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Revision surgery for laryngotracheal stenosis in children: A single center's 44 years experience

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Objectives: Outcome measures of revision open airway surgery in pediatric laryngotracheal stenosis (LTS) are reported.

Methods: Data on 46 pediatric LTS patients undergoing revision open airway surgery were collected retrospectively. The measured outcomes were decannulation rate, time to decannulation, postoperative complications, additional surgery to achieve decannulation, and functional results.

Results: The most common revision surgery was partial cricotracheal resection (PCTR) in 21/46, followed by extended PCTR (ePCTR) in 20/46, and laryngotracheal reconstruction (LTR) in 5/46 patients. A 90.7% overall decannulation rate (ODR) and a 74.4% operation-specific decannulation rate (OSDR) were achieved. Delayed decannulation was identified in children aged 5 years or less ($p = 0.038$) and in patients with previous primary open airway surgery ($p = 0.039$). Complications were observed in 52.2% of patients. To achieve optimal airway patency, additional open or endoscopic airway surgeries were necessary in 30.4% and 47.7% of patients, respectively. Age 5 years or less ($p = 0.034$), multiple comorbidities ($p = 0.044$), revision ePCTR ($p = 0.023$), and laryngeal stenting ($p = 0.018$) were risk factors requiring additional open surgery to achieve age-appropriate airway. Failed primary open airway surgery ($p = 0.034$) and comorbidities ($p = 0.044$) were risk factors for a higher rate of additional endoscopic surgeries. Postoperatively 63.0% of patients achieved normal breathing, 82.2% were dysphonic and 91.1% were orally fed.

Conclusions: In this report, the patient's age under 5 years, previous primary open airway surgery, medical comorbidities, and laryngeal stenting had a significant negative impact on revision open airway surgery outcomes.

Key Words: laryngotracheal stenosis, revision airway surgery, laryngotracheal reconstruction.

Level of Evidence: Level 4

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INTRODUCTION

The treatment of laryngotracheal stenosis (LTS) in children remains to this day a challenge for airway surgeons.[1,2] Surgical treatments range from endoscopic to open airway surgery and include laryngotracheal reconstruction (LTR), partial cricotracheal resection (PCTR) and extended PCTR (ePCTR) with an additional cartilage graft augmentation.[2–4]

The overall decannulation rate (ODR) after primary open airway surgery is estimated between 83% and 96%.[4–13] However, up to 22% of patients need a revision open airway surgery to achieve successful decannulation.[2,7,8,13–15]

It is known that the best chance for LTS patients lies in the success of the first or primary surgical treatment. Sequela of a failed airway surgery can lead to advancement in stenosis grade, additional stenotic sites, and distortion of the laryngeal framework with worsening of functional disabilities.[2]

Meticulous preoperative aerodigestive endoscopic evaluation allows the surgeon to choose the most appropriate surgery and this is the first step toward a successful treatment outcome.[1,5,16] Insufficient preoperative planning, inadequate patient selection, and failure of surgical technique have been identified as the main reasons for primary surgery failure.[6,14,17] Furthermore, impaired vocal fold (VF) mobility, multiple stenotic airway sites, hidden airway lesions, severe gastroesophageal reflux (GER) and additional medical comorbidities can affect the successful outcome of airway surgery.[3,5,16,18]

A thorough re-assessment is crucial to identify the reason for the primary treatment failure and to plan the revision surgery.[14] The preoperative assessment and the choice of type of surgery are even more important in revision surgery to prevent further complications and avoid a second failure. Even though LTR and single-stage (SS) procedures are possible in selected cases, based on previous studies, the preferred revision surgery is a double-stage (DS) PCTR with or without graft augmentation.[3,4,14]

Decannulation rates, time to decannulation, postoperative complications, additional postoperative surgery,

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and the functional results of revision open airway surgery in pediatric LTS are presented in this report.

MATERIALS AND METHODS

Patient population

This study was conducted at a single tertiary medical center with expertise in managing complex pediatric LTS. Data on 46 pediatric patients (24 male and 22 female) with congenital, acquired, or mixed (acquired on congenital) LTS undergoing revision open airway surgery from 1978 to 2022 were collected retrospectively. The study was reviewed and approved by the local ethics committee and the Institutional Review Board (CER-VD 2020-00486).

The inclusion criteria for patient selection were: previous unsuccessful primary open airway surgery or multiple endoscopic airway surgeries (>3) performed with curative intent that failed to achieve optimal airway patency or decannulation.

All the included patients were referred from other medical institutions, of which 4/46 had the primary open airway surgery at our clinic. Data collected from medical charts and referring physicians included: demographic characteristics (gender, age at revision surgery), LTS characteristics (etiology, grade, site, cranio-caudal length), preoperative status (type of primary airway surgery, medical comorbidities, tracheostomy dependency, VF mobility), revision open airway surgery data (type, stenting), postoperative status (complications, tracheostomy dependency, VF mobility, time to decannulation, additional open and endoscopic surgeries) and functional results (breathing, voice impairment, feeding).

Measured outcomes

The measured outcomes were decannulation rate, time to decannulation, postoperative complications, additional surgery to achieve decannulation, and functional results. Complications were defined as minor (granulations, uni-site thin cicatricial stenosis that required endoscopic treatment) or major (dehiscence, recurrent laryngeal nerve palsy, recurrent stenosis needing additional open airway surgery).

Breathing function was subjectively evaluated as normal, mild (dyspnea at exertion), and moderate (dyspnea at rest) difficulty. Voice impairment was defined clinically as mild (hoarse voice with difficulties being heard in a loud environment), moderate (weak voice and easy fatigability), and severe dysphonia (breathy voice with difficulty in communicating).

Preoperative evaluation

The preoperative evaluation was performed as per previous publications.[1,3,5,14,16] It included transnasal flexible laryngo-tracheo-bronchoscopy under general anesthesia in spontaneous ventilation for dynamic assessment of VF mobility, obstructive sleep apnea-related upper airway narrowings, laryngo-tracheo-broncho-malacia, and synchronous aerodigestive lesions. Direct laryngo-tracheoscopy was performed to check passive VF mobility, confirm cricoarytenoid fixation, and map the site and the length of the LTS. The sizing of the airway was measured by passing telescopes through the stenosis and the percentage of luminal obstruction was extrapolated from the Cotton-Myer grading scale.[19] Antibiotics were prescribed based on tracheobronchial aspirate and culture studies and patients were screened for GER and eosinophilic esophagitis.

The operative technique of revision open airway surgery

At least 6 months following the primary open intervention, revision LTR, PCTR, or ePCTR were performed, as previously described,[1,2,4] along with additional technical modifications.[20,21]

In DS surgery, the tracheostomy was maintained at the end of the surgery and laryngeal stenting was used (LT-mold since 2001, and before that other stents and T-tubes were used).

Postoperative management

In case of PCTR/ePCTR the neck was placed in flexion and kept calm for 3 weeks. Trans-pyloric feeding was preferred to reduce GER and all patients were given anti-reflux medications. After SS procedures, the first endoscopy was performed at 5–10 days postoperatively to assess the safety of the planned extubation. Follow-up endoscopies were performed at intervals of 1, 3, and 12 months. Additional endoscopies were performed in case of complications and included dilation (balloon, bougie), granulation tissue ablation, and laser interventions to optimize the airway.

Statistical analysis

Normality of data distribution was assessed with the Shapiro–Wilk test. Normally distributed data were represented with the mean, standard deviation (SD), and 95% confidence interval (CI) and non-normally distributed data with the median and interquartile range (IQR). Differences in distribution between groups were tested by χ^2 or Fisher's exact test, whereas differences in means were analyzed with a t-test or Mann–Whitney test in case of non-normal distribution. A p Value <0.05 was considered statistically significant.

RESULTS

Patients' characteristics

The median age at revision open airway surgery was 5.6 years (IQR: 2.7–10.0, range: 1.0–18.0). Only one patient was lost to follow-up and the mean follow-up time in the remaining 45 patients was 3.8 years (SD 4.8, range: 0.4–23.0, 95% CI 2.4–5.2).

As shown in Table 1, a previous failed primary open or endoscopic airway surgery was performed in 33/46 (71.7%) and 13/46 (28.3%) patients, respectively. In 34/46 (73.9%) patients, more than one LTS site was identified, most commonly the subglottis in 45/46 (97.8%) (Table 1). Only one patient had a patent subglottis and presented an acquired combined grade III supraglotto-glottic stenosis.

Decannulation rate

A PCTR, ePCTR, and LTR were performed in 21/46 (45.6%), 20/46 (43.5%), and 5/46 (10.9%) patients, respectively. The ODR (includes additional revision surgeries) was superior in patients with LTR, followed by PCTR and ePCTR (5/5 (100.0%) vs. 16/17 (94.1%) vs. 18/21 (85.7%)), but the difference was not statistically significant (p = 0.50). The operation-specific decannulation rate (OSDR) was significantly superior in PCTR, followed by ePCTR and LTR (15/17 (88.2%) vs. 11/21 (52.4%) vs. 2/5 (40.0%), p = 0.032).

TABLE 1.
Preoperative revision open airway surgery characteristics.

	Revision open airway surgery characteristics
	Number of patients = 46 (%)
Age at revision open airway surgery	
≤5 years	22 (47.8)
≤10 years	13 (28.3)
≤18 years	11 (23.9)
Type of primary airway surgery	
Endoscopic	13 (28.3)
LTR	24 (52.2)
PCTR	6 (13.0)
ePCTR	3 (6.5)
LTS etiology	
Acquired	25 (54.3)
Mixed	18 (39.1)
Congenital	3 (6.5)
LTS grade	Median 3.0 (IQR: 3.7–4.0, range: 2–4)
I	0 (0.0)
II	9 (19.6)
III	25 (54.3)
IV	12 (26.1)
LTS length in cm (31 patients)	Mean 2.6 (SD 1.0, range: 0.7–5.5, 95% CI 2.2 to 3.0)
LTS site[a]	
Subglottic	45 (97.8)
Glottic	28 (60.9)
Supraglottic	11 (23.9)
Tracheal	8 (17.4)
Number of LTS sites	Median 2 (IQR: 1–3, range: 1–3)
1	12 (26.1)
2	22 (47.8)
3	12 (26.1)
4	0 (0.0)
Associated comorbidities	
No	16 (34.8)
Yes	30 (65.2)
Airway[b]	10/30 (33.3)
Non-airway	20/30 (66.7)
Non-airway comorbidities (20 patients)[a]	
Cardiac	7 (35.0)
Prematurity	7 (35.0)
Syndromic	6 (30.0)
Neurologic	4 (20.0)
Respiratory	3 (15.0)
Other	3 (15.0)
Number of comorbidities (30 patients)	Median 1 (IQR: 1–2, range: 1–4)
1	19 (63.3)
2	8 (26.7)
3	1 (3.3)
4	2 (6.6)

(Continues)

TABLE 1.
Continued

Abbreviations: CI, confidence interval; ePCTR, extended partial cricotracehal resection; IQR, interquartile range; LTR, laryngotracheal reconstruction; LTS, laryngotracheal stenosis; PCTR, partial cricotracheal resection; SD, standard deviation.

[a]Percentages do not add to 100% because patients had more than one LTS site/comorbidity.

[b]Included airway comorbidities: laryngo-tracheo-bronchomalacia, tracheoesophageal fistula.

The ODR and OSDR after revision open airway surgery were 39/43 (90.7%) and 32/43 (74.4%), respectively. Only 4/43 (9.3%) patients are awaiting decannulation at the time of the study completion. Three patients have not been able to travel (due to the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) pandemic) to our institution to conclude the treatment. One patient has not been decannulated because of neurologic complications due to Guillain-Barre syndrome.

Time to decannulation in DS procedures

Revision SS and DS procedures were performed in 15/46 (32.6%) and 31/46 (67.4%) patients, respectively. In the SS group, 12/12 (100%) were decannulated and 3/3 (100%) extubated at the time of surgery or within a week.

In the 27/31 (87.1%) decannulated patients after DS procedures, the median time to decannulation was 6.0 months (IQR: 3.5–12.7, range: 0.7–48.0, mean 11.5). Postoperative laryngeal stenting was used in 24/46 (52.2%) patients. A T-tube or similar prosthesis was used in 10/24 (41.7%) and an LT-mold in 14/24 (58.3%) patients for a median time of 4.0 weeks (IQR: 2.5–5.0, range: 1–12) and 8.0 weeks (IQR: 8–9, range: 6–12), respectively.

As presented in Table 2, the statistically significant risk factors for a longer time to decannulation were age 5 years or less at the time of revision surgery ($p = 0.038$) and previous primary open airway surgery ($p = 0.039$) (Table 2).

Postoperative complications and additional surgeries

Postoperative complications were observed in 24/46 (52.2%) patients, described as minor in 13/24 (54.2%) and as major in 11/24 (45.8%). As shown in Table 3, none of the analyzed factors had a statistically significant influence on the incidence of complications (Table 3).

TABLE 2.
Potential risk factors influencing the time to decannulation in patients after double-stage revision open airway surgery.

Risk factors (number of patients = 27)	Time to decannulation (months) Mean (SD)	Difference in means	95% CI	p Value
Age at revision open airway surgery				
≤5 years (13)	15.0 (13.3)	6.9	−2.3–16.1	0.038[a]
>5 years (14)	8.1 (9.7)			
Type of primary airway surgery				
Endoscopic	2.8 (1.6)	11.1	−21.8–-0.6	0.039
Open	13.9 (12.4)			
LTS etiology				
Congenital or mixed (9)	15.1 (13.9)	5.5	−4.5–15.4	0.176
Acquired (18)	9.6 (10.7)			
Number of LTS sites				
1 (7)	5.8 (6.4)	7.6	−18.2–2.9	0.063[a]
>1 (12)	13.4 (14.0)			
LTS grade				
I or II (6)	7.8 (3.4)	4.8	−16.1–6.6	0.400
III or IV (21)	12.6 (13.2)			
LTS length				
≤ 3 cm (17)	12.4 (12.4)	7.4	−21.9–7.1	0.297
> 3 cm (4)	19.8 (12.8)			
Missing values (6)				
Associated comorbidities				
No (10)	8.7 (6.0)	4.4	−14.1–5.4	0.369
Yes (17)	13.1 (14.2)			
Type of associated comorbidities				
Non-airway (11)	14.7 (17.0)	4.7	−10.9–20.4	0.527
Airway (6)	10.0 (6.8)			
Number of comorbidities				
1 (12)	11.0 (12.7)	7.0	−23.2–9.1	0.369
> 1 (5)	18.0 (17.8)			
Preoperative VF mobility				
Normal or limited VF abduction (10)	6.9 (5.8)	10.5	−23.6–2.6	0.107
One or both VF fixed (17)	17.4 (17.9)			
Postoperative laryngeal stenting				
T-tube or similar (10)	12.2 (12.3)	3.1	−16.8–9.6	0.482[a]
LT-mold (14)	15.3 (13.6)			

Abbreviations: CI, confidence interval; LTS, laryngotracheal stenosis; SD, standard deviation; VF, vocal fold.
[a]Mann–Whitney non-parametric test was used in case of non-normal distribution.

Additional open surgery was performed in 14/46 (30.4%) patients to achieve optimal airway patency. As presented in Table 3, there was a statistically significant difference in the number of additional open surgeries between patients aged 5 years or younger at the time of revision open airway surgery compared to those older than 5 years ($p = 0.034$), patients with more than one compared to those with one associated comorbidity ($p = 0.044$), patients that had a revision ePCTR compared to LTR and PCTR ($p = 0.023$) and those that needed laryngeal stenting compared to those that did not ($p = 0.018$) (Table 3).

More than three postoperative additional endoscopic surgeries were necessary in patients with suboptimal open airway surgery results. As shown in Table 3, a statistically significant higher rate (>3) of endoscopic airway surgeries was identified in patients that had a primary open compared to endoscopic airway surgery ($p = 0.034$) and those that had associated comorbidities compared to those without comorbidities ($p = 0.044$) (Table 3).

Functional results

As shown in Figure 1, preoperatively 42/46 (91.3%) patients were tracheostomy dependent and postoperatively normal breathing was achieved in 29/46 (63.0%) of patients. Preoperative and postoperative dysphonia was identified in 25/45 (55.5%) and 37/45 (82.2%) patients, respectively. Oral feeding was possible in 35/45 (77.8%)

TABLE 3.
Revision open airway surgery outcomes: postoperative complications, additional open and endoscopic airway surgery.

Risk factors	Postoperative complications			Additional open airway surgery			Additional endoscopic airway surgery		
	No (22, 47.8%)	Yes (24, 52.2%)	*p* Value	No (32; 69.6%)	Yes (14, 30.4%)	*p* Value	≤3 (23, 52.3%)	>3 (21, 47.7%)	*p* Value
Age at revision open airway surgery									
≤ 5 years	11 (50.0)	11 (45.8)	0.243	12 (37.5)	10 (71.4)	0.034	8 (34.8)	13 (61.9)	0.072
> 5 years	11 (50.0)	13 (54.2)		20 (62.5)	4 (28.6)		15 (65.2)	8 (38.1)	
Type of primary airway surgery									
Endoscopic	8 (36.4)	5 (20.8)	0.243	12 (37.5)	1 (7.1)	0.072	10 (43.5)	3 (14.3)	0.034
Open	14 (63.6)	19 (79.2)		20 (62.5)	13 (92.9)		13 (56.5)	18 (85.7)	
LTS etiology									
Congenital or mixed	10 (45.5)	11 (45.8)	0.979	14 (43.8)	7 (50.0)	0.695	10 (43.5)	9 (42.9)	0.967
Acquired	12 (54.5)	13 (54.2)		18 (56.3)	7 (50.0)		13 (73.9)	12 (57.1)	
Number of LTS sites									
1	8 (36.4)	4 (16.7)	0.129	10 (31.3)	2 (14.3)	0.294	6 (26.1)	6 (28.6)	0.853
> 1	14 (63.6)	20 (83.3)		22 (68.8)	12 (85.7)		17 (73.9)	15 (71.4)	
LTS grade									
I or II	4 (18.2)	5 (20.8)	1.000	5 (15.6)	4 (28.6)	0.423	2 (8.7)	7 (33.3)	0.064
III or IV	18 (81.8)	19 (79.2)		27 (84.4)	10 (71.4)		21 (91.3)	14 (66.7)	
LTS length (31 patients)									
≤ 3 cm	12 (80.0)	12 (75.0)	1.000	14 (73.7)	10 (83.3)	0.676	9 (64.3)	13 (86.7)	0.215
> 3 cm	3 (20.0)	4 (25.0)		5 (26.3)	2 (16.7)		5 (35.7)	2 (13.3)	
Associated comorbidities									
No	10 (45.5)	6 (25.0)	0.146	14 (43.8)	2 (14.3)	0.054	11 (47.8)	4 (19.0)	0.044
Yes	12 (54.5)	18 (75.0)		18 (56.3)	12 (85.7)		12 (52.2)	17 (81.0)	
Type of comorbidities (30 patients)									
Non airway	7 (58.3)	13 (72.2)	0.461	13 (72.2)	7 (58.3)	0.461	8 (66.7)	11 (64.7)	0.913
Airway	5 (41.7)	5 (27.8)		5 (27.8)	5 (41.7)		4 (33.3)	6 (35.3)	
Number of comorbidities (30 patients)									
1	9 (75.0)	10 (55.6)	0.442	14 (77.8)	5 (41.7)	0.044	9 (75.0)	9 (52.9)	0.273
> 1	3 (25.0)	8 (44.4)		4 (22.2)	7 (58.3)		3 (25.0)	8 (47.1)	
Revision open airway surgery[a]									
LTR	1 (4.5)	4 (16.7)	0.229	2 (6.3)	3 (21.4)	0.023	1 (20.0)	4 (19.0)	0.168
PCTR	12 (54.5)	8 (33.3)		18 (56.3)	2 (14.3)		13 (56.5)	7 (33.3)	
ePCTR	9 (40.9)	12 (50.0)		12 (37.5)	9 (64.3)		9 (39.1)	10 (47.6)	
Postoperative laryngeal stenting									
No	13 (59.1)	9 (37.5)	0.143	19 (59.4)	3 (21.4)	0.018	14 (60.9)	8 (38.1)	0.131
Yes	9 (40.9)	15 (62.5)		13 (40.6)	11 (78.6)		9 (39.1)	13 (62.9)	
Preoperative VF mobility									
Normal or limited VF abduction	13 (59.1)	9 (37.5)	0.143	17 (53.1)	5 (35.7)	0.277	13 (56.5)	9 (42.9)	0.365
One or both VF fixed	9 (37.5)	15 (62.5)		15 (46.9)	9 (64.3)		10 (43.5)	12 (57.1)	

Abbreviations: DS, double-stage; ePCTR, extended partial cricotracehal resection; LTR, laryngotracheal reconstruction; LTS, laryngotracheal stenosis; PCTR, partial cricotracheal resection; SS, single-stage; VF, vocal fold.
[a]X^2 test was performed.

patients preoperatively and in 41/45 (91.1%) patients postoperatively (Figure 1).

DISCUSSION

Primary airway surgery results have been thoroughly reported, but the outcomes of revision airway surgery remain largely unknown.[4–7,10,13,17,22–25] Distortion and instability of the laryngeal framework, lack of healthy mucosa and limitations of further airway resection are some of the issues encountered in revision airway surgeries.[13,14,22]

Revision surgery has been recommended at least 6 months following a failed primary surgery[17] and the reported average interval between surgeries is 2 to 4 years.[13,24] Nevertheless, almost half (22/46, 47.8%) of our patients were less than 5 years of age and the median age at revision surgery was 5.6 years. Although

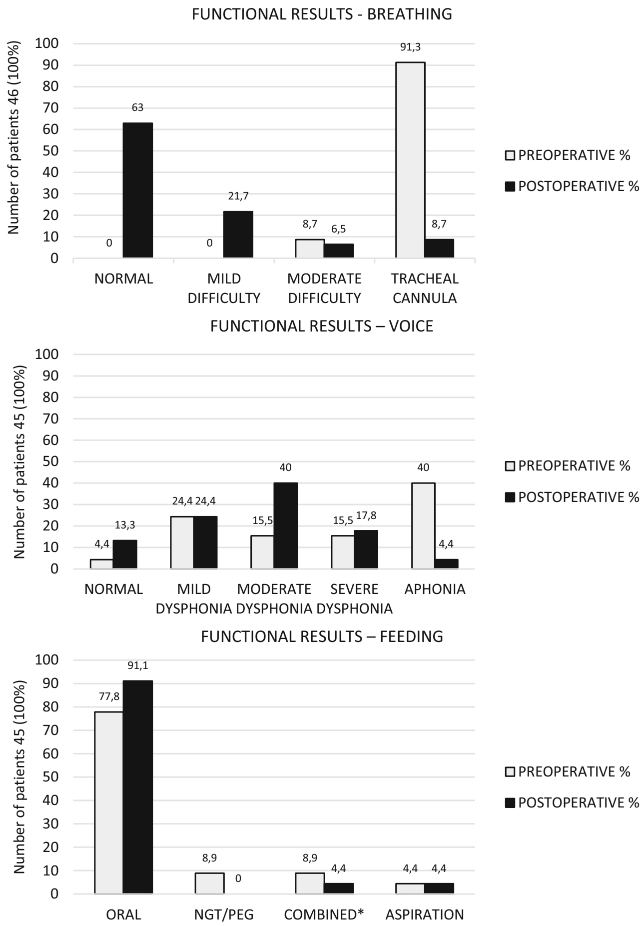

FIGURE 1. Functional results of revision open airway surgery. NGT, nasogastric tube; PEG, percutaneous gastrostomy. *Combined feeding: oral and nasogastric tube/percutaneous gastrostomy.

all our patients were referred from other medical institutions, a relatively long mean follow-up time of 3.8 years was achieved, with patients being followed up to 23 years.

The failed primary surgery was an open airway surgery in 71.7% (33/46) of our patients, most commonly an LTR (24/33, 72.7%), similar to previous reports.[7,8] Still, LTR remains one of the most frequently performed airway surgeries because it can address subglottic and glottic stenosis and is relatively easier compared to PCTR.[4,8,11,12,15,26] In the remaining 28.3% (13/46) of our patients, revision surgery followed failed multiple primary endoscopic procedures. As reported by other authors, up to 55.0% of open airway surgeries are performed after failed endoscopic treatments have aggravated the LTS.[5,13,25,27]

The majority (43/46, 93.5%) of our patients had acquired or mixed LTS, most commonly in the subglottis (45/46, 97.8%). In this report, known risk factors for airway surgery failure, like glottic involvement and multiple LTS sites,[4–7,9,11,25] were identified in 60.9% (28/46) and 73.9% (34/46) of our patients, respectively. Grade III LTS, identified in more than half (25/46, 54.3%) of our patients, has the most variable surgical outcomes and can be treated by LTR or PCTR.[2,11] In our opinion, PCTR is more appropriate and based on the high number of failed primary LTRs in our group, we can speculate that the choice of primary surgery was most probably inappropriate.

In concordance with previous reports,[3,4,14] the most commonly performed revision airway surgery in our group of LTS patients was PCTR in 21/46 (45.6%), followed by ePCTR in 20/46 (43.5%) and LTR in 5/46 (10.9%) patients. A previously operated subglottis is deficient in cartilage and the scarred stenotic area is an inadequate wound bed for cartilage graft healing. Consequently, the most appropriate surgery is removing the diseased stenotic site, and this is best achieved by PCTR.

Based on our results, a 90.7% ODR and a 74.4% OSDR can be achieved in pediatric revision open airway surgery, comparable to the decannulation rates in primary open airway surgery.[4–13,26] The most successful airway revision surgery in our group of patients was PCTR, with 94.1% ODR and statistically significantly higher OSDR compared to revision ePCTR and LTR (88.2% vs. 52.4% vs. 40.0%, $p = 0.032$), similar to previously published studies.[3,14] Compared to LTR, revision PCTR has the advantage of forming a mucosalized subglottis with healthy mucosa and thus less probability of granulation and re-stenosis. Lower decannulation rates of ePCTR have been observed in both primary and revision surgeries, possibly due to grafting and more complex airway disease to begin with.[4,7,28] Nevertheless, a high ODR in revision LTR (100%) and ePCTR (85.7%) was achieved in our study, similar to the 70.0% ODR described in literature.[4–8,17]

The postoperative complication rate in our cohort was 52.2% (24/46), somewhat higher than the reported 24.0% rate in primary open airway surgeries.[5,13] However, half (13/24, 54.2%) of the complications in our patients were minor and solved by endoscopic surgery.

The mean time to decannulation in DS procedures was 11.5 months (median = 6 months), which is slightly longer than the mean 5–10 months described in primary DS surgeries.[5,8,13]

Additional endoscopic or open surgeries were necessary to achieve decannulation in 47.7% (21/44) and 30.4% (14/46) of our patients, respectively. In comparison, half of the primary open surgeries are reportedly followed by additional endoscopic treatments.[13,14,22]

A higher LTS grade, longer and multiple stenotic sites have been previously identified as risk factors for complications and delayed decannulation,[5,25] but our report could not confirm these results. In our opinion, correct preoperative assessment of the LTS enables the surgeon to opt for the ideal surgery and lowers the chances of failure. The child's age at revision surgery equal to or less than 5 was a risk factor for an additional open airway surgery ($p = 0.034$) and these children had longer time to decannulation compared to older children (15.0 vs. 8.1 months, $p = 0.038$). Even though airway surgery can be successful in very young children, surgery at an early age has been associated with higher surgery failure rates.[17,26,29,30]

Primary open airway surgery can cause severe damage to the airway mucosa and aggravate the LTS, leading to technically more difficult revision surgeries. Therefore, compared with those after primary endoscopic surgery, patients after primary open surgery had a longer decannulation time (2.8 vs. 13.9 months, $p = 0.039$), a propensity for additional open surgeries ($p = 0.072$), and a significantly higher rate of additional endoscopic surgeries ($p = 0.034$).

Although medical comorbidities have been identified as risk factors for delayed decannulation,[9,15,26] our results could not confirm this. On the other hand, comorbidities were a significant risk factor for additional endoscopic surgeries ($p = 0.044$). In addition, patients with multiple comorbidities had a significantly higher rate of additional open surgeries ($p = 0.044$).

In concordance with previous reports,[2] additional open surgery to achieve optimal airway was more common after revision ePCTR compared with LTR and PCTR (64.3% vs. 21.4% vs. 14.3%, $p = 0.023$). Possible factors adding to revision ePCTR failure are: (1) graft prolapse and necrosis because of insufficient blood supply to the previously operated scarred larynx, (2) a full laryngofissure and posterior cricoid split could make the airway unstable, and (3) an extensive tracheal resection could predispose the revision surgery to higher rates of anastomosis dehiscence.[2,14,15,25]

Failure to identify posterior glottic stenosis and VF immobility have been described as important factors for airway surgery failure.[6,17,24] In our opinion, fixation of VF is not a risk factor for failure, if it is addressed during surgery. Cartilage grafts can undergo chondrolysis, therefore in select cases, we prefer a slightly large-for-age posterior cricoid graft and its higher positioning to overexpand the inter-arytenoid space and avoid the arytenoid cartilages from prolapsing medially. When we perform ePCTR in cases with cricoarytenoid ankyloses, we open the cricoarytenoid joints to restore mobility.[20]

We agree that the choice of the stent must be personalized and that correct stenting does not critically influence the surgery outcomes, as previously reported.[4,14,31,32] Nevertheless, our results show that compared to non-stented patients, those with stenting had more postoperative complications and a statistically significant higher rate of additional open surgeries (78.6% vs. 21.4%, $p = 0.018$). More complications were seen when the earlier design of the LT-mold was used. In recent years we have seen fewer complications with the newer LT-molds, and our results on this topic will be published.

Relatively little is known about the revision airway surgery functional results in children. Normal breathing was achieved in 63.0% (29/46) of our patients. Although most patients were preoperatively dysphonic (25/45, 55.5%) or aphonic (18/45, 40.0%), only 4.4% (2/45) of patients remained aphonic postoperatively. Moderate dysphonia was the most common voice outcome in 40.0% (18/45) of patients. Similar to previous reports in children after posterior laryngeal grafting,[22] our results show that most (41/45, 91.1%) patients achieved safe oral feeding postoperatively.

Retrospective data collection has limited the evaluation of the influence of GER and postoperative infections on revision surgery outcomes. This study's strength is a long period of observation, during which surgery indications and techniques have somewhat changed. Still, as patients were operated in a single medical institution following the same operative protocols, major differences in treatment are not to be expected.

CONCLUSIONS

The primary measures of airway surgery success are optimal airway lumen and decannulation, but the ultimate goals for the patient are phonation and safe swallowing. A thorough preoperative assessment and meticulous surgical technique are essential for successful revision surgery. High decannulation rates and good functional results can be achieved in revision open airway surgery for recurrent LTS in children. The identified factors with a significant negative impact on revision open airway surgery outcomes were the patient's age under 5 years, previous primary open airway surgery, medical comorbidities, and laryngeal stenting.

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CONFLICT OF INTEREST STATEMENT

The authors report no conflicts of interest.

REFERENCES

1. Kou Y-F, Rutter MJ, Sandu K, Guilcher P. Pediatric open airway reconstruction. *Curr Otorhinolaryngol Rep*. 2021;9(1):37-51.
2. Sandu K, Monnier P. Cricotracheal resection. *Otolaryngol Clin N Am*. 2008; 41(5):981-998.
3. Bailey M, Hoeve H, Monnier P. Paediatric laryngotracheal stenosis: a consensus paper from three European centres. *Eur Arch Otorhinolaryngol*. 2003;260(3):118-123.
4. Rutter MJ, Hartley BE, Cotton RT. Cricotracheal resection in children. *Arch Otolaryngol Head Neck Surg*. 2001;127(3):289-292.
5. Fiz I, Monnier P, Koelmel JC, et al. Implementation of the European laryngological society classification for pediatric benign laryngotracheal stenosis: a multicentric study. *Eur Arch Otorhinolaryngol*. 2019;276(3): 785-792.
6. White DR, Cotton RT, Bean JA, Rutter MJ. Pediatric cricotracheal resection: surgical outcomes and risk factor analysis. *Arch Otolaryngol Head Neck Surg*. 2005;131(10):896-899.
7. Yamamoto K, Jaquet Y, Ikonomidis C, Monnier P. Partial cricotracheal resection for paediatric subglottic stenosis: update of the Lausanne experience with 129 cases. *Eur J Cardiothorac Surg*. 2015;47(5):876-882.
8. Yamamoto K, Monnier P, Holtz F, Jaquet Y. Laryngotracheal reconstruction for pediatric glotto-subglottic stenosis. *Int J Pediatr Otorhinolaryngol*. 2014;78(9):1476-1479.
9. George M, Ikonomidis C, Jaquet Y, Monnier P. Partial cricotracheal resection for congenital subglottic stenosis in children: the effect of concomitant anomalies. *Int J Pediatr Otorhinolaryngol*. 2009;73(7):981-985.
10. Agrawal N, Black M, Morrison G. Ten-year review of laryngotracheal reconstruction for paediatric airway stenosis. *Int J Pediatr Otorhinolaryngol*. 2007;71(5):699-703.
11. Pullens B, Hoeve LJ, Timmerman MK, van der Schroeff MP, Joosten KF. Characteristics and surgical outcome of 98 infants and children surgically treated for a laryngotracheal stenosis after endotracheal intubation: excellent outcome for higher grades of stenosis after SS-LTR. *Int J Pediatr Otorhinolaryngol*. 2014;78(9):1444-1448.
12. Padia R, Sjogren P, Smith M, Muntz H, Stoddard G, Meier J. Systematic review/meta-analysis comparing successful outcomes after single vs. double-stage laryngotracheal reconstruction. *Int J Pediatr Otorhinolaryngol*. 2018;108:168-174.
13. Cheung PKF, Koh HL, Cheng ATL. Complications and outcomes following open laryngotracheal reconstruction: a 15 year experience at an

Australian paediatric tertiary referral Centre. *Int J Pediatr Otorhinolaryngol*. 2021;145:110687.
14. de Alarcon A, Rutter MJ. Revision pediatric laryngotracheal reconstruction. *Otolaryngol Clin N Am*. 2008;41(5):959-980.
15. Bajaj Y, Cochrane LA, Jephson CG, et al. Laryngotracheal reconstruction and cricotracheal resection in children: recent experience at great Ormond street hospital. *Int J Pediatr Otorhinolaryngol*. 2012;76(4):507-511.
16. Monnier P, Dikkers FG, Eckel H, et al. Preoperative assessment and classification of benign laryngotracheal stenosis: a consensus paper of the European laryngological society. *Eur Arch Otorhinolaryngol*. 2015; 272(10):2885-2896.
17. Younis RT, Lazar RH, Bustillo A. Revision single-stage laryngotracheal reconstruction in children. *Ann Otol Rhinol Laryngol*. 2004;113(5):367-372.
18. Rutter MJ, Link DT, Liu JH, Cotton RT. Laryngotracheal reconstruction and the hidden airway lesion. *Laryngoscope*. 2000;110(11):1871-1874.
19. Myer CM 3rd, O'Connor DM, Cotton RT. Proposed grading system for subglottic stenosis based on endotracheal tube sizes. *Ann Otol Rhinol Laryngol*. 1994;103(4 Pt 1):319-323.
20. Sandu K, Monnier P. Partial cricotracheal resection with tracheal intussusception and cricoarytenoid joint mobilization: early experience in a new technical variant. *Laryngoscope*. 2011;121(10):2150-2154.
21. Gorostidi F, Reinhard A, Monnier P, Sandu K. External bioresorbable airway rigidification to treat refractory localized tracheomalacia. *Laryngoscope*. 2016;126(11):2605-2610.
22. Kou YF, Redmann A, Tabangin ME, et al. Airway and swallowing outcomes following Laryngotracheoplasty with posterior grafting in children. *Laryngoscope*. 2021;131(12):2798-2804.
23. Maeda K, Ono S, Baba K. Management of laryngotracheal stenosis in infants and children: the role of re-do surgery in cases of severe subglottic stenosis. *Pediatr Surg Int*. 2013;29(10):1001-1006.
24. Choi SS, Zalzal GH. Pitfalls in laryngotracheal reconstruction. *Arch Otolaryngol Head Neck Surg*. 1999;125(6):650-653.
25. George M, Jaquet Y, Ikonomidis C, Monnier P. Management of severe pediatric subglottic stenosis with glottic involvement. *J Thorac Cardiovasc Surg*. 2010;139(2):411-417.
26. Gustafson LM, Hartley BE, Liu JH, et al. Single-stage laryngotracheal reconstruction in children: a review of 200 cases. *Otolaryngol Head Neck Surg*. 2000;123(4):430-434.
27. Balakrishnan K, Sidell DR, Bauman NM, et al. Outcome measures for pediatric laryngotracheal reconstruction: international consensus statement. *Laryngoscope*. 2019;129(1):244-255.
28. Jaquet Y, George M, Monnier P. Management of severe glotto-subglottic stenosis in children. *Laryngoscope*. 2012;122(Suppl 4):S75-S76.
29. Zalzal GH, Choi SS, Patel KM. Ideal timing of pediatric laryngotracheal reconstruction. *Arch Otolaryngol Head Neck Surg*. 1997;123(2): 206-208.
30. Roxbury CR, Jatana KR, Shah RK, Boss EF. Safety and postoperative adverse events in pediatric airway reconstruction: analysis of ACS-NSQIP-P 30-day outcomes. *Laryngoscope*. 2017;127(2):504-508.
31. Preciado D. A randomized study of suprastomal stents in laryngotracheoplasty surgery for grade III subglottic stenosis in children. *Laryngoscope*. 2014;124(1):207-213.
32. Monnier P. A new stent for the management of adult and pediatric laryngotracheal stenosis. *Laryngoscope*. 2003;113(8):1418-1422.