A Novel Surgical Technique for Thyroid Cancer with Intra-Cricotracheal Invasion: Windmill Resection and Tetris Reconstruction

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Abstract The most effective treatment for thyroid cancer (TC) invading into the larynx and trachea is a complete surgical resection of the tumor, but currently employed techniques are less than ideal. We report a novel surgical technique, which we named Windmill resection and Tetris reconstruction, for patients with TC invading into the laryngeal lumen. We treated eight cases of TC with invasion into the laryngeal lumen by Windmill resection and Tetris reconstruction. We analyzed complications, clinical data, and pathological findings for all patients. Patients included one man and seven women (mean age 69 ± 10 years). Histopathology of TC indicated papillary cancer in five patients, poorly differentiated cancer in one patient, anaplastic cancer in one patient, and squamous cell carcinoma in one patient. Unilateral recurrent laryngeal nerve (RLN) palsy was confirmed preoperatively by laryngoscope in four patients, and none had bilateral RLN palsy. All patients underwent Windmill resection and Tetris reconstruction along with total thyroidectomy (three patients), subtotal thyroidectomy (three patients), and lobectomy (two patients). Neck dissection was performed in all patients. The average resected length of the larynx and trachea was

29 ± 6 mm. Air leakage at the suture line occurred in three patients; two required further surgery, while the third was closed by insertion of a Penrose drain. Postoperative RLN palsy occurred in five patients. Aspiration was observed in two patients and resolved within 4 weeks. Pneumonia, atelectasis, and pleural effusion occurred in some patients. No other complications, including hemorrhage, wound infection, or airway stenosis, occurred. There was no postoperative mortality and no recurrence at the anastomotic site. Two patients underwent permanent tracheostomy due to permanent bilateral RLN palsy. Two patients, one with anaplastic cancer and the other with poorly differentiated cancer, recurred 13 and 21 months after surgery, while patients with papillary thyroid cancer had no local recurrence. Importantly, laryngeal functions such as phonation and swallowing were preserved in all patients. This novel surgical technique may be as effective as window resection of the larynx for local control of TC and contributes to the quality of life of patients by resulting in a less unsightly surgical wound.

Keywords Thyroid cancer · Laryngeal invasion · Cricotracheal invasion · Tracheal invasion · Tetris

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Introduction

Laryngotracheal invasion occurs in 3.6 to 22.9 % of patients with thyroid cancer [1] and leads to decreased survival and higher local recurrence rate [2–6]. The most effective treatment for thyroid cancer invading into the larynx and trachea is a complete surgical resection of the tumor. Surgical options in this situation include the shave procedure, partial laryngectomy, and total laryngectomy. The shave procedure is usually performed when the tumor is visibly adhered to the trachea or cricothyroid

muscle without gross invasion into the intraluminal perichondrium. On the other hand, intraluminal extension requires resection of the tracheal wall and a portion of the larynx, including the cricotracheal cartilage. The extensive laryngectomy for radical resection precludes death from local tumor growth and suffocation and leads to long-term survival [7–10]. However, this procedure always results in substantial functional deficits, including dysphonia, dysgeusia, and dysosmia.

A function-preserving surgical method of resection and reconstruction for thyroid cancer invading into the intraluminal of cricotracheal region has not yet been established. We report a novel surgical technique, which we named Windmill resection and Tetris reconstruction, for patients with thyroid cancer invading into the laryngeal lumen and discuss complications and advantages.

Patients and Methods

Patients

We recruited nine thyroid cancer patients with tumor invasion into the intra-laryngotracheal lumen at the Noguchi Thyroid Clinic and Hospital Foundation between April 2009 and January 2011. One patient, with preoperative diagnosis of papillary carcinoma of the thyroid, was excluded when postoperative histopathology indicated adenoid cystic carcinoma from the trachea. The remaining eight

patients gave their written informed consent to participate in the study.

Preoperative Evaluation

Preoperative examination included physical examination, blood tests including thyroid function tests, ultrasonography, laryngoscopy, and radiological imaging. All intra-laryngotracheal luminal invasions were confirmed by bronchoscopy, neck computed tomography, and neck magnetic resonance imaging. Endoscopic diagnosis of luminal invasion was made by confirming localized redness that indicates neovascularity and telangiectasias (Fig. 1) [11]. A positron emission tomography scan was performed in patients in whom distant metastasis was suspected.

Surgical Procedure

The surgical procedure is illustrated in Fig. 2, with specific cases illustrated in Figs. 3 and 4. The tumor invading into the larynx was resected *en bloc* as much as possible. First, we performed thyroidectomy with central compartment dissection under general anesthesia. Patients who were preoperatively diagnosed with metastatic lymph nodes underwent modified lateral compartment neck dissection. The recurrent laryngeal nerve (RLN) was amputated if the tumor invaded the RLN. To identify the location of the intraluminal laryngotracheal invasion, tracheotomy was performed below the lowest extent of tumor invasion as defined beforehand by

Fig. 1 Preoperative bronchoscopy of patients 4 (a, b) and 5 (c, d). Bronchoscopic examination revealed an extramural comprehension of the tumor in the subglottic cavity (a) and vascular enlargement at the surface (b). Wide invasion of the tumor was observed in the right laryngotracheal wall (c). Image-enhanced endoscopy (*i*-SCAN, Pentax, Tokyo, Japan) clearly visualized tumor (d)

bronchoscopy. The tumor was removed by resection of the half around of cricotracheal cartilage with/without a part of thyroid cartilage, with cricothyroid muscle, and with tracheal rings (Figs. 2a, 3a, and 4a). Frozen sections of the resected specimen confirmed that the upper and lower margins were tumor free.

For primary reconstruction of the resected larynx and trachea, a diagonal opposing segment of the cranial end of the lower trachea symmetrical to the resected segment of the upper trachea was cut away to form a lap joint (Figs. 2c, 3b, c, and 4b). End-to-end laryngotracheoplasty was then performed with 3-0 absorbable monofilament sutures (PDSII®, Ethicon, Somerville, NJ), ensuring no tension on the anastomotic site (Figs. 2d, 3d, and 4c). An airtight closure was

confirmed by deflating the endotracheal tube, after which the anesthesiologist performed a Valsalva maneuver, while the operative field was flooded with saline. A low-pressure cuff was extubated when the operation was finished. At the time of extubation, we performed laryngoscopy to determine presence or absence of the RLN palsy. In case of bilateral RLN palsy, a tracheal stoma was made by releasing the central suture (Fig. 5).

Data Collection and Postoperative Follow-up

Demographic data, pathological variables, associated and pathological conditions, and surgical data were recorded. The patients were monitored for postoperative complications,

Fig. 2 Surgical scheme. A thyroid cancer invaded into the cricotracheal cartilage (a). The cricotracheal cartilage with tumor invasion was resected as same as tracheal fenestration (b). The symmetric diagonal part of the normal lower trachea was resected and was modified to fit with the resected larynx. “The Windmill resection” (c). End-to-end laryngotracheoplasty named “the Tetris reconstruction” (d). The point *x* is joined to the point *y* (c, d)

Fig. 3 Photographs of operation in patient 4. A thyroid cancer invaded into the cricotracheal lumen. An *arrow* indicates the intratracheal exposed tumor (a). An *arrow* indicates that the diagonal (contralateral and inferior) normal trachea was resected to fit with the resected larynx. Lower dissected part of the trachea is lifted by two stitched

sutures (b). Closure of the proximal and distal stump (c). End-to-end laryngotracheoplasty performed by 3-0 absorbable monofilament sutures with the single knot tie outside tracheal lumen (d). The procedure resulted in a less unsightly surgical wound (e)

mortality, and postoperative conditions. Indicators of thyroid and parathyroid function were measured on postoperative days (POD) 1 and 5 and at the time of hospital discharge. Routine chest radiography was performed on POD 1. Patients came to our hospital every 1 to 3 months after discharge. Laryngoscopy was performed at the end of surgery, within 7 days of surgery, and every 3rd month after discharge.

Results

Patient Demographics and Preoperative Conditions

One man and seven women were analyzed for this study (Table 1). Average age was 69 ± 10 years (range 56–84 years). Mean follow-up period was 15 ± 7 months (range

2–23 months). Histopathology of thyroid cancer indicated papillary cancer in five patients, poorly differentiated cancer in one patient, anaplastic cancer in one patient, and squamous cell carcinoma in one patient. Metastases to neck lymph nodes were detected in three patients. Distant metastases, including to the lung and bone, were not detected preoperatively. Unilateral RLN was confirmed preoperatively by laryngoscopy in four patients, while none showed bilateral RLN paralysis. Bronchoscopy and radiological findings showed thyroid cancer invading into the intraluminal larynx and trachea in all patients (Fig. 1).

Treatments

All patients underwent the Windmill resection and Tetris reconstruction for intraluminal laryngotracheal invasion

Fig. 4 Photographs of operation in patient 2. The tumor was resected with larynx and three rings of the trachea (arrow, **a**). Closure of the proximal and distal stump (**b**). One-stage reconstruction performed by 3-0 absorbable monofilament sutures with the single knot tie outside tracheal lumen (**c**). Postoperative surgical wound is very clear (**d**)

with total thyroidectomy (three patients), subtotal thyroidectomy (three patients), and lobectomy (two patients). Lymph node dissection was performed in seven patients (central compartment in seven patients, ipsilateral compartment in three patients, and bilateral compartment in one patient). Average blood loss and operation time were 200 ± 167 mL and 304 ± 61 min, respectively. Resection laterality of the larynx was right side in four patients and left side in the other four patients. The average resected length of the larynx and trachea was 29 ± 6 mm (range 20–35 mm).

Postoperative complications are summarized in Table 2. Hypoparathyroidism occurred in two patients; the condition was temporary in one patient and permanent in the other. Dehiscence occurred in three patients; two required further surgery, whereas the third experienced a small anastomotic dehiscence, which closed spontaneously

during the insertion of a Penrose drain for 2 weeks. RLN palsy occurred postoperatively in five patients (Table 1). Aspiration was observed in two patients, but this symptom disappeared within 4 weeks. Pneumonia, atelectasis, and pleural effusion were also noted but did not result in serious postoperative problems. No other complications, including hemorrhage, wound infection, and airway stenosis, occurred during follow-up. Patients were discharged 29 ± 12 days after the operation. Iodine 131 ablation was performed on patients 3 and 6 (see Table 1 for patient designations). Patient 1 underwent postoperative chemotherapy (cisplatin and adriamycin). Postoperative extrabeam radiation was not performed on any patient. A staged operation for mediastinal metastasis was performed on patient 1, 3 months after initial surgery.

Postoperative Outcome

Tracheostomy was not needed in six patients, but two patients underwent permanent tracheostomy due to permanent bilateral RLN palsy (Table 1 and Fig. 5). Two patients with anaplastic (patient 1) and poorly differentiated cancer (patient 3) recurred 13 and 21 months, respectively, after surgery, but the remaining patients with papillary thyroid cancer had no local recurrence. There was no postoperative mortality during follow-up. Laryngeal functions, such as phonation and swallowing, were well preserved in all patients. Laryngoplasty (thyroplasty type 1) was performed on one patient to ameliorate postoperative hoarseness.

Fig. 5 Photograph of patient with laryngotracheal stoma due to postoperative bilateral RLN palsy (patient 8). The stoma was midline, and the patient was free from pain due to use of a tracheostomy tube

Table 1 Clinical characters and surgical parameters of patients

Patient	Age/sex	Pathology	Operation	Tumor side	Resected length (cm)	Laryngeal palsy (At diagnosis)	(Post-op)
1	56/F	Anaplastic	Lobectomy + D2	Left	25	Unilateral	Unilateral
2	60/F	Metastatic SCC	Subtotal thyroidectomy + D1	Left	25	No	Unilateral
3	61/F	Poorly differentiated cancer	Total thyroidectomy + D2	Right	25	Unilateral	Unilateral
4	64/M	Pap	Lobectomy + D1	Right	20	No	No
5	74/F	Pap	Subtotal thyroidectomy + D1	Right	35	Unilateral	Bilateral
6	75/F	Pap	Total thyroidectomy + D2	Left	20	No	Unilateral
7	75/F	Pap	Subtotal thyroidectomy + D3	Left	30	No	Unilateral
8	84/F	Pap	Total thyroidectomy + D1	Right	35	Unilateral	Bilateral

SCC squamous cell carcinoma, D1 neck dissection of central compartment, D2 neck dissection of central and unilateral compartment, D3 neck dissection of central and bilateral compartment

Discussion

The surgical procedures for resection and reconstruction of thyroid cancer invading into the larynx can be divided into three categories: complete laryngectomy, one-stage partial resection and reconstruction of the larynx, and multiple-stage surgery for resection and reconstruction. Complete laryngectomy causes permanent laryngeal dysfunction. The multiple-stage operation requires a temporary laryngeal stoma and a secondary flap operation for closing of the stoma. The conventional method of preserving laryngeal function in such cases has involved laryngeal stoma. In some cases, laryngeal stomas can be closed after secondary or later surgery at the cost of leaving an unsightly scar (Fig. 6). A one-stage operation can spare the patient the discomfort of the stoma and result in a much more aesthetic

scar (Figs. 3e and 4d). Although a quality of life (QOL) questionnaire was never applied in the evaluation of the results, we believe that this novel method is an improvement over conventional methods.

When using the sleeve resection and reconstruction procedure, it is very difficult to preserve bilateral laryngeal nerve function in cases in which the tumor has invaded into the larynx. Bilateral laryngeal nerve injury causes laryngeal dysfunction and dysphonia and necessitates permanent tracheostomy.

Grillo et al. first described the one-stage resection and reconstruction by “bayonet line” for thyroid cancer invading into the larynx and trachea, in six patients [12]. The procedure preserved laryngeal function and provided excellent QOL for patients. The bayonet line is the extended line from the sleeve tracheal resection and reconstruction. By contrast, our method has been refined from the window resection and secondary reconstruction surgery. In the case of intraoperative bilateral laryngeal nerve damage due to invasion of the tumor, our procedure can be altered to a midline laryngo-tracheal stoma or a multiple-stage operation for closing the stoma (Fig. 5).

In the bayonet line method, the cricotracheal excision line is partly diagonal to the tracheal rings, which makes the excision and suture technically difficult. The Windmill resection and Tetriss reconstruction procedure we report here is simpler and reduces the risk of dehiscence. Moreover, the risk of postoperative airway stenosis in our method is expected to be lower because the laryngotracheal sutures do not lie in the same plane; sutures are not coplanar in three separate horizontal and vertical suture planes. If stenosis of one suture plane occurs, the result is constriction of different segments of the trachea at different planes. In fact, there was no postoperative airway stenosis in our group of eight patients.

The other aggressive one-stage reconstruction method reported recently for thyroid cancer with cricotracheal invasion

Table 2 Complications after the Windmill resection and Tetriss reconstruction

	Number of patients (%)	Therapy
Hypothyroidism	8 (100)	T4 supplement
Hypoparathyroidism	2 (25)	Calcium and vitamin D supplement
Dehiscence	3 (38)	2 re-reconstruction surgery, 1 observation
Recurrent nerve paralysis (newly occur)	5 (63)	Observation
Dysphagia	2 (25)	Observation
Pneumonia	2 (25)	Antibiotics administration
Pleural effusion	2 (25)	Observation
Atelectasis	2 (25)	Observation
Hemorrhage	0 (0)	—
Wound infection	0 (0)	—
Airway stenosis	0 (0)	—

Fig. 6 Photographs of patients treated previously. **a** Simple window resection of tumor invading into the larynx made lateral laryngotracheal stoma. QOL for patients with a stoma was poor. **b** Multiple-stage operation for closing the stoma led to the ugly scar in the neck and the site of collection of the local flap

uses free tissue transfer and a tracheal autologous graft [13–17]. Maciejewski et al. reported on the utility of a free radical forearm flap with a mesh ring or prosthesis [13]. Kobayashi et al. recommended using a tracheal autologous graft for repair of the tracheal defect; the graft has as much rigidity as a prosthesis to support the respiratory tract. These authors emphasize that the autologous graft is biologically compatible and can be completed in one surgical field [14]. Compared to our new method, however, the graft method is significantly more complex and involves more sutures.

The rate of complications following one-stage laryngeal resection and reconstruction is rarely mentioned in the literature. Most reports of postoperative complications in the literature discuss primary tracheal resection and reconstruction without laryngeal invasion. After primary tracheal resection and reconstruction, overall postoperative mortality was reported to range from 2.5 to 18 % [18–22]. The main fatal complications included dehiscence, airway stenosis, pneumonia, and wound infection. The rate of dehiscence and airway stenosis were reported to range from 5.7 to 7.5 % and from 3.8 to 8 %, respectively [18–23].

In our surgical method, dehiscence occurred at a much higher rate than in previous reports (Table 2). The suture leaked from the larynx to trachea suture side in two patients, who needed further surgery. The suture at the laryngotracheal edge requires a delicate technique. The use of nonabsorbable ligatures for tracheal reconstruction can cause exuberant granulation and lead to postoperative tracheal stenosis [24]. Therefore, we used absorbable monofilament for larynx–trachea sutures. The absorbable monofilament may be the optimum choice for the larynx–trachea suture, to avoid thread failure due to tension at the sites of anastomosis during coughing and swallowing.

Aspiration and subsequent pneumonia occurred in two patients. This might be caused by RLN palsy, limitation of laryngeal movement, and reduction in tension from the infrahyoid muscles. Recovery from aspiration was observed at least 4 weeks after surgery.

In conclusion, various surgical procedures for thyroid cancer with laryngotracheal invasion have been described, but a standard therapy is not established. Our Windmill resection and Tetris reconstruction method is a new and

promising surgical procedure, offering improved comfort, more aesthetic results, and good postoperative recovery.

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