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MINIREVIEWS

Prosthetic reconstruction of the trachea: A historical perspective

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Abstract

This review discusses the history of tracheal reconstruction; from early work to future challenges. The focus is primarily on prosthetic tracheal reconstruction in the form of intraluminal stents, patch repairs, circumferential repairs and replacement of the trachea. A historical perspective of materials used such as foreign materials, autografts, allografts, xenografts and techniques, along with their advantages and disadvantages, is provided.

Key words: Tracheal stenosis; Trachea; Prostheses and implants; Stents

Core tip: Reconstruction of tracheal defects has historically been difficult, predominantly due to the lack of an intrinsic blood supply. Direct anastomosis is generally considered to be the best option. For larger defects, stenting and prosthetic reconstruction remain the primary methodologies. In light of the recent scandal surrounding tracheal replacement, this article aims to give a historical review of tracheal reconstruction methods.

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INTRODUCTION

Tracheal reconstruction has been widely researched over the last 50 years. There are numerous indications for tracheal reconstruction, most frequently post-intubation injuries, idiopathic stenosis, neoplasia and re-stenosis following surgery[1].

Following tracheal resection, primary reconstruction with direct anastomosis of the patient's own tracheobronchial tissue is generally accepted as the best

option[2-7]. Anatomical studies suggest that up to half of the trachea can be resected in adults and directly anastomosed, without undue tension, by implementing mobilisation techniques such as suprahyoid release incisions and/or dissection of the hilum and pulmonary ligament[8]. This has been corroborated in large studies, with acceptable safety profiles and good long-term results, although the limits vary depending upon the patient's age, body habitus, local anatomy, co-morbidities and previous treatments[1,9-12].

In patients with very extensive pathology, direct anastomosis following resection is not possible and as such, either stenting or replacement with a prosthesis remain the two principle options. This provides a significant subset of patients. For example, long-segment defects (greater than 50% of the trachea) constitute approximately half of tracheal stenosis cases, although more recently this has been innovatively and successfully managed *via* a slide tracheoplasty procedure[13,14]. A range of materials have been attempted and no ideal prosthesis has yet been developed. The ideal prosthesis is airtight, of adequate consistency to prevent collapse, well accepted by the host thus causing minimal inflammatory reaction, impervious to fibroblastic and bacterial invasion of the lumen and allows ingrowth of respiratory epithelium along the lumen[15,16].

In this review article we will provide a historical overview of tracheal reconstructive trends.

EARLY WORK

In the late 1890s and into the twentieth century, interest in tracheal reconstruction evolved[17-20]. Initially, as with many surgical specialities, a knowledge base was formed principally through isolated case reports. The focus at this time was autogenous replacements such as skin alone, or skin and fascial grafts[21,22]. Daniel *et al*[23] heralded the advent of a more scientific approach with experimental animal studies. Throughout this period there was a transition from autogenous materials to solid prostheses such as tantalum, polyethylene, acrylic and steel tubes[24-27]. No ideal prosthesis was found and outcomes were variable. Indeed, often composite approaches were taken, usually in the form of a solid prosthesis with fascia lata grafts. The level of evidence remained low.

1950s TO THE POROUS PROSTHESIS

Following this initial interest and *in vivo* work (Table 1), Gebauer was amongst the first to develop porous prostheses to counteract some of the drawbacks of solid prostheses[28,29]. It was found that a porous prosthesis more closely approximates the function of tracheal cartilages as compared to a solid prosthesis[30]. However complications including strictures, granulation formation, chronic infection, pressure necrosis from the prosthesis and dislodgement remained problematic. Erosion of the brachiocephalic artery was also not infrequent. The porous structure was calculated to permit ingrowth of host connective tissue thus incorporating the prosthesis into the tracheal site; it was found that a minimal porosity of 40 to 60 μm is necessary for capillary ingrowth[31]. There was a proliferation of literature and animal studies in this field during the 1950s and 1960s[32-36]. This culminated in a better understanding of an ideal prosthesis in that the graft should be airtight, have adequate consistency, be well accepted by the host, cause minimal inflammatory reaction, be impervious to fibroblastic and bacterial invasion into the lumen but ideally allow ingrowth of respiratory epithelium along the lumen[15,33,35]. The decision of material to trial was often dependent upon industrial and commercial advances and availability, ranging from steel wire, tantalum, marlex, PTFE, dacron and teflon[2,29-36]. Combinations of materials were often employed. Towards the end of this period, as a result, prosthetic reconstruction of the trachea was being performed in human patients[37,38]. The most promising outcomes were with Silicone prostheses. The Neville group pioneered this approach and developed the Neville prosthesis, a silicone based mould under high compression available as straight or bifurcated tubes[15,16]. In this series of 62 patients, outcomes were reported to be good and the use of silicone was explicated by its resilience, non-reactivity, smooth inner surface and ability to be readily moulded[15,39]. This, therefore, fulfilled all the criteria for an ideal graft except for ciliated epithelium traversing the inner surface. Suture line granulomas remained problematic and were treated endoscopically[15,16,37]. This connective tissue ingrowth initially serves to fix and integrate the porous prostheses but this continued proliferation leads to scar tissue, obstruction and stenosis alongside with resultant chronic infection[31].

At this time, progress was also being made in surgical techniques, led by Grillo's team in Boston. Anatomic studies indicated that up to half the trachea in adults can be resected and closed primarily with an end to end anastomosis[8]. The same group has validated this with resulting large case series with low morbidity and mortality[3,4,9-11,13,31]. Slide tracheoplasty and other mobilisation techniques including suprahyoid release incisions, dissection of the hilum and pulmonary ligament have all been successfully used to achieve primary closure. Undoubtedly this remains the gold standard management of tracheal resection. However, it is not always possible and is dependent upon the patient's age, body habitus, local anatomy, extent of disease, co-morbidities and previous treatments such as radiotherapy[3,4,9-11,13,31].

These studies therefore established that primary repair remains the method of choice and should be employed wherever possible. In addition, it was concluded that an entirely satisfactory tracheal graft will never be available[31,35]. The silicone airway is at least as satisfactory as any prosthesis yet fashioned for tracheal replacement and any alternative must be wholly dependable with minimal morbidity and mortality[31]. This remains the

Table 1 Tracheal reconstruction methodology over time

Year	First author	Category[1]	Material	Study type (number)
1898	Bruns[17]		Prosthesis unknown	Human
1911	Hohmeier[18]	Autogenous	Fascia lata	Animal
1912	Levit[19]	Autogenous	Fascia	Human (1)
1927	Fairchild[20]	Autogenous	Skin	Human (1)
1935	LeJeune[21]	Autogenous	Split thickness skin graft	Human (2)
1945	Crafoord[22]	Autogenous	Cutaneous and costal cartilage	Human (1)
1946	Belsey[24]	Solid prosthesis	Steel with fascia lata	Human (1)
1948	Clagett[25]	Solid prosthesis	Polyethylene	Human (1)
1948	Daniel[23]	Solid prosthesis	Fascia, Metal Tube	Animal
1948	Longmire[26]	Solid prosthesis	Acrylic tube	Human (1)
1949	Rob[27]	Solid prosthesis	Tantalum with fascia lata	Human (4)
1949	Kergin	Autogenous	Pericardium and bronchus	Human (1)
1950	Jarvis	Solid prosthesis	Stainless Steel	Human (1)
1950	Gebauer[29]	Porous prosthesis	Wire-enforced dermal graft	Human (11)
1951	Bucher[30]	Porous prosthesis	Stainless steel wire mesh	Animal
1952	Cotton[2]	Solid prosthesis	Stainless steel tube	Human (2)
1953	Edgerton	Solid prosthesis	Split grafts with foam rubber	Human (12)
1953	Pressman[32]	Autogenous	Decalcified bone	Animal
1955	Morfit	Solid prosthesis	Polyethylene	Animal
1962	Beall[35]	Solid prosthesis	Polyethylene	Animal
1964	Aletras	Solid prosthesis	Teflon frame with pericardium	Animal
1967	Graziano[33]	Porous prosthesis	Silicon with dacron	Animal
1968	Pearson[34]	Porous prosthesis	Marlex (Polyethylene)	Animal
1973	Monk	Autogenous	Dermal grafts	Human (6)
1973	Demos	Porous prosthesis	Silicone	Animal
1974	Montgomery[38]	Porous prosthesis	Silicone t tube	Human (94)
1974	Pearson	Porous prosthesis	Marlex (Polyethylene)	Human (6)
1976	Neville[37]	Porous prosthesis	Silicone	Human (26)
1977	Lindholm	Autogenous	Bone/periosteum/muscle	Human (2)
1982	Neville[15]	Porous prosthesis	Neville prosthesis (silicon with dacron rings)	Human (54)
1982	Westaby	Porous prosthesis	Bifurcated silicone stent	Human (1)
1985	Toomes[6]	Porous prosthesis	Neville prosthesis (silicon with dacron rings)	Human (9)
1986	Scherer[67]	Tissue engineering	Bioprosthesis	Animal
1989	Har-El	Autogenous	Alloplast implanted muscle flap	Animal
1990	Neville[39]	Porous prosthesis	Silicone tubes	Human (62)
1990	Cull	Porous prosthesis	PTFE	Animal
1990	Jorge	Porous prosthesis	PTFE	Animal
1990	Kato[66]	Autogenous	Oesophagus and Silicone T tube	Animal
1990	Letang[65]	Homograft	Jejunum and Silicone T tube	Animal
1990	Varela	Porous prosthesis	Stainless steel wire mesh	Human (5)
1992	East[64]	Autogenous	Composite fascia, septum	Human (1)
1994	Okumura[63]	Porous prosthesis	Collagen and Marlex mesh	Animal
1996	Sharpe	Porous prosthesis	Marlex and pericardium	Human (1)
1996	Elliott[62]	Homograft	Homograft	Human (5)
1997	Kiriyama[61]	Homograft	Oesophageal autograft	Animal
1997	Teramachi[60]	Porous prosthesis	Marlex with collagen	Animal
2000	Sekine[59]	Porous prosthesis	Marlex	Animal
2003	Pfitzmann[58]	Homograft	Oesophagus	Human (1)
2004	Kim[57]	Porous prosthesis	Skin and polypropylene mesh	Animal
2005	Martinod[56]	Homograft	Allogenic aorta	Animal
2005	Shi[55]	Porous prosthesis	Polyprophyelene mesh with polyurethane/collagen	Animal
2006	Jaillard[54]	Homograft	Allograft aorta	Animal
2008	Sato[53]	Porous prosthesis	Polyprophyelene mesh with collagen	Animal
2008	Macchiarini[79]	Homograft	Stem cell seeded homograft	Human
2009	Nakamura[51]	Porous prosthesis	Polyprophlene with additional collagen, stem cells	Animal
2010	Makris[50]	Homograft	Allograft aorta	Animal
2010	Sato[49]	Tissue engineering	Bioprosthesis	Animal
2010	Tsukada[74]	Tissue engineering	Bioprosthesis	Animal
2011	Yu[47]	Autogenous/prosthesis	Radial forearm flap with PTFE or polyethlene	Human (7)
2011	Jungebluth[48]	Tissue engineering	Stem cell bioartificial scaffold	Human (1)
2012	Elliott[46]	Tissue engineering	Stem cell bioartificial scaffold	Human (1)
2012	Gray[45]	Tissue engineering	Stem cell bioartificial scaffold	Animal
2012	Tani	Tissue engineering	Collagen scaffold with FGF	Animal
2012	Wurtz[77]	Homograft	Allograft aorta with fascial graft and external cartilage	Animal
2014	Chang[40]	Tissue engineering	Stem cell bioartificial (3D Printed) scaffold	Animal
2016	Delaere[78]	Allotransplant	Vascularised allograft	Human

[1]A number of these are composite strategies. PTFE: Polytetrafluoroethylene; FGF: Fibroblast growth factor.

case today.

1990s ONWARDS

Further avenues of research have evolved in the last few decades. This has focussed on homografts, various composite strategies (including further work on porous prostheses) and latterly, tissue engineering[1,5,9,10,12,14,40-67].

Scherer *et al*[67] were first to experiment with bioprostheses by transplanting tracheas from various animals as autografts, allografts and xenografts. Rejection seemed to be avoided[31,67]. This preceded a plethora of animal studies, particularly transplantation studies, and in the last few years, attempts to translate this to patients[40,41,43,44,49,50,54,56,61]. Recently, research has focused on tracheal stem cell regeneration. Despite initial positive results, the outcomes have been generally poor and as such should be used with caution[42]. Pedicled flaps may serve to implant and maintain the stem cell generated trachea prior to reconstruction[41]. A recent pilot study has used three-dimensional printing of an artificial tracheal graft[40]. In addition, there has been some focus on the use of intestinal (either jejunal or oesophageal) tubes to replace the trachea[66]. This autogenous tissue reconstruction can be categorised into free grafts with and without foreign material support (*e.g.*, the composite wire and fascia or dermal grafts); vascularised tissue flaps (*e.g.*, pedicled intercostal muscle) and autogenous tube construction (*e.g.*, oesophagus)[31]. Autologous tracheal replacement using radial forearm fasciocutaneous free flap has also demonstrated positive outcomes[68].

Further homografts include pericardium and aorta[50,54,56]. Patch repair of the trachea using pericardial allografts[69] and xenografts[70] have been shown to have good outcomes[71]. More recently, aortic homografts used as a bioprosthetic device for patch repair have also shown favourable results[72,73]. Circumferential replacement of the trachea using aortic allografts has shown poorer results, in both animal[74] and human[75] models. Wurtz demonstrated that silicone-stented aortic allografts have no cartilage regeneration, probably due to ischaemia prior to neoangiogenesis[76]. This led to proposals of a composite, fascial flap-wrapped allogeneic aortic graft with external cartilage ring support[77]. Again, no reconstruction has been as successful as direct anastomosis, or even silicone prostheses alone.

CONTROVERSIES AND FUTURE DEVELOPMENTS

The intriguing yet unsolved surgical dilemma of tracheal replacement remains a challenge to clinicians. Currently, work from the Leuven group (Delaere *et al*[78]) have shown promising results with the judicious use of allotransplants. Surgical ingenuity will lead to novel approaches to these problems[3]. However, it is important to note that these techniques should not create more problems than they solve and patients are to be treated as an individual with a duty of care attached to that. As a corollary to this, it is worth highlighting that where a series of animal experiments are successful, application of these procedures to humans almost inevitably presents greater issues and a higher failure rate[3]. Work on tracheal regeneration using stem-cell implanted scaffolds[44,48,79], which has been the centre of recent controversy, showed questionable data and ultimately poor results.

CONCLUSION

Direct revascularisation of the trachea is unsuitable due to its lack of an intrinsic blood supply. Its anatomical features (proximity to major vessels, segmental blood supply) and the presence of a variety of different tissue types (respiratory epithelium, cartilage, blood vessels) make reconstruction difficult. Recent attempts with tissue-engineered transplants have all failed due to this reason[80]. Tracheal reconstruction is optimal when primary anastomosis is possible with undue tension. Patients requiring reconstruction should be managed in a multidisciplinary team at a high volume tertiary referral centre to optimise treatment. Tracheal replacement can be divided into prosthesis, homograft and autogenous tissue reconstruction, or a combinatorial methodology. None have proven ideal conduits as tracheal replacements. The most convincing evidence has historically been silicone based prostheses, and more recently revascularised tracheal homografts and allotransplants. Stenting of the trachea has shown poor results. In emergent situations, endobronchial debulking and laser is preferable over stenting as this may prevent primary surgery.

REFERENCES

1 **Grillo HC**. Development of tracheal surgery: a historical review. Part 2: Treatment of tracheal diseases. *Ann Thorac Surg* 2003; **75**: 1039-1047 [PMID: 12645751 DOI: 10.1016/s0003-4975(02)04109-7]

2 **Cotton BH**, Hills B, Penido JR. Resection of the trachea for carcinoma; report of two cases. *J Thorac Surg* 1952; **24**: 231-245 [PMID: 13000917]

3 **Grillo HC**. Tracheal replacement. *Ann Thorac Surg* 1990; **49**: 864-865 [PMID: 2369183 DOI: 10.1016/0003-4975(90)90857-3]

4 **Grillo HC**, Mathisen DJ. The trachea. *Ann Thorac Surg* 1990; **49**: 845-846 [PMID: 2187427 DOI: 10.1016/0003-4975(90)90045-8]

5 **Preciado D**, Cotton RT, Rutter MJ. Single-stage tracheal resection for severe tracheal stenosis in older children. *Int J Pediatr Otorhinolaryngol* 2004; **68**: 1-6 [PMID: 14687680 DOI: 10.1016/j.ijporl.2003.08.054]

6 **Toomes H**, Mickisch G, Vogt-Moykopf I. Experiences with prosthetic reconstruction of the trachea and bifurcation. *Thorax* 1985; **40**: 32-37 [PMID: 3969653 DOI: 10.1136/thx.40.1.32]

7 **Wychulis AR**, Neville WE. Tracheal and bronchial reconstructive procedures. *Surg Gynecol Obstet* 1974; **139**: 433-445 [PMID: 4605394]

8 **Grillo HC**, Dignan EF, Miura T. Extensive resection and reconstruction of mediastinal trachea without prosthesis or graft: an anatomical study in man. *J Thorac Cardiovasc Surg* 1964; **48**: 741-749 [PMID: 14221240]

9 **Grillo HC**, Mark EJ, Mathisen DJ, Wain JC. Idiopathic laryngotracheal stenosis and its management. *Ann Thorac Surg* 1993; **56**:

80-87 [PMID: 8328880 DOI: 10.1016/0003-4975(93)90406-8]
10 **Grillo HC**, Donahue DM, Mathisen DJ, Wain JC, Wright CD. Postintubation tracheal stenosis. Treatment and results. *J Thorac Cardiovasc Surg* 1995; **109**: 486-492; discussion 492-493 [PMID: 7877309 DOI: 10.1016/S0022-5223(95)70279-2]
11 **Grillo HC**, Zannini P, Michelassi F. Complications of tracheal reconstruction. Incidence, treatment, and prevention. *J Thorac Cardiovasc Surg* 1986; **91**: 322-328 [PMID: 3512918]
12 **Donahue DM**, Grillo HC, Wain JC, Wright CD, Mathisen DJ. Reoperative tracheal resection and reconstruction for unsuccessful repair of postintubation stenosis. *J Thorac Cardiovasc Surg* 1997; **114**: 934-938; discussion 934-938 [PMID: 9434688 DOI: 10.1016/S0022-5223(97)70007-2]
13 **Grillo HC**, Wright CD, Vlahakes GJ, MacGillivray TE. Management of congenital tracheal stenosis by means of slide tracheoplasty or resection and reconstruction, with long-term follow-up of growth after slide tracheoplasty. *J Thorac Cardiovasc Surg* 2002; **123**: 145-152 [PMID: 11782768 DOI: 10.1067/mtc.2002.119068]
14 **Fuchs JR**, Terada S, Ochoa ER, Vacanti JP, Fauza DO. Fetal tissue engineering: in utero tracheal augmentation in an ovine model. *J Pediatr Surg* 2002; **37**: 1000-1006; discussion 1000-1006 [PMID: 12077758]
15 **Neville WE**. Reconstruction of the trachea and stem bronchi with Neville prosthesis. *Int Surg* 1982; **67**: 229-234 [PMID: 7160980]
16 **Neville WE**. Prosthetic reconstruction of trachea. *Rev Laryngol Otol Rhinol* (Bord) 1982; **103**: 153-154 [PMID: 7146682]
17 **Bruns P**. Resektion der Trachea hei primaren trachealkrebs. *Beitr Z Klin Chir* 1898; **21**: 1
18 **Hohmeier F**. A new procedure for closing tracheal defects. *Munchen Med Wehnschr* 1911; **58**: 1
19 **Levit H**. Repair of tracheal defects with free grafts of fascia lata. *Arch F Klin Chir* 1912; **97**: 1
20 **Fairchild FR**. Reconstruction of the trachea. *Surg Gynecol Obstet* 1927; **44**: 4
21 **LeJeune F**, Owens N. Chronic Laryngeal Stenosis. *Ann Otol Rhinol Laryngol* 1935; **44**: 1 [DOI: 10.1177/000348943504400206]
22 **Crafoord C**, Lindgren AGH. Mucous and salivary gland tumours in the bronchi and trachea. *Acta Chir Scandinav* 1945; **92**: 1
23 **Daniel RA**. The regeneration of defects of the trachea and bronchi; an experimental study. *J Thorac Surg* 1948; **17**: 335-349 [PMID: 18865477]
24 **Belsey R**. Stainless steel wire suture technique in thoracic surgery. *Thorax* 1946; **1**: 39-47 [PMID: 20986398 DOI: 10.1136/thx.1.1.39]
25 **Clagett OT**, Grindlay JH, Moersch HJ. Resection of the trachea; an experimental study and a report of a case. *Arch Surg* 1948; **57**: 253-266 [PMID: 18099766 DOI: 10.1001/archsurg.1948.01240020258008]
26 **Longmire WP**. The repair of large defects of the trachea. *Ann Otol Rhinol Laryngol* 1948; **57**: 875-883 [PMID: 18885460 DOI: 10.1177/000348944805700322]
27 **Rob CG**, Bateman GH. Reconstruction of the trachea and cervical oesophagus; preliminary report. *Br J Surg* 1949; **37**: 202-205, illust [PMID: 15395088 DOI: 10.1002/bjs.18003714609]
28 **Gebauer PW**. Further experiences with dermal grafts for healed tuberculous stenosis of the bronchi and trachea. *J Thorac Surg* 1950; **20**: 628-667; passim [PMID: 14779363]
29 **Gebauer PW**. Experiences with surgical reconstruction of the trachea. *Am Rev Tuberc* 1950; **62**: 176-189 [PMID: 15432880]
30 **Bucher RM**, Burnett WE, Rosemond GP. Experimental reconstruction of tracheal and bronchial defects with stainless steel wire mesh. *J Thorac Surg* 1951; **21**: 572-583 [PMID: 14841793]
31 **Grillo HC**. Tracheal replacement: a critical review. *Ann Thorac Surg* 2002; **73**: 1995-2004 [PMID: 12078821 DOI: 10.1016/S0003-4975(02)03564-6]
32 **Pressman JJ**. Experimental tracheal implants. *Trans Annu Meet Am Bronchoesophagol Assoc* 1953; **45**: 18-29 [PMID: 13169194]
33 **Graziano JL**, Spinazzola A, Neville WE. Prosthetic replacement of the tracheal carina. *Ann Thorac Surg* 1967; **4**: 1-11 [PMID: 6035883 DOI: 10.1016/S0003-4975(10)66472-7]
34 **Pearson FG**, Henderson RD, Gross AE, Ginsberg RJ, Stone RM. The reconstruction of circumferential tracheal defects with a porous prosthesis. An experimental and clinical study using heavy Marlex mesh. *J Thorac Cardiovasc Surg* 1968; **55**: 605-616 [PMID: 5651571]
35 **Beall AC**, Harrington OB, Greenberg SD, Morris GC, Usher FC. Tracheal replacement with heavy Marlex mesh. Circumferential replacement of the cervical trachea. *Arch Surg* 1962; **84**: 390-396 [PMID: 13866123 DOI: 10.1001/archsurg.1962.01300220014002]
36 **Aletras H**, Bjoerk VO, Hultquist G, Rodriguez L. A new method for tracheal reconstruction. *Thorax* 1964; **19**: 358-368 [PMID: 14214931 DOI: 10.1136/thx.19.4.358]
37 **Neville WE**, Bolanowski PJ, Soltanzadeh H. Prosthetic reconstruction of the trachea and carina. *J Thorac Cardiovasc Surg* 1976; **72**: 525-538 [PMID: 966785]
38 **Montgomery WW**. Silicone tracheal T-tube. *Ann Otol Rhinol Laryngol* 1974; **83**: 71-75 [PMID: 4811582 DOI: 10.1177/000348947408300112]
39 **Neville WE**, Bolanowski JP, Kotia GG. Clinical experience with the silicone tracheal prosthesis. *J Thorac Cardiovasc Surg* 1990; **99**: 604-612; discussion 612-613 [PMID: 2319780]
40 **Chang JW**, Park SA, Park JK, Choi JW, Kim YS, Shin YS, Kim CH. Tissue-engineered tracheal reconstruction using three-dimensionally printed artificial tracheal graft: preliminary report. *Artif Organs* 2014; **38**: E95-E105 [PMID: 24750044 DOI: 10.1111/aor.12310]
41 **Jana T**, Khabbaz E, Bush CM, Prosser JD, Birchall MA, Nichols CA, Postma GN, Weinberger PM. The body as a living bioreactor: a feasibility study of pedicle flaps for tracheal transplantation. *Eur Arch Otorhinolaryngol* 2013; **270**: 181-186 [PMID: 22829157 DOI: 10.1007/s00405-012-2105-5]
42 **Farwell DG**, Birchall MA, Macchiarini P, Luu QC, de Mattos AM, Gallay BJ, Perez RV, Grow MP, Ramsamooj R, Salgado MD, Brodie HA, Belafsky PC. Laryngotracheal transplantation: technical modifications and functional outcomes. *Laryngoscope* 2013; **123**: 2502-2508 [PMID: 23483551 DOI: 10.1002/lary.24053]
43 **Tani A**, Tada Y, Takezawa T, Imaizumi M, Nomoto Y, Nakamura T, Omori K. Regeneration of tracheal epithelium using a collagen vitrigel-sponge scaffold containing basic fibroblast growth factor. *Ann Otol Rhinol Laryngol* 2012; **121**: 261-268 [PMID: 22606930 DOI: 10.1177/000348941212100412]
44 **Jungebluth P**, Moll G, Baiguera S, Macchiarini P. Tissue-engineered airway: a regenerative solution. *Clin Pharmacol Ther* 2012; **91**: 81-93 [PMID: 22130120 DOI: 10.1038/clpt.2011.270]
45 **Gray FL**, Turner CG, Ahmed A, Calvert CE, Zurakowski D, Fauza DO. Prenatal tracheal reconstruction with a hybrid amniotic mesenchymal stem cells-engineered construct derived from decellularized airway. *J Pediatr Surg* 2012; **47**: 1072-1079 [PMID: 22703772 DOI: 10.1016/j.jpedsurg.2012.03.006]
46 **Elliott MJ**, De Coppi P, Speggiorin S, Roebuck D, Butler CR, Samuel E, Crowley C, McLaren C, Fierens A, Vondrys D, Cochrane L, Jephson C, Janes S, Beaumont NJ, Cogan T, Bader A, Seifalian AM, Hsuan JJ, Lowdell MW, Birchall MA. Stem-cell-based, tissue engineered tracheal replacement in a child: a 2-year follow-up study. *Lancet* 2012; **380**: 994-1000 [PMID: 22841419 DOI: 10.1016/S0140-6736(12)60737-5]
47 **Yu P**, Clayman GL, Walsh GL. Long-term outcomes of microsurgical reconstruction for large tracheal defects. *Cancer* 2011; **117**: 802-808 [PMID: 20872878 DOI: 10.1002/cncr.25492]
48 **Jungebluth P**, Alici E, Baiguera S, Blomberg P, Bozóky B, Crowley C, Einarsson O, Gudbjartsson T, Le Guyader S, Henriksson G, Hermanson O, Juto JE, Leidner B, Lilja T, Liska J, Luedde T, Lundin V, Moll G, Roderburg C, Strömblad S, Sutlu T, Watz E, Seifalian A, Macchiarini P. Tracheobronchial transplantation with a stem-cell-seeded bioartificial nanocomposite: a proof-of-concept study. *Lancet* 2011; **378**: 1997-2004 [PMID: 22119609 DOI: 10.1016/S0140-6736(11)61715-7]
49 **Sato T**, Araki M, Nakajima N, Omori K, Nakamura T. Biodegradable polymer coating promotes the epithelization of tissue-engineered airway prostheses. *J Thorac Cardiovasc Surg* 2010; **139**: 26-31 [PMID: 19660391 DOI: 10.1016/j.jtcvs.2009.04.006]
50 **Makris D**, Holder-Espinasse M, Wurtz A, Seguin A, Hubert T, Jaillard S, Copin MC, Jashari R, Duterque-Coquillaud M, Martinod

E, Marquette CH. Tracheal replacement with cryopreserved allogenic aorta. *Chest* 2010; **137**: 60-67 [PMID: 19801581 DOI: 10.1378/chest.09-1275]

51 **Nakamura T**, Sato T, Araki M, Ichihara S, Nakada A, Yoshitani M, Itoi S, Yamashita M, Kanemaru S, Omori K, Hori Y, Endo K, Inada Y, Hayakawa K. In situ tissue engineering for tracheal reconstruction using a luminar remodeling type of artificial trachea. *J Thorac Cardiovasc Surg* 2009; **138**: 811-819 [PMID: 19660365 DOI: 10.1016/j.jtcvs.2008.07.072]

52 **Sato T**, Tao H, Araki M, Ueda H, Omori K, Nakamura T. Replacement of the left main bronchus with a tissue-engineered prosthesis in a canine model. *Ann Thorac Surg* 2008; **86**: 422-428 [PMID: 18640308 DOI: 10.1016/j.athoracsur.2008.04.015]

53 **Sato T**, Nakamura T. Tissue-engineered airway replacement. *Lancet* 2008; **372**: 2003-2004 [PMID: 19022497 DOI: 10.1016/S0140-6736(08)61599-8]

54 **Jaillard S**, Holder-Espinasse M, Hubert T, Copin MC, Duterque-Coquillaud M, Wurtz A, Marquette CH. Tracheal replacement by allogenic aorta in the pig. *Chest* 2006; **130**: 1397-1404 [PMID: 17099016 DOI: 10.1378/chest.130.5.1397]

55 **Shi H**, Xu Z, Qin X, Zhao X, Lu D. Experimental study of replacing circumferential tracheal defects with new prosthesis. *Ann Thorac Surg* 2005; **79**: 672-676; discussion 676-677 [PMID: 15680856 DOI: 10.1016/j.athoracsur.2004.01.013]

56 **Martinod E**, Seguin A, Holder-Espinasse M, Kambouchner M, Duterque-Coquillaud M, Azorin JF, Carpentier AF. Tracheal regeneration following tracheal replacement with an allogenic aorta. *Ann Thorac Surg* 2005; **79**: 942-948; discussion 949 [PMID: 15734409 DOI: 10.1016/j.athoracsur.2004.08.035]

57 **Kim J**, Suh SW, Shin JY, Kim JH, Choi YS, Kim H. Replacement of a tracheal defect with a tissue-engineered prosthesis: early results from animal experiments. *J Thorac Cardiovasc Surg* 2004; **128**: 124-129 [PMID: 15224031 DOI: 10.1016/j.jtcvs.2003.09.045]

58 **Pfitzmann R**, Kaiser D, Weidemann H, Neuhaus P. Plastic reconstruction of an extended corrosive injury of the posterior tracheal wall with an autologous esophageal patch. *Eur J Cardiothorac Surg* 2003; **24**: 463-465 [PMID: 12965325 DOI: 10.1016/S1010-7940(03)00340-3]

59 **Sekine T**, Nakamura T, Shimizu Y, Liu Y, Ueda H, Matsumoto K. Experimental carinal replacement with an Y-shaped collagen-conjugated prosthesis. *Thorac Cardiovasc Surg* 2000; **48**: 125-129 [PMID: 10903056 DOI: 10.1055/s-2000-9635]

60 **Teramachi M**, Nakamura T, Yamamoto Y, Kiyotani T, Takimoto Y, Shimizu Y. Porous-type tracheal prosthesis sealed with collagen sponge. *Ann Thorac Surg* 1997; **64**: 965-969 [PMID: 9354510 DOI: 10.1016/S0003-4975(97)00755-8]

61 **Kiriyama M**, Masaoka A, Yamakawa Y, Niwa H, Fujii Y. Experimental reconstruction of the mediastinal trachea with a wing-shaped reversed esophageal flap. *Ann Thorac Surg* 1997; **64**: 349-354 [PMID: 9262573 DOI: 10.1016/S0003-4975(97)00448-7]

62 **Elliott MJ**, Haw MP, Jacobs JP, Bailey CM, Evans JN, Herberhold C. Tracheal reconstruction in children using cadaveric homograft trachea. *Eur J Cardiothorac Surg* 1996; **10**: 707-712 [PMID: 8905270 DOI: 10.1016/S1010-7940(96)80328-9]

63 **Okumura N**, Nakamura T, Natsume T, Tomihata K, Ikada Y, Shimizu Y. Experimental study on a new tracheal prosthesis made from collagen-conjugated mesh. *J Thorac Cardiovasc Surg* 1994; **108**: 337-345 [PMID: 8041181]

64 **East C**, Grant H, Jones B. Tracheal reconstruction using a composite microvascular temporoparietal fascia flap and nasal septal graft. *J Laryngol Otol* 1992; **106**: 741-743 [PMID: 1402371 DOI: 10.1017/S0022215100120754]

65 **Letang E**, Sánchez-Lloret J, Gimferrer JM, Ramírez J, Vicens A. Experimental reconstruction of the canine trachea with a free revascularized small bowel graft. *Ann Thorac Surg* 1990; **49**: 955-958 [PMID: 2369195 DOI: 10.1016/0003-4975(90)90875-7]

66 **Kato R**, Onuki AS, Watanabe M, Hashizume T, Kawamura M, Kikuchi K, Kobayashi K, Ishihara T. Tracheal reconstruction by esophageal interposition: an experimental study. *Ann Thorac Surg* 1990; **49**: 951-954 [PMID: 2369194 DOI: 10.1016/0003-4975(90)90873-5]

67 **Scherer MA**, Ascherl R, Geissdörfer K, Mang W, Blümel G, Lichti H, Fraefel W. Experimental bioprosthetic reconstruction of the trachea. *Arch Otorhinolaryngol* 1986; **243**: 215-223 [PMID: 3778294 DOI: 10.1007/BF00464433]

68 **Fabre D**, Kolb F, Fadel E, Mercier O, Mussot S, Le Chevalier T, Dartevelle P. Successful tracheal replacement in humans using autologous tissues: an 8-year experience. *Ann Thorac Surg* 2013; **96**: 1146-1155 [PMID: 23998399 DOI: 10.1016/j.athoracsur.2013.05.073]

69 **Foroulis CN**, Simeoforidou M, Michaloudis D, Hatzitheofilou K. Pericardial patch repair of an extensive longitudinal iatrogenic rupture of the intrathoracic membranous trachea. *Interact Cardiovasc Thorac Surg* 2003; **2**: 595-597 [PMID: 17670132 DOI: 10.1016/S1569-9293(03)00142-7]

70 **Carter JJ**, Evans D, Shah P, Ura M. Iatrogenic tracheal rupture: bovine pericardial patch repair without flap reinforcement. *Interact Cardiovasc Thorac Surg* 2012; **14**: 502-503 [PMID: 22228286 DOI: 10.1093/icvts/ivr132]

71 **Fanous N**, Husain SA, Ruzmetov M, Rodefeld MD, Turrentine MW, Brown JW. Anterior pericardial tracheoplasty for long-segment tracheal stenosis: long-term outcomes. *J Thorac Cardiovasc Surg* 2010; **139**: 18-23; discussion 23-25 [PMID: 19910004 DOI: 10.1016/j.jtcvs.2009.09.040]

72 **Udelsman BV**, Eaton J, Muniappan A, Morse CR, Wright CD, Mathisen DJ. Repair of large airway defects with bioprosthetic materials. *J Thorac Cardiovasc Surg* 2016; **152**: 1388-1397 [PMID: 27751243 DOI: 10.1016/j.jtcvs.2016.07.074]

73 **Chahine AA**, Tam V, Ricketts RR. Use of the aortic homograft in the reconstruction of complex tracheobronchial tree injuries. *J Pediatr Surg* 1999; **34**: 891-894 [PMID: 10359201 DOI: 10.1016/S0022-3468(99)90393-7]

74 **Tsukada H**, Ernst A, Gangadharan S, Ashiku S, Garland R, Litmanovich D, DeCamp M. Tracheal replacement with a silicone-stented, fresh aortic allograft in sheep. *Ann Thorac Surg* 2010; **89**: 253-258 [PMID: 20103247 DOI: 10.1016/j.athoracsur.2009.09.005]

75 **Wurtz A**, Porte H, Conti M, Desbordes J, Copin MC, Azorin J, Martinod E, Marquette CH. Tracheal replacement with aortic allografts. *N Engl J Med* 2006; **355**: 1938-1940 [PMID: 17079776 DOI: 10.1056/NEJMc066336]

76 **Wurtz A**, Porte H, Conti M, Dusson C, Desbordes J, Copin MC, Marquette CH. Surgical technique and results of tracheal and carinal replacement with aortic allografts for salivary gland-type carcinoma. *J Thorac Cardiovasc Surg* 2010; **140**: 387-393.e2 [PMID: 20381819 DOI: 10.1016/j.jtcvs.2010.01.043]

77 **Wurtz A**, Hysi I, Kipnis E, Zawadzki C, Hubert T, Jashari R, Copin MC, Jude B. Tracheal reconstruction with a composite graft: fascial flap-wrapped allogenic aorta with external cartilage-ring support. *Interact Cardiovasc Thorac Surg* 2013; **16**: 37-43 [PMID: 23049080 DOI: 10.1093/icvts/ivs422]

78 **Delaere P**, Van Raemdonck D. Tracheal replacement. *J Thorac Dis* 2016; **8**: S186-S196 [PMID: 26981270]

79 **Macchiarini P**, Jungebluth P, Go T, Asnaghi MA, Rees LE, Cogan TA, Dodson A, Martorell J, Bellini S, Parnigotto PP, Dickinson SC, Hollander AP, Mantero S, Conconi MT, Birchall MA. Clinical transplantation of a tissue-engineered airway. *Lancet* 2008; **372**: 2023-2030 [PMID: 19022496 DOI: 10.1016/S0140-6736(08)61598-6]

80 **Delaere P**, Vranckx J, Verleden G, De Leyn P, Van Raemdonck D. Tracheal allotransplantation after withdrawal of immunosuppressive therapy. *N Engl J Med* 2010; **362**: 138-145 [PMID: 20071703 DOI: 10.1056/NEJMoa0810653]

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