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Tracheo-carinal reconstructions using extrathoracic muscle flaps☆

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Abstract

Objectives: Prospective evaluation of tracheo-carinal airway reconstructions using pedicled extrathoracic muscle flaps for closing airway defects after non-circumferential resections and after carinal resections as part of the reconstruction for alleviation of anastomotic tension. **Methods**: From January 1996 to June 2006, 41 patients underwent tracheo-carinal airway reconstructions using 45 extrathoracic muscle flaps (latissimus dorsi, $n = 25$; serratus anterior, $n = 18$; pectoralis major, $n = 2$) for closing airway defects resulting from (a) bronchopleural fistulas (BPF) with short desmoplastic bronchial stumps after right upper lobectomy ($n = 1$) and right-sided (pleuro) pneumonectomy ($n = 13$); (b) right ($n = 9$) and left ($n = 3$) associated with partial carinal resections for pre-treated centrally localised tumours; (c) partial non-circumferential tracheal resections for pre-treated tracheal tumours, tracheo-oesophageal fistulas (TEF) and chronic tracheal injury with tracheomalacia ($n = 11$); (d) carinal resections with the integration of a muscle patch in specific parts of the anastomotic reconstruction for alleviation of anastomotic tension ($n = 4$). The airway defects ranged from 2×1 cm to 8×4 cm and involved up to 50% of the airway circumference. The patients were followed by clinical examination, repeated bronchoscopy, pulmonary function testing and CT scans. The minimum follow-up time was 6 months. **Results**: Ninety-day mortality was 7.3% (3/41 patients). Four patients (9.7%) sustained muscle flap necrosis requiring re-operation and flap replacement without subsequent mortality, airway dehiscence or stenosis. Airway dehiscence was observed in 1/41 patients (2.4%) and airway stenosis in 1/38 surviving patients (2.6%) responding well to topical mitomycin application. Follow-up on clinical grounds, by CT scans and repeated bronchoscopy, revealed airtight, stable and epithelialised airways and no recurrence of BPF or TEF in all surviving patients. **Conclusions**: Tracheo-carinal airway defects can be closed by use of pedicled extrathoracic muscle flaps after non-circumferential resections and after carinal resections with the muscle patch as part of the reconstruction for alleviation of anastomotic tension.

Keywords: Tracheal resections; Carinal resections; Extrathoracic muscle flaps; Tumours; Tracheo-oesophageal fistulas; Tracheal injury

1. Introduction

Intrathoracically transposed extrathoracic muscle flaps have been used for the treatment of infected pleural spaces with and without associated lung resection [1—7], as well as for the mediastinal reinforcement after pneumonectomy following neoadjuvant radio-chemotherapy [8,9]. They have also been used for the separation of the airway and adjacent mediastinal structures in the context of the treatment of infected vena cava superior prostheses, aortobronchial fistulas and non-malignant tracheo-oesophageal fistulas [10—12].

Recently, successful closure of post-pneumonectomy bronchopleural fistulas (BPF) was described using muscle flaps in the presence of a short bronchial stump with desmoplastic reactions [6,7,13,14]. In these situations, the muscle flap was not used to reinforce the bronchial suture line but was sutured as a muscle patch in the airway defect without attempt to approximate the bronchial margins in order to alleviate undue tension and the risk of recurrent fistulas.

We adopted the technique of extrathoracic muscle flaps as airway substitute for closing tracheo-carinal defects for various indications and reported on 13 patients who underwent repair of tracheo-carinal airway defects by muscle flaps for non-circumferential tumour resections, large tracheo-oesophageal fistulas, delayed tracheal injuries and bronchopleural fistulas [15]. The airway defects ranged from 2×1 cm to 8×4 cm and involved up to 50% of the airway circumference. All patients underwent successful airway reconstruction with no mortality and were extubated within

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24 h. Bronchoscopy revealed integration and epithelialisation of the muscle flap without dehiscence and stenosis in any patient. The flow—volume loop was preserved in all patients and dynamic virtual CT scan-derived bronchoscopy revealed no significant difference in the endoluminal cross-surface areas of the airway at the level of the muscle flap between inspiration and expiration [15].

This report deals with our extending experience with this technique in a larger number of patients and its integration in the context of carinal resections as part of the reconstruction for alleviation of anastomotic tension.

2. Patients and methods

All patients who underwent tracheo-carinal airway reconstruction by use of an extrathoracic muscle flap (latissimus dorsi, LD; serratus anterior, SA; pectoralis mayor, PM) from 1996 to 2006 were the subject of this study. Patient follow-up was ensured prospectively by clinical examination, pulmonary function testing, repeat bronchoscopy and CT scans. Minimum follow-up was 6 months after the operation.

Closure of airway defects by use of an extrathoracic muscle flap after resection was considered if direct re-approximation of the airway margins by sutures seemed risky or not feasible. This included airway defects after non-circumferential tracheo-carinal resections for chronic bronchopleural fistula with a short desmoplastic stump, non-malignant tracheo-oesophageal fistula (TEF), chronic tracheal injury with tracheomalacia and tumours involving the trachea or carina. These flaps were also considered to bridge airway defects after carinal resections as part of the reconstruction for alleviation of anastomotic tension.

The technique has been previously described [15]. The latissimus dorsi or serratus anterior muscle was dissected through a posterolateral thoracotomy incision and the pectoralis anterior muscle by additional ventral incisions while preserving their proximal vascular blood supply. Preference was given to the latissimus dorsi muscle while the serratus anterior muscle was used if the latissimus dorsi muscle had been divided at a previous intervention. A pectoralis muscle flap was only considered if a latissimus dorsi and serratus anterior muscle flap was not available, for instance for salvage redo-operations after failure of a serratus anterior muscle flap repair. The chest was entered through a standard posterolateral thoracotomy. The extrathoracic pedicled muscle flap was transposed into the chest cavity via an accessory thoracotomy through the bed of a resected segment of the second rib. It was sutured into the airway defect with resorbable interrupted sutures under slight tension and with bronchoscopic control in order to maintain stability of the airway and to prevent endoluminal protrusion of the muscle flap. Thirty percent of the airway circumference was the maximum circumferential extent of resection accepted for reconstruction by use of a muscle flap alone. In cases where there was a defect of more than 30% of the airway circumference, mechanical reinforcement of the reconstruction was obtained by embedding a rib segment into the muscle flap [15]. Fifty percent of the airway circumference was the maximal circumferential extent of resection accepted for coverage by use of a muscle flap reinforced by an embedded rib segment.

Morbidity and 90-day mortality were recorded. Repeat bronchoscopies were routinely performed during the post-operative course in order to assess the viability of the muscle flap, its integration in the airway, epithelialisation of the endoluminal surface of the muscle flap as well as stability of the reconstructed airway. CT scan and pulmonary function testing were routinely performed at 3 and 6 months after the operation and before and after these time points if clinically indicated.

3. Results

From 1996 to 2006, 41 patients underwent tracheo-carinal reconstructions using 45 extrathoracic muscle flaps for bridging airway defects. There were 27 men and 14 women with an age at operation ranging from 14—70 years. Patients' characteristics, follow-up and outcome are summarised in Table 1, and the distribution of the patients according to the type of reconstruction is shown in Figs. 1—3.

3.1. Closure of chronic BPF with a short bronchial stump

One patient with BPF and empyema following right upper lobectomy who was unable to tolerate a completion pneumonectomy underwent re-thoracotomy, debridement of the infected pleural space, resection of the infected bronchial stump and closure of the resulting 2 cm $\times$ 1 cm airway defect by a SA flap which also resulted in obliteration of the pleural space (Fig. 1a). Thirteen patients with right-sided post-(pleuro) pneumonectomy BPF and short desmoplastic bronchial stump underwent re-thoracotomy, debridement of the infected chest cavity, debridement of the bronchial stump and closure of the resulting airway defect by a SA muscle flap (Fig. 1b). The cavity was packed with towels or a vacuum-assisted closure device followed by its obliteration according to Clagett and Geraci. The bridged airway defects varied from 2 $\times$ 2 cm to 3 $\times$ 2 cm.

3.2. Closure of lateral tracheo-carinal defects after pneumonectomy and partial carinal wedge resection

Twelve patients underwent pneumonectomy and partial resection of the carina and distal part of the trachea for centrally localised tumours extending to the lateral tracheo-bronchial angle and distal trachea. Ten patients had neoadjuvant radio-chemotherapy or chemotherapy and all but two patients had R0 resections. In all patients, the tumour involved was $\sim$2 cm of the lateral tracheal wall and the required longitudinal extent of airway resection was felt to preclude a carinal pneumonectomy without undue anastomotic tension. The airway defects patched with LD ranged from 4 $\times$ 2 cm to 5 $\times$ 2 cm. Nine patients underwent right-sided and three left-sided pneumonectomy (Fig. 1c and d). On the left side, the aortic arc was mobilised after division of the ductus botalli ligament and the LD flap was transposed between the aortic arch and the airway after tunnelisation between the left subclavian artery and the aortopulmonary window had been performed.

Table 1
Patients' characteristics and outcome after closure of airway defects by extrathoracic muscle flaps

Age	Underlying disease	Previous RT/CT	Airway defect (cm)	Follow-up (months)	Status
Closure of chronic BPF with a short bronchial stump					
69	BPF after RUL for NSCLC	No	2 × 1	84	Alive NED
59	BPF after P for NSCLC	Yes	3 × 2	108	Alive NED
47	BPF after EPP for mesothelioma	Yes	2 × 2	18	DoD
70	BPF after P for NSCLC	Yes	2 × 2	Lost of follow-up	
58	BPF after EPP for mesothelioma	Yes	2 × 2	6	DoD
48	BPF after P for TBC	No	2 × 2	8	Dead (GI bleeding)
55	BPF after P for NSCLC	No	2 × 2	36	Alive NED
45	BPF after EPP for stage IV thymoma	Yes	2 × 2	18	Dead (PE)
65	BPF after completion P for NSCLC	Yes	2 × 2	36	Alive NED
62	BPF after P for NSCLC	Yes	2 × 2	1	Dead (MOF)
32	BPF after P for TBC	No	2 × 2	11	Alive NED
60	BPF after P for NSCLC	Yes	2 × 2	Lost of follow-up	
64	BPF after completion P for NSCLC	Yes	3 × 2	26	Dead (cardiac)
45	BPF after EPP for mesothelioma	Yes	3 × 2	2	Dead (MOF)
Closure of tracheal defects after non-circumferential tracheal resections					
14	Congenital TEF, destroyed right lung	No	4 × 2	60	Alive NED
23	Congenital TEF	No	3 × 2	48	Alive NED
64	Acquired TEF after oesophagectomy	Yes	3 × 1	26	DoD
64	Acquired TEF after oesophagectomy	Yes	5 × 2	12	Dead (cardiac)
62	Delayed tracheal injury	No	6 × 2	36	Alive NED
45	Delayed tracheal injury	No	8 × 2	84	Alive NED
62	Delayed tracheal injury	No	6 × 2	28	Alive NED
68	Tracheal tumour (SCC)	Yes	8 × 4	24	DoD
47	Tracheal tumour (SCC)	Yes	5 × 3	72	Alive NED
70	Recurrent tracheal tumour (SCC)	Yes	5 × 3	18	Dead (stroke)
41	Thyroid cancer with tracheal invasion	Yes	5 × 3	18	Alive, recurrence
Closure of tracheo-carinal defects after pneumonectomy and partial carinal wedge resection					
53	T4 NSCLC with carinal involvement	Yes	4 × 2	84	Alive NED
54	T4 NSCLC with carinal involvement	Yes	4 × 2	11	Alive NED
60	T4 NSCLC with carinal involvement	Yes	4 × 2	24	Alive NED
47	T4 NSCLC with carinal involvement	Yes	4 × 2	18	Alive NED
65	T4 NSCLC with carinal involvement	Yes	4 × 2	60	Alive NED
45	T4 NSCLC with carinal involvement	Yes	4 × 2	32	Alive NED
62	T4 NSCLC with carinal involvement	No	4 × 2	9	Alive NED
64	T4 NSCLC with carinal involvement	Yes	4 × 2	18	Alive, recurrence
60	Recurrent NSCLC (completion P)	Yes	4 × 2	20	Alive NED
45	Angiosarcoma with carinal involvement	No	5 × 2	6	DoD
48	Recurrent carcinoid tumour (completion P)	Yes	4 × 2	1	Dead (ARDS)
21	Sarcoma metastasis (carinal involvement)	Yes	4 × 2	6	Alive NED
Integration of muscle flaps in complex tracheo-carinal reconstructions					
58	T4 NSCLC with carinal involvement	Yes	2 × 2	22	DoD
51	T4 NSCLC with carinal involvement	Yes	3 × 2	18	Alive NED
55	Adenoid—cystic carcinoma of carina	No	3 × 2	8	Alive NED
51	Adenoid—cystic carcinoma of carina	No	3 × 2	18	Alive NED

RT, radiotherapy; CHT, chemotherapy; BPF, bronchopleural fistula; RUL, right upper lobe; NSCLC, non-small cell lung cancer; NED, no evidence of disease; P, pneumonectomy; EPP, extrapleural pneumonectomy; DoD, dead of disease; TBC, tuberculosis; PE, pulmonary embolism; MOF, multiple organic failure; TEF, tracheo-oesophageal fistula; SCC, squamous cell carcinoma; ARDS, adult respiratory distress syndrome.

3.3. Closure of tracheal defects after non-circumferential tracheal resections (Fig. 1e)

Four patients revealed a non-circumferential tumour involvement of the intrathoracic trachea with an extension of >4 cm in length rendering primary resection and end-to-end anastomosis hazardous. All but one patient were pre-treated by radiochemotherapy with partial response and underwent a non-circumferential resection of the trachea for their residual tumour. Three patients had R0 and one R1 resections. The airway defects measured 5 × 3—8 × 4 cm and were closed by a LD muscle flap alone in two patients (<30% of the tracheal circumference) and by a LD flap reinforced by an embedded rib segment in two (30—50% of the tracheal circumference) [15].

Four patients had non-malignant tracheo-oesophageal fistulas, two a congenital TEF and two a TEF occurring 2 and 4 years after an Ivor—Lewis operation and mediastinal irradiation for oesophageal cancer, respectively, without evidence of tumour recurrence at the trachea and the gastric pull-up 5 cm after debridement. The two patients with a congenital TEF underwent repair of the oesophagus by interrupted sutures and the tracheal defect was closed by a LD flap which was then interposed between the airway and the oesophagus (Fig. 2). One of these patients underwent right pneumonectomy for a destroyed lung. The two patients with acquired TEF underwent repair of the tracheal defect by a SA flap followed by primary repair for one and resection of the gastric pull-up in the other patient.

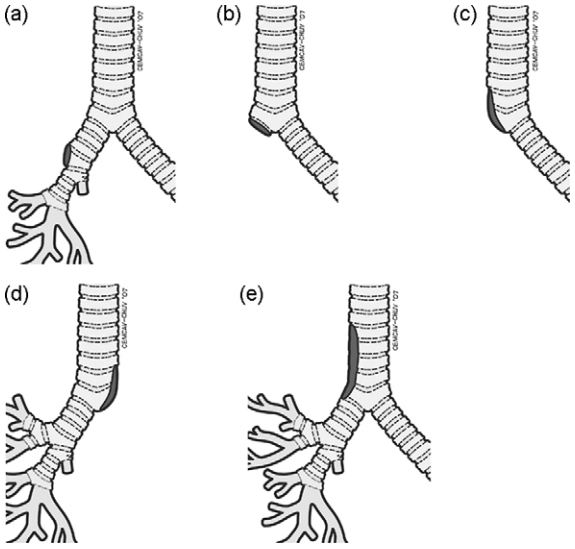


Fig. 1. Pattern of tracheo-carinal airway defects closed by muscle flaps: (a) closure of a chronic BPF after right upper lobectomy, (b) closure of chronic right-sided post-pneumonectomy BPF with a short desmoplastic bronchial stump; closure of lateral tracheo-carinal defects after (c) right-sided and (d) left-sided pneumonectomy and partial tracheo-carinal wedge resection for centrally located pre-treated tumours; (e) closure of tracheal defects after non-circumferential resection for non-circumferential pre-treated tumours, non-malignant tracheo-oesophageal fistula and chronic tracheal injury.

Three patients revealed tracheomalacia due to a flaccid intrathoracic membranous part of the trachea after delayed and unrecognised tracheal injury. They underwent right-sided posterolateral thoracotomy, dissection of the trachea and the oesophagus protruding into the trachea, resection of a virtually inexistent *pars membranacea* and tracheal reconstruction by a LD flap. The airway defects ranged from 6×2 cm to 8×2 cm.

3.4. Integration of muscle flaps in complex tracheo-carinal reconstructions

Two patients underwent sleeve bilobectomy associated with partial resection of the carina and the lateral trachea for centrally localised NSCLC pre-treated by radiochemotherapy. After hilar release, direct hemi-circumferential approximation of the right lower lobe bronchus and the carina was performed on the medial aspect of the

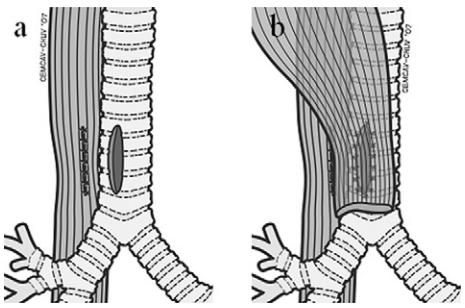


Fig. 2. Repair of tracheo-oesophageal fistulas by muscle flaps: (a) repair of the oesophagus by interrupted sutures, (b) closure of the tracheal defect by a muscle flap and interposition of the muscle flap between the repaired airway and oesophagus.

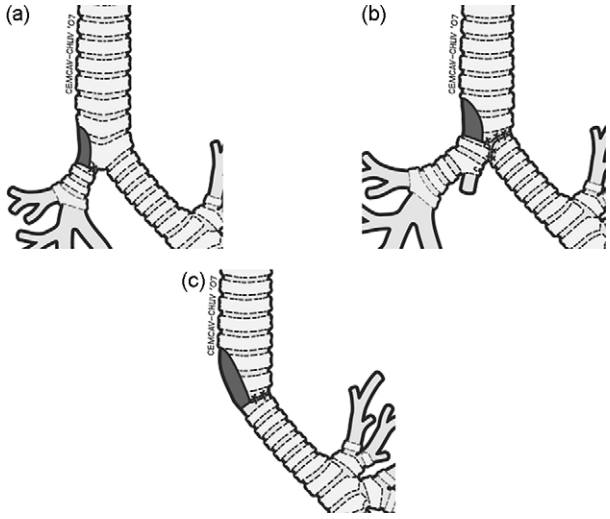


Fig. 3. Integration of muscle flaps in tracheo-carinal reconstructions after carinal resection for alleviation of anastomotic tension: (a) closure of lateral airway defects after right upper sleeve bilobectomy and partial carinal resection; closure of a lateral airway defect after carinal resection associated with (b) right sleeve lobectomy and (c) right pneumonectomy.

reconstruction. The remaining lateral airway defect between the trachea and the lobar bronchus was closed by a LD patch without direct approximation of the proximal and distal airway for alleviation of anastomotic tension (Fig. 3a). The bridged airway defects measured 2×2 and 2×3 cm. Both patients had R0 resections.

One patient underwent resection of the distal trachea and carina together with both main stem bronchi and the right upper lobe for an adenoid—cystic carcinoma of the carina. Reconstruction was performed by re-implantation of the distal left main stem bronchus and the intermediate bronchus into the distal trachea. Direct approximation of

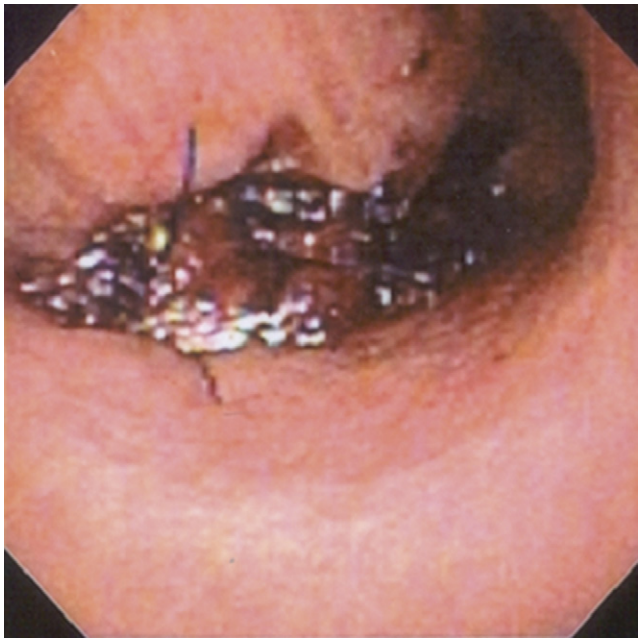


Fig. 4. Muscle flap necrosis detected at control bronchoscopy 3 days after closure of post-pneumonectomy BPF by a SA flap.

the proximal and distal airway was performed for the left hemi-circumference of the reconstruction, whereas the remaining lateral right-sided defect was closed by a LD muscle flap in order to avoid undue anastomotic tension (Fig. 3b). The bridged airway defects measured 2 × 3 cm. An R0 and R1 resection was obtained on the distal and proximal resection margins, respectively, and postoperative radiotherapy up to 60 gy was applied.

One patient underwent right-sided carinal pneumonectomy and resection of the distal trachea for adenoid–cystic carcinoma emerging from the right main stem bronchus. Direct approximation of the proximal and distal airway was performed for the left-sided hemi-circumference of the reconstruction, whereas the remaining right-sided airway defect was closed by a LD muscle patch (Fig. 3c). The bridged airway defects measured 2 cm × 3 cm. An R0 and R1 resection was obtained on the distal and proximal resection margins respectively, and postoperative radiotherapy up to 60 gy was applied.

3.5. In-hospital mortality

The postoperative in-hospital mortality was 7.3% (3/41patients). Two patients died from multiple organ failure after SA repair for right post-pneumonectomy BPF and thoracic irradiation (60 gy); one revealed an intact airway reconstruction and one a dehiscence at the level of the SA patch despite a viable muscle flap. One patient died from ARDS after right completion pneumonectomy and thoracic irradiation with an intact airway reconstruction.

3.6. Muscle flap necrosis

Muscle flap necrosis occurred in 4/41 patients (9.7%), twice after LD and twice after SA repair. In all patients muscle flap necrosis was discovered timely by bronchoscopy early in the postoperative course, followed by prompt re-operation and replacement of the necrotic flap before airway dehiscence had occurred (Fig. 4). LD and SA flaps were replaced by SA and PM flaps, respectively, which were sutured in the airway defect after the necrotic muscle had been removed. Follow-up revealed no postoperative mortality and no further airway complications in these patients.

3.7. Airway complications

Airway dehiscence was observed in the postoperative course in 1/41patients (2.4%). This patient initially underwent closure of a post-pneumonectomy BPF resulting from pneumonectomy and irradiation by a SA flap. Since bronchoscopy revealed a small dehiscence (<20% of the circumference) at the inferior part of the muscle patch without flap necrosis and well-vascularised carinal mucosa, no further airway repair was attempted and the chest cavity was kept packed with towels which were changed every 2–3 days. However, the patient died from multiple organic failure in the further postoperative course.

Airway stenosis was observed during follow-up in 1/38 surviving patients (2.6%). This patient underwent resection of the distal trachea and carina together with both main stem bronchi and the right upper lobe for an adenoid–cystic carcinoma of the carina. Early postoperative radiotherapy was applied to the reconstructed airway due to R1 resection. The patient developed significant stenosis at the level of the anastomosis of left distal main stem bronchus 6 weeks after the operation requiring repeat dilatation and mitomycin application (Fig. 5c). A satisfactory result was obtained 4 months after the operation as judged on clinical grounds and flow–volume curves.

There were no further airway complications and no recurrence of TEF or BPF in the surviving patients during follow-up, including the patients with flap replacement.

Fig. 6 shows the outcome of six patients undergoing closure of airway defects by muscle flaps in the presence of complex airway reconstructions such as reinforcement of the muscle flap with embedded rib segment or integration of the flap in carinal anastomoses. There was no evidence of airway dehiscence and stenosis in 6/6 and 5/6 patients, respectively (Fig. 5a and b).

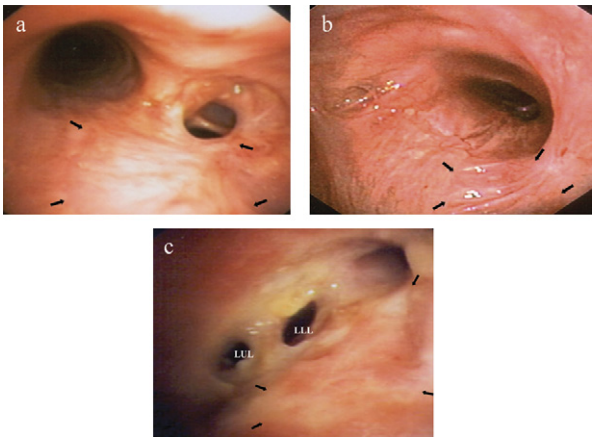
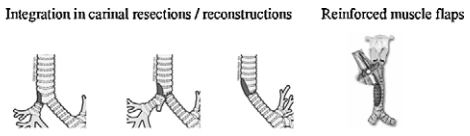


Fig. 5. Integration of muscle flaps in tracheo-carinal reconstructions after carinal resection for alleviation of anastomotic tension: bronchoscopic result revealing patent airways and epithelialisation of the endoluminal surface of the muscle flap used as patch integrated in the anastomosis after partial carinal resection and right upper sleeve bilobectomy (a, b) and after carinal resection associated with right upper sleeve lobectomy (c). The latter demonstrated stenosis at the level of the distal left main bronchus (LUL, left upper lobe; LLL, left lower lobe). Arrows indicate the borders of the muscle flap.



Number of patients	2	1	1	2
Airway dehiscence	0	0	0	0
Airway stenosis	0	1	0	0

Fig. 6. Airway complications after complex tracheo-carinal reconstructions using extrathoracic muscle flaps.

4. Discussion

Primary suture or end-to-end anastomosis associated with release manoeuvres in order to avoid undue anastomotic tension remains the standard approach to maintain tracheo-

carinal airway integrity after resection [16—21]. However, primary closure of the airway by suture lines may be hazardous if resection is performed after previous operations, infections, chemotherapy or thoracic irradiation, which due to scarring and desmoplastic reaction of tissues, may render the intrathoracic airway stiff and inflexible. This holds especially true if end-to-end anastomosis after a lengthy resection is performed under those circumstances. The desmoplastic reactions and fragility of the tissues induced by previous infections, operations or radiochemotherapy may render tension-free reapproximation of tracheo-carinal airways hazardous, which may not be compensated by release manoeuvres. In addition, even under favourable circumstances the maximum length of tracheo-carinal resections with end-to-end anastomosis is limited and should not exceed about 4 cm if severe complications due to anastomotic breakdown are to be prevented [21].

Tracheal replacement would be ideally suited for reconstruction after lengthy tracheo-carinal resections. However, there is actually no clinically established substitute available for this purpose and the requirements for such a substitute, iterated by Grillo [22] appear unavailable to date. The technique of lateral tracheal or carinal patching after resection has been advocated but frequently failed due to inadequate resection margins because structural stability was the prominent consideration.

Fortunately, the need for more extensive tracheo-carinal resections is uncommon and airway patency is preserved by irradiation and stents in most cases. However, lengthy (>4 cm) non-circumferential lesions requiring resection in healthy tissues do exist in surgical practice, which may result in airway defects not amenable to closure by sutures. We have identified a number of these situations in our previous report such as airway defects resulting from resections for chronic bronchopleural fistula with a short desmoplastic stump, non-malignant tracheo-oesophageal fistula, delayed tracheo-carinal injury and pre-treated tumours involving the trachea or carina. As a consequence, a limited number of well-selected patients underwent non-circumferential tracheo-carinal resection and closure of their airway defects by intrathoracically transposed extrathoracic pedicled muscle flaps. Non-circumferential tracheo-carinal defects of up to 30% of the airway circumference were successfully closed by a LD or SA muscle flap alone, and those with a defect of 30—50% of the circumference by use of muscle flap reinforced by an embedded rib followed by temporary stenting for 4 weeks. Most of the patients with malignancies were pre-treated by radiochemotherapy and had a complete resection.

There was no postoperative mortality in this small series of patients and extubation was performed within 24 h after operations. Bronchoscopy and pulmonary function testing of the reconstructions revealed patent airways in all patients without stenosis and epithelialisation of the endoluminal surface of the muscle flap. In addition, the reconstructed airways were stable and showed no tendency to collapse during respiration as assessed by virtual dynamic CT-bronchoscopy.

Although these results suggested functional and morphologic integrity of the reconstructed airways, the invited commentary to our report cautioned their interpretation due to the small patient series. In addition, it raised a number of questions concerning the strength of the repair, the risk of disruption during excessive coughing and other abrupt increase of intrabronchial pressure, the need of temporary stenting and the size thresholds of the airway defects [23].

The current report deals with our extended experience with tracheo-carinal airway reconstructions using extrathoracic muscle flaps in a series of 41 patients. In addition, the indication for this technique was extended for bridging airway defects after carinal resections, where the flap was integrated as a lateral muscle patch in the anastomosis for alleviating excessive anastomotic tension.

The results of the current study endorse our previous findings. The 90-day mortality was 7.3% but was not related to airway complications in 2/3 patients. Airway complications were observed in 2/41 patients, one with a small dehiscence at the inferior part of the muscle patch after SA closure of a post-pneumonectomy BPF and one with anastomotic stenosis after carinal resection together with both main stem bronchi and the right upper lobe followed by early adjuvant radiotherapy. However, the stenosis was not related to the lateral muscle patch and responded well to topical mitomycin application. All other patients had uneventful healing of the airways and endoluminal stenting was not required in any patient except one, who underwent stenting for 4 weeks after resection of 50% of the airway circumference and reinforcement of the muscle flap by an embedded rib segment. Follow-up on clinical grounds, by CT scan and repeat bronchoscopies revealed a permanently stable and intact reconstructed airway without stenosis or endoluminal muscle protrusion and epithelialisation of the endoluminal surface of the muscle patch in the patients. The same holds true for the patient with temporary stenting after stent removal. There was no disruption of the repaired airway and no recurrence of BPF or TEF in any surviving patient during follow-up. Routine check bronchoscopies were performed in uncomplicated situations on postoperative days 1, 3 and 7, before discharge and 3 and 6 months after the operation. However, bronchoscopy was performed on a regular basis (daily if necessary) as long as required after complex reconstructions or in the presence of complications such as retention of secretions, pneumonia or doubtful viability of the muscle flap.

Of particular interest was the possibility to integrate this technique for carinal resections. In these situations, the muscle flap was used as a lateral patch integrated in the anastomosis for alleviation of anastomotic tension. In addition, the muscle flap allowed for coverage of the reconstructed airway, separation of airways, vessels and oesophagus, and served as effective mediastinal reinforcement. Although this was performed in a relatively small proportion of patients, it resulted in airtight, permanently stable reconstructions, epithelialisation of the anastomosis and the endoluminal surface of the muscle patch and no tendency of accumulation of endobronchial secretion. However, these complex reconstructions required specific anaesthesiological techniques and skills such as cross-field intubation and jet ventilation. Cardiopulmonary bypass may also be helpful [24] and has been used in one of the patients in our series with carinal resection. Since some concern has been expressed in using cardiopulmonary bypass in the

context of tumour resection, caution is indicated in its application in the context of surgical oncology.

Extrathoracic muscle flaps are well-suited substitutes for non-circumferential tracheo-carinal airway defects and fulfil most of the requirements for tracheal replacement. Their relative thickness and mechanical properties allow for a solid anchoring of the muscle patch to the edges of the airway defect and suturing of the patch into the defect under guaranteed stability of the reconstruction without endoluminal protrusion of the muscle. The maximum extent of resection, which can be bridged by such a muscle flap, is not known. The maximum longitudinal extent measured up to 8 cm but the circumferential extent was limited to approximately 30 and 50% of the airway circumference for non-reinforced and reinforced flaps, respectively. However, the most useful indications for this technique were the closure of large lateral tracheo-carinal defects and the integration of muscle patches in the reconstruction after carinal resections for alleviation of anastomotic tension. In both situations, airway stability was maintained by bridging of the defects by a muscle flap alone.

Pedicled intercostal muscle flaps have also demonstrated their prophylactic and therapeutic potential in the context of tracheo-bronchial surgery and are widely used for the reinforcement of bronchial stumps or anastomosis after neoadjuvant treatment and for the closure of small fistulas [24,25]. However, the airway defects in our series were considered too large to be bridged with this technique, especially in the context of the desmoplastic reaction of the surrounding tissues induced by previous chemotherapy or irradiation. In addition, the extrathoracic flaps allowed for the coverage of the reconstructed airways and the entire mediastinum and were considered as an additional guarantee of the wound healing in these complex and risky situations.

Although our results demonstrated the feasibility and usefulness of extrathoracic muscle flaps for closing intrathoracic airway defects, the technique of intrathoracic transposition of pedicled muscle flaps may be accompanied by technical errors leading to flap necrosis due to a compromised vascularisation. Four patients (9.7%) in this series sustained muscle flap necrosis requiring re-operation and flap replacement. A high degree of suspicion and prompt recognition of this complication is required and is best diagnosed at bronchoscopy followed by prompt re-operation and replacement of the non-viable muscle flap (LD by SA and SA by PM). These reserve flaps and their vascularisation must therefore be kept intact during the preceding interventions. All four redo-operations in our series were successful without mortality or further airway complications as they were performed before airway dehiscence had occurred.

In conclusion, extrathoracic muscle flaps can be used to bridge tracheo-carinal airway defects after non-circumferential resection or in the context of carinal resections with preservation of airway integrity. This technique is of particular interest in two clinical circumstances: (a) closure of large lateral tracheo-carinal defects and (b) the integration of the muscle patch in specific parts of the anastomotic reconstruction after carinal resections, in order to avoid undue anastomotic tension. It is not designed to compete with the well-established principles of tracheo-carinal surgery, but to augment the armamentarium of surgical techniques in situations where re-adaptation of the resected airways by sutures seems risky and accompanied with undue tension.

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Appendix A. Conference discussion

Dr R. Santosham (*Chennai, India*): In all these conditions, like tracheo-oesophageal fistulae, lateral defects following tracheal resection and bronchopleural fistulae, we have used omentum. And we have found it equally good. The advantage is it's extremely vascular. You can put a nice sandwich. But the only problem is when the circumferential defect in the trachea is too large, more than 30—40%, then it tends to get sucked in. In all the other situations we have had excellent results with omentum.

Dr D. Mathisen (*Boston, Massachusetts, USA*): Just two questions. One, I think you pointed out that most people would agree that primary repair still is desirable, but when you get into these unusual situations having a fallback position using these muscles is important to know about. But the two questions I had are, how long before re-epithelialisation does that occur? How long does it take that to occur? And do you have problems initially with granulations and having to do endoscopies?

And then, in those patients who had cancer, are these lateral resections effective in terms of dealing with the cancer?

Dr Ris: We have observed that epithelialisation of the endoluminal muscle surface will occur about 2 months after the repair. We have not encountered granulation formation at the level of the muscle substitute or at the margins of the airway defects. Only one patient of the entire series developed an airway stenosis after reconstruction and subsequent irradiation, which responded well to topical mitomycin application. Only in one patient we felt that an endoluminal silicone stent was necessary which was removed 4 weeks later.

In all other situations there was no stent required.

From the clinical point of view, there was no retention of secretions, no cough and no other clinical symptoms indicating compromised healing of the reconstructed airway.

I agree that the situations requiring this technique are rare and we had had only a few of these patients during a 10-year period. These were very exceptional situations with non-circumferential tracheo-carinal tumours, usually pre-treated with radiation and chemotherapy demonstrating a nice response with a small non-circumferential residual disease. On the other hand, we found this technique especially helpful in the context of complex tracheo-carinal reconstructions where muscle patches were integrated in tracheo-carinal anastomoses in order to avoid undue tension on the suture lines.

Dr G. Rocco (*Naples, Italy*): This is actually an excellent job. I do also favour the use of intrathoracic muscle flap in all these situations. However, I have one question for you.

Which are your criteria to use the embedded rib? Is it the length of the defect, your personal concern about the size of the defect, or what else?

Dr Ris: We used this technique in two patients where we thought that the circumferential defect might be too large with the risk of mechanical instability after the reconstruction using a muscle flap alone. However, in one of these patients we also used a stent for 4 weeks with uncomplicated airway recovery after stent removal. Actually we do not really know whether the outcome was related to the embedded rib or to the stent. However, we felt that the imbedded rib might increase the stability of the reconstruction.

Dr Rocco: The reason why I'm asking it's because the case you showed maybe deserved a little segment of rib to give your flap some stability. But you didn't put a rib in there?

Dr Ris: No.