

## ORIGINAL RESEARCH

# From the clavicle to the windpipe: Tracheal window resections reconstructed with calcifying periosteum in thyroid cancer

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**Abstract**

**Objectives:** We aimed to evaluate the outcomes of tracheal window resection and reconstruction using a vascularized periosteal flap (intended for calcification) harvested from the medial clavicle. This is one of several surgical techniques for tracheal resection and reconstruction used for patients with thyroid carcinoma invading the trachea. Importantly, in partial tracheal resection postoperative dynamic airway collapse must be prevented. Reconstruction of the tracheal defect with a vascularized periosteal flap is one method of achieving a stable airway.

**Methods:** Twelve patients with locally advanced thyroid carcinoma who underwent tracheal resection and reconstruction at Oslo University Hospital from 2004 to 2017 were studied retrospectively. The primary outcome was a stable airway not requiring airway stenting. The secondary outcomes were the time to decannulation, morbidity, and survival.

**Results:** Eleven of 12 patients did not require airway stenting postoperatively after a median of 111 days. Seven patients developed postoperative complications. The median observation time was 74.8 months (range 10.5-153.5) for all patients. The median disease-free survival was 40 months (range 0-147). By February 1, 2020, seven patients were alive, of whom five showed no evidence of disease.

**Conclusions:** Tracheal reconstruction with a vascularized periosteal flap yielded good results in terms of establishing a stable airway. This procedure is a viable reconstructive option that allows for decannulation by preventing airway collapse, thereby potentially mitigating the need for end-to-end (ETE) anastomosis or sleeve resections. For selected patients, this procedure may prevent local fatal complications from thyroid cancer invading the trachea.

**Level of evidence:** Level 4.

**KEYWORDS**

thyroid neoplasms/surgery, thyroidectomy/methods, tracheal resection, treatment outcome

## 1 | INTRODUCTION

The incidence rate of aerodigestive tract invasion is 1% to 8% in thyroid carcinoma (TC) and 10% to 20% in recurrent TC<sup>1</sup> which is associated with significant morbidities such as dyspnea, dysphagia, and bleeding. The mainstay for treatment in this context is radical surgical excision. Tracheal resection and reconstruction may be necessary in cases of cancer invading the trachea, and for the different techniques, postoperative airway stability remains a matter of concern. In cases of invasion of the trachea by, the main surgical options are shaving, window resection, sleeve resection, or circumferential resection with end-to-end (ETE) anastomosis.<sup>2</sup> ETE anastomosis is a well-established technique; however, tension, anastomotic dehiscence, laryngeal stenosis, anastomotic stricture,<sup>3,4</sup> and securing a safe airway postoperatively may present problems. The American Head and Neck Society consensus statement states that “the mortality rate from tracheal or laryngotracheal resection has been reported to be as high as 5% to 9% in some series, prompting some to advocate the use of tracheal window resections in selected cases.”<sup>5</sup>

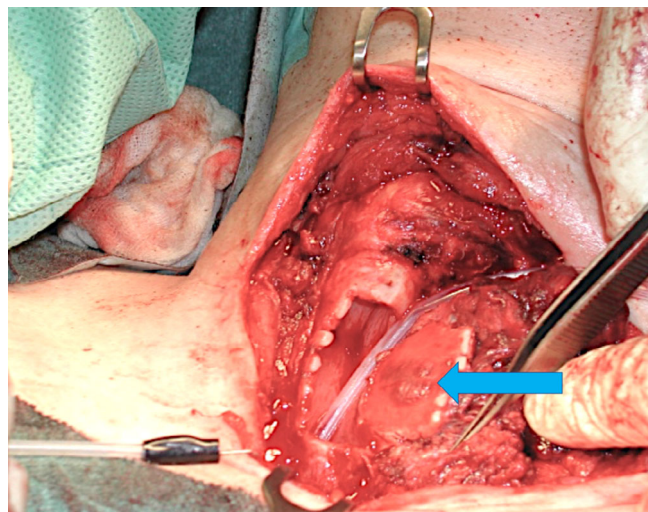
In the 1980s, Friedman et al<sup>6</sup> described a technique for tracheal resections of the cervical parts of the trachea using reconstruction with a myoperiosteal flap from the sternocleidomastoid (SCM) muscle. The flap consisted of fibrous clavicular periosteum that can provide an airtight, tension-free closure of a defect in the trachea with attached muscle for vascularization. An important potential benefit of this technique is a stable airway postoperatively without permanent need for stenting or a tracheal cannula. The procedure is associated with a lower risk for complications such as dehiscence and stenosis that may arise from ETE anastomosis. The resection may include the cricoid cartilage, which can be a challenging area to resect and reconstruct. This reconstruction can be used to repair defects of the trachea associated with curative surgery or palliative surgery with the intent to prevent local complications from cancer invading the trachea.

## 2 | SURGICAL NOTES

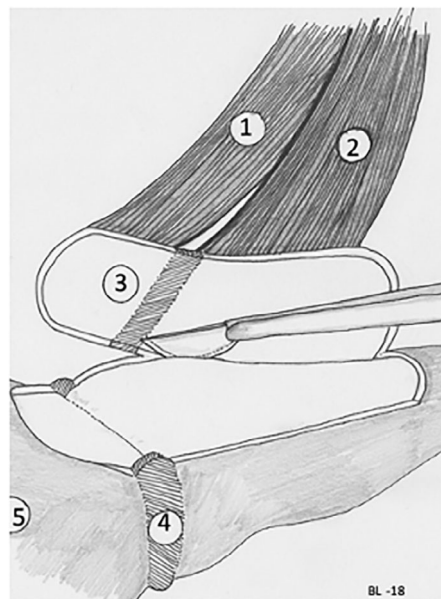
Preoperatively the size of the tracheal resection was judged following endoscopy and computed tomography (CT)/magnetic resonance imaging (MRI). Intraoperatively the size of the tracheal resection was determined by visible tumor invasion. Frozen sections were used to secure free margins. In some patients, parts of the cricoid cartilage were resected along with the tracheal wall. During the operation, ventilation was switched from endotracheal intubation to jet ventilation via a catheter to facilitate resection of the cervical parts of the trachea (Figure 1).

Reconstruction was carried out by preparing a vascularized periosteal flap from the clavicle, including part of the sternoclavicular joint capsule to gain additional potential stiffness and strength. The length of the periosteal flap was at least the same as the length of the tracheal defect. The sternal and clavicular heads of the SCM muscle were kept attached to the mobilized periosteum to maintain vascularization (Figure 2).

The preferred choice for temporary stenting of the trachea during healing was a T-tube, rather than a tracheal cannula. The flap was



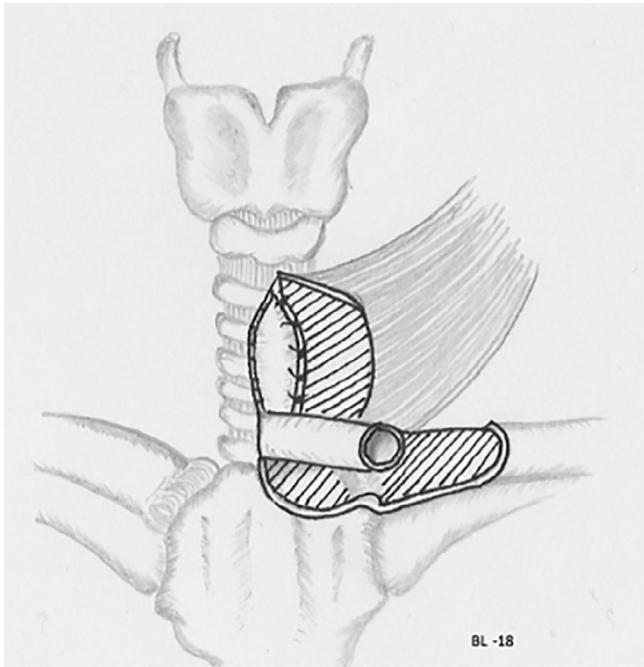
**FIGURE 1** Window resection of the trachea. Tumor is shown with arrow. Ventilation switched to Jet-ventilation



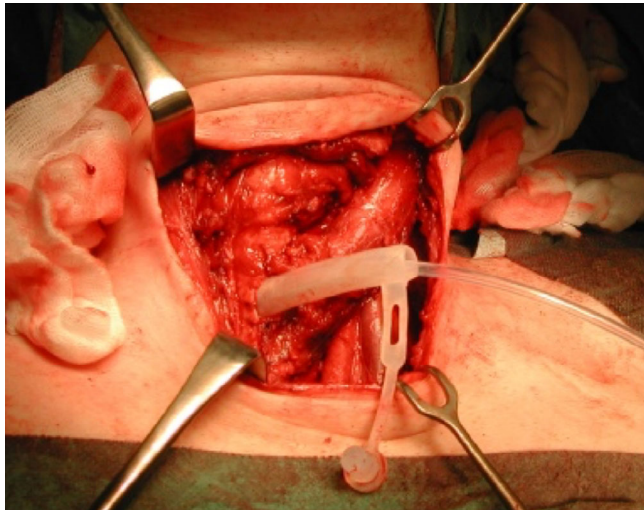
**FIGURE 2** Harvest of myoperiosteal flap from the clavicle and manubrium. (1) sternal head of sternocleidomastoid muscle, (2) clavicular head of sternocleidomastoid muscle, (3) periosteum, (4) sternoclavicular joint capsule, (5) manubrium

sutured without tension and with a close fit around the outer part of the T-tube (Figures 3 and 4). Some subcutaneous emphysema was anticipated postoperatively, which could be relieved by means of a passive drainage or active drainage connected to a thoracic drainage system. After surgery, the T-tube was kept open for a short period of time to avoid subcutaneous emphysema. For the remaining period, the horizontal arm of the T-tube was kept closed and the T-tube served only as a stent.

In our department, we have performed reconstruction of the tracheal defect with a vascularized periosteal flap since 2004. This study



**FIGURE 3** Partially closed tracheal resection with T-tube. Myoperiosteal flap and harvest-area marked by hatched fields



**FIGURE 4** After the repositioning of the myoperiosteal flap, muscle is seen to the right. Note a tight fit around the T-tube

evaluated the outcome of patients with invasive thyroid cancer treated with this technique at our institution. The primary outcome of the study was a structurally stable airway without airway stenting, and the secondary outcomes were time before stent removal (or decannulation), morbidity, and survival.

### 3 | MATERIALS AND METHODS

We identified 12 patients with thyroid cancer invading the trachea who underwent tracheal or cricotracheal window resection and

reconstruction with a vascularized myoperiosteal flap from 2004 to 2017 at the Oslo University Hospital's Department of Otorhinolaryngology, Head and Neck Surgery. Patients who underwent tracheal resection due to diagnoses other than thyroid cancer or treatment with ETE anastomosis were excluded from this study. The observation time started from the date of tracheal reconstruction to February 1, 2020, or otherwise until death or termination of follow-up.

Data were extracted from medical records and histopathologic and radiologic reports. The parameters described were sex, age, etiology, preoperative recurrent laryngeal nerve paralysis (RLNP), radioiodine treatment, and external radiotherapy (RT). Patients were retrospectively staged according to the classification by Shin et al<sup>7</sup> based on preoperative tracheal examination, perioperative findings, and histopathologic reports. The American Joint Committee on Cancer's Cancer Staging Manual 8th edition was used for TNM classification.<sup>8</sup> Classifications of recurrent disease were marked as rTNM. Patients with recurrent disease underwent salvage surgery. Preoperative CT or MRI data were reviewed to assess the extent of airway invasion.

The perioperative parameters included length of tracheal defect, type of stent, postoperative complications, and length of hospital stay. The length of the resected part of the trachea was obtained from histopathologic reports and perioperative findings. The status of the surgical margin was classified as no residual tumor (R0), microscopic residual tumor (R1), or macroscopic residual tumor (R2). Postoperative complications were categorized as follows: minor complications (granulomas managed endoscopically) and major complications (chyle leaks or necrosis if surgical intervention under general anesthesia was required, infection in the surgical field or pneumonia if there was systemic affection and need for antibiotic treatment, and permanent hypocalcemia). Acquired RLNP was noted. The time to airway stent (or tracheal cannula) removal was recorded as the duration (days) from tracheal surgery to stent (or cannula) removal.

The postoperative parameters consisted of the airway status and disease status at the end of the observation time, postoperative RT, and additional procedures such as lymph node ablation and lymph node dissection (LND). The patients underwent follow-up including: clinical examination, neck ultrasound, tracheoscopy (assessment for patency, stenosis, granulomatous tissue, and recurrent disease), blood tests, and, for most patients, a CT scan.

This study was approved by the Privacy Commissioner of Data at Oslo University Hospital. Images were released with consent from patients, from the Department of Radiology at Oslo University Hospital, and the Privacy Commissioner.

Patient data were registered and analyzed using SPSS version 25 (IBM Corp., Armonk, New York). Due to the small sample size, only descriptive statistics are presented.

### 4 | RESULTS

This study comprised six males and six females, with a median age of 64 years (range 33-84). An overview of patient data is shown in

**TABLE 1** Overview of patients

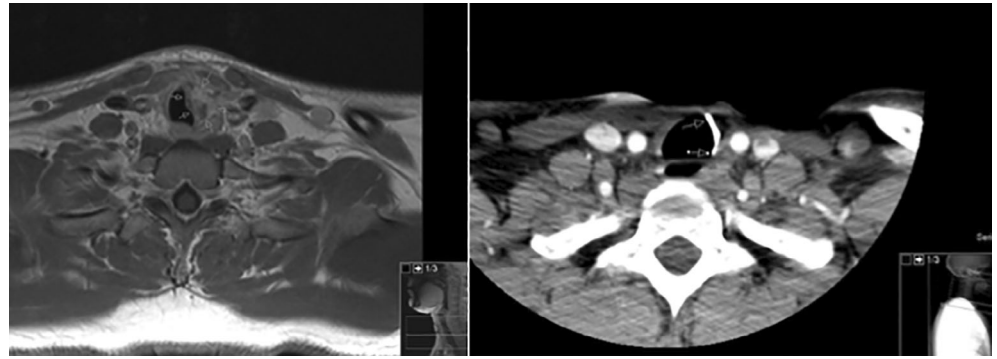
Pat. no	TNM classification	Tracheal resection, cm	Surgical margins	Type of TC	Cricoid resection	Postoperative complications	Airway status	RLN status	Status end of study	Observation time, months
1	T4aN1bM0	5.0	R0	PTC	No	None <sup>b</sup>	Normal	RLNP p.o.	Alive, NED	147
2	T4aN1bM0	4.0	R0	PTC	No	Pneumonia, deltopectoral flap 11 mo p.o., osteoradionecrosis 16 mo p.o. Hypocalcemia.	Normal	Preoperative RLNP	Alive, NED	133.5
3	T4aN0M0	2.5	R0	PTC FVPTC TCPTC	Yes	None	Normal	Preoperative RLNP	Alive, NED	86.5
4	T4aN1bM1	4.5	R0	PTC	No	Postoperative pulmonary embolism, chyle leak	Normal	RLNP p.o.	Alive, regional and distant metastatic disease (12 mo p.o.)	73
5	T4aN1bM0	2.1	R1	PTC	Yes	None	Normal		Alive, regional metastatic disease (48 mo p.o.)	76.5
6	T4aN1bM0	4.0	R1	PTC PDTC	Yes	Wound infection	Re-cannulated 23 mo p.o.	Preoperative RLNP	Death with cancer. Local recurrent and regional metastatic disease (10 mo p.o.)	31
7	T4aN1bM0	3.0	R1	ATC	No	Pneumonia, wound infection, revision and a pectoralis major flap, pleural effusion	Larynx at night	RLNP p.o.	Death with cancer	10.5
8 <sup>a</sup>	rT4aN1bM0	3.6	R0	PTC	Yes	None	Normal	Preoperative RLNP	Death without cancer	107
9 <sup>a</sup>	rT4aN0M0	2.7	R0	FTC	Yes	Wound infection <sup>b</sup>	Normal	RLNP p.o.	Alive, NED	32
10 <sup>a</sup>	rT4aN0M0	1.3	R0	FVPTC PTC	Yes	Wound infection	Normal	RLNP p.o.	Alive, NED	28.5
11 <sup>a</sup>	rT4aN1bM0	2.0	R1	PTC	Yes	None	Normal	Bilateral preoperative RLNP	Death with cancer Distant metastatic disease (85 mo p.o.)	153.5
12 <sup>a</sup>	rT4aN1bM0	4.0	R1	PTC	Yes	None <sup>b</sup>	Permanent canula	Preoperative RLNP	Death with cancer	10.5

Abbreviations: ATC, anaplastic thyroid cancer; FTC, follicular thyroid cancer; FVPTC, follicular variant of papillary thyroid cancer; NED, no evidence of disease; p.o., postoperative(y); PDTC, poorly differentiated thyroid cancer; Prop, preoperative; PTC, papillary thyroid cancer; RLNP, recurrent laryngeal nerve paresis; TCPTC, tall cell papillary thyroid cancer.

<sup>a</sup>Patient with recurrent disease and salvage surgery.

<sup>b</sup>Received endoscopic treatment for granuloma(s).

**FIGURE 5** On the left, T1-weighted contrast enhanced image MRI preoperatively. Tumor infiltration in the trachea indicated by arrowheads. On the right, postoperative CT of the same patient 7.5 years later. Arrowheads indicate the calcified periosteal flap



**FIGURE 6** Preoperative images on the left, postoperative images (respectively 5, 0.5, and 8 years) after surgery on the right

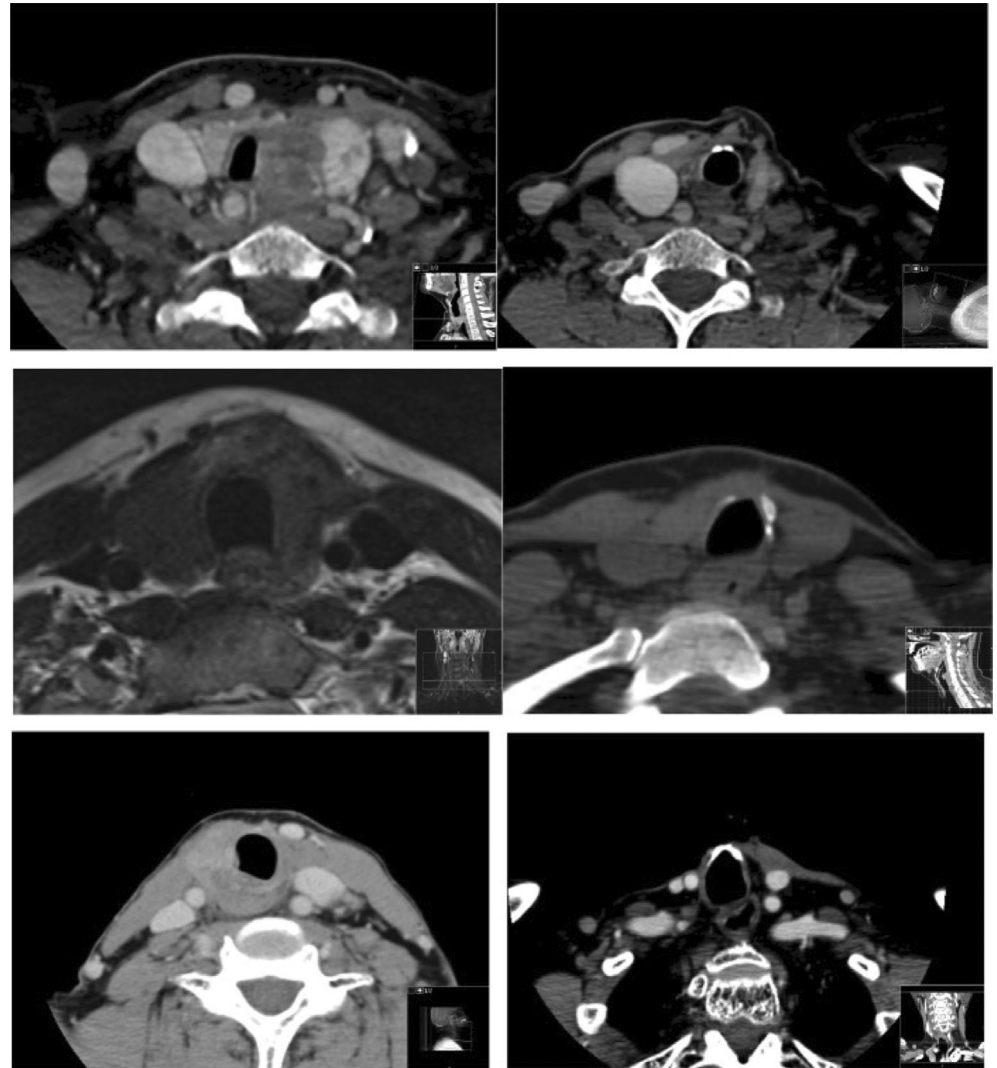


Table 1. One patient underwent preoperative external RT. Six patients had preoperative RLNP. All patients had a Shin stage 4 tumor, except for one patient with a Shin stage 3 tumor. Primary classifications (TNM) and recurrence classifications (rTNM) are included in Table 1 to illustrate the extent of disease at the time of tracheal surgery. The median hospital stay was 15 days (range 6-71). Histopathologic examination results showed papillary thyroid carcinoma (PTC) (10 patients), follicular variant of papillary thyroid carcinoma (FPTC) (2 patients),

follicular TC (FTC) (1 patient), poorly differentiated TC (PDTTC) (1 patient), anaplastic TC (1 patient), and tall-cell PTC (1 patient). The median observation time was 74.8 months (range 10.5-153.5) for all patients, 86.5 months (range 28.5-147) in patients with R0 resections, and 31 months (range 10.5-153.5) in patients with R1 resections. The median observation time was 76.5 months (range 10.5-147) in patients who underwent primary surgery and 32 months (range 10.5-153.5) in those who underwent salvage surgery. One patient had

a follow-up at 25 months and did not proceed with a further follow-up due to an unrelated health condition. At 107 months, the next of kin reported no airway stenting, no respiratory distress, and no local symptoms at the neck; thus, the observation time was rendered as 107 months. The median disease-free survival was 40 months (range 0-147). By February 1, 2020, seven patients were alive, five of whom had no evidence of disease. Five patients died, one of whom had no cancer.

Five of the 12 patients underwent thyroid surgery with tracheal resection and reconstruction as the initial surgical treatment. Two patients who had previous thyroid surgery at local hospitals were referred to our department due to perioperative discovery of tracheal invasion, and underwent tracheal resection within 5 weeks. Five patients underwent tracheal resection as a salvage procedure due to recurrent disease, with a median of 2 years after initial thyroid surgery (range 0.5-12). All 12 patients underwent surgery with window resection of the trachea, eight of which included partial resection of the cricoid cartilage. One patient had thoroscopic removal of mediastinal metastasis as part of the primary treatment. No patient required a sternum split. Of the 12 patients, nine were stented with a T-tube and three with a regular tracheal cannula. The median length of the resected part of the trachea was 3.3 cm (range 1.3-5.0).

In 11 patients, the T-tube (or tracheostomy cannula) was removed after a median of 111 days (range 8-360). Of the 12 patients, 10 patients had postoperative radiology images, of which seven showed calcifications of the periosteal flap (Figures 5 and 6). There was no perioperative mortality or deaths occurring later as a consequence of the surgery. Three patients required unilateral RLNP sacrifice as part of the tracheal resection due to tumor growth. One patient developed RLNP during the course of partial tracheal necrosis. Two patients required repositioning of the T-tube under general anesthesia. With regard to minor complications, three patients had endoscopic treatment for granulomas, one during T-tube removal. In terms of other complications, four patients were treated for wound infections, two patients had postoperative pneumonia, and one developed permanent hypocalcemia. One patient who had a pulmonary thromboembolism 15 days after surgery also required surgery for chyle leakage and was treated without further consequences. One patient who received RT 2 months postoperatively was treated for osteoradionecrosis of the clavicle and manubrium with a deltopectoral flap 11 months after the first surgery and a pectoralis major flap 16 months after the first surgery. One patient who had received preoperative chemoradiotherapy for anaplastic TC had three reoperations under general anesthesia for necrosis of the SCM muscle, chondroradionecrosis in parts of the trachea, and later revision of a pectoralis major flap, and was also treated for pleural effusion.

With regard to adjuvant treatment, four patients received postoperative RT, two of whom received palliative RT 2 and 8 years after surgery, respectively. Three patients had postoperative ethanol lymph node ablation. Two patients had additional LNDs of the neck for local recurrence 4 to 6 years after primary treatment.

In the long term, 10 patients remained cannula-free. One patient had a permanent cannula until death due to the inability to cooperate

with further treatment. One patient was re-tracheotomized 23 months after the initial surgery due to local recurrence and had a cannula until death. None of the examined patients showed significant stenosis on tracheoscopy at follow-up.

## 5 | DISCUSSION

Reconstruction of window tracheal defects with a local SCM-based periosteal flap provided a durable repair and prevented dynamic airway collapse in our cohort of patients. The SCM reconstruction described here was based on our expectation of the vascularized periosteum's capacity to calcify, providing stiffness to the tracheal wall and thus preventing dynamic airway collapse. The calcification may be verified on postoperative CT scans (Figures 5 and 6). In addition, this reconstruction facilitated a tension-free closure of the defect. The periosteum creating the new inner surface of the reconstructed trachea is likely to epithelialize.<sup>9</sup> We have not found existing studies on the calcification of periosteal flaps, but we have seen that the majority of our patients demonstrated calcifications on postoperative CT scans.

The main outcome of this study was a stable airway. In our study, all but one patient had successful stent removal. The median time to airway stent removal (or decannulation) was 111 days, which is longer than that in the study by Friedman et al<sup>9</sup> where the mean length of time before decannulation was 68.1 days (range 7-313). The rationale for keeping the stent for a longer time was to allow calcification and stiffening of the reconstructed part of the trachea. In patients with a T-tube, the function was primarily stenting, and the horizontal leg through the cervical stoma was kept closed for the majority of the period. The studies by Friedman et al<sup>6,9</sup> showed a shorter time before decannulation, but included a planned change of stent.

It is important to note that the success of the SCM technique is dependent on the presence of periosteum and an adequate blood supply to the flap. When the SCM reconstruction is simply referred to as a local muscle or perichondrial flap, this may present a misinterpretation that will impact on the success of the procedure. Some studies thus may not have taken advantage of the calcifying properties of the periosteum.<sup>2,3,10,11</sup> If the surgery has not included a proper mobilization of the periosteum, then this may result in a soft muscular flap leading to dynamic collapse in the tracheal window. The blood supply of the SCM flap has been described by Kierner et al.<sup>12</sup> If the circulation is compromised due to an inadequate amount of vascularized muscle attached to the periosteal flap, then this may also lead to unsatisfactory results in terms of establishing a stable airway.

One of the secondary outcomes in our study was morbidity. Tracheal resection and reconstruction are associated with a significant risk for complications. In our study, there were several postoperative complications, but there was no perioperative mortality. Treatment with chemo-/radiotherapy may lead to poor healing, and in our cohort this treatment is strongly suspected of having affected two patients. In the future, protecting the harvest area during RT could be considered if justified from an oncological viewpoint.

Both sleeve resections and ETE anastomoses are associated with the risk of postoperative stenosis, which can be difficult to treat. In our study, postoperative stenosis was not observed clinically or on tracheoscopy at follow-up. Comparing the findings of our study with those of other series on patients with TC using different techniques, the SCM periosteal flap seemed superior to free flaps and secondary closure in terms of achieving a stable airway<sup>13-18</sup> with a low percentage of permanent tracheostomies. Series of ETE anastomoses or sleeve resections showed good results in terms of establishing a stable airway; however, many of the results demonstrated non-negligible mortality<sup>19-21</sup> and morbidity<sup>20,22-24</sup> due to complications (Table 2).

Preoperative RLNP can be a robust marker for invasive cancer<sup>26</sup> and was seen in 50% of patients in our cohort. An important goal of all types of tracheal resection is to preserve at least one recurrent laryngeal nerve. In a window resection, there is less risk for bilateral RLNP, as in most cases it is only a unilateral procedure.<sup>1</sup> If tracheal resection and reconstruction is performed for thyroid cancer, then the tumor invading the trachea is often localized on the lateral rather than the medial aspect, thus putting fewer recurrent laryngeal nerves at risk.

As window resection with reconstruction may be a less known technique, it is adequate to make comparisons with other techniques. If an ETE anastomosis or sleeve resection is performed without a sternum split, then a length of 5 to 6 cm can be resected with neck flexion alone.<sup>10</sup> Window resections up to 6 cm in vertical length without major complications have been reported.<sup>9</sup> In a study by Brauckhoff et al,<sup>27</sup> it was stated that window resections should be reserved for tumors less than 2 cm in vertical length and invading less than 25% of the circumference of the trachea. In our study, circumference measurement data were incomplete, but the median resected vertical length of the trachea was 3.3 cm with the longest resection of 5 cm.

The window resection can include parts of the thyroid and cricoid cartilage. Cricoid resections may represent an additional challenge in achieving a stable airway as observed in the series by Moritani.<sup>16</sup> Particularly in high resections, window resection with periosteal SCM reconstruction can provide the framework for a stable airway.

Circumferential resections require a larger resection of the unaffected trachea, disrupting the continuity of the tracheal wall and blood supply. An advantage of window resection over ETE anastomosis is the tension-free closure, which thus reduces the risk of anastomotic dehiscence. In ETE anastomosis and sleeve resections, there is limited scope for a repeat procedure due to the already reduced tracheal length. One could argue that window resections might be applied for salvage or stenosis surgery after ETE anastomoses or sleeve resections, as these procedures may have already reduced the operable tracheal length. However, we have not used this approach in our department or found any references to it in the literature.

With regard to the establishment of a stable airway, our results indicate that a window resection can be as extensive as an ETE anastomosis in terms of the length of the resected area. The defect covered with the periosteal flap can be at least 5 cm in length. This technique may be well suited to patients who are not candidates for ETE anastomosis, or who have high cervical lateralized tumors, or tumors close to or affecting the cricoid cartilage. In tumors with intrathoracic tracheal invasion, we found sleeve resection or ETE anastomosis to be a better option.

Some of the limitations to this study are its retrospective design and the limited number of patients. Given the rarity of this disease, a randomized controlled study is not likely to be feasible, but a multicenter study could provide a sufficient number of patients. The survival rates in our study are subject to the effects of the small patient population and an observation time of less than 5 years for two surviving patients. Due

**TABLE 2** Overview of articles for comparison with other techniques

Reference	Technique	No. of pat	Permanent tracheostomy	Complications	Mortality
Friedman <sup>9</sup>	WR + SCM	27 <sup>b</sup>	3.7%	48%	0%
Peng <sup>25</sup>	WR + SCM	16	12.5%	N/A	N/A
Tsukuhara <sup>22</sup>	Sleeve	12	16.6%	50%	0%
Lin <sup>19</sup>	Sleeve	19	N/A	26.3%	5.2%
Gaissert <sup>23</sup>	ETE	82	4.3%	39%	1.2%
Gozen <sup>20</sup>	ETE	14 <sup>a</sup>	7%	42.8%	7.1%
Piazza <sup>24</sup>	ETE	27	3.7%	37%	0%
Nakao <sup>21</sup>	ETE	40	N/A	32.5%	15%
Kubo <sup>13</sup>	Free flap	11	9%	45%	0%
Liu <sup>14</sup>	Free flap	14	21.4%	42.8%	0%
Yu <sup>15</sup>	Free flap	7	42.8%	71.4%	14%
Moritani <sup>16</sup>	Secondary closure	76	60.5%	0%	5.2%
Ebihara <sup>17</sup>	Secondary closure	41	36.6%	N/A	N/A
Ito <sup>18</sup>	Secondary closure	109	16.5%	22.9%	N/A
Our study	WR + SCM	12	8,3%	58.3%	0%

Abbreviations: ETE, end-to-end anastomosis; N/A, not available; SCM, sternocleidomastoid muscle flap; WR, window resection.

<sup>a</sup>Fourteen of which 2 were thyroid carcinomas.

<sup>b</sup>Twenty seven of which 9 were thyroid carcinomas.

to the small sample size in this study, it is difficult to draw general conclusions on the expected morbidity and mortality.

The treatment of this patient group is associated with complex challenges (and controversies) from both the surgical and oncological perspectives. Surgeons must carefully consider the most suitable procedure for the patient and the best method to prevent postoperative complications. By presenting our results, we hope that this technique may be reintroduced into the surgical armamentarium for the management of patients with tracheal defects after surgical treatment for invasive thyroid cancer. The outcomes can indicate that the success of the procedure may allow for both curative or palliative interventions.

## 6 | CONCLUSIONS

This study showed that tracheal reconstruction with a vascularized periosteal flap yielded good results in establishing a stable airway after tracheal window resection, and may be considered a supplementary technique to ETE anastomosis or sleeve resection. The majority of patients in this cohort developed calcifications of the myoperiosteal flap.

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### CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

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