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Postoperative outcome of tracheal resection in benign and malignant tracheal stenosis

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BACKGROUND: Tracheal or cricotracheal resection is the standard of care for definitive treatment of tracheal stenosis. However, the incidence is low, the management is complex, and only a few centres have reported their experience. Therefore, more clinical reports on this topic are needed.

METHODS: We performed a retrospective analysis of all patients who underwent tracheal or cricotracheal resection for malignant or benign tracheal stenosis in our institution between 2001 and 2016. Fisher's exact test was used for analysis of complications and recurrence. P-value <0.05 was considered statistically significant.

RESULTS: 37 patients, aged 19–74, underwent tracheal (n = 21, 56.8%) or cricotracheal (n = 16, 43.2%) resection for idiopathic (n = 15, 40.5%), neoplasm-related (n = 11, 29.7%), postintubation/-tracheotomy (n = 10, 27%), and congenital (n = 1, 2.7%) stenosis. Cervical incision was applied in 28 patients (75.7%), and an extended access (5 thoracotomy, 3 hemiclamshell, 1 partial-sternotomy) was required in 9 patients (24.3%). Mediastinal lymphadenectomy was done in 7 patients (18.9%), all with neoplasm-related stenosis. Median resection length was 2.8 cm (range 1.0–6.0), and longer than 4.0 cm in 6 cases (16.2%). Release manoeuvre was performed in 7 patients (18.9%). All patients were extubated immediately after surgery and median hospital stay was 5 days (range 3–15). Median follow-up was 6 months (range, 1-93). There was no 30-day mortality, and no dehiscence or fistula occurred at the suture line. Complications were seen in 11 patients (29.7%), significantly correlating to malignant stenosis (p = 0.011) and surgical procedure, meaning extended access (p = 0.011), mediastinal lymphadenectomy (p = 0.016), and release manoeuvres (p = 0.016). Temporary hoarseness was the most common complication (n = 5, 13.5%), but remained persistent in only one patient (n = 1, 2.7%). Recurrence was seen only in patients with idiopathic stenosis (n = 5, 13.5%).

CONCLUSIONS: Our results confirm good efficacy for surgical resection of tracheal stenosis. The complication rate is relatively low in comparison to the literature, suggesting the importance of managing tracheal stenosis in a tertiary referral centre.

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Introduction

Tracheal or cricotracheal resection with primary anastomosis is the standard of care for definitive treatment of tracheal stenosis. High success (83–97%) and low mortality rates (0–5%) have been reported in several series [1-9]. Nonetheless, complication rates after surgery remain high (17–46%) [1-3, 6, 7, 9, 22-26]. Endoscopic procedures – such as balloon dilatation, laser treatment and stenting – have been developed and applied. They provide immediate relief and are well tolerated; due to high recurrence rates with the need of repeated interventions, however, they are not satisfactory in the long term [7, 8, 10, 11].

The main reason for tracheal stenosis is previous intubation or tracheotomy, resulting from mucosal injury or abnormal wound healing around the stoma site. Introduction of low pressure and large volume cuffs reduced the incidence, but 2–12% of intubated patients will still develop tracheal stenosis [12-15]. Other causes are primary tracheal tumours (predominantly adenoid cystic carcinoma and squamous cell carcinoma) and idiopathic stenosis. The latter occurs almost exclusively in middle-aged women at the subglottic area, and its cause remains unclear. High rates of recurrences in idiopathic stenosis have been observed, especially when treated by endoscopic procedures (rates up to 87% after 5 years) [16, 17]. Better outcomes have been described after surgery (6% and 36% recurrences) [18-21]. Nonetheless, the ideal management of idiopathic stenosis is still discussed in the literature.

Tracheal surgery is challenging and associated with high morbidity rates [1-3, 6, 7, 9, 22-26]. Due to its rigidity, short length, and close proximity to neurovascular structures (recurrent laryngeal nerves), tracheal resection can cause serious complications. Anastomotic dehiscence and injuries of the neurovascular bundle can be particularly critical, with potentially life-threatening consequences. Further challenges in tracheal surgery are excessive length resection and airway management during surgery. The trachea is usually not only the surgical site, but also the channel to ensure oxygenation; this is why, for some cases with highly critical stenosis or complex reconstructions

extracorporeal membrane oxygenation, (EMCO)-assisted surgery might be beneficial [27].

Recently, several studies about surgical management of tracheal stenosis have been published [23, 25-26, 28-31]. However, the current reports are mostly retrospective, making use of small samples, which is not enough to clarify the indications and contraindications of this technique; therefore, clinical practice needs to accumulate more experience. This manuscript is on this exact topic, giving it important reference value for clinical practice.

Materials and methods

Approval of the ethical committee of Zurich was obtained prior to initiation of this study (BASEC-Nr. 2016-01377).

Our institute is a tertiary referral centre in Switzerland for adult thoracic surgery, where tracheal surgery is always performed by an experienced senior surgeon. For our study, we included all patients who underwent elective tracheal and cricotracheal resection – due to malignant or benign stenosis – at Zurich University Hospital between 2001 (implementation date of surgery database) and 2016. Patients were excluded if they required carinal or bronchial sleeve resection (due to non-comparable surgery), or if the indication for surgery was not a malignant or benign stenosis (such as tracheal perforation requiring emergency procedures with relevant comorbidities and thus high-risk constellations). Pre-existing data (medical and operative records) were reviewed for aetiology, previous treatments, operative and anaesthetic details, hospital stay, complications, 30-day mortality, and recurrence. Dimension of stenosis was measured from preoperative bronchoscopy and computer tomography. Length of resected segments was reported from pathological reports. All patients were invited for clinical examination and imaging with chest x-ray one month after surgery. If patients were fully recovered and symptom-free, we completed a follow-up within 6 months, telling them to seek medical advice at our department if any symptoms recurred. Further consultations were conducted depending on the patient's symptoms and for follow-up care in tumour patients. Complications were graded according to the Clavien-Dindo classification, and complication symptoms were considered as persistent when they were still present at the first follow-up one month after surgery [32].

Descriptive statistics were used to summarise patients' characteristics. Continuous data were presented as medians (ranges). Categorical variables were summarised as frequencies (%). Fisher's exact test was used to analyse the impact of surgical procedure (extended approach, mediastinal lymphadenectomy, release manoeuvres) and aetiology (malignant stenosis, idiopathic stenosis, postintubation/-tracheotomy stenosis) on complications. Fisher's exact test was also used to analyse the impact of aetiology on recurrence. A p-value <0.05 was considered statistically significant. SPSS version 25 (IBM corp., Armonk, NY) was used for data analysis.

Results

Thirty-seven patients were eligible for our study. Median age was 53 years (range 19–74), and 23 patients (62.2%) were female. All patients with idiopathic stenosis were female. Median follow-up was 6 months (range 1–93). Median hospital stay was 5 days (range 3–15).

All patients were preoperatively assessed with a pulmonary function test, computer tomography, and bronchoscopy to determine resectability, surgical access and the potential need for release manoeuvres. Patients with suspected tracheal tumour underwent endoscopic biopsy; if malignancy was proved, they were discussed pre- and operatively at an interdisciplinary tumour board. Depending on the symptoms, further staging was performed with FDG-PET computer tomography (four patients) or magnetic resonance imaging (MRI) of the brain (one patient), where no metastasis was found.

Eight patients (21.6%; five with idiopathic stenosis, two with post-tracheotomy stenosis, and one with adenoid cystic carcinoma) underwent ten prior endoscopic procedures (nine laser excisions with or without dilatation, one electrocautery incision with dilatation) with a median time of 2.5 years (range 0.2–10) from first intervention to surgery. Two patients with post-tracheotomy stenosis underwent prior surgery, one laryngoplasty, and one tracheal resection.

The predominant symptoms were progressive dyspnoea on exertion (n = 35, 94.6%), stridor (n = 28, 75.7%) and coughing (n = 16, 43.2%), with a median time of 12 months from onset of symptoms to surgery (range 1–72).

Most of the patients suffered from idiopathic stenosis (n = 15, 40.5%), followed by neoplasm-related (n = 11, 29.7%), postintubation/-tracheotomy (n = 10, 27%), and congenital stenosis (n = 1, 2.7%). Nine neoplasm-related stenoses were malignant. Of the remaining two patients, one had a neurofibroma and the other a polypoid tumor of the trachea. Nine of the postintubation/-tracheotomy stenoses were post-tracheotomy related, and one post-intubation related (table 1).

A total of 13 complications (35.1%) occurred in eleven patients (29.7%), the most common being temporary hoarseness (n = 5, 13.5%) due to swelling or partial vocal cord paresis. Hoarseness was completely regressive, either spontaneously or with vocal therapy at the patient's first follow-up one month after surgery. Only one patient suffered from persistent nerve palsy (n = 1, 2.7%). Table 2 gives an overview of all complications graded by Clavien-Dindo [32].

We present all variables we tested (Fisher's exact test) for complications in table 3, and illustrate the significant variables in figure 1; these variables were extended access (p = 0.011), mediastinal lymphadenectomy (p = 0.016), release manoeuvres (p = 0.016), and for malignant stenosis

Table 1: Aetiology of tracheal stenosis.

Aetiology	Number of patients (%)
Idiopathic	15 (40.5)
Neoplasms	11 (29.7)
– Adenoid cystic carcinomas	7 (18.9)
– Squamous cell carcinomas	2 (5.4)
– Benign	2 (5.4)
Iatrogenic	10 (27)
– Post-tracheotomy	9 (24.3)
– Postintubation	1 (2.7)
Others (congenital)	1 (2.7)
Total	**37 (100)**

(p = 0.011). There was no 30-day hospital mortality. Median hospital day was 5 days (range 3-15).

Recurrence occurred in five patients (13.5%), all of them suffering from idiopathic stenosis, which was significantly more frequent (33.3%, p = 0.04) in comparison to the other aetiologies (table 4). The five patients were treated with eleven interventional bronchoscopies (four laser excisions with dilatation, seven electrocautery incisions with dilatation) and one re-operation (cricotracheal resection) in total.

Six patients had histologically positive resection margins, all of them suffering from adenoid cystic carcinoma. One had additionally positive lymph nodes. All but one underwent adjuvant radiotherapy. The patient without adjuvant radiotherapy was at our department for resection of a recurrence, and had had intensive irradiation seven years earlier. Therefore, irradiation capacity was exceeded. Median follow-up care lasted for 44 months (range 1–93), although two patients continued follow-up care at another hospital. One patient with adenoid cystic carcinoma had bilateral pulmonary metastasis five years after tracheal resection. The remaining patients were tumour free.

Surgical technique and airway management

Twenty-one tracheal resections (56.8%) and 16 cricotracheal resections (43.2%) were accomplished. In the idiopathic group (n = 15), mostly cricotracheal resection (n = 14, 93.3%) was performed; whereas in eleven patients (73.3%), the technique described by Mathisen (replacement of the posterior part of the laryngeal mucosa with a dorsal mucosal flap from the distal trachea) was used [33].

We used cervical incision if stenosis was located in the cervical part of the trachea (n = 28, 75.7%), and more extended access (five right-sided thoracotomies, three right-sided hemiclamshell, one partial-sternotomy) if the lesion was located in the lower half of the trachea (n = 9, 24.3%). A majority (seven of nine, 77.8%) of the extended accesses was done in patients with malignant stenosis. One (partial-sternotomy) was performed in a patient with post-tracheotomy stenosis, and one (thoracotomy) in the patient with congenital stenosis.

Extensive lymph node dissection can destroy blood supply to the trachea. Therefore, in patients with malignant disease, only adjacent regional lymph nodes were resected en bloc with the specimen. In patients who underwent extended approach, mediastinal lymph nodes were sampled for prognostic information (n = 7, 18.9). In patients with malignant stenosis, a no-touch isolation technique was used – meaning en bloc resection of the tumour – with the aim to reduce cancer cell circulation. We used this technique even though the benefit has not been proven in previous studies for colon cancer and has not been studied for tracheal cancer [34]. Resection margins were controlled with frozen section in seven patients with malignant stenosis. If anastomosis tension allowed it, second margin resection was performed. In two patients, margins were grossly positive, and resection of more airway was not possible without endangering the safety of anastomosis, which was why frozen section was skipped.

Median dimension of stenosis at the time of surgery was 60% (range 20–90%) and median resection length was 2.8 cm (range 1.0–6.0). Six patients (18.9%) had a resection longer than 4.0 cm. We routinely performed tracheal mobilisation of the pretracheal plane – and, to a lesser extent, of the post-tracheal plane – to enhance mobility of the airway. This procedure was not considered as a release manoeuvre. Hilar release manoeuvre contained hilar mobilisation, division of inferior pulmonary ligament, and pericardial release (incision of the pericardium inferior to the pulmonary vein), and was performed in seven patients (18.9%) for extended resections in the lower part of

Table 2: Postoperative complications graded by Clavien-Dindo.

Complications	Number of complications (%)	Clavien-Dindo classification I–III (%)	Persistent symptoms after 1 month
Hoarseness	6 (16.2)	I (5×) and III	Yes (1, hoarseness)
Paresis of the diaphragm	1 (2.7)	I	No
Chylothorax	2 (5.4)	II and III	No
Wound infection	1 (2.7)	III	Yes (pain)
Arial fibrillation	1 (2.7)	II	No
Tracheal obstruction (necrosis, mucosal flap)	2 (5.4)	III (2×)	No
Total	**13 (35.1)**	**I: 6 (16.2) II: 2 (5.4) III: 5 (13.5)**	**2 (5.4)**

Table 3: Impact of surgical procedure and aetiology on complications.

Variable	Complications (n = 11)	No complications (n = 26)	p-value
Extended access	6	3	0.011*
Mediastinal lymphadenectomy	5	2	0.016*
Release manoeuvre	5	2	0.016*
Cricotracheal resection	4	12	0.0723
Malignant stenosis	6	3	0.011*
Idiopathic stenosis	3	12	0.466
Postintubation/-tracheotomy stenosis	1	9	0.224

Table 4: Impact of aetiology on recurrence.

Aetiology	Recurrence (n = 5)	No recurrence (n = 32)	p-value
Idiopathic stenosis (15)	5	10	0.04*
Other aetiology (22)	0	22	

the trachea. Therefore, we used right-sided thoracotomy or hemiclamshell as an approach. We did not use laryngeal or suprahyoid release, because anastomosis tension never required it. We did not use muscle-flap to protect anastomosis.

Anastomosis was created using a polydioxanone suture (4-0 or 3-0) in running technique for pars membranacea and interrupted technique for pars cartilaginea. The recurrent laryngeal nerves were not isolated, in order to avoid risking damage or neuropraxia. We did not install intraoperative nerve monitoring. Cervical submuscular drainage was inserted in twelve patients (32.4%). A chin stitch was never applied.

Airway management was either performed by cross-field ventilation (n=17, 45.9%) or by jet ventilation (n=20, 54.1%), both permitting ventilation with minimal obstruction of the surgical field. For the cross-field ventilation a sterile small sized tube (mostly 6.0 mm) was applied through the operative field into the distal airway. For the jet ventilation a lengthy, small caliber catheter, releasing high gas flow was advanced through the orotracheal tube into the distal airway. Extracorporeal membrane oxygenation (ECMO) was not used in this series. At the end of surgery, all patients were extubated immediately with no incidence of re-intubation until discharge day.

Table 5 presents the most important results (surgical technique, airway management, prior treatments, complications, and recurrence), splitting benign and malignant stenosis.

Comment

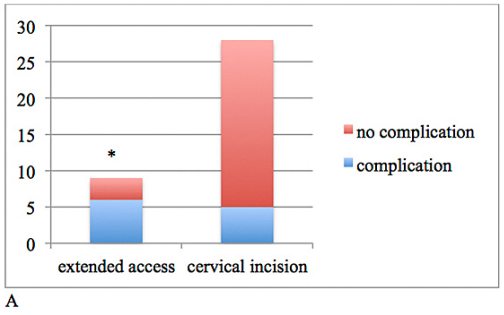
Our study addressed postoperative results and long-term outcomes of tracheal surgery for benign and malignant tracheal stenosis, and we demonstrated high efficacy of this procedure. There was no 30-day mortality, and recurrence appeared in patients with idiopathic stenosis only. Furthermore, we did not observe any anastomotic dehiscence or fistulas. Complication rate was 29.7% and compares favourably with those reported in the literature. In their large series of tracheal resections, Grillo et al. – and later Wright et al. – noted complication rates of 18.2% and 32.6%, respectively [1-3]. Smaller groups reported rates between 17% and 46% [6, 7, 9, 22-26]. Consequently, complications in tracheal surgery are an issue and should be discussed.

We graded complications according to the Clavien-Dindo classification [32]. The minority (n = 5, 13.5%) was classified as grade III, requiring surgical or endoscopic intervention. The reasons for complications were: sternal wound infection (repetitive debridement); chylothorax (ligation of ductus thoracicus); vocal cord paralysis (vocal cord medialisation); and early postoperative tracheal obstructions due to non-vital tissue and mucosal flap (interventional bronchoscopy). The remaining complications (n = 8, 21.6%) could either be managed with pharmacological treatment, or did not require treatment and were classified as grade II or I. Those were hoarseness, paralysis of the diaphragm, chylothorax, and atrial fibrillation. The most common complication was temporary hoarseness (n = 5, 13.5%). Only one patient (2.7%) suffered from persistent hoarseness. In the literature, hoarseness-rates after tracheal surgery between 4% and 17.3% are reported [1, 6, 9, 22-24]. True injury to the recurrent laryngeal nerve is rare and described in 2% [1, 3]. Mostly, it remains unclear if the cause of hoarseness is laryngeal oedema, inflammation, transient vocal cord paresis, or true nerve injury; and if immobility of the vocal cord has been demonstrated, the potential for recovery is unknown. To avoid damage of re-

Table 5: Results split by benign and malignant stenosis.

Results	Benign stenosis (n = 28) Number of patients (%)	Malignant stenosis (n = 9) Number of patients (%)	Total (n = 37) Number of patients (%)
Median age	54 years	52 years	52 years
Sex (f/m)	19/9	4/5	23/14
Median follow-up	4 months	44 months	6 months
Prior treatment of stenosis	9 (32.1)	1 (11.1)	10 (27.0)
– Interventional bronchoscopy	7 (25)	1 (11.1)	8 (21.6)
– Laryngoplasty	1 (3.6)	0	1 (2.7)
– Tracheal resection	1 (3.6)	0	1 (2.7)
Surgical technique			
– Tracheal resection	12 (42.9)	9 (100)	21 (56.8)
– Cricotracheal resection	16 (57.1)	0	16 (43.2)
Extended approach	2 (7.1)	7 (77.8)	9 (24.3)
– Thoracotomy	1 (3.6)	4 (44.4)	5 (13.5)
– Hemiclamshell	0	3 (33.3)	3 (8.1)
– Partial sternotomy	1 (3.6)	0	1 (2.7)
Mediastinal lymphadenectomy	0	7 (77.8)	7 (18.9)
Release manoeuvres	0	7 (77.8)	7 (18.9)
– Hilar release	0	7 (77.8)	7 (18.9)
– Laryngeal release	0	0	0
Airway management			
– Cross-field ventilation	13 (46.4)	4 (44.4)	17 (45.9)
– Jet ventilation	15 (53.6)	5 (55.6)	20 (54.1)
– ECMO	0	0	0
Complications	6 (21.4)	5 (55.6)	11 (29.7)
Recurrence of stenosis	5 (17.8)	0	5 (13.5)

Figure 1: Graphic illustration of the variables correlating significantly with complications: A) extended approach, B) mediastinal lymphadenectomy and release manoeuvres (the same patient group), C) malignant stenosis. * p <0.05 by Fisher's exact test.



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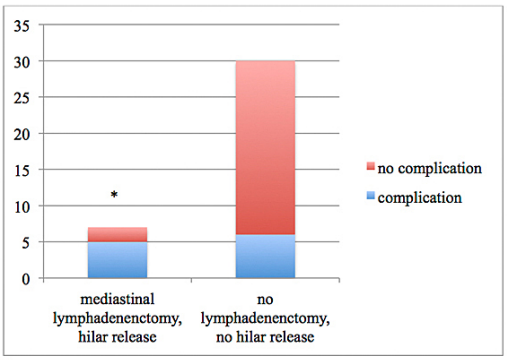

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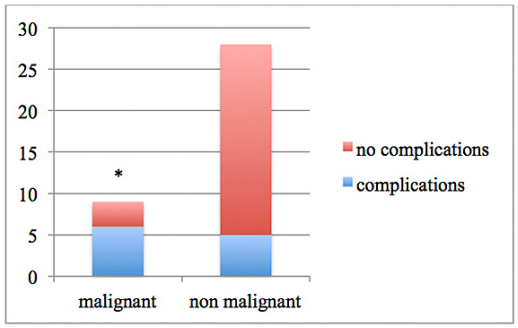

C

current laryngeal and devascularisation of the trachea, it is essential to keep the dissection close to the trachea and to avoid extended paratracheal lymph node dissection in malignancies. No attempt to identify nerves should be made. In a publication of Kadakia et al., intraoperative nerve monitoring did not reveal a protective benefit for nerve injury during tracheal surgery [35].

We observed significantly more complications in patients with extended access, mediastinal lymphadenectomy, and release manoeuvres, which we correlate to the more extensive dissection related to these procedures. There was also a significant correlation between complications and malignant disease, which might be explained by the higher frequency of aforementioned procedures within this group. Some authors anticipate lower postoperative morbidity for tracheal tumours compared to post-tracheotomy/-intubation stenosis, due to the lack of surrounding inflammation [3, 6]. Previous radiation is known to increase the likelihood of complication and mortality [36]. We operated on one patient with previous intensive irradiation seven years before and recurrence of an adenoid cystic carcinoma. This patient suffered from two operation-related complications (vocal cord paralysis and chylothorax).

Cystic adenoid carcinoma is considered a low-grade and slow-growing bronchial carcinoma, which originates from the submucosal glands. It is mostly localised in the distal third of the trachea, and characterised by infiltrative local growth with long submucosal and perineural invasion, which explains the common finding (59%) of malignant cells at the resection margins [37]. The surgeon must often compromise total resection for safety. Patients with tumour-bearing margins should undergo adjuvant radiotherapy. Five-year survival rates range between 52% and 79%. Positive resection margins and positive lymph nodes appear to have little effect on survival [37, 38]. Within our survey, we operated on seven patients with adenoid cystic carcinoma, and six had positive resection margins (85.7%).

A feared complication in tracheal surgery is anastomotic dehiscence. It was responsible for seven of the twelve deaths in Grillo's survey. Wright et al. observed a clear increase of mortality (7.4% vs 0.6%) among patients with anastomotic complications [2, 3]. In the literature, the incidence of anastomotic dehiscence ranges between 1% and 6% [1, 2, 3, 7, 9, 23, 24]. Fortunately, we had no single incident in our study. An explanation could be the low number (n = 6, 16.2%) of resections over 4.0 cm. Some authors found a resection length of 4.0 cm or longer to be an independent risk factor for anastomotic separation, whereas others did not find a correlation between resection length and anastomotic complications [1, 3, 7, 9]. However, the key to avoiding anastomotic complications is preventing anastomotic tension and, whenever this is a concern, to consider liberal use of release manoeuvres. It is important to know the localisation of the lesion to determine which release manoeuvre should be used, and through which surgical approach. Laryngeal and suprahyoid release manoeuvres are more effective in cervical resections, whereas hilar release manoeuvres are more effective in distal resections. It should be noted that laryngeal release brings with it the risk of aspiration and dysphagia, which is why most institutions use the suprahyoid technique described by Montgomery in 1974, resulting in a decreased incidence of laryngeal dysfunction. Dissection of the pretracheal plane should routinely be performed to enhance the mobility of the trachea [39]. This procedure alone was enough to provide tension-free anastomosis for cervical resections in our series. We did not use further laryngeal or suprahyoid release. In general, 4–5 cm resection length is the upper limit for safe anastomosis, even though safe resection length is considered highly individual and varies with age, neck length, previous treatment, and body habitus.

In extreme cases, an airway replacement could potentially benefit many patients. Over the last decade, new procedures in the field of airway transplantation have gained attention. Martinod et al. recently presented an innovative approach, using a cryopreserved aortic allograft after tracheal (n = 5), bronchial (n = 7), or carinal (n = 1) resection in 13 patients [40]. To prevent airway collapse, the aortic allograft was supported by a stent. Histological and molecular analysis showed regeneration of respiratory epithelium and de novo generation of cartilage within the aortic allografts, which allowed removal of stents after 5 months. Ninety-day morbidity and 90-day mortality was

30.8% and 7.7%, respectively, and the authors concluded that airway bioengineering using stented aortic matrices was feasible. Larger studies and long-term data in this field are necessary before this technique can be widely performed. However, the future holds much promise for successfully treating patients with extreme tracheal diseases.

We want to mention two cases (5.4%) of early postoperative intraluminal obstruction in our series. The patients suffered from recurrence of stridor and dyspnoea within 8 to 10 days after discharge. The first patient had an obstructing mucosal flap at the level of anastomosis, which was removed by interventional bronchoscopy. The second showed non-vital tissue around the anastomosis site, which was superinfected with fungus. Anastomosis was in good condition, in both cases, and the patients had an uneventful recovery. Both patients suffered from idiopathic stenosis initially. Formation of granulation tissue is described between 1% and 17.9% in the literature [1, 3, 9, 23-25]. A presumed reason is some degree of anastomotic separation, allowing ingrowth of granulation tissue. Healing mostly occurs spontaneously in minor degrees. Another reason for granulation tissue is irritating suture material, although this is rare since adoption of absorbable sutures [2, 3]. In Grillo's group, only 1.6% developed granulation after changing suture material to the absorbable kind, compared to 23.6% before [2].

Recurrence was found to be significantly more frequent (33.3%) in patients with idiopathic stenosis. Similar findings (rates between 6% and 36%) were described by other authors [18-21, 33, 43]. We had no recurrence in the remaining patients, which is highly positive when compared to series investigating mainly iatrogenic stenosis (rates between 4% and 17%) [2, 6-9, 22, 25]. Idiopathic stenosis is a unique form of subglottic stenosis with unknown cause and controversial management strategies. Some authors consider it a potentially progressive disease without definitive cure, and therefore advocate for repeated palliative procedures [41]. Other groups demonstrated successful surgical resection, and concluded that resection effectively cures patients [18-21, 33, 43]. Gnagi et al. looked at patient satisfaction after surgical resection of idiopathic stenosis compared with other treatment modalities (mostly bronchoscopic balloon dilatation and laser treatment). They found significantly increased satisfaction and symptom resolution after surgical treatment [42]. In our opinion, tracheal or cricotracheal resection should be the treatment of choice, presenting lower restenosis rates compared to endoscopic treatment [16, 17, 33].

The complexity of tracheal surgery is also related to the difficulty of airway management. In most cases, adequate oxygenation can be achieved with intubation after induction of general anaesthesia. Later, during open airway surgery, oxygenation is maintained by ventilation of the distal airway over a sterile cross-field tube, or by advancing a small-diameter catheter with high-flow oxygen supply (jet ventilation). However, in some severely narrowed airways, the risk of hypercapnia is too high and the deployment of veno-venous ECMO before any sedation presents the safest option to maintain normal gas exchange. Once oxygenation is optimised, general intravenous anaesthesia and muscle relaxation can be safely initiated. ECMO-assisted surgery also has clear advantages in complex reconstructions (i.e., carinal reconstruction). It allows a completely tubeless operative field, which can be very conducive to performing a fine procedure in a small surgical space. Furthermore, no repetitive moving of airway tubes risks established anastomosis or desaturation periods during surgery. Therefore, in situations with highly critical airways or when complex surgical procedures are required, the use of ECMO must be considered to achieve optimal surgical outcome [27].

Limitations of this study include its retrospective design, and the fact that it is based on a single institution's experience with a small number of patients. The study population was inhomogeneous, including malignant and benign origins of stenosis. Nevertheless, we selected objective endpoints and had few missing data, making our conclusion stronger. The fact that only two surgeons were performing the procedure helped to avoid individual factors.

In conclusion, our results confirm the efficacy of surgical resection of tracheal stenosis. However, tracheal surgery should be regarded as a major intervention, with a high potential for complications correlated to malignant stenosis and to the procedure itself, the extended access, mediastinal lymphadenectomy, and release manoeuvre. Special emphasis should therefore be given to careful planning and execution of the procedure. Despite the occurrence of complications, most are minor and not long-lasting. Recurrence may occur in patients with idiopathic stenosis, which should be considered and discussed with the patient preoperatively. Nonetheless, operative treatment of benign and malignant tracheal stenosis can be performed safely and with good postoperative outcome.

Disclosure statement

WW has served as advisory board member and speaker for Astra Zeneca and has received teaching grants and speaker honoraria from Medtronic. The other authors report no conflict of interest.

References

1 Wright CD, Li S, Geller AD, Lanuti M, Gaissert HA, Muniappan A, et al. Postintubation Tracheal Stenosis: Management and Results 1993 to 2017. Ann Thorac Surg. 2019;108(5):1471–7. doi: http://dx.doi.org/10.1016/j.athoracsur.2019.05.050. PubMed.

2 Grillo HC, Donahue DM, Mathisen DJ, Wain JC, Wright CD. Postintubation tracheal stenosis. Treatment and results. J Thorac Cardiovasc Surg. 1995;109(3):486–92, discussion 492–3. doi: http://dx.doi.org/10.1016/S0022-5223(95)70279-2. PubMed.

3 Wright CD, Grillo HC, Wain JC, Wong DR, Donahue DM, Gaissert HA, et al. Anastomotic complications after tracheal resection: prognostic factors and management. J Thorac Cardiovasc Surg. 2004;128(5):731–9. doi: http://dx.doi.org/10.1016/j.jtcvs.2004.07.005. PubMed.

4 Bisson A, Bonnette P, el Kadi NB, Leroy M, Colchen A, Personne C, et al. Tracheal sleeve resection for iatrogenic stenoses (subglottic laryngeal and tracheal). J Thorac Cardiovasc Surg. 1992;104(4):882–7. doi: http://dx.doi.org/10.1016/S0022-5223(19)34666-5. PubMed.

5 Couraud L, Jougon JB, Velly JF. Surgical treatment of nontumoral stenoses of the upper airway. Ann Thorac Surg. 1995;60(2):250–9, discussion 259–60. doi: http://dx.doi.org/10.1016/0003-4975(95)00464-V. PubMed.

6 Piazza C, Del Bon F, Paderno A, Grazioli P, Mangili S, Lombardi D, et al. Complications after tracheal and cricotracheal resection and anastomosis for inflammatory and neoplastic stenoses. Ann Otol Rhinol Laryngol. 2014;123(11):798–804. doi: http://dx.doi.org/10.1177/0003489414538764. PubMed.

7 Mutrie CJ, Eldaif SM, Rutledge CW, Force SD, Grist WJ, Mansour KA, et al. Cervical tracheal resection: new lessons learned. Ann Thorac Surg. 2011;91(4):1101–6, discussion 1106. doi: http://dx.doi.org/10.1016/j.athoracsur.2010.11.066. PubMed.

8 D'Andrilli A, Maurizi G, Andreetti C, Ciccone AM, Ibrahim M, Poggi C, et al. Long-term results of laryngotracheal resection for benign stenosis from a series of 109 consecutive patients. Eur J Cardiothorac Surg.

2016;50(1):105–9. doi: http://dx.doi.org/10.1093/ejcts/ezv471. PubMed.
9 Bibas BJ, Terra RM, Oliveira Junior AL, Tamagno MF, Minamoto H, Cardoso PF, et al. Predictors for postoperative complications after tracheal resection. Ann Thorac Surg. 2014;98(1):277–82. doi: http://dx.doi.org/10.1016/j.athoracsur.2014.03.019. PubMed.
10 Herrington HC, Weber SM, Andersen PE. Modern management of laryngotracheal stenosis. Laryngoscope. 2006;116(9):1553–7. doi: http://dx.doi.org/10.1097/01.mlg.0000228006.21941.12. PubMed.
11 Yamamoto K, Kojima F, Tomiyama K, Nakamura T, Hayashino Y. Meta-analysis of therapeutic procedures for acquired subglottic stenosis in adults. Ann Thorac Surg. 2011;91(6):1747–53. doi: http://dx.doi.org/10.1016/j.athoracsur.2011.02.071. PubMed.
12 Norwood S, Vallina VL, Short K, Saigusa M, Fernandez LG, McLarty JW. Incidence of tracheal stenosis and other late complications after percutaneous tracheostomy. Ann Surg. 2000;232(2):233–41. doi: http://dx.doi.org/10.1097/00000658-200008000-00014. PubMed.
13 Stauffer JL, Olson DE, Petty TL. Complications and consequences of endotracheal intubation and tracheotomy. A prospective study of 150 critically ill adult patients. Am J Med. 1981;70(1):65–76. doi: http://dx.doi.org/10.1016/0002-9343(81)90413-7. PubMed.
14 Heffner JE, Miller KS, Sahn SA. Tracheostomy in the intensive care unit. Part 2: Complications. Chest. 1986;90(3):430–6. doi: http://dx.doi.org/10.1378/chest.90.3.430. PubMed.
15 Walz MK, Peitgen K, Thürauf N, Trost HA, Wolfhard U, Sander A, et al. Percutaneous dilatational tracheostomy--early results and long-term outcome of 326 critically ill patients. Intensive Care Med. 1998;24(7):685–90. doi: http://dx.doi.org/10.1007/s001340050645. PubMed.
16 Maldonado F, Loiselle A, Depew ZS, Edell ES, Ekbom DC, Malinchoc M, et al. Idiopathic subglottic stenosis: an evolving therapeutic algorithm. Laryngoscope. 2014;124(2):498–503. doi: http://dx.doi.org/10.1002/lary.24287. PubMed.
17 Perotin JM, Jeanfaivre T, Thibout Y, Jouneau S, Lena H, Dutau H, et al. Endoscopic management of idiopathic tracheal stenosis. Ann Thorac Surg. 2011;92(1):297–301. doi: http://dx.doi.org/10.1016/j.athoracsur.2011.03.129. PubMed.
18 Grillo HC, Mark EJ, Mathisen DJ, Wain JC. Idiopathic laryngotracheal stenosis and its management. Ann Thorac Surg. 1993;56(1):80–7. doi: http://dx.doi.org/10.1016/0003-4975(93)90406-8. PubMed.
19 Wang H, Wright CD, Wain JC, Ott HC, Mathisen DJ. Idiopathic subglottic stenosis: factors affecting outcome after single-stage repair. Ann Thorac Surg. 2015;100(5):1804–11. doi: http://dx.doi.org/10.1016/j.athoracsur.2015.05.079. PubMed.
20 Ashiku SK, Kuzucu A, Grillo HC, Wright CD, Wain JC, Lo B, et al. Idiopathic laryngotracheal stenosis: effective definitive treatment with laryngotracheal resection. J Thorac Cardiovasc Surg. 2004;127(1):99–107. doi: http://dx.doi.org/10.1016/j.jtcvs.2002.11.001. PubMed.
21 Morcillo A, Wins R, Gómez-Caro A, Paradela M, Molins L, Tarrazona V. Single-staged laryngotracheal reconstruction for idiopathic tracheal stenosis. Ann Thorac Surg. 2013;95(2):433–9, discussion 439. doi: http://dx.doi.org/10.1016/j.athoracsur.2012.09.093. PubMed.
22 Rubikas R, Matukaitytė I, Jelisiejevas JJ, Račkauskas M. Surgical treatment of non-malignant laryngotracheal stenosis. Eur Arch Otorhinolaryngol. 2014;271(9):2481–7. doi: http://dx.doi.org/10.1007/s00405-014-2981-y. PubMed.
23 Marulli G, Rizzardi G, Bortolotti L, Loy M, Breda C, Hamad AM, et al. Single-staged laryngotracheal resection and reconstruction for benign strictures in adults. Interact Cardiovasc Thorac Surg. 2008;7(2):227–30, discussion 230. doi: http://dx.doi.org/10.1510/icvts.2007.168054. PubMed.
24 Rea F, Callegaro D, Loy M, Zuin A, Narne S, Gobbi T, et al. Benign tracheal and laryngotracheal stenosis: surgical treatment and results. Eur J Cardiothorac Surg. 2002;22(3):352–6. doi: http://dx.doi.org/10.1016/S1010-7940(02)00342-1. PubMed.
25 Amorós JM, Ramos R, Villalonga R, Morera R, Ferrer G, Díaz P. Tracheal and cricotracheal resection for laryngotracheal stenosis: experience in 54 consecutive cases. Eur J Cardiothorac Surg. 2006;29(1):35–9. doi: http://dx.doi.org/10.1016/j.ejcts.2005.10.023. PubMed.
26 Negm H, Mosleh M, Fathy H. Circumferential tracheal resection with primary anastomosis for post-intubation tracheal stenosis: study of 24 cases. Eur Arch Otorhinolaryngol. 2013;270(10):2709–17. doi: http://dx.doi.org/10.1007/s00405-013-2367-6. PubMed.
27 McRae K, de Perrot M. Principles and indications of extracorporeal life support in general thoracic surgery. J Thorac Dis. 2018;10(S8, Suppl 8):S931–46. doi: http://dx.doi.org/10.21037/jtd.2018.03.116. PubMed.
28 El-Fattah AM, Kamal E, Amer HE, Fouda M, Elwahab AE, Tawfik A. Cervical tracheal resection with cricotracheal anastomosis: experience in adults with grade III-IV tracheal stenosis. J Laryngol Otol. 2011;125(6):614–9. doi: http://dx.doi.org/10.1017/S0022215110002537. PubMed.
29 Ahn HY, Su Cho J, Kim YD, i H. Surgical outcomes of post intubational or post tracheostomy tracheal stenosis: report of 18 cases in single institution. Ann Thorac Cardiovasc Surg. 2015;21(1):14–7. doi: http://dx.doi.org/10.5761/atcs.oa.13-00335. PubMed.
30 Marques P, Leal L, Spratley J, Cardoso E, Santos M. Tracheal resection with primary anastomosis: 10 years experience. Am J Otolaryngol. 2009;30(6):415–8. doi: http://dx.doi.org/10.1016/j.amjoto.2008.08.008. PubMed.
31 Shiraishi T, Yanagisawa J, Higuchi T, Hiratsuka M, Hamatake D, Imakiire N, et al. Tracheal resection for malignant and benign diseases: surgical results and perioperative considerations. Surg Today. 2011;41(4):490–5. doi: http://dx.doi.org/10.1007/s00595-010-4303-3. PubMed.
32 Clavien PA, Barkun J, de Oliveira ML, Vauthey JN, Dindo D, Schulick RD, et al. The Clavien-Dindo classification of surgical complications: five-year experience. Ann Surg. 2009;250(2):187–96. doi: http://dx.doi.org/10.1097/SLA.0b013e3181b13ca2. PubMed.
33 Axtell AL, Mathisen DJ. Idiopathic subglottic stenosis: techniques and results. Ann Cardiothorac Surg. 2018;7(2):299–305. doi: http://dx.doi.org/10.21037/acs.2018.03.02. PubMed.
34 Takii Y, Shimada Y, Moriya Y, Nakamura K, Katayama H, Kimura A, et al.; Colorectal Cancer Study Group (CCSG) of Japan Clinical Oncology Group. A randomized controlled trial of the conventional technique versus the no-touch isolation technique for primary tumor resection in patients with colorectal cancer: Japan Clinical Oncology Group Study JCOG1006. Jpn J Clin Oncol. 2014;44(1):97–100. doi: http://dx.doi.org/10.1093/jjco/hyt156. PubMed.
35 Kadakia S, Mourad M, Badhey A, Lee T, Gessaroli M, Ducic Y. The role of intraoperative nerve monitoring in tracheal surgery: 20-year experience with 110 cases. Pediatr Surg Int. 2017;33(9):977–80. doi: http://dx.doi.org/10.1007/s00383-017-4119-y. PubMed.
36 Muehrcke DD, Grillo HC, Mathisen DJ. Reconstructive airway operation after irradiation. Ann Thorac Surg. 1995;59(1):14–8. doi: http://dx.doi.org/10.1016/0003-4975(94)00751-R. PubMed.
37 Gaissert HA, Grillo HC, Shadmehr MB, Wright CD, Gokhale M, Wain JC, et al. Long-term survival after resection of primary adenoid cystic and squamous cell carcinoma of the trachea and carina. Ann Thorac Surg. 2004;78(6):1889–96, discussion 1896–7. doi: http://dx.doi.org/10.1016/j.athoracsur.2004.05.064. PubMed.
38 Maziak DE. Biology of adenoid cystic carcinoma of the tracheobronchial tree and principles of management. Thorac Surg Clin. 2018;28(2):145–8. doi: http://dx.doi.org/10.1016/j.thorsurg.2018.01.002. PubMed.
39 Broussard B, Mathisen DJ. Tracheal release maneuvers. Ann Cardiothorac Surg. 2018;7(2):293–8. doi: http://dx.doi.org/10.21037/acs.2018.01.14. PubMed.
40 Martinod E, Chouahnia K, Radu DM, Joudiou P, Uzunhan Y, Bensidhoum M, et al. Feasibility of bioengineered tracheal and bronchial reconstruction using stented aortic matrices. JAMA. 2018;319(21):2212–22. doi: http://dx.doi.org/10.1001/jama.2018.4653. PubMed.
41 Dedo HH, Catten MD. Idiopathic progressive subglottic stenosis: findings and treatment in 52 patients. Ann Otol Rhinol Laryngol. 2001;110(4):305–11. doi: http://dx.doi.org/10.1177/000348940111000403. PubMed.
42 Gnagi SH, Howard BE, Anderson C, Lott DG. Idiopathic subglottic and tracheal stenosis: a survey of the patient experience. Ann Otol Rhinol Laryngol. 2015;124(9):734–9. doi: http://dx.doi.org/10.1177/0003489415582255. PubMed.
43 Menapace DC, Modest MC, Ekbom DC, Moore EJ, Edell ES, Kasperbauer JL. Idiopathic Subglottic Stenosis: Long-Term Outcomes of Open Surgical Techniques. Otolaryngol Head Neck Surg. 2017;156(5):906–11. doi: http://dx.doi.org/10.1177/0194599817691955. PubMed.