Tracheobronchial stenting

Airway stenting can be a life-preserving intervention in patients with critical airway obstruction. It may be safely performed using flexible bronchoscopy under conscious sedation as a day-case procedure in selected patients, but a high incidence of complications limits its use to palliation of malignancy or bridging treatment in benign disease.

Central airway obstruction can present with distressing and potentially life-threatening symptoms that may require immediate action. It is estimated that 30% of patients with lung cancer will suffer from large airway complications (Stohr and Bolliger, 1999). In addition, benign airway obstruction is not always amenable to surgical correction and may require alternative procedures to stabilize the airway.

Airway stenting can rapidly relieve breathlessness and has an established role in the treatment of central airway stenosis. Improved stent design has made insertion easier, improved stent-airway conformity and reduced complication rates. Currently a large selection of stents is available of various lengths, diameters and shapes (e.g. straight, Y-shaped, J-shaped).

Unfortunately, no ideal stent is available. Complications are frequent, particularly late after insertion. For this reason, alternative treatments such as surgery, chemotherapy or radiotherapy or other interventional bronchoscopic procedures (laser, argon plasma coagulation, electrocautery, cryotherapy) should be considered before stent insertion. In airway obstruction caused by benign disease, airway stenting is usually a last resort or a bridge to surgical treatment. Overall, a good understanding of the type and location of the lesion, the underlying pathological process and the physical properties of the stent is required in order to choose the right stent for the right patient.

Indications for stent implantation

Malignant airway obstruction

Compression of the central airways commonly occurs with tumours of the lung, thyroid, larynx and oesophagus but can also be caused by lymphoma and metastatic disease. Usually, anticancer treatment (radiotherapy and/or chemotherapy) should be considered before attempting to stent the airway. However, temporary endobronchial stenting to improve breathlessness before tumour-specific therapy can take effect is a valuable option in severe malignant airway stenosis (Witt et al, 1997).

For intrinsic tumour growth, it is preferred to use debulking therapies such as cryotherapy, argon plasma coagulation or laser, repeated as necessary and complemented by stent insertion if required. If the airway is compressed externally, stent insertion is required to stabilize the airway lumen. In general, covered stents are used in malignant airway obstruction to prevent recurrence of obstruction by tumour ingrowth.

Dr Ute Oltmanns *is Specialist Registrar and* **Dr Mark Slade** *is Clinical Director of Thoracic Services, Papworth Hospital NHS Foundation Trust, Papworth Everard, Cambridge CB23 3RE*

Correspondence to: Dr M Slade

Malignant aero-digestive fistula

Fistulae between the oesophagus and the trachea or main bronchi can complicate a number of thoracic malignancies, particularly oesophageal carcinoma. Fistulae cause cough, fetor and recurrent aspiration pneumonia, and survival is often very short. Stent insertion into the oesophagus alone is rarely sufficient to seal the airway defect completely and the stent may protrude into the airway lumen leading to ventilatory compromise. Most commonly, an airway and oesophageal stent are deployed at the same time. Where the airway defect is situated close to the main carina, a Y-stent is required in the airway.

Post-transplant anastomotic complications

Airway strictures and dehiscences following lung transplantation remain a complex clinical problem despite major improvements in surgical techniques over recent years. Airway compromise as a result of anastomotic failure develops in up to 24% of lung transplant recipients (Inci and Weder, 2010). Although balloon dilatation can occasionally be effective, many patients require temporary or permanent airway stenting. Careful selection of the stent is necessary because stent removal may be indicated in the future.

Benign central airway obstruction

Benign airway obstruction can be short and web-like or extend over a longer segment. There are multiple causes of benign airway stenosis including trauma (intubation, radiation, acid aspiration), primary benign airway tumours (papillomatosis, hamartoma, amyloidosis), inflammatory conditions such as Wegener's granulomatosis, and tracheobronchomalacia. Most commonly the treatment of choice in benign airway stenosis is surgical correction, usually by tracheal sleeve resection. Only where a patient is considered inoperable and other interventional procedures have failed should a stent be considered, balancing carefully the short-term benefits against possible long-term complications.

Stents then and now

The first frequently used airway stent was a T-tube (Montgomery, 1965). It is made of silicone and inserted into the proximal trachea via a tracheostomy. The tracheo-

stomy limb can be opened for airway suctioning or closed to facilitate speaking.

The Dumon stent was introduced in 1990 and was the first stent to permit entirely endoscopic deployment. It is made of silicone, has a smooth inner surface and external studs to prevent migration. Insertion is via rigid bronchoscopy under general anaesthesia. Repositioning and removal are straightforward making it an attractive choice for benign airway obstruction. Dumon stents are cheap and can readily be modified at the time of insertion, for example to facilitate ventilation of a lobar take-off within the stenosed segment. Complications following insertion include migration and obstruction by secretions or granulation tissue.

The Polyflex stent consists of a polymer mesh embedded in silicone. It can be removed easily and newer versions with studs on the outside have decreased the frequency of migration (Wassermann et al, 1997). Other polymeric stents include the Noppen and Hood stents.

Metallic stents consist of a mesh tube that is delivered into position in collapsed form and – once released – is either expandable with an intraluminal balloon, or self-expanding owing to the intrinsic properties of the stent. Early expandable stents such as the Palmaz and Strecker stents were made of stainless steel or tantalum. They have been largely replaced by self-expanding metallic airways stents which are the current industry standard.

Newer self-expanding metallic airways stents, such as the Ultraflex stent, are made of nitinol, a nickel-titanium alloy with remarkable properties that is ideally suited to stent design. Nitinol is extremely elastic at body temperature allowing it to adapt well to complex airway stenoses while still showing adequate resistance to airway compression. Metal stents are either uncovered or covered with a polyurethane membrane. Uncovered metal stents have the advantage of facilitating mucociliary clearance and ventilation of lobar side branches. Problems with migration are rare because the mesh wires become overgrown by respiratory epithelium. However, recurrent airway obstruction as a result of tumour or granulation tissue ingrowth means that in malignant airway obstruction covered stents are generally preferred. Despite the many advantages of metallic airway stents, it is important to remember that there are major complications associated with their long-term use including stent wire fracture. They are also relatively expensive and extremely difficult to remove if they have been in place for more than 30 days. Some self-expanding metallic stents are illustrated in *Figure 1*.

Patient selection and preparation for stent insertion

Before stent insertion, the bronchoscopist should take into account:

1. Any alternative treatment options (including chemo- or radiotherapy, debulking or dilating procedures)
2. The patient's symptoms, condition and prognosis
3. The suitability of the lesion for stenting
4. The choice of the right stent
5. Whether the appropriate expertise is available.

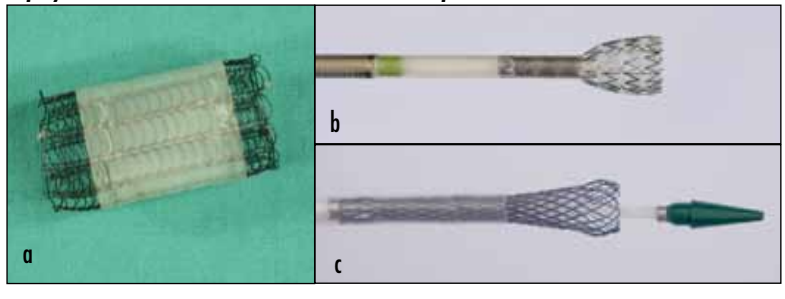
The ideal airway lesion is short, dumbbell shaped and situated in the lower half of the trachea or one of the main lobar bronchi. It has no lobar take-off in the stenosed segment. In conical lesions, with a progressively tapering airway, stents are more likely to migrate proximally – the 'toothpaste' effect. Above all, the patient's symptoms should be considered carefully. Stenting is a palliative procedure, with some potentially severe complications, and so the bronchoscopist should never be in the position of trying to persuade the patient to have a stent inserted.

Pre-procedure patient assessment

The work-up for tracheobronchial stenting necessarily depends upon the patient's condition. In near-complete tracheal obstruction, intubation and immediate rigid bronchoscopy by the most experienced available practitioner without any pre-procedure work-up may be entirely appropriate. Almost always, however, in addition to a history and physical examination and standard pre-bronchoscopy tests it is appropriate to request airway computed tomography scanning, spirometry, a flow-volume loop and an assessment of breathlessness, such as the MRC or Borg dyspnoea scores. Some operators favour a prior flexible bronchoscopy to assess the lesion anatomy. Once these tests have been undertaken, it will often be possible to arrive at a complete specification for the desired stent.

Airway computed tomography scanning, particularly if carried out on a high-speed multidetector scanner, can be used to create multiplanar reformat and virtual bronchoscopy images. These enable assessment of the diameter of the stenosed segment and, if present, the adjacent normal airway to be estimated. Where the target bronchus has no segment of normal calibre throughout its length, estimates of its usual calibre can be obtained by measuring the corresponding contralateral airway. Images displayed on lung window settings provide a

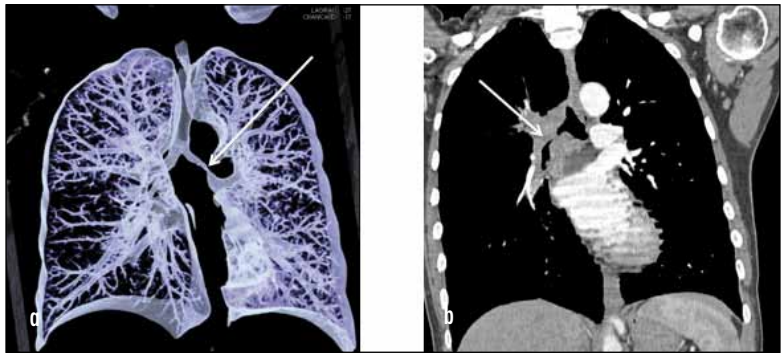
Figure 1. Some self-expanding metallic airway stents in current use. a. A covered Ultraflex stent. b. An Alveolus Aero fully-covered stent, half-deployed. The green marker corresponds to the proximal end of the stent in normal use. A blue suture is just visible through the external catheter at the proximal end of the stent. c. A part-deployed Micro-Tech stent, which also has a clear plastic outer sheath.



more accurate impression of the likely endobronchial appearances. Dynamic computed tomography images, obtained during expiration, can further define regions where dynamic airway collapse occurs, sometimes as a consequence of the destruction of airway cartilage by underlying tumour. Examples of pre-stent reformatted computed tomography images are shown in *Figure 2*.

Standard flexible bronchoscopy provides visual assessment of the severity and length of airway stenoses, the patency of any adjacent lobar take-off (particularly the right upper lobe), and the presence or absence of endobronchial tumour. Radial endobronchial ultrasound can provide additional information on integrity of the underlying airway cartilage.

Figure 2. Reformatted computed tomography images demonstrating stenosis of (a) the left main bronchus and (b) right main bronchus. Both of these lesions were successfully stented.



Stent selection

In general, metallic stents are easier to insert but have a higher complication rate than polymer stents. The benefits of metallic over silicone stents outweigh the disadvantages in malignant airway obstruction where life expectancy is usually short. In benign airway obstruction, however, the placement of metallic stents can be hazardous because the risk of complications increases with time. Stenting in these patients may be only temporarily required but removal of metallic stents is potentially extremely difficult (Alazemi et al, 2010). In 2005, the US Food and Drug Administration issued a medical device safety alert warning against the use of metallic stents in benign tracheal stenosis except where careful consideration had been given to alternative treatment options (Food and Drug Administration, 2005). If airway stenting is indicated in benign airway obstruction, preference should be given to polymer stents. The pros and cons of metallic *vs* silicone stenting are summarized in *Table 1*.

In order to minimize the possibility of tumour ingrowth, covered stents are almost always used in malignant airway obstruction, except when airway compres-

Table 1. A comparison of silicone and metallic stent properties

Quality		Silicone stent	Metallic stent
Ease of deployment	Flexible bronchoscopy	No	Yes
	Moderate sedation + local anaesthesia	No	Yes
	Day-case procedure	Usually not	Yes
Complications	Granulation tissue in/over growth	Little	More
	Tumour in/over growth	Only at ends	Yes in uncovered portion
	Migration	Significant	Less common, except fully-covered stents
	Fracture/degeneration	Very rare	Significant with longer follow-up
	Infection	Uncommon	More common
	Tracheobronchial perforation	Very rare	Possible, more common with stiffer stents
	Mucus impaction	Common	Uncommon
Material properties	Modifiable	Easily	No
	Ease of repositioning	Easy	Immediately – fair
			Subsequently – not advised
	Ease of insertion	Fair	Good
	Conforms to complex stenoses	No – single diameter	Yes
	High internal-external diameter ratio	No	Yes
	Elasticity during e.g. coughing	Poor	Excellent – nitinol
			Fair – other metals
	Permits mucociliary clearance	No	Yes – uncovered stent
			No – covered stent
Cost		Less	More

sion is purely extrinsic and it is necessary to stent across a patent lobar bronchus (usually the right upper lobe). The stent diameter is chosen to be approximately 2 mm greater than the normal diameter of the target airway, to reduce the possibility of stent migration. The length of the stent should be 0.5 cm longer both proximally and distally than the stenosed segment. The required stent length is commonly estimated from flexible bronchoscopy. Stent sizing devices such as Aerosizer (Merit Medical) are available to facilitate this process. Usually a 4 cm stent is appropriate for the left main bronchus, and 2–4 cm stents for the right main bronchus, depending upon the patency of the right upper lobe. Stent length can also be estimated from coronally reformatted computed tomography images.

Insertion

A dedicated environment, such as a bronchoscopy suite or theatre room, and trained staff are essential for a successful stent placement. In critically ill patients the procedure can be performed safely at the bedside on the intensive care unit. Guidelines recommend performing at least 10 supervised stent insertions before attempting this procedure alone. In order to maintain competence, between five and ten procedures should be performed annually (Bolliger et al, 2002). Among interventional bronchoscopy practitioners with access to a full range of techniques, stents are most commonly inserted using rigid bronchoscopy, general anaesthesia and direct endoscopic, rather than fluoroscopic, visualization (Herth et al, 2001). This allows a safe airway, good visualization of the lesion and easier manipulation of the stent and it is probably the most rapid and controlled insertion method. The majority of pulmonologists are not trained to use rigid bronchoscopy (Prakash et al, 1991). Newly developed introducer systems have the advantage of allowing the safe insertion of expandable endobronchial stents with flexible bronchoscopy under conscious sedation and on an outpatient basis (Hautmann et al, 2000).

Before stent insertion the airway lumen is maximized by balloon dilatation and/or debulking. In metallic stenting, a guidewire is passed into the airway and the stent delivery device (holding the compressed stent on its end) is advanced over the guidewire into position. The self-expanding stent is deployed under direct endoscopic vision by pulling back the outer sheath. Stent position can be verified bronchoscopically or by fluoroscopy. The procedure for insertion and adjustment of self-expanding metallic airways stents is illustrated in *Figures 3* and *4*.

Silicone stents are deployed by preloading the folded stent into the distal end of a rigid bronchoscope, which is then passed into the stenosed airway. The stent is deployed by pushing it from the end of the bronchoscope. It can then be helped to expand, and its position be adjusted, by the use of rigid bronchoscopic forceps.

After deployment, self-expandable metallic airway stents gradually enlarge to their final dimensions over 24–48 hours. Balloon dilatation may be used within the stent to speed this process, but this is generally neither necessary nor advisable. Following deployment, the position of a silicone stent can easily be adjusted under rigid bronchoscopy if necessary. Minor adjustments to the position of metal stents can be made, but in the spontaneously breathing patient manipulation of the stent can induce coughing and displacement or fracture of the stent.

Figure 3. Metallic stent deployment in the right main bronchus. a. A guidewire is passed. b. An ultraflex covered stent is passed over the guidewire and the position of the proximal end of the stent is confirmed endoscopically. c. The stent has been released from the delivery device, which is carefully withdrawn with a twisting motion to ensure that it is free from the stent. Care is taken not to dislodge the newly-released stent. d. The final stent position is checked endoscopically.

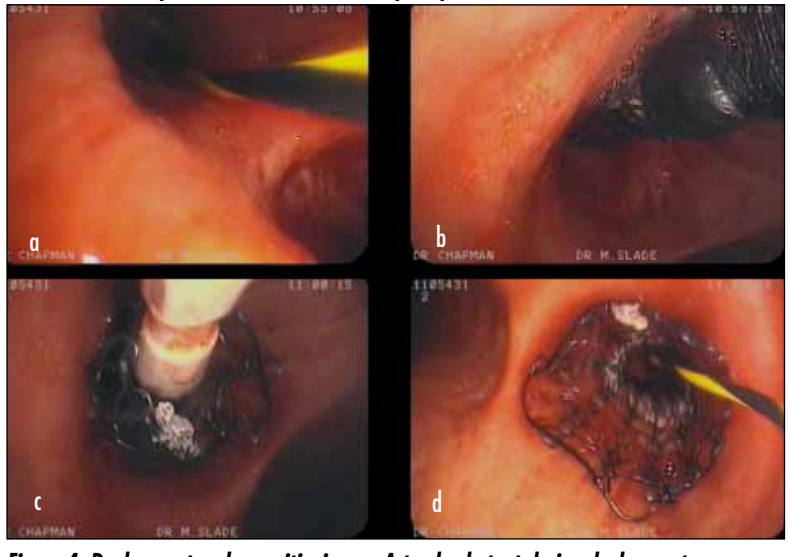
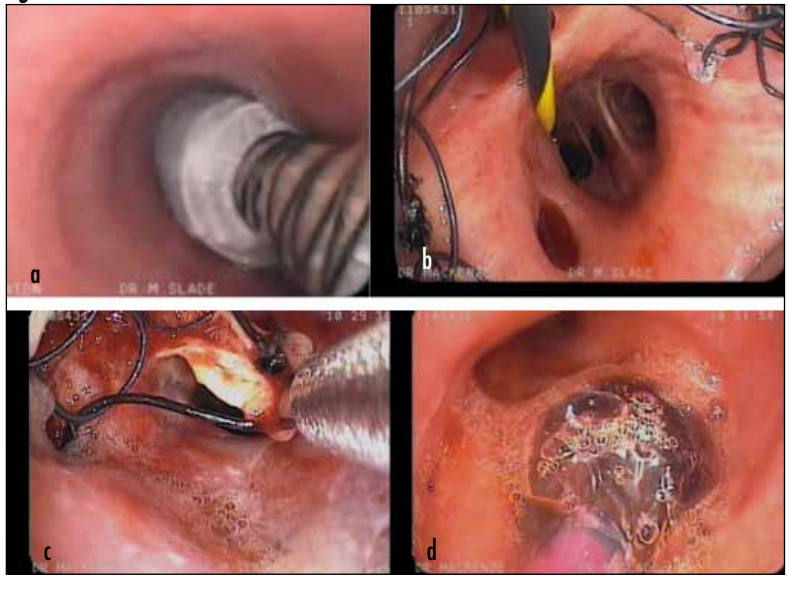


Figure 4. Deployment and repositioning. a. A tracheal stent during deployment, illustrating endoscopic confirmation of stent positioning and distal to proximal release. b. Confirming satisfactory distal position of a right main bronchial stent, leaving the middle and lower lobe bronchial openings patent. c. Attempted distal repositioning of a stent by grabbing its distal suture. d. Post deployment balloon dilatation of a stent in right main bronchus.



Outcomes

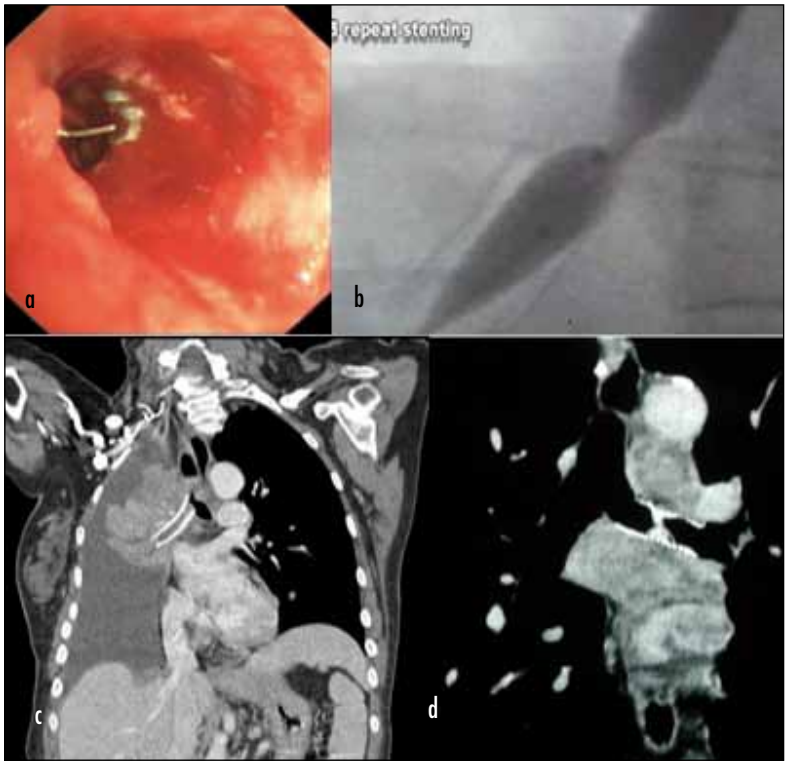
Endobronchial stents lead to consistent relief of stridor, breathlessness and cough in both malignant and benign airway stenosis (Razi et al, 2010). Where paired data exist forced expiratory volume in 1 second, forced vital capacity and airway resistance also appear improved (Vergnon et al, 1995; Eisner et al, 1999; Hautmann et al, 2000). Airway stenting may facilitate weaning from mechanical ventilation (Saad et al, 2003; Noppen et al, 2007). In malignant airway disease, progression of the underlying tumour usually limits the long-term palliative benefit of airway stents (Breitenbucher et al, 2008). The median survival in these patients following stent insertion is 3–4 months (Lemaire et al, 2005; Breitenbucher et al, 2008). In benign airway obstruction survival is longer and mainly depends on the underlying disease process.

Follow up and dealing with complications

Follow up

The provision of a stent card or alert bracelet is recommended, detailing the size and location of the stent, and providing advice and a telephone number for use in emergencies. There is no consensus regarding follow-up procedures after stent insertion. It is appropriate to see patients 1–4 weeks after stent insertion to assess symptoms, lung function and radiographic appearances. Quality of life and dyspnoea scores provide useful additional information. Routine bronchoscopy post-procedure is practised by some and can detect early complications such as mucus impaction and granulation tissue formation before symptoms arise. Some patients require regular bronchoscopies to clear thick mucus impaction or granulation tissue. Others argue that it is sufficient to perform bronchoscopy once symptoms are present (Matsuo and Colt, 2000). Considering that endobronchial stenting is a palliative procedure, the least invasive approach is probably justified in order to minimize patient discomfort. Multidetector computed tomography scanning detects the majority of stent complications and is appropriate if symptoms warrant investigation (Ferretti et al, 2003; Dialani et al, 2008).

Figure 5. Stent complications. a. A fractured strut of the proximal part of a left main bronchial stent is seen protruding into the bronchial lumen. This fracture was caused by an attempt to reposition the stent using forceps. The stent mesh was grabbed instead of the green suture, which is also just visible. b. A stricture has formed at the proximal end of an existing right main bronchial stent and is being ballooned. c. Tumour ingrowth is visible into a right main bronchial stent. There is associated collapse of the right lung and a right pleural effusion. d. A left main bronchial stent is obstructed by mucus impaction 6 weeks after placement.



Complications

Immediate complications during or shortly after stent deployment are rare (Hautmann et al, 2000; Breitenbucher et al, 2008; Chung et al, 2010). Most complications are related to interference of the stent with normal airway anatomy and physiology. Their frequency varies according to stent type, duration of post-stenting survival and underlying disease. Complication rates are therefore higher in patients with benign airway stenosis as life expectancy is longer (Chung et al, 2010). Case series showed that the rate of complications requiring intervention after metallic stent insertion in benign airway stenosis was 48% (Madden et al, 2006), 46% (Saad et al, 2003) and 37% (Chan et al, 2008) respectively, and that most problems occur >30 days after the procedure (Lemaire et al, 2005). Major stent-related complications are migration, mucous impaction, obstruction as a result of granulation tissue or tumour ingrowth, infection, fracture, tracheobronchial perforation and haemoptysis. These are illustrated in *Figure 5*. Migration is mainly associated with the use of polymer stents. In a large retrospective study, migration rate of Dumon stents was 9.5% overall but 18.6% when used for tracheal stenosis (Dumon et al, 1996).

Stent colonization with bacteria including potentially pathogenic organisms such as Pseudomonas and Staphylococcus is common (Noppen et al, 1999). In most cases this does not result in clinical signs of infection but halitosis is a frequent complaint. Treatment is difficult because systemic antibiotics may not reach the biofilm but aerosol treatment may be of some benefit. A review suggests that stent-associated respiratory tract infections are as frequent as one in five patients (Agrafiotis et al, 2009). The most common type of infection was pneumonia (47%) followed by bronchial infection, cavitating pneumonia or lung abscess and intraluminal fungal infection. Stent removal may be necessary in some cases, particularly in staphylococcal infection. Granulation tissue and recurrent tumour can be removed by endo-

bronchial cryotherapy, argon plasma cautery or mechanical coring out. Laser can also be used but needs to be applied with care in order to avoid damage to stent wires. Stent fracture may require removal of the stent if a wire fragment protrudes into the mucosa and is at risk of causing bleeding or perforation. Fatal stent-related complications are rare and mainly caused by stent erosion of the airway and adjacent blood vessel (Nouraei et al, 2001).

Removal

Removal of polymer stents is possible at any time after insertion. For this reason polymer stents are the best choice if temporary stenting is required. Depending upon the stent type and the presence or absence of granulation tissue or tumour ingrowth, metallic stents may remain relatively easy to remove for roughly 30 days, especially if the reason for removal is migration. However, metallic stents that have been in situ for longer, or have fractured or caused bronchial perforation, may be extremely difficult, hazardous and costly to remove (Lunn et al, 2005; Noppen et al, 2005; Alazemi et al, 2010). Removal should only be attempted in centres with considerable expertise in interventional rigid bronchoscopy, thoracic surgery and critical care. Conflicting descriptions of the difficulties of stent removal exist (Noppen et al, 2005; Alazemi et al, 2010; Ranu et al, 2010). The removal of a covered self-expanding metallic airways stent, which had become displaced 2 days after deployment, is illustrated in *Figure 6*.

The future

Current research is addressing some of the major problems of stent design. The ideal airway stent should:

1. Be easy to insert and remove but not migrate
2. Maintain airway patency without causing mucosal damage
3. Promote clearance of secretion
4. Be tailored to individual needs
5. Be biologically inert and avoid granulation tissue growth.

The development of drug-eluting and bioabsorbable stents that would reduce the risk of granulation tissue growth and infection as well as obviate the need for stent removal may offer a solution.

Conclusions

Airway stenting is an effective palliative procedure to relieve breathlessness as a result of central airway stenosis. New and improved insertion techniques add to the attractiveness of the procedure but the absence of large prospective trials means that no evidence-based recommendations can be issued. Procedural skills, experience and a dedicated environment are essential for a safe and beneficial airway stenting. Complications of airway stents can be severe and limit their usefulness. Future technical developments in stent design may widen the indications for the procedure. BJHM

Figure 1 *is reproduced courtesy of Laurence Pengelly;* Figures 2–6 *are reproduced courtesy of Dr Mark Slade.*

Conflict of interest: Dr M Slade has organized courses in interventional pulmonology which have benefited from unrestricted educational grants of £500 annually from Boston Scientific Ltd, makers of the Ultraflex stent; Dr U Oltmanns: none.

Agrafiotis M, Siempos II, Falagas ME (2009) Infections related to airway stenting: a systematic review. *Respiration* **78:** 69–74

Alazemi S, Lunn W, Majid A et al (2010) Outcomes, health-care resources use, and costs of endoscopic removal of metallic airway stents. *Chest* **138:** 350–6

Bolliger CT, Mathur PN, Beamis JF et al (2002) ERS/ATS statement on interventional pulmonology. European Respiratory Society/ American Thoracic Society. *Eur Respir J* **19:** 356–73

Breitenbucher A, Chhajed PN, Brutsche MH, Mordasini C, Schilter D, Tamm M (2008) Long-term follow-up and survival after Ultraflex stent insertion in the management of complex malignant airway stenoses. *Respiration* **75:** 443–9

Chan AL, Juarez MM, Allen RP, Albertson TE (2008) Do airway metallic stents for benign lesions confer too costly a benefit? *BMC Pulm Med* **8:** 7

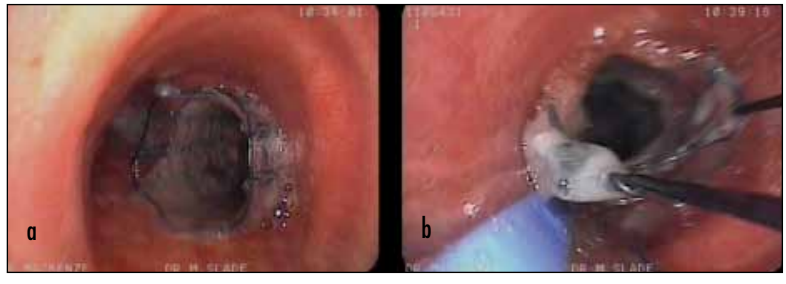
Chung FT, Lin SM, Chou CL, Chen HC, Liu CY, Yu CT, Kuo HP (2010) Factors leading to obstructive granulation tissue formation after ultraflex stenting in benign tracheal narrowing. *Thorac Cardiovasc Surg* **58:** 102–7

Dialani V, Ernst A, Sun M et al (2008) MDCT detection of airway stent complications: comparison with bronchoscopy. *AJR Am J Roentgenol* **191:** 1576–80

Dumon JF, Cavaliere S, Diaz-Jimenez JP, Vergnon J-M, Venuta F, Dumon M-C, Kovitz K (1996) Seven-year experience with the Dumon prosthesis. *J Bronchol* **3:** 6–10

Eisner MD, Gordon RL, Webb WR, Gold WM, Hilal SE, Edinburgh K, Golden JA (1999) Pulmonary function improves after expandable metal stent placement for benign airway obstruction. *Chest* **115:** 1006–11

Figure 6. Stent removal. a. An ultraflex covered stent has migrated within 48 hours of placement in the right main bronchus. b. It is removed by pulling it into an endotracheal tube using forceps to grab the proximal stent suture. This has the effect of pulling the cylindrical stent into a more conical shape at its proximal end, facilitating removal.



KEY POINTS

- In severe central airway obstruction, airway stenting can bring immediate relief and may be life-saving.
- Metallic airway stenting is possible as a day-case procedure using flexible bronchoscopy with conscious sedation.
- In benign disease, airway stenting is usually used only as a temporary measure, pending definitive airway surgery.
- Randomized trials examining the effectiveness of airway stenting are lacking.
- The complications of airway stenting are common and occasionally very serious or fatal. Palliative airway procedures should only be undertaken by operators experienced in their use and in the management of their complications, and only after detailed patient consenting.

Ferretti GR, Kocier M, Calaque O, Arbib F, Righini C, Coulomb M, Pison C (2003) Follow-up after stent insertion in the tracheobronchial tree: role of helical computed tomography in comparison with fiberoptic bronchoscopy. *Eur Radiol* **13:** 1172–8

Food and Drug Administration (2005) Public Health Notification: Complications from metallic tracheal stents in patients with benign airway obstruction. (www.fda.gov/MedicalDevices/Safety/AlertsandNotices/PublicHealthNotifications/UCM062115 accessed 5 February 2011)

Hautmann H, Bauer M, Pfeifer KJ, Huber RM (2000) Flexible bronchoscopy: a safe method for metal stent implantation in bronchial disease. *Ann Thorac Surg* **69:** 398–401

Herth F, Becker HD, Locicero J III, Thurer R, Ernst A (2001) Successful bronchoscopic placement of tracheobronchial stents without fluoroscopy. *Chest* **119:** 1910–12

Inci I, Weder W (2010) Airway complications after lung transplantation can be avoided without bronchial artery revascularization. *Curr Opin Organ Transplant* **15:** 578–81

Lemaire A, Burfeind WR, Toloza E, Balderson S, Petersen RP, Harpole DH Jr, D'Amico TA (2005) Outcomes of tracheobronchial stents in patients with malignant airway disease. *Ann Thorac Surg* **80:** 434–7; discussion 437–8

Lunn W, Feller-Kopman D, Wahidi M, Ashiku S, Thurer R, Ernst A (2005) Endoscopic removal of metallic airway stents. *Chest* **127:** 2106–12

Madden BP, Loke TK, Sheth AC (2006) Do expandable metallic airway stents have a role in the management of patients with benign tracheobronchial disease? *Ann Thorac Surg* **82:** 274–8

Matsuo T, Colt HG (2000) Evidence against routine scheduling of surveillance bronchoscopy after stent insertion. *Chest* **118:** 1455–9

Montgomery WW (1965) T-Tube Tracheal Stent. *Arch Otolaryngol* **82:** 320–1

Noppen M, Pierard D, Meysman M, Claes I, Vincken W (1999) Bacterial colonization of central airways after stenting. *Am J Respir Crit Care Med* **160:** 672–7

Noppen M, Stratakos G, D'Haese J, Meysman M, Vinken W (2005) Removal of covered self-expandable metallic airway stents in benign disorders: indications, technique, and outcomes. *Chest* **127:** 482–7

Noppen M, Stratakos G, Amjadi K, De Weerdt S, D'Haese J, Meysman M, Vincked W (2007) Stenting allows weaning and extubation in ventilator- or tracheostomy dependency secondary to benign airway disease. *Respir Med* **101:** 139–45

Nouraei SM, Pillay T, Hilton CJ (2001) Emergency management of aorto-bronchial fistula after implantation of a self-expanding bronchial stent. *Eur J Cardiothorac Surg* **20:** 642–4

Prakash UB, Offord KP, Stubbs SE (1991) Bronchoscopy in North America: the ACCP survey. *Chest* **100:** 1668–75

Ranu H, Evans J, Sheth A, Madden BP (2010) Removal of long-term tracheal stents with excellent tracheal healing. *Ann Thorac Surg* **89:** 598–9

Razi SS, Lebovics RS, Schwartz G, Sancheti M, Belsley S, Connery CP, Bhora FY (2010) Timely airway stenting improves survival in patients with malignant central airway obstruction. *Ann Thorac Surg* **90:** 1088–93

Saad CP, Murthy S, Krizmanich G, Mehta AC (2003) Self-expandable metallic airway stents and flexible bronchoscopy: long-term outcomes analysis. *Chest* **124:** 1993–9

Stohr S, Bolliger CT (1999) Stents in the management of malignant airway obstruction. *Monaldi Arch Chest Dis* **54:** 264–8

Vergnon JM, Costes F, Bayon MC, Emonot A (1995) Efficacy of tracheal and bronchial stent placement on respiratory functional tests. *Chest* **107:** 741–6

Wassermann K, Koch A, Muller-Ehmsen J, Reuter M, Michel O, Eckel HE (1997) Clinical and laboratory evaluation of a new thin-walled self-expanding tracheobronchial silicone stent: progress and pitfalls. *J Thorac Cardiovasc Surg* **114:** 527–34

Witt C, Dinges S, Schmidt B, Ewert R, Budach V, Baumann G (1997) Temporary tracheobronchial stenting in malignant stenoses. *Eur J Cancer* **33:** 204–8