# Long-Segment Tracheal Reconstruction With Free Radial Forearm Flap Reinforced by Rib Cartilage

*Céline Thomet, MD,* Ali Modarressi, MD,* Eva Meia Rüegg, MD,* Pavel Dulguerov, MD,† and Brigitte Pittet-Cuénod, MD**



**Abstract:** Long-segment tracheal reconstruction remains a challenge. The ideal tracheal substitute should be an epithelialized tube to prevent stenosis and sufficiently rigid to maintain airflow patency. An autologous technique using a radial forearm free flap reinforced by rib cartilage has been recently described for tracheal reconstruction. We report here two cases of complex tracheal reconstruction with a modification of this technique, which consists of the creation of two independent skin paddles to allow the reconstruction of the trachea and a second adjacent defect (eg, cervical skin, esophagus). Airway patency was achieved with no stenosis, prolonged stenting, fistula, or necrosis after 26 and 44 months, respectively. We suggest that the satisfactory outcome obtained with this modified technique is a valuable option for tracheal and adjacent defect reconstruction without the need for a second flap.

**Key Words:** trachea, microvascular reconstruction and transplant surgery, airway stenosis/reconstruction

(*Ann Plast Surg* 2018;80: 525–528)

Treatment of tracheal neoplasms or stenosis is usually achieved by tracheal resection and direct end-to-end anastomosis. The safely resectable tracheal length has increased from the 2 cm cited in the initial reports of pioneers[1] to approximately 5 cm in recent publications,[2–4] with or without different tracheal release maneuvers.[5] Despite this progress, defects longer than 6 cm cannot be closed directly[6] and a tracheal substitution is necessary beyond that length. Such extensive tracheal defects have been replaced by prosthetic materials, allotransplantation of the trachea or aorta, bioengineered tissue, or autologous grafts (small bowel, esophagus, or skin).[7] However, these procedures have resulted in major complications, such as infection, prosthetic dislocation, immunologic rejection, stenosis, or necrosis.[8] Furthermore, because of the collapsibility of the constructs, prolonged stenting was often required.

A new technique of tracheal reconstruction using a tubed forearm fasciocutaneous free flap reinforced by autologous rib cartilage has been reported by Olias et al[9] using a two-step technique and, more recently, by Fabre et al[10] in a one-step approach. This technique seemed to fulfill most of the characteristics of an ideal tracheal substitute. The radial forearm flap, as well as the use of rib grafts, is a well-known technique in head and neck reconstruction, and we believe that this approach should be popularized. In this report, we describe our first two cases of complex tracheal reconstruction with a new modified strategy, which consists of the creation of two independent skin paddles to allow the reconstruction of the trachea and a second adjacent defect (eg, cervical skin and esophagus).

Received April 9, 2017, and accepted for publication, after revision January 10, 2018.
From the *Division of Plastic, Reconstructive and Esthetic Surgery; and †Division of Otorhinolaryngology – Head & Neck Surgery, Geneva University Hospitals and Faculty of Medicine, Geneva, Switzerland.
Conflicts of interest and sources of funding: The authors declare no conflict of interest.
Reprints: Brigitte Pittet-Cuénod, MD, Plastic Reconstructive and Esthetic Surgery, Geneva University Hospitals, 4 Rue Gabrielle Perret-Gentil, 1211 Geneva 14/ Switzerland. E-mail: brigitte.pittet-cuenod@etu.unige.ch.

ISSN: 0148-7043/18/8005–0525
DOI: 10.1097/SAP.0000000000001399

## PREOPERATIVE PLANNING AND SURGICAL TECHNIQUE

An accurate analysis of the tumor and the adjacent structures to be removed was assessed preoperatively by the multidisciplinary tumor board team. The size and location of the tracheal defect, as well as the need to remove additional structures, were determined to allow the reconstructive team to precisely anticipate the size and shape of the flap. Because the creation of the neotrachea was performed at the donor site with the flap still connected to the vessels, it was necessary to choose in advance the skin paddle to be used to reconstruct the trachea and the paddle for the adjacent defect.

The procedure was performed in a two-team approach. The head and neck unit colleagues performed the tumor resection, whereas the reconstructive team harvested a rectangular fasciocutaneous forearm flap including the cephalic vein. The width of the flap should measure 9 cm to allow an adequate diameter of the neotrachea, whereas the length will be dependent on the longitudinal extent of the defect. If two skin paddles were necessary, these were precisely outlined beforehand and special care was taken not to compromise the radial pedicle and the cephalic vein during the dissection of the two paddles (Fig. 1). To strengthen the skin paddle for tracheal reconstruction, cartilage from the 7th to the 9th ribs was harvested. Rib cartilage was delicately carved into thin pliable sticks of 2-mm thick, 5-mm wide, and 90-mm long. If the sticks were too short, two cartilages were fixed together. In our two cases, it was necessary to place several sutures to avoid sharp angles while bending at the junction between the two of them (Fig. 2). The cartilage sticks were inserted subcutaneously directly under the dermis of the skin paddle reserved for the tracheal reconstruction (Fig. 3). Because the radial forearm free flap is particularly reliable thanks to its numerous perforators, the choice of using the proximal or the distal paddle for tracheal reconstruction depended not only on the localization of the defects but also on the distance from recipient vessels. Subdermis tunnels were first dissected with scissors every 1.5 cm, respecting the width of the cartilage sticks. The sticks were inserted in Penrose drains to allow them to glide more easily in these subcutaneous tunnels and the drains were then removed. The flap was then sutured to form a tube with the skin inside and the fascia on the outside (Fig. 4). The cartilage ends were sutured together and covered with the fascia to prevent a collapse of the tubular shape. The flap was disconnected only when the molding was accomplished and the tumor resection achieved to limit the ischemic time. Vascular anastomoses were performed under the microscope between the radial artery and the cephalic vein of the flap and the recipient neck vessels.

## CASE REPORTS

### Case 1

A 35-year-old man was diagnosed with a cystic adenoid carcinoma of the trachea. A 5-cm tracheal resection with end-to-end anastomosis was first performed, together with a bilateral neck dissection. Despite suprahyoid release and manual blunt dissection of the intrathoracic trachea, undue suture tension resulted in anastomosis dehiscence with subsequent mediastinitis, motivating a sternotomy and several

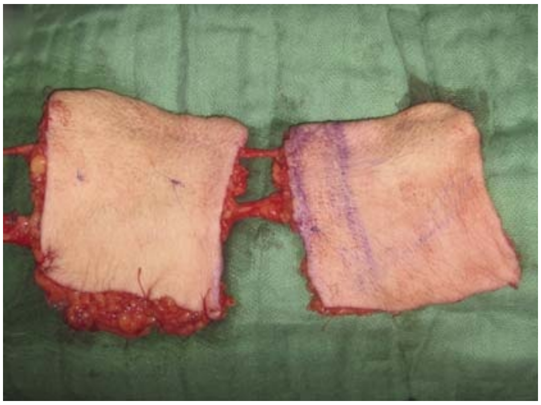

**FIGURE 1.** Radial forearm free flap separated into two paddles for the reconstruction of the trachea and another adjacent defect (case 2).

wound debridements. Furthermore, the resection margins were focally positive and an additional trachea resection was planned, contraindicating direct tracheal closure. Three weeks after the first procedure, surgical revision included an "en bloc" resection of the mediastinal wound with the tracheal dehiscence, resulting in an anterior neck skin defect of 5 × 3 cm and a tracheal defect of 6 cm. Reconstruction of both defects was performed as described previously with a free radial forearm flap reinforced by three costal cartilage strips separated into two skin paddles. The proximal paddle was used to reconstruct the trachea, and the distal paddle was used to reconstruct the overlying skin defect of the neck (Fig. 5). Anastomoses were performed on the superior thyroid artery and the thyrocervical venous trunk. A temporary Dumont stent was placed inside the tubed flap to prevent potential obstruction due to postoperative edema. The sternotomy was closed with bilateral musculocutaneous pectoral advancement flaps 2 weeks after the reconstruction. The total duration of the entire operation was 15 hours, including 3 hours for flap harvesting and modeling and 3 hours 30 minutes for microsurgery and flap inset.

After 2 months, the patient was progressively able to speak, his larynx being intact, and eat normally with logopedics (Fig. 6). The stent was removed 4 months postoperatively. Despite postoperative radiation, pulmonary and bone metastasis developed 17 months after the operation, which did not respond to chemotherapy. The patient died 27 months after the reconstruction, but no tracheal flap-related problems were noted during this interval.

**FIGURE 2.** Cartilage from the 7th to the 9th ribs harvested and carved into thin pliable sticks of 2-mm thick, 5-mm wide, and 90-mm long. If the sticks were too short, two pieces were fixed together with sutures.

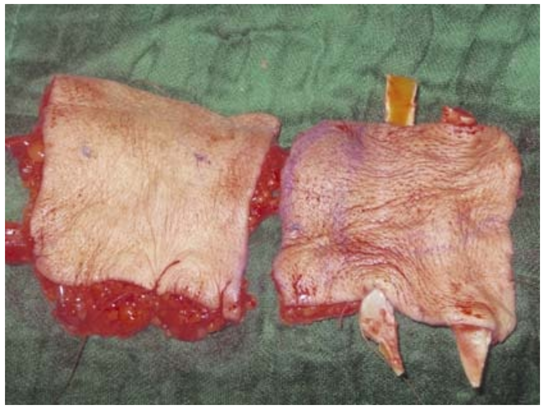

**FIGURE 3.** Cartilage strips inserted subcutaneously in the paddle for tracheal reconstruction (case 2).

## Case 2

A 70-year-old man with a grade II subglottic chondrosarcoma was first treated with cricotracheal resection.[11] Ten months later, a relapse of the initial tumor with esophageal involvement required a total laryngectomy with the removal of an additional 6 cm of trachea and an adjacent anterior esophageal wall resection. Reconstruction was performed with two skin paddles: the distal paddle with two strips of costal cartilage was used for the tracheal reconstruction and a definitive tracheostoma, and the proximal paddle for the reconstruction of the anterior wall of the esophagus (Figs. 1, 3, 4, 7). The radial artery was anastomosed to the superior thyroid artery and the external jugular vein to the cephalic vein. The operation lasted 9 hours, including 2 hours 40 minutes for flap harvesting and 4 hours for microsurgery and flap inset. No stent was needed, but a soft silicone tracheostomy cannula was used during 6 days, followed by a nighttime soft tracheostomy cannula. Six weeks after the reconstruction, the patient received adjuvant radiotherapy on the tumor bed and the cervical regions, which was well tolerated One year after the reconstruction, a tracheoesophageal fistula was performed and the patient obtained a satisfactory tracheoesophageal voice (Fig. 8). He is alive with a stable flap 3 years after the procedure.

## DISCUSSION

Several requirements are essential for a suitable tracheal substitute. These include a laterally rigid framework to prevent collapse and

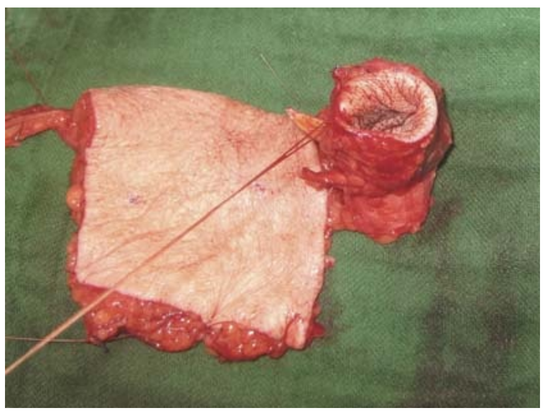

**FIGURE 4.** Paddle with the cartilage strips sutured into a tube to form the neotrachea (case 2).

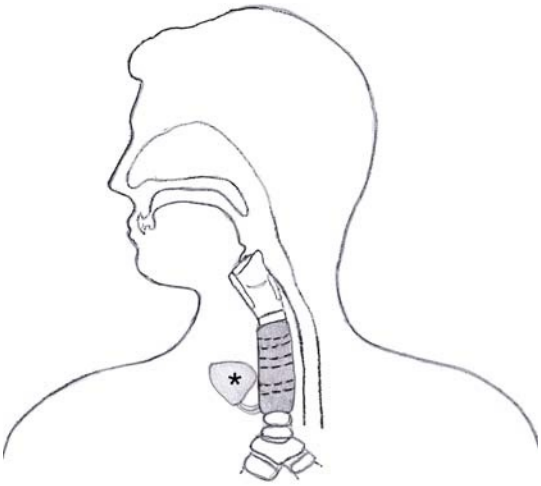


**FIGURE 5.** Schematic view of case 1 representing the flap inset with the tubed paddle for the tracheal reconstruction and the second paddle for the cervical skin defect (*).

to allow airflow, a longitudinal flexibility for neck mobility, and an epithelium layer to prevent stenosis. In addition, the reconstruction should be airtight, stable over time, and well integrated with the surrounding tissues to prevent chronic inflammation and stenosis. Finally, the tracheal substitute should be biocompatible and not elicit an immune response.[12] Techniques for long-segment tracheal reconstruction can be grouped into the following four categories: (1) synthetic materials, (2) tracheal allografts; (3) bioengineering constructs; and (4) autologous tissue grafts.

The results of synthetic materials for tracheal reconstruction have been extensively reviewed,[8,12] and it was concluded that no technique was associated with long-lasting satisfactory results. When the synthetic material was used to add rigidity to autogenous flaps,[13] the results were more promising, although the defects treated were rarely circumferential and rarely beyond 6 cm. Direct tracheal transplantation has been deemed unfeasible because of the segmental blood supply of the trachea. Cadaveric tracheal allografts treated by different chemicals to remove viable cells and decrease immunogenicity have been used. Mixed results have been published with significant mortality, a high number of revision procedures and a modest rate of decannulation, especially in children.[14,15] However, it may be possible to achieve a better outcome when the tracheal allograft is first "wrapped" in a flap for vascularization, before a microvascular anastomosis in the neck.[16] Possible shortcomings include the unpredictable waiting time to find a suitable donor, the multiple stages of the procedure, duration of the process close to 1 year, and the need for immunosuppression therapy.[17,18]


**FIGURE 6.** Two-month postoperative follow-up showing the external cervical skin flap (*), sternotomy scars, and costal cartilage harvest (case 1).

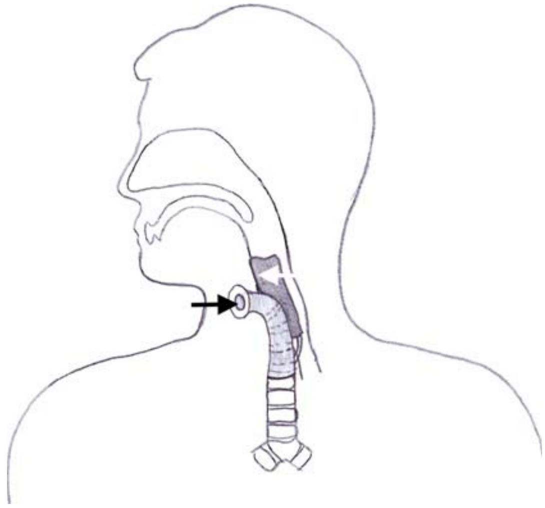

**FIGURE 7.** Schematic view of case 2 showing the inset of the double paddle flap for the reconstruction of the trachea, definitive tracheostoma (black arrow) and the anterior wall of the esophagus (white arrow).

**FIGURE 8.** Three-year postoperative follow-up of case 2 after radiotherapy showing the definitive tracheostoma (black arrow).

Furthermore, this promising technique seems to be unsuitable for patients with cancer. Some excitement was generated when allogenic aortas were found to be suitable tracheal replacements in short-term animal experiments,[19] but the clinical experience with this technique has been disappointing with major morbidity, repeated procedures, and the need for prolonged stenting.[20]

Bioengineered tracheal constructs probably represent the future of long-segment tracheal replacements. In the first reported case,[21] cadaveric trachea was used with techniques similar to allografts, that is, removal of external tissue and chemical decellularization, but the novelty was the seeding of the cadaveric tracheal scaffold with cultured autologous bronchial cells and cartilage in a custom bioreactor. The early evolution was favorable with viable cartilage and epithelial cells, as well as lack of rejection. However, after 1 year, a progressive stenosis developed and required iterative stenting.[22] A similar pediatric case has also been published.[23] In 2011, Jungebluth et al[24] reported a completely bioengineered tracheal implantation, but since then, the patient has died and concerns about the data have been raised.[25]

At present, none of the previously mentioned techniques have proven success for long-term tracheal replacement. Indeed, the technique using a free fasciocutaneous flap reinforced by autologous cartilage presents several advantages: (1) it allows replacing long circular segments of the trachea; (2) it requires a one-stage procedure, and thus, the resection of the tumor and the reconstruction can be performed at the same time; (3) the autologous nature of the reconstruction does not require immunosuppressant therapy; (4) once in a tube shape, the cutaneous part of the flap provides the epithelial lining; and (5) the use of cartilage strips for support is sufficient to maintain airway patency, and hence, the use of long-term stents is not necessary. The free radial forearm flap is a well-known workhorse and presents the advantage of rapid harvest and high reliability. Morbidity at the donor site can be greatly decreased by using a full thickness skin graft.[21] Furthermore, the morbidity from cartilage rib harvesting is minimal. In addition, if adjacent defects are present, a supplementary skin paddle on the same vascular pedicle of the flap offers a fast, simple, and robust reconstruction.

One drawback of this technique is the absence of ciliated epithelium, resulting in the absence of mucociliary clearance and the necessity to clear secretions by coughing. This was essentially the only requirement not fulfilled for the ideal tracheal substitute as outlined by Grillo.[12] Although this was not a problem for our patients who had a normal respiratory function, it should probably only be performed in those with sufficient mucociliary clearance. Of note, its role in narrow respiratory conduits, such as segmental bronchi, remains to be evaluated. In addition, similar to pediatric ear reconstruction by autologous rib cartilage,[26] the mechanisms of growth of the transferred tracheal cartilage are unfavorable, and it is unclear whether this technique should be employed in children.

In conclusion, we suggest that the free radial forearm flap reinforced by rib cartilages strips is a relatively simple, one-stage solution to a longstanding problem. Short circular tracheal defects can be treated by end-to-end anastomosis, whereas defects longer than 6 cm can now be replaced by this technique. A supplementary skin paddle on the same vascular pedicle of the flap offers a more versatile option in the case of complex reconstruction. Although a 3-year follow-up seems sufficient, only time will confirm the long-term stability, lack of circumferential collapse, and need for a stent. Future research should be directed toward biocompatible, nonresorbable materials and, ideally, capable of acting as a growth rib substitute.

## REFERENCES

1. Belsey R. Resection and reconstruction of the intrathoracic trachea. *Br J Surg*. 1950;38:200–205.
2. Merati AL, Rieder AA, Patel N, et al. Does successful segmental tracheal resection require releasing maneuvers? *Otolaryngol Head Neck Surg*. 2005;133:372–376.
3. Cordos I, Bolca C, Paleru C, et al. Sixty tracheal resections—single center experience. *Interact Cardiovasc Thorac Surg*. 2009;8:62–65.
4. Donahue DM, Grillo HC, Wain JC, et al. Reoperative tracheal resection and reconstruction for unsuccessful repair of postintubation stenosis. *J Thorac Cardiovasc Surg*. 1997;114:934–938.
5. Heitmiller RF. Tracheal release maneuvers. *Chest Surg Clin N Am*. 1996;6:675–682.
6. Yu P, Clayman GL, Walsh GL. Human tracheal reconstruction with a composite radial forearm free flap and prosthesis. *Ann Thorac Surg*. 2006;81:714–716.
7. Kucera KA, Doss AE, Dunn SS, et al. Tracheal replacements: part 1. *ASAIO J*. 2007;53:497–505.
8. Doss AE, Dunn SS, Kucera KA, et al. Tracheal replacements: part 2. *ASAIO J*. 2007;53:631–639.
9. Olias J, Millan G, da Costa D. Circumferential tracheal reconstruction for the functional treatment of airway compromise. *Laryngoscope*. 2005;115:159–161.
10. Fabre D, Kolb F, Fadel E, et al. Successful tracheal replacement in humans using autologous tissues: an 8-year experience. *Ann Thorac Surg*. 2013;96:1146–1155.
11. Purohit BS, Dulguerov P, Burkhardt K, et al. Dedifferentiated laryngeal chondrosarcoma: combined morphologic and functional imaging with positron-emission tomography/magnetic resonance imaging. *Laryngoscope*. 2014;124:E274–E277.
12. Grillo HC. Tracheal replacement: a critical review. *Ann Thorac Surg*. 2002;73:1995–2004.
13. Yu P, Clayman GL, Walsh GL. Long-term outcomes of microsurgical reconstruction for large tracheal defects. *Cancer*. 2011;117:802–808.
14. Propst EJ, Prager JD, Meinzen-Derr J, et al. Pediatric tracheal reconstruction using cadaveric homograft. *Arch Otolaryngol Head Neck Surg*. 2011;137:583–590.
15. Jacobs JP, Quintessenza JA, Andrews T, et al. Tracheal allograft reconstruction: the total North American and worldwide pediatric experiences. *Ann Thorac Surg*. 1999;68:1043–1051.
16. Delaere P, Vranckx J, Verleden G, et al. Tracheal allotransplantation after withdrawal of immunosuppressive therapy. *N Engl J Med*. 2010;362:138–145.
17. Xu L, Zhang S, Li J, et al. Human tracheal allotransplant with greater omentum for revascularization. *Exp Clin Transplant*. 2014;12:448–453.
18. Delaere PR, Vranckx JJ, Meulemans J, et al. Learning curve in tracheal allotransplantation. *Am J Transplant*. 2012;12:2538–2545.
19. Martinod E, Seguin A, Pfeuty K, et al. Long-term evaluation of the replacement of the trachea with an autologous aortic graft. *Ann Thorac Surg*. 2003;75:1572–1578.
20. Wurtz A, Porte H, Conti M, et al. 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.
21. Macchiarini P, Jungebluth P, Go T, et al. Clinical transplantation of a tissue-engineered airway. *Lancet*. 2008;372:2023–2030.
22. Gonfiotti A, Jaus MO, Barale D, et al. The first tissue-engineered airway transplantation: 5-year follow-up results. *Lancet*. 2014;383:238–244.
23. Elliott MJ, De Coppi P, Speggiorin S, et al. Stem-cell-based, tissue engineered tracheal replacement in a child: a 2-year follow-up study. *Lancet*. 2012;380:994–1000.
24. Jungebluth P, Alici E, Baiguera S, et al. Tracheobronchial transplantation with a stem-cell-seeded bioartificial nanocomposite: a proof-of-concept study. *Lancet*. 2011;378:1997–2004.
25. Vogel G. Trachea transplants test the limits. *Science*. 2013;340:266–268.
26. Kizhner V, Barak A. Framework changes using costal cartilage for microtia reconstruction. *Arch Otolaryngol Head Neck Surg*. 2008;134:768–770.