The Journal of Laryngology & Otology (2008), ***122***, *391–396.*

doi:10.1017/S0022215107008109

Main Article

Laryngotracheal augmentation using titanium mesh

A A Gaafar, A A El-Daly, H A Gaafar

Abstract

Background: The management of laryngotracheal stenosis is still a serious surgical challenge. The fact that there are currently numerous reconstruction procedures indicates that there is at present no standard treatment.

Study design: Titanium mesh was used instead of traditional homografts in reconstruction of the anterior laryngotracheal wall in 12 tracheostomised patients with benign chronic laryngotracheal stenosis. The anterior laryngotracheal wall was split, followed by excision of scar tissue and fixation of the titanium plate at the split end. A Silastic® stent was inserted above the tracheostomy tube and fixed in place by running sutures fixed to the skin by buttons. The stent was removed endoscopically six weeks later and a trial of decannulation was undertaken.

Results: Endoscopically, good epithelisation was seen on the inner surface of the mesh in 10 cases and decannulation was possible. Four of these patients required endoscopic debulking of granulation tissue. Decannulation was impossible in two cases, one due to excessive granulation tissue and the other due to prolapse of the titanium mesh into the tracheal lumen (the mesh was removed endoscopically and a Montgomery T-tube inserted).

Conclusion: Titanium mesh was found to be a good alternative for augmentation of the anterior laryngotracheal wall. It offered rigid support, with fewer of the complications reported with other grafts.

Key words: Trachea; Pathologic Constriction; Titanium; Reconstructive Surgical Procedures

Introduction

Laryngotracheal stenosis can be clinically devastating. Rehabilitation of patients to a state of normal respiratory and phonatory function is a formidable challenge. The fact that there are currently numerous reconstruction procedures indicates that, at present, there is no standard treatment method. Kimura *et al.*[1] described a technique of tracheal stenosis treatment that involved splitting the anterior wall of the trachea and inserting a costal cartilage graft. The complications of this technique included anastomotic breakdown, restenosis, graft resorption, chondritis, pneumothorax and granulation tissue formation.[1,2] The following grafts have also been used: the hyoid–sternohyoid myo-osseus flap,[3] tracheal cartilage autograft,[4] composite nasal septal graft[5] and auricular cartilage graft.[6] The variety of grafts developed for laryngotracheal lumen augmentation suggests that, at present, no ideal graft has been found.

Researchers have developed a variety of tracheal prostheses made of synthetic biomaterials such as steel wire, glass, Lucite® and gortex. Alloplastic materials have always had limited success, due to frequent dislodgement, infection and rejection.[7]

The ideal grafting material for tracheal reconstruction should: (1) provide adequate structural support to maintain airway patency; (2) integrate into the recipient tissue to avoid the need for removal; (3) produce minimal inflammatory response to avoid scar formation and stenosis; (4) rapidly mucosalise to allow for improved mucociliary transport; and (5) be readily available.[8]

Titanium is a hypoallergenic material which has been used extensively in orthopaedic and maxillofacial surgery, with excellent long-term results.[9,10] Titanium mesh has been used for sternal reconstruction following median sternotomy, giving effective stabilisation in this mobile area.[11] In the airway, titanium has been previously used for internal fixation of laryngeal injuries[12,13] and in medialisation thyroplasty.[14] Titanium mixed with nickel to form an alloy (Nitinol) has been used in the formation of self-expandable tracheal stents. These stents have been successfully used for the management of benign and malignant tracheal stenosis.[15,16]

Our aim was to assess the use of titanium mesh, instead of traditional homografts, in single-stage reconstruction of the anterior laryngotracheal wall in cases of benign laryngotracheal stenosis.

From the Department of Otolaryngology Head & Neck Surgery, University of Alexandria, Egypt.
Accepted for publication: 12 February 2007. First published online 14 May 2007.

Patients and methods

The study group comprised 12 tracheostomised patients suffering from chronic benign laryngotracheal stenosis, who presented to the department of otolaryngology and head and neck surgery at the Alexandria Medical School, Egypt.

Pre-operative evaluation

All patients were subjected to pre-operative clinical and radiological evaluation by computed tomography scanning. Endoscopy of the larynx and trachea under general anaesthesia was performed in order to assess the exact site, length and diameter of the stenosed segment.

Patients with glottic or supraglottic involvement were excluded from the study.

Operative procedure

Reconstruction was performed under general anaesthesia, with endotracheal intubation through the tracheostomy orifice. A transverse anterior neck incision that included the tracheostomy orifice was utilised. The upper skin flap was elevated in a subplatysmal plane to the level of the thyrohyoid membrane.

The strap muscles were exposed and carefully separated in the midline, exposing the anterior laryngotracheal wall. The isthmus of the thyroid gland was divided (if this had not been done in the previous tracheostomy), followed by splitting of the cricoid cartilage and the upper tracheal rings (Figure 1a). If indicated, the split was extended superiorly to involve the lower half of the thyroid cartilage just below the anterior commissure, or inferiorly to communicate with the tracheostomy orifice. Any scar tissue was removed.

A Silastic stent was then inserted to expand the lumen. The stent was fixed in place by non-absorbable sutures exiting from the skin on both sides of the neck. The upper end of the stent lay below the level of the vocal folds and the lower end lay just above the tracheostomy orifice.

The split ends of the trachea were fixed in its expanded position by a 0.4 mm titanium mesh (Mondeal Medical Systems, Tuttlingen, Germany).

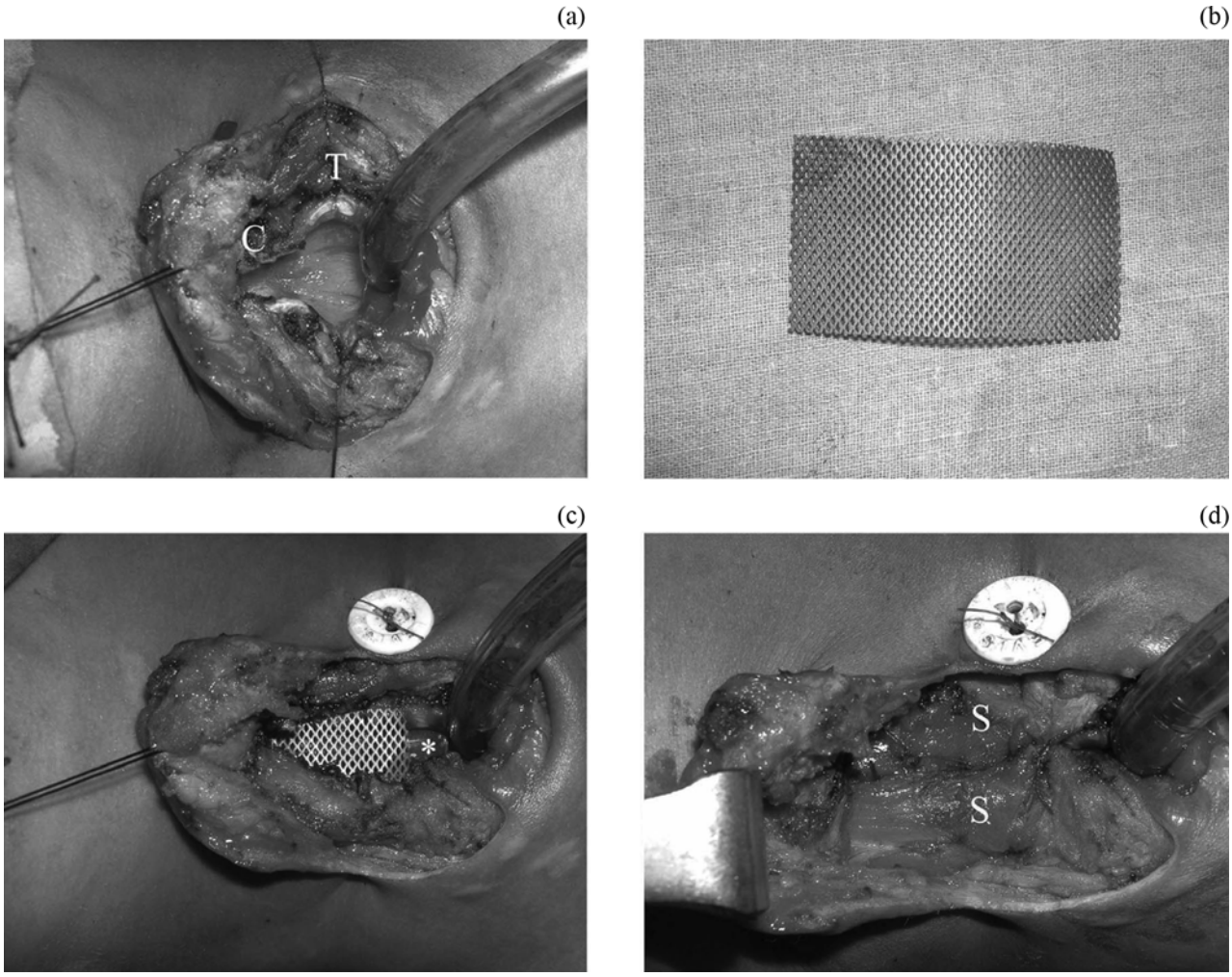

FIG. 1

Operative procedure. (a) Splitting the cricoid cartilage (C) and upper tracheal rings (T). (b) The titanium mesh before reshaping. (c) The titanium mesh after reshaping, sutured to the anterior laryngotracheal wall with Silastic stent (*) stenting the lumen and fixed to the skin by running sutures. (d) Strap muscles (S) sutured in the midline, covering the outer surface of the mesh.

https://doi.org/10.1017/S0022215107008109 Published online by Cambridge University Press

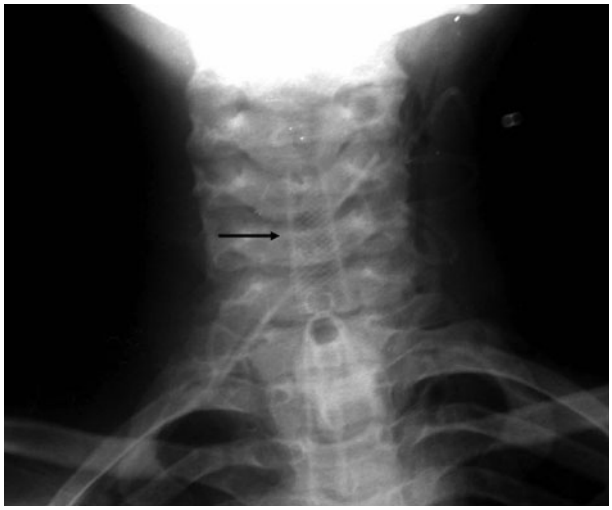

FIG. 2
Post-operative plain X-ray showing the titanium mesh (arrow) in place.

The mesh was cut and fashioned at the time of the surgery according to the length and diameter of the newly formed airway. The mesh was sutured to the laryngotracheal wall by Vicryl sutures (Figure 1b and 1c). The strap muscles were used to cover the titanium mesh (Figure 1d). The inner aspect of the mesh was left bare for re-epithelisation from the surrounding airway epithelium.

A Penrose drain was inserted and the skin was closed in two layers leaving the old tracheostomy orifice. A tracheostomy tube of appropriate size was inserted at the end of the procedure.

Post-operative care

All patients received parental antibiotics, oral anti-inflammatory agents and corticosteroids for seven days. A plain neck X-ray was performed to assess the position of the titanium mesh (Figure 2).

The patients were readmitted six weeks later and the Silastic stent removed endoscopically under general anaesthesia. The lumen was inspected and any granulation tissue was removed. One cubic centimetre of mitomycin-C (0.5 mg/ml) was applied topically for five minutes. A trial of decannulation was commenced gradually by inserting a smaller tracheostomy tube for two days, followed by complete decannulation. Patients were followed up regularly, every two weeks for two months and then every month. Any signs or symptoms of airway distress were reported. At the end of the follow-up period, the patient's respiratory reserve was classified subjectively as good (i.e. normal daily activity without dyspnoea), fair (i.e. dyspnoea on normal daily activity) or guarded (i.e. dyspnoea at rest).

Results

Twelve patients with benign chronic laryngotracheal stenosis were included in this study. There were 10 men (83.33 per cent) and two women (16.67 per cent), aged 19–54 years ($\pm$11.78). The aetiology of stenosis was post-intubation in 58.3 per cent (7/12) of cases (Table I). Six patients (50 per cent) had a previous failed endoscopic treatment (Table I). The stenosis was in the cervical trachea in seven cases (58.3 per cent), laryngotracheal in four cases (33.3 per cent) and subglottic in one case (8.4 per cent) (Table II).

The operative procedure was successfully completed in all patients, with no intra-operative or immediate post-operative complications reported. The average operating time was one hour. The titanium mesh was well tolerated by all patients. On removal of the Silastic stent after six weeks, good neo-epithelisation was found on the inner mesh surface in the 10 patients in whom decannulation was possible. Some non-significant granulation tissue was present, mainly at the lower end of the stent, just above the tracheostomy orifice (Figure 3).

Decannulation was impossible in two cases. In one patient, this was due to excessive granulation tissue, with collapse of the suprastomal part of the trachea. In the second patient, the mesh prolapsed into the lumen, leading to airway obstruction; the mesh was removed endoscopically and a Montgomery T-tube was inserted.

On follow up, four patients showed mild to moderate respiratory distress. Endoscopy revealed varying degrees of granulation tissue formation. Endoscopic

TABLE I
CHARACTERISTICS OF STUDY CASES

Pt no	Sex	Age (years)	Aetiology*	Previous treatment
1	Male	19	Trauma	–
2	Male	24	Post-tracheostomy	–
3	Female	32	Post-tracheostomy	Bronchoscopic dilation
4	Male	27	Post-intubation	Laser dilation × 2
5	Male	54	Post-intubation	Laser dilation
6	Male	46	Post-tracheostomy	–
7	Male	57	Post-intubation	–
8	Female	51	Post-intubation	–
9	Male	43	Post-intubation	Bronchoscopic dilation
10	Male	48	Post-intubation	–
11	Male	39	Post-intubation	Dilation + T-tube
12	Male	45	Trauma	T-tube

*Of laryngotracheal stenosis. Pt no = patient number

https://doi.org/10.1017/S0022215107008109 Published online by Cambridge University Press

TABLE II

SUMMARY OF OPERATIVE OUTCOMES

Pt no	Site	Complications	Management	FU (months)	Decannulation
1	LT	–	–	36	Y
2	T	GT	Endoscopic debulking	32	Y
3	T	–	–	25	Y
4	SG	–	–	12	Y
5	LT	–	–	17	Y
6	T	–	–	20	Y
7	T	Mesh prolapse into lumen	Endoscopic removal & T-tube insertion	3	N (T-tube)
8	LT	GT × 2	Endoscopic debulking	11	Y
9	T	GT	Endoscopic debulking	19	Y
10	LT	Excessive GT + suprastomal collapse	Tracheostomy	LFU	N
11	T	GT × 3	Debulking	27	Y
12	T	–	–	5	Y

LT = laryngotracheal; T = tracheal; SG = subglottic; GT = granulation tissue; FU = follow up period; LFU = lost to follow up; Y = yes; N = no

debulking and mitomycin-C application was performed, with immediate improvement of respiration (Table II).

The follow-up period ranged from three to 36 months (Table II). At the end of the follow-up period, 10 patients were decannulated (83.3 per cent). Respiratory reserve was good in seven patients and fair in three patients. Two patients (16.7 per cent) were unable to be decannulated.

Discussion

Laryngotracheoplasty is now standard care for symptomatic laryngotracheal stenosis. The reasons for unsuccessful decannulation after a laryngotracheoplasty may be multifactorial, depending on the techniques and grafts used. Excessive granulation tissue may develop, requiring further procedures. Cartilaginous grafts may become infected, be resorbed or collapse into the tracheal lumen. Bulky regional skin–muscle flaps may dehisce under tension or collapse into the tracheal lumen. Medial migration of the split ends of the anterior cartilaginous tracheal rings ensues, with subsequent restenosis. Donor site morbidity may compound these problems.[1–3]

The search for novel methods of treatment for tracheal stenosis has led many groups to investigate the feasibility of using synthetic material to reconstruct airway defects.

Over a three-year period, we performed laryngotracheoplasty using titanium mesh in 12 patients suffering from chronic laryngotracheal stenosis. The mesh was easily designed and sutured to the split laryngotracheal ends. It was covered by strap muscle in order to support the outer surface and to provide a scaffold for new epithelisation. After six weeks, the mesh was found to be incorporated into the recipient tissue, with neo-epithelisation on the inner surface of the mesh, in 10 out of 12 patients, in whom decannulation was possible.

Casiano *et al.*[17] used pored titanium plates with a strap muscle flap for reconstruction of the anterior laryngotracheal wall in nine patients suffering from laryngotracheal stenosis. Seven (78 per cent) patients were able to be decannulated, six needed no further intervention and one acquired granulation tissue formation requiring further endoscopic debulking. An advantage of titanium mesh is that it causes only a mild inflammatory reaction due to its hypoallergenic nature. Also, the presence of pores allows for mucociliary clearance and for regrowth of new epithelium through these pores, allowing the mesh to become easily incorporated into the recipient tissue.

Schultz *et al.*[18] histologically examined the cervical trachea of 11 mice, 15–41 days after titanium tracheal prosthesis implantation. They found a mild inflammatory reaction, with fibroblast colonisation of the titanium pores and a cylindrical ciliary epithelial layer developed on the endoluminal side of the prosthesis. According to these authors, these findings supply surgical and histological validation for the usefulness of a porous titanium tracheal prosthesis in the management of tracheal stenosis.

We routinely used Silastic intraluminal stenting for six weeks. This helped support the reconstructed area; also, removal of the stent after six weeks gave the chance to examine the lumen and to clean any secretions or granulation tissue. Zalzal[19] stated that stenting is required following laryngotracheal reconstruction in order to: (1) counteract scar contracture; (2) provide a scaffold to allow epithelium to cover the lumen of the airway; and (3) hold the reconstructed area in place and prevent mechanical disruption caused by movement of the laryngotracheal complex during breathing and swallowing.

The main complication encountered in our series was granulation tissue formation, which occurred in five patients. In one patient, this was excessive, preventing decannulation. In the other four patients, granulation tissue recurred after decannulation. This was managed by endoscopic debulking, corticosteroids and local application of mitomycin-C. Topical application of mitomycin-C has been noted to reduce the recurrence of granulation tissue after laryngotracheoplasty and stent removal.[20] Granulation tissue formation has been reported following use of such different grafting materials as costal cartilage,[21] hyoid bone[22] and thyroid cartilage.[23]

https://doi.org/10.1017/S0022215107008109 Published online by Cambridge University Press

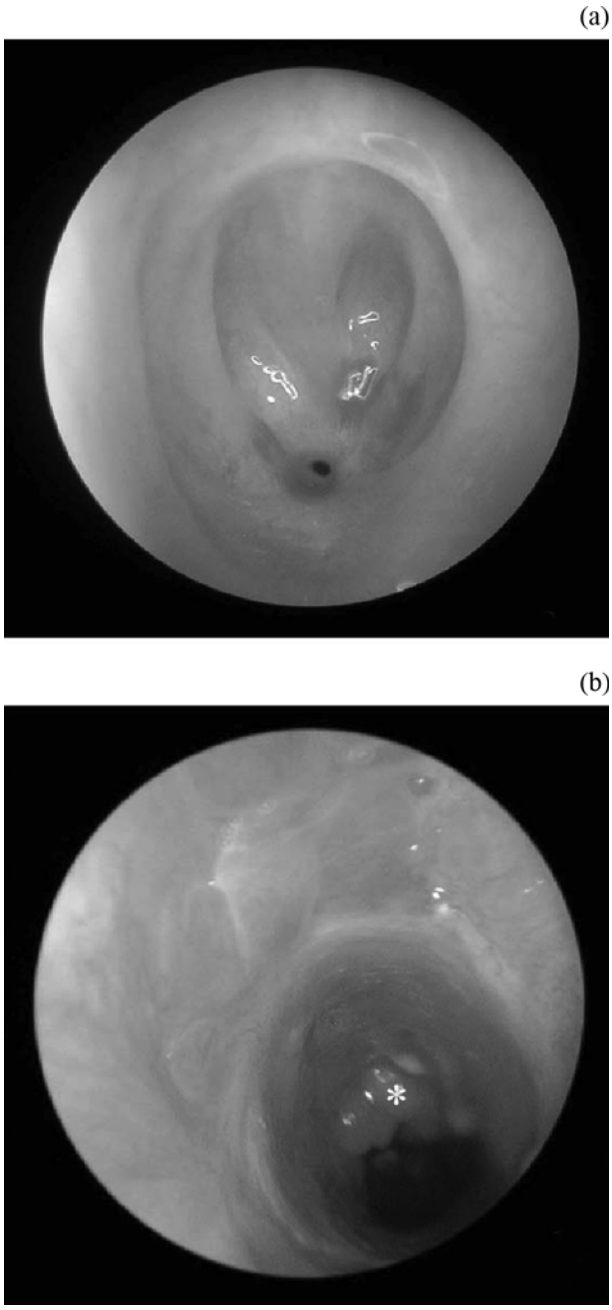

FIG. 3

Laryngotracheoscopic views. (a) Pre-operative, showing scar tissue nearly obliterating the upper tracheal lumen; (b) post-operative, showing satisfactory lumen with apparently healthy neo-epithelisation on the inner surface of the titanium mesh (a small granuloma (*) is seen at the site of the old tracheostomy).

In one of our patients (8.3 per cent), the titanium mesh prolapsed into the tracheal lumen, leading to airway obstruction immediately after removal of the stent. The mesh was easily removed endoscopically and a Montgomery T-tube was inserted.

Decannulation was possible in 10 out of our 12 patients (83.3 per cent) but failed in two patients, one of whom subsequently had a T-tube placed. The decannulated patients' respiratory reserve was good in seven cases and fair in three cases. Different graft materials have varying rates of successful decannulation. For costal cartilage grafts, the incidence of successful decannulation has varied in different series, ranging from 66.5 to 90 per cent.[21,24] For muscle flaps, different studies have found successful decannulation rates ranging from 86 to 93 per cent.[25,26]

- **The management of laryngotracheal stenosis represents a serious surgical challenge**
- **This paper describes the use of titanium mesh instead of traditional homografts in reconstruction of the anterior laryngotracheal wall in 12 tracheostomised patients with benign chronic laryngotracheal stenosis**
- **Endoscopically, good epithelisation was found on the inner surface of the mesh in 10 cases and decannulation was possible**
- **Titanium mesh was found to be a good alternative for augmentation of the anterior laryngotracheal wall, offering rigid support and a low incidence of complications**

In our opinion, titanium mesh fulfills the criteria for ideal grafting material.[8] It provides adequate structural support in order to maintain airway patency. Because of its micropores, it does not impede mucociliary clearance, and it rapidly integrates into the recipient tissue so does not need to be removed. As titanium is hypoallergenic, it produces minimal inflammatory response, thus avoiding scar formation and stenosis. Finally, it is readily available. In addition, the use of titanium mesh prevents donor site morbidity, which can complicate the use of homografts.

Conclusion

Titanium mesh was found to be a good alternative for augmentation of the anterior laryngotracheal wall. It offered rigid support, with the advantages of less inflammatory reaction, no impedance to mucociliary clearance, rapid integration with recipient tissues and no donor site morbidity. The incidence of complications was less than that for other traditional homografts. If needed, endoscopic removal could be easily performed.

References

1 Kimura K, Mukohara N, Tsugawa C, Matsumoto Y, Sugimura C, Murata H *et al.* Tracheoplasty for congenital stenosis of the entire trachea. *J Pediatric Surg* 1982;**17**:869–71
2 Biller HF, Lawson W, Weisberg V. Staged repair of extensive tracheal and laryngotracheal stenosis. *Ann Otol Rhinol Laryngol* 1986;**95**:586–9
3 Ward PH, Canalis R, Fee W. Composite hyoid-sternohyoid muscle grafts in humans. *Arch Otolaryngol* 1977;**103**:531–4
4 Backer CL, Mavroudis C, Dunham ME, Lauren DH. Repair of congenital tracheal stenosis with a free tracheal autograft. *J Thorac Cardiovasc Surg* 1998;**115**:869–74
5 Toohill RJ. Panel discussion: the management of advanced laryngotracheal stenosis. Composite septal graft in the management of advanced laryngotracheal stenosis. *Laryngoscope* 1981;**91**:233–7

https://doi.org/10.1017/S0022215107008109 Published online by Cambridge University Press

6 Heatley DG, Randell RA, Garner FT. Auricular cartilage versus costal cartilage as a grafting material in experimental laryngotracheal reconstruction. *Laryngoscope* 1995;**105**: 983–7
7 Agora JA, Spector GH. Reconstructive surgery of the larynx. In: Hinchliffe R, ed. *Scientific Foundation of Otolaryngology*. Chicago: W Heinemann Medical Publications, 1976;894–919
8 Gubbels SP, Richardson M, Trune D, Bascom DA. Tracheal reconstruction with porcine small intestine submucosa in a rabbit model. *Otolaryngol Head Neck Surg* 2006;**134**:1028–35
9 Eck KR, Bridwell KH, Ungacta FF, Lapp MA, Lenke LG, Riew KD. Analysis of titanium mesh cages in adults with minimum 2-year follow-up. *Spine* 2000;**25**:2407–15
10 Kuttenberger JJ, Hardt N. Long-term results following reconstruction of craniofacial defects with titanium micromesh systems. *J Craniomaxillofac Surg* 2001;**29**:75–81
11 Ioannis D, Dilip O, Unnikrishnan RN. Single stage sternal reconstruction using titanium mesh for dehiscence following open-heart surgery. *Interact Cardiovasc Thorac Surg* 2005;**4**:49–51
12 Verschueren DS, Bell RB, Bagheri SC, Dierks EJ, Potter BE. Management of laryngo-tracheal injuries associated with craniomaxillofacial trauma. *J Oral Maxillofac Surg* 2006;**64**:203–14
13 Mello F, Francisco VC, Ricardo L. The management of laryngeal fractures using internal fixation. *Laryngoscope* 2006;**110**:2143–6
14 Hans FM. Practical applications of laryngeal framework surgery. *Otolaryngol Clin North Am* 2006;**39**:55–75
15 Vinograd I, Klin B, Brosh T, Weinberg M, Flomenblit Y, Nevo Z. A new intratracheal stent made from Nitinol, an alloy with "shape memory effect". *J Thorac Cardiovasc Surg* 1994;**107**:1255–61
16 Yauagihara K, Mizuro H, Wada H, Hitomi S. Tracheal stenosis treated with self-expanding Nitinol stent. *Ann Thorac Surg* 1997;**63**:1786–90
17 Casiano RA, Patete M, Lindquist T. Tracheoplasty using titanium reconstructive plates with strap-muscle flap. *Otolaryngol Head Neck Surg* 1994;**111**:205–10
18 Schultz P, Vautier D, Chluba J, Marcellin L, Debry C. Survival analysis of rats implanted with porous titanium tracheal prosthesis. *Ann Thorac Surg* 2002;**73**:1747–51
19 Zalzal GH. Use of stents in laryngotracheal reconstruction in children: indications, technical considerations and complications. *Laryngoscope* 1988;**98**:849–54
20 Ward RF, April MM. Mitomycin-C in the treatment of tracheal cicatrix after tracheal reconstruction. *Int J Ped Otorhinolaryngol* 1998;**44**:221–6
21 Cotton RT, O'Conner DM. Pediatric laryngotracheal reconstruction: 20 years experience. *Acta Otorhinolaryngol Belg* 1995;**49**:367–72
22 Freeland AP. The long term results of hyoid-sternohyoid grafts in the correction of subglottic stenosis. *J Laryngol Otol* 1986;**100**:665–74
23 Thawely SE, Ogura JH. The use of the thyroid graft for treatment of laryngotracheal stenosis. *Laryngoscope* 1981;**91**:226–32
24 Cotton RT, Richardson MA, Seid AB. Management of advanced glottic and subglottic stenosis in infancy and childhood. *Laryngoscope* 1981;**91**:221–5
25 Eliachar I. Reconstruction of pediatric larynx and upper trachea with the sternohyoid rotary door flap. *Arch Otolaryngol Head Neck Surg* 1991;**117**:316–20
26 Eliachar I. The rotary door flap: a breakthrough in laryngotracheal reconstruction. *Ear Nose Throat J* 1992;**71**:584–6

Address for correspondence:
Dr Alaa Gaafar,
Fakhry Hospital,
251 Al-Khobar,
Saudi Arabia.

Fax: +966 3 8641107
E-mail: gaafar_a@hotmail.com

Dr A Gaafar takes responsibility for the integrity of the content of the paper.
Competing interests: None declared