the observed airway disease is significant enough to explain the patient's symptoms. Generally, central airway size must be reduced by approximately 50% before symptoms will arise [1]. Reduction in tracheal lumen diameter to approximately 8 mm will often produce dyspnea on exertion; lumen size of 5 mm or less usually leads to dyspnea at rest [1]. If a lesion is physiologically significant enough to cause burdensome dyspnea, intervention should be considered.

Alternatively, an airway lesion may be present without causing sufficient obstruction to cause a patient's dyspnea (or it may be only a minor cause). In this case, observation alone may be warranted. An important caveat to keep in mind, however, is whether postponing an intervention would lead to a more difficult or riskier procedure later. If other interventions that address the malignant CAO are either not feasible or not timely in terms of their effect on dyspnea (e.g. chemotherapy for lymphoma), then timely bronchoscopic intervention before the patient is in extremis should be considered. A recent study demonstrated that urgent and emergent therapeutic bronchoscopy is associated with higher rates of complications than elective procedures [4].

Several other factors must also be considered when contemplating stent placement. Although immediate complications are relatively rare after therapeutic bronchoscopy, long-term complications are not. These include infection, formation of granulation tissue, and stent migration – any of which may require repeat bronchoscopy in already debilitated patients (see below for a detailed description of complications based on recent data). Similar consideration must also be given to the fact that stent placement often requires general anesthesia. Importantly, patients with malignant CAO have limited life expectancy and may have specific goals of care that need to be heeded. This is not to suggest that stent placement is a poor choice in someone with a poor prognosis. There can be a definite palliative benefit of stents for dyspneic patients with malignant CAO at the end of life [5]. Finally, from a technical standpoint, there must be patent airways distal to the area of obstruction for stent placement to be successful; if distal patency is not present, stenting will be of no benefit. This can be determined by preprocedural imaging in some circumstances, although often this cannot be known with certainty until the time of bronchoscopy. All of these factors must be considered to make an individualized decision for each patient.

Recent data are available to help inform the patient selection process [2]. Via the multicenter American College of Chest Physicians Quality Improvement Registry, Evaluation, and Education (AQuIRE) registry, Ost *et al.* appraised 1115 therapeutic bronchoscopy procedures in 947 patients with malignant central airway obstruction at 15 centers. One-third of these cases included stent placement. Technical success, defined as having airway patency restored, was achieved in 93% of patients. Stenting was associated with the highest rates of successful restoration of airway patency. Interestingly, those patients with higher baseline dyspnea (Borg score) and nonlobar obstruction had greater improvements in dyspnea and health-related quality of life after therapeutic bronchoscopy. Moreover, patients with higher American Society of Anesthesiology (ASA) score and poorer functional status also had greater improvements in health-related quality of life. Hence, the patients

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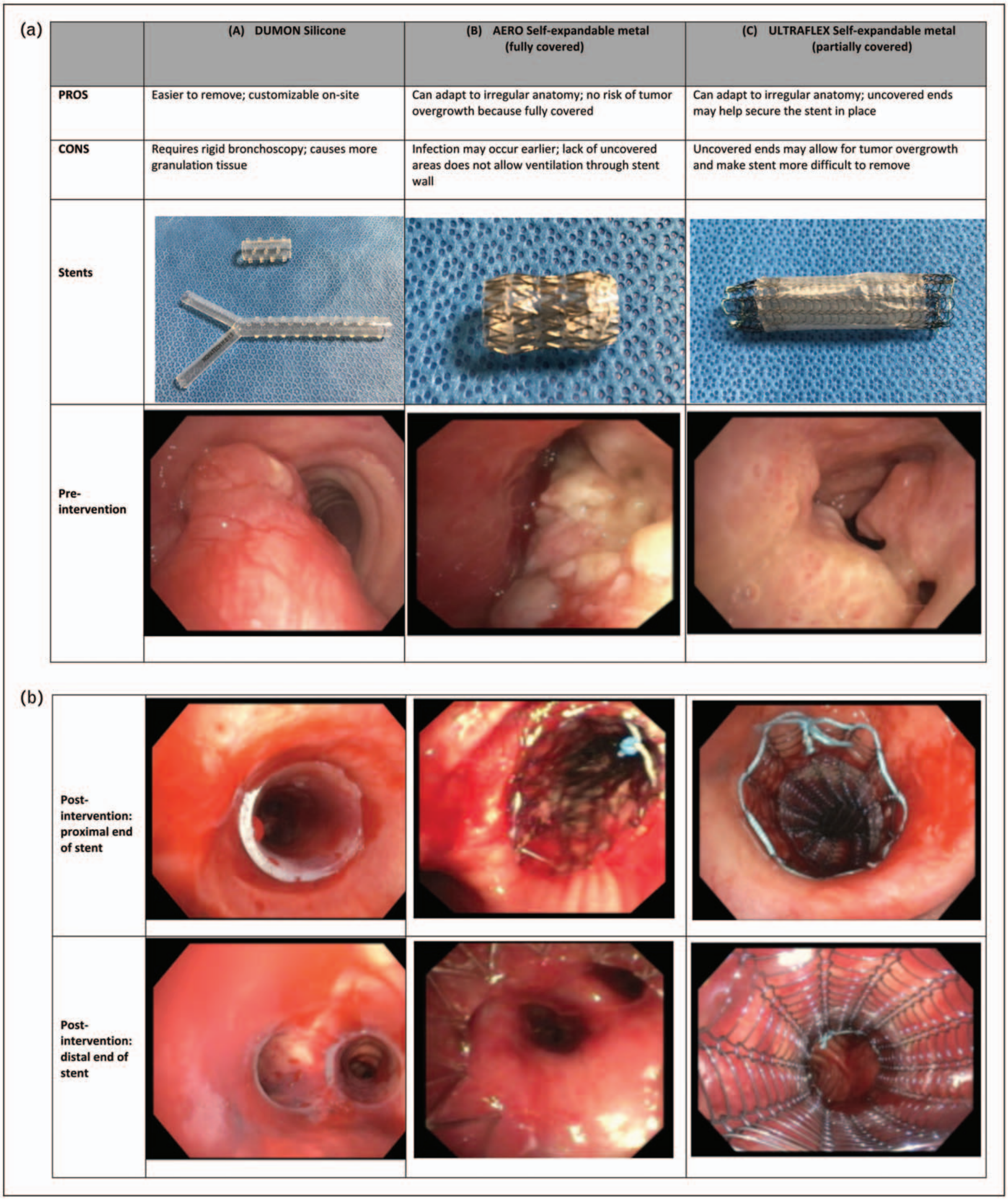

FIGURE 1. Three of the more commonly used stents. Column A shows two forms of the Dumon silicone stent, the tube and Y designs. The top bronchoscopic image is of tumor invading the distal trachea and left main stem bronchus. The following image is of the proximal (tracheal) limb of the deployed Y-stent. The bottom image is of the distal limbs branching into the left and right main stem bronchi. Column B shows the fully covered AERO stent. The top bronchoscopic image is of near total obstruction of the right main stem bronchus. The following two images show the proximal and distal ends of the stent showing patency of the right main stem bronchus and patent middle and lower lobes, respectively (the right upper lobe could not be recanalized). Column C shows the partially covered Ultraflex stent, used to treat a trachea that was diffusely infiltrated by several tumors. Full patency was restored with the main carina visible past the distal end of the stent.

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perceived as being at greatest risk for these procedures have the greatest potential to gain from them. This is an important finding. These patients should not be too quickly discounted as candidates for therapeutic bronchoscopy, including stenting. They may be the very ones who will respond the most to such interventions.

In sum, there are various factors to be considered when evaluating a patient for airway stenting including type and severity of obstruction, potential complications, the timing of intervention, and the pretest probability of how much the patient stands to benefit from the proposed procedure.

COMPLICATIONS

Another recent advancement has been in understanding the complications of therapeutic bronchoscopy in malignant central airway obstruction, including stenting, and associated risk factors. A large, multicenter study, also based on the AQuiRE registry, examined the incidence of complications of 1115 procedures performed in 947 patients at 15 centers [4]. CAO was defined as at least 50% obstruction of the trachea, main stem bronchi, bronchus intermedius, or lobar bronchus. Thirty-six per cent of the 947 patients had any stent placed. Over twice as many metal stents were placed as silicone stents. Overall, there was only a 3.9% short-term complication rate, with a range across centers of 0.9–11.7%. Six patients (0.5%) died due to procedural complications. Risk factors for complications included urgent and emergent procedures, ASA score above 3, redo therapeutic bronchoscopy, and moderate sedation. Unexpected escalation of care occurred in 4.4% of patients, with 1.3% developing unexpected respiratory failure and 0.5% having bleeding requiring intervention. Of note, none of these events were associated with stent placement. Death within 30 days of procedure was associated with stent placement, Eastern Cooperative Oncology Group (ECOG) score above 1, ASA above 3, and intrinsic or mixed obstruction. With regard to the association with stent placement, this could be due to the confounding effect of a greater burden of disease, leading to both the need for a stent, and also worse survival. Stents may also have been used in patients who had exhausted all other alternatives due to disease progression. Nonetheless, the authors suggested judicious use of stents.

In a relatively recent retrospective analysis measuring incidence rates for respiratory infection in patients with airway stents for malignant CAO, Grosu *et al.* [6] showed that stent placement, preprocedural obstruction at least 50%, and male sex were associated with development of lower respiratory tract infection (LRTI). Seventy-two patients with malignant central airway obstruction were included, 24 of whom underwent stent placement. Stent placement and male sex remained as predictors in the multivariate analysis. The incidence rate of LRTI in stented patients was 0.0057 infections per person-day; in nonstented patients, the rate was 0.0011 infections per person-day, giving a statistically significant incidence rate risk difference of 0.0046 infections per day. This corresponds to a 13% increased risk of LRTI per month in stented patients compared with those without stents. In turn, this is equal to one infection for every eight stents placed. Moreover, ECOG at least 2, stenting, and LRTI were associated with decreased survival. However, only LRTI remained associated with survival in the multivariate model. Taken together, given the incidence rate of stent infections and the association of LRTI with death, the emphasis on carefully deciding when to place a stent cannot be overstated.

Another relevant study was a retrospective analysis of complications in patients who received airway stents for malignant CAO at a large referral cancer center over a 5.5-year period [7]. One hundred and seventy-two patients underwent 195 stent procedures. Ultraflex metal stents were used in 118 cases (61%), AERO metal stents in 31 (16%), and Dumon silicone stents (both straight and Y-shaped) in 46 (24%). Overall, the most common complications were infection, migration, granulation tissue formation, and mucus plugging. The median time to infection was 1 month; AERO stents seemed to confer an increased risk of infection compared with other stents. Twenty-three per cent of patients with respiratory infection died within 14 days of the infection. For stent migration, the median time to event was 1.4 months. Silicone tube stents had an increased risk of migration compared with metal stents [hazard ratio 3.52, 95% confidence interval (CI) 1.41–8.82, $P = 0.007$]. Y-stents were not included in this specific analysis as these tend to not migrate because the bronchial limbs hold them in place. The median time to granulation tissue was also 1.4 months. Silicone stents and LRTIs were associated with an increased risk of granulation in the multivariate analysis. Mucus plugging occurred at a median of 1.3 months. Silicone and left-sided stents were associated with increased risk, whereas poststent chemotherapy seemed protective. Tumor overgrowth, hemoptysis, fistula formation, and stent fracture were less common and were not associated with any particular stent type. It is interesting and worth remembering that time to any of the complications listed above was approximately 1–1.4 months. This could help guide when and how frequently to have patients follow-up after their

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procedure to monitor for said complications. In terms of overall survival, silicone stents and tracheal stents were associated with decreased mortality, whereas LRTI and prestent radiation therapy were associated with the converse. Possibly, there was some degree of selection bias associated with silicone stent placement, as these may have been placed in healthier patients who are thereby better able to tolerate the more technically difficult placement of these stents compared with metal stents. Silicone stents are also easier to remove. There may have been a bias toward placing these in patients whose disease burden was expected to improve, thereby allowing stent removal later.

The past few years have seen helpful advancements in our understanding of airway stent complications and therapeutic bronchoscopy for malignant CAO. The data can be used to inform clinical decision-making and help to quantify some of the risks associated with airway stents.

RECENT ADVANCES IN AIRWAY STENTS

Other recent developments have been in the design of airway stents, particularly in four areas: three-dimensional (3D) printed stents, drug-eluting stents, biodegradable stents, and mini stents.

Three-dimensional printed stents

Three-dimensional printing of stents allows stents to be tailored to an individual's airway anatomy more so than currently available techniques that can customize stents only to a crude, approximate degree. Currently, at the time of bronchoscopy, stents can be cut shorter or have a hole cut to allow ventilation of a side airway. Stents can also be ordered with more specific angles, widths, and lengths, but these usually take several weeks to manufacture and deliver. A 3D printed stent could theoretically be prepared in days or even hours after an airway problem has presented itself and be designed to fit an individual patient's irregular anatomy [8▪].

There have been recent reports of success in these endeavors in humans. Guibert *et al.* [9] demonstrated placement of a 3D printed stent into a narrowed and tortuous post-transplant airway that could not be relieved by a traditional stent. The patient noted immediate improvement in dyspnea, quality of life, and lung function. Cheng *et al.* [10] designed and placed a 3D printed Montgomery T tube into a patient with a similarly complex tracheal anastomotic dehiscence. This tube was much better seated compared with his prior tracheostomy; this likely is the main reason that he was without granulation tissue or mucus plugging many weeks after discharge. Additionally, while not taking an endoluminal approach, Morrison *et al.* [11] created 3D airway splints that were surgically placed around main stem bronchi in three infants with tracheobronchomalacia. Two were eventually able to be liberated from mechanical ventilation completely. A feasibility study is currently under way to test this approach in a series of patients [12].

The area of research is still in its infancy but has potential as the field of 3D printing continues to develop. Freitag *et al.* [8▪] and Cheng *et al.* [13▪] have each recently published very thorough reviews of the process of 3-D printing for the airways.

Drug-eluting stents

The concept of drug-eluting stents for the airway has gained attention because patients with malignant CAO often have exhausted their candidacy for further radiation or cannot tolerate the systemic effects of traditional chemotherapy. Along with the mechanical benefit of the stent itself, sustained release of a cytotoxic drug would provide in-situ therapy.

The area of research is still in its early stages, but studies in animals have shown some promising results. Recently, Wang *et al.* [14] randomly assigned eight beagles to receive a bare metal stent or a paclitaxel-eluting stent into the trachea. The dogs were sacrificed at intervals over a course of 5 months. Paclitaxel-treated beagles showed much less granulation tissue than did control dogs, with continued release of the drug into the stented area and the adjacent area. Very low levels of drug were detected elsewhere in the lung, with none detectable in the blood.

Other drug-eluting airway stents have been studied in animal models. Cisplatin-eluting stents were studied in rabbits, with 15 stents inserted into the trachea with a measurable, steady release of the drug over several weeks [15]. Serum levels remained low throughout the observation period, and there were only mild mucosal changes on gross examination. Zhu *et al.* [16] placed tracheal stents eluting the antimitotic drug mitomycin into rabbits and compared these with nonmitomycin stents and nonstented controls. Mitomycin-treated rabbits had the least granulation formation and mucus trapping at 12 weeks compared with the other groups.

Various other drugs have been considered for stents, including pirfenidone, which recently was shown to trigger airway fibroblast apoptosis and to reduce cell viability; other agents being studied are those that are currently used in coronary artery drug-eluting stents such as sirolimus and everolimus

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[17–19]. Interestingly, not only drugs but genetic material can be transferred via stents. As a proof of concept, Kruklitis *et al.* [20] transfected reporter and therapeutic genes from an adenoviral vector on a tracheal stent to tracheal mucosa in a rat tumor model. The treated rats showed reduced growth of tracheal tumor, and also a trend toward improved survival.

Biodegradable stents

Biodegradable stents have been successfully used in the urology, gastrointestinal, and cardiology realms. The idea of their use for malignant CAO has appeal, because, given that the goal is palliation, it would allow one to avoid a second procedure for stent removal. Moreover, because these stents do not remain in the airway for a prolonged time, one might theoretically also reduce the rate of late complications (e.g. granulation tissue, infection).

To date, only five studies in humans have been conducted, with mixed results. None of these has been in the setting of malignant CAO. The largest was by Lischke *et al.* [21], who described a series of 20 stents made of bioresorbable polydioxanone placed in six patients with postlung transplant bronchial stenosis. Stenosis was relieved in all patients, although symptomatic changes were not reported. There were no immediate complications. Four patients ultimately needed restenting due to restenosis at a median time of 5 months. One died of pulmonary embolism; the other five were doing well at 4 years of follow-up with a median intervention-free time of 24 months. Fuehner *et al.* [22] described a similar series of 10 patients with post-transplant stenosis. Eleven stents were placed, also made of polydioxanone (although several biodegradable polymer options are available). All patients had symptom relief and improvements in lung function and 6-min walk distance. One patient required stent removal at 4 days due to bleeding, and four patients developed in-stent restenosis. However, by 6 months, no patient needed further interventions. Stents were completely degraded by a median of 141 days. Of note, the aforementioned drug-eluting stents developed by Chao *et al.* [15] and Zhu *et al.* [16] were biodegradable as well. Further experience is clearly needed, but biodegradable stents may be a viable tool in our armamentarium in the future.

Mini stents

In the past year, there has been increasing attention in the literature to lobar stents – also called 'mini stents.' The rationale is that improving patency could potentially prevent a lobar pneumonia that could lead to sepsis and/or respiratory failure in already debilitated and immunocompromised patients. Additionally, in lung cancer patients after lung resection, losing a single lobe would be losing a larger percentage of gas exchange area than if they had two full lungs. This same reasoning can be applied for single lung transplant patients who are living with a single functional lung. Therefore, preserving function of a single lobe may be quite beneficial.

Sethi *et al.* recently presented a fairly large series of outcomes with the iCAST stent (Atrium Medical, Hudson, New Hampshire, USA) [23]. This is a balloon-expandable, fully covered metallic stent that has been used frequently in the treatment of vascular occlusive disease, but approved recently by the US Food and Drug Administration (FDA) for use in the airway. One hundred and twenty-two stents were placed in 38 patients, half of whom had malignant lobar airway obstruction. Ninety-five per cent of patients had symptomatic improvement based on questioning during follow-up. Fifteen of 16 patients with pulmonary function testing before and after stent placement had an average increase of 12.3% in forced expiratory volume in 1 second. Overall, complications occurred in 20%, and included migration (10%), granulation tissue formation (5%), deployment malfunction (2%), and stent dislodgement immediately after deployment (2%). Of note, no infections were detected, and the authors theorized that this was due to the small size of the stent, thereby minimizing impairment of mucociliary clearance and expectoration.

Majid *et al.* [24] reported on a series of 21 small stents placed in 18 patients. These investigators also used the Atrium iCAST stent. Ninety-five per cent of stents were placed in lobar airways; 72% of patients had malignant stenosis. There was a statistically significant improvement in dyspnea as measured by modified Medical Research Council score, from a median of 3 to 2 after stent placement. Complications included migration (9.5%), granulation tissue (9.5%), mucus plugging (4.8%), and stent crush (4.8%); five stents had to be removed due to complications. Seven stents were removed with patency maintained over a median of 170 days, but how many of these were for malignant versus benign disease was not specified.

Finally, Fruchter *et al.* [25] described a series of 14 patients status post lobar stent, 4 of which were for cancer and 10 for a variety of nonmalignant diseases. Stents used were the SMART nitinol stent (Cordis, Miami, Florida, USA) or Palmaz stent (Johnson & Johnson, New Brunswick, New Jersey, USA; and Interventional Systems, Warren, New Jersey, USA). There were no immediate complications. Thirteen of the 14 had improved symptoms (e.g. cough, dyspnea,

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quality of life). Only two patients needed unscheduled bronchoscopy for retained secretions. The rest had scheduled bronchoscopy to remove granulation tissue and secretions. One patient had postobstructive PNA due to granulation tissue.

Other smaller series have been recently reported as well [26,27]. Current nonrandomized data suggest that they may be helpful in the right clinical context.

CONCLUSION

The main advances in airway stenting in the past 1–2 years have been in making stents more versatile, particularly in allowing more complex and smaller airways to be treated. Whether treatment of small airway stenosis is beneficial and worth the risk is still unknown, because only preliminary data are available. For the standard and widely used stents, the advances have been with regard to understanding their complications, success rates, and utility. As both cancer life expectancy and technology increase over time, the incidence of malignant CAO and the tools available for treatment will likely grow as well. Airway stents are well seated to bridge these together.

Acknowledgements

None.

Financial support and sponsorship

None.

Conflicts of interest

None.

REFERENCES AND RECOMMENDED READING

Papers of particular interest, published within the annual period of review, have been highlighted as:
- ▪ of special interest
- ▪▪ of outstanding interest

1. Michaud G. Malignant central airway obstruction. In: Ernst A, Herth FJF, editors. Principles and Practice of Interventional Pulmonology. New York, NY: Springer; 2013. pp. 259–268.
2. Ost DE, Ernst A, Grosu HB, *et al.* Therapeutic bronchoscopy for malignant central airway obstruction: success rates and impact on dyspnea and quality of life. Chest 2015; 147:1282–1298.
3. ▪▪ Murgu SD, Egressy K, Laxmanan B, *et al.* Central airway obstruction: benign strictures, tracheobronchomalacia, and malignancy-related obstruction. Chest 2016; 150:426–441.

This is a thorough review of both benign and malignant central airway obstruction.

4. Ost DE, Ernst A, Grosu HB, *et al.* Complications following therapeutic bronchoscopy for malignant central airway obstruction: results of the AQuIRE registry. Chest 2015; 148:450–471.
5. Vonk-Noordegraaf A, Postmus PE, Sutedja TG. Tracheobronchial stenting in the terminal care of cancer patients with central airways obstruction. Chest 2001; 120:1811–1814.
6. Grosu HB, Eapen GA, Morice RC, *et al.* Stents are associated with increased risk of respiratory infections in patients undergoing airway interventions for malignant airways disease. Chest 2013; 144:441–449.
7. Ost DE, Shah AM, Lei X, *et al.* Respiratory infections increase the risk of granulation tissue formation following airway stenting in patients with malignant airway obstruction. Chest 2012; 141:1473–1481.
8. ▪ Freitag L, Gordes M, Zarogoulidis P, *et al.* Towards individualized tracheobronchial stents: technical, practical and legal considerations. Respiration 2017; 94:442–456.

This is an extensive review of 3D printing of stents.

9. Guibert N, Didier A, Moreno B, *et al.* Treatment of posttransplant complex airway stenosis with a three-dimensional, computer-assisted customized airway stent. Am J Respir Crit Care Med 2017; 195:e31–e33.
10. Cheng GZ, Folch E, Brik R, *et al.* Three-dimensional modeled T-tube design and insertion in a patient with tracheal dehiscence. Chest 2015; 148:e106–e108.
11. Morrison RJ, Hollister SJ, Niedner MF, *et al.* Mitigation of tracheobronchomalacia with 3D-printed personalized medical devices in pediatric patients. Sci Transl Med 2015; 7:287er4.
12. ClinicalTrials.gov [Internet]. Bethesda (MD): National Library of Medicine (US); 2000. Identifier NCT02889029, Management of complex airway stenoses with dedicated tailored stents wrought by 3d computer-assisted conception. 2016 Sept 5 [cited 27 Jan 2018] [about 5 screens]. https://clinicaltrials.gov/ct2/show/NCT02889029.
13. ▪ Cheng GZ, Estepar RS, Folch E, *et al.* Three-dimensional printing and 3D slicer powerful tools in understanding and treating structural lung disease. Chest 2016; 149:1136–1142.

This is an extensive review of 3D printing of stents.

14. Wang T, Zhang J, Wang J, *et al.* Paclitaxel drug-eluting tracheal stent could reduce granulation tissue formation in a canine model. Chin Med J (Engl) 2016; 129:2708–2713.
15. Chao YK, Liu KS, Wang YC, *et al.* Biodegradable cisplatin-eluting tracheal stent for malignant airway obstruction: in vivo and in vitro studies. Chest 2013; 144:193–199.
16. Zhu GH, Ng AH, Venkatraman SS, *et al.* A novel bioabsorbable drug-eluting tracheal stent. Laryngoscope 2011; 121:2234–2239.
17. Walter RF, Zarogoulidis P, Mairinger FD, *et al.* Cell viability of fibroblasts to pifenidone and sirolimus: a future concept for drug eluting stents. Int J Pharm 2014; 466(1–2):38–43.
18. Hohenforst-Schmidt W, Zarogoulidis P, Pitsiou G, *et al.* Drug eluting stents for malignant airway obstruction: a critical review of the literature. J Cancer 2016; 7:377–390.
19. Zarogoulidis P, Darwiche K, Tsakiridis K, *et al.* Learning from the cardiologists and developing eluting stents targeting the motor pathway for pulmonary application: a future concept for tracheal stenosis. J Mol Genet Med 2013; 7:65–86.
20. Kruklitis RJ, Fishbein I, Singhal S, *et al.* Stent-mediated gene delivery for site-specific transgene administration to the airway epithelium and management of tracheobronchial tumors. Respiration 2014; 88:406–417.
21. Lischke R, Pozniak J, Vondrys D, *et al.* Novel biodegradable stents in the treatment of bronchial stenosis after lung transplantation. Eur J Cardiothorac Surg 2011; 40:619–624.
22. Fuehner T, Suhling H, Greer M, *et al.* Biodegradable stents after lung transplantation. Transpl Int 2013; 26:e58–e60.
23. Sethi S, Gildea TR, Almeida FA, *et al.* Clinical success stenting distal bronchi for 'lobar salvage' in bronchial stenosis. J Bronchology Interv Pulmonol 2018; 25:9–16.
24. Majid A, Kheir F, Chung J, *et al.* Covered balloon-expanding stents in airway stenosis. J Bronchology Interv Pulmonol 2017; 24:174–177.
25. Fruchter O, Abed El Raouf B, Rosengarten D, Kramer MR. Long-term outcome of short metallic stents for lobar airway stenosis. J Bronchology Interv Pulmonol 2017; 24:211–215.
26. Argento AC, Puchalski JT. Distal airway stenting: how far is too far? J Bronchology Interv Pulmonol 2015; 22:e15–e16.
27. El Raouf BA, Kramer MR, Fruchter O. Bronchial anthracofibrosis: treatment using airway stents. Int J Tuberc Lung Dis 2013; 17:1118–1120.

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