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Application of modified spiral tracheoplasty in thyroid carcinoma with trachea invasion: a retrospective analysis of 15 cases

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Abstract

Background To describe the indications, techniques and preliminary experience of modified spiral tracheoplasty in the reconstruction of large tracheal defect after thyroidectomy.

Methods The medical records of patients who underwent tracheal torsion to repair large tracheal defects after thyroid carcinoma surgery from January 2019 to January 2022 were retrospectively reviewed. The extent of tracheal defect, duration of tracheal reconstruction, postoperative complications and surgery results were analyzed.

Results The duration of tracheal reconstruction was 30–60 min. No postoperative bleeding, incision infection, tracheostomy stenosis occurred. Recurrent laryngeal nerve palsy occurred in 5 patients. All patients were followed up for 24 to 60 months. The 2-year overall survival rate was 100%, the 2-year local control rate of trachea was 100%, and the 2-year tumor-free survival rate was 81.8%.

Conclusion The modified spiral tracheoplasty is a safe and effective method to repair the large defect of trachea after thyroid carcinoma invading the trachea.

Keywords Tracheal repair, Tracheal resection, Thyroid carcinoma, Tracheoplasty, Surgical technique

Background

Thyroid carcinoma (THCA) is the ninth most common cancer worldwide. THCA can occur in different age groups, and the median age at diagnosis is about 50 years old. Women account for about 75% of all patients with THCA [1–3]. The incidence of THCA has gradually increased in the past decades, but the 5-year relative survival rate has reached 98.5% [4]. Among patients with differentiated thyroid carcinoma, approximately 24% die from airway obstruction due to local spread. The trachea is anatomically close to the thyroid gland and is affected by the extrathyroidal extension of THCA. The incidence of tracheal invasion by THCA is 1-8% [5, 6]. Complete resection of local lesions leads to the best palliative care and the longest survival, and is considered to be the main goal of surgical treatment for THCA [7]. Therefore, surgery is the preferred treatment for THCA invading the trachea. About 90% of patients with THCA invading the laryngotracheal survive 10 years after complete resection [8, 9]. At present, the common surgical methods for THCA invading the trachea include shaving,

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window resection and sleeve resection [10, 11]. Shaving can be used to remove the superficial tracheal invasion. However, as the tumor progresses, THCA may invade the tracheal lumen and cause airway obstruction or bleeding, which is life-threatening. In these cases, a window or sleeve resection of the tracheal wall is often required. Depending on the extent of resection, Various surgical approaches have been proposed to reconstruct the trachea. The surgical strategies mainly include sleeve resection with end-to-end anastomosis, window resection with sternocleidomastoid musculo-periosteal flap reconstruction, spiral tracheoplasty and modified tracheostomy with secondary flap repair, as well as complex techniques using free flaps with autologous or allograft support [12, 13]. Each procedure has its advantages and disadvantages as well as limitations of indications. For large defect width, it is often necessary to choose end-to-end anastomosis after sleeve resection. However, for cases with excessive defect length, end-to-end anastomosis will be difficult, and even lead to excessive tension and cracking of the anastomosis after operation [14–17]. The consensus statement of the American Head and Neck Society states that the mortality rate after tracheal or laryngotracheal resection is as high as 5–9% [18]. Therefore, how to effectively repair the trachea after THCA invasion is still a clinical difficulty. Xia et al. [19] compared the advantages of various repair methods applied to different types of tracheal defects in 106 patients, and recommended spiral tracheoplasty to repair extensive tracheal defects.

Spiral tracheoplasty involves transection of the remaining contralateral trachea, rotation of the upper and lower ends by 90 degrees in opposite directions and anastomosis [17]. The distance between the broken end of the trachea can be reduced by rotation to reduce the tension of the anastomosis. The traction tension of the upper and lower tracheal valves to the original position will reduce the possibility of postoperative tracheal stenosis. At present, there are only case reports of spiral tracheoplasty for reconstruction of tracheal defect after THCA invasion of the trachea. By further improving the traditional spiral tracheoplasty, we propose the modified spiral tracheoplasty to repair the large tracheal defect after THCA surgery. The modified spiral tracheoplasty refers to transection the residual trachea in the middle and separate it from the posterior esophagus. The upper and lower ends of the tracheal valve are twisted about 90 degrees in the opposite direction and then anastomosed. The modified spiral tracheoplasty can be applied to larger tracheal defects. For example, in cases where the cricoid cartilage is invaded, the lower trachea can be twisted close to 180 degrees to achieve anastomosis of the trachea to the thyroid cartilage. In this study, We retrospectively analyzed 15 patients who used modified spiral tracheoplasty to repair extensive tracheal defects after THCA, and summarized the extent of tracheal defects, the duration of tracheal reconstruction, postoperative complications and repair effects, aiming to explore the feasibility and efficacy of modified spiral tracheoplasty in the repair of large tracheal defects after THCA.

Methods

Patients

A retrospective analysis was conducted on 15 patients with extensive defects of the trachea caused by THCA invading the trachea who were treated with modified spiral tracheoplasty in the Department of Otorhinolaryngology Head and Neck Surgery, the Second Xiangya Hospital, Central South University from January 2019 to January 2022. Ethics approval was granted by the Institutional Clinical Research Supervision Committee. There were 5 males and 10 females. The mean age was 53.07±11.09 years (range, 36–67 years). The primary tumor was located on the left side in 7 cases and on the right side in 8 cases. The pathological type was papillary thyroid carcinoma. THCA invaded the cricoid cartilage in 3 cases. All patients received iodine-131 therapy within 3 months after surgery. Then, thyroid stimulating hormone suppression therapy was performed to control thyroid stimulating hormone below 0.1mU/L. All patients were reexamined by neck ultrasound and thyroid function every 3 months. Contrast-enhanced CT was performed every 6 months. Patients were followed up monthly by telephone. Detailed information is provided in Table 1.

Techniques

The patient was in the supine position and intubated nasotracheal under general anesthesia. First, the lateral cervical lymph node dissection was performed on the side of the tumor, then the fine capsular dissection technique was used for total thyroidectomy, and finally the bilateral central lymph node dissection was performed. For patients with obvious tumor invasion of the recurrent laryngeal nerve, the integrity of the recurrent laryngeal nerve can be judged by the naked eye during surgery. For other patients, we monitor the integrity of the recurrent laryngeal nerve intraoperatively by stimulating the recurrent laryngeal nerve with a probe using a intraoperative neuromonitoring instrument.

For total thyroidectomy, the healthy side of the thyroid gland is removed first and then dissociate to the affected side. When dissociated to the location of tumor invasion of trachea, the degree of tumor invasion of trachea was carefully distinguished. The trachea was incised 0.5 cm from the trachea invaded by the tumor (the safe margin), and then the involved trachea and thyroid tissue were removed under direct vision, leaving the healthy

Table 1 Clinical data of 15 patients with extensive tracheal defects after thyroid cancer surgery repaired with modified spiral tracheoplasty

No.	Age	Sex	TNM classifications	Past Medical History	Location of the tumor	Cricoid cartilage was invaded	Length of tracheal defect(cm)	Tracheal defects accounted for circumferential proportion	Time to tracheal reconstruction(min)	Complication	Follow-up time(month)
1	48	F	T4aN1aM0	Diabetes	Left	No	5.5	50%	50	None	60
2	52	F	T4aN1bM0	None	Right	No	6	60%	60	None	57
3	50	F	T4aN1bM0	Hypertension, diabetes	Right	No	6	50%	50	None	53
4	36	M	T4bN1aM0	Hypertension	Right	Yes	6.5	50%	60	right vocal cord was paralyzed	50
5	36	F	T4aN1bM0	None	Left	No	7.5	40%	30	None	After 17 months of follow-up, lung metastasis occurred, and a second iodine-131 treatment was performed
6	67	F	T4aN0M0	diabetes	Right	No	5.5	40%	30	None	40
7	66	F	T4bN1aM0	None	Left	No	5	50%	50	left vocal cord was paralyzed	35
8	40	M	T4aN1bM0	None	Left	No	6	40%	30	None	After 16 months of follow-up, the left level VI area lymph node recurred and reoperation
9	43	M	T4aN0M0	None	Right	No	5	60%	30	None	32
10	66	F	T4aN1bM0	None	Right	Yes	7.5	50%	40	bilateral vocal cord paralysis	30
11	55	M	T4aN1bM0	None	Left	No	5	60%	30	None	24
12	63	F	T4aN0M0	None	Left	No	5	50%	40	None	20
13	55	M	T4aN1aM0	None	Right	No	6.5	50%	30	None	16
14	67	F	T4aN1bM0	Diabetes	Right	No	6	40%	40	right vocal cord was paralyzed	15
15	52	F	T4aN0M0	None	Left	Yes	7	60%	50	bilateral vocal cord was paralyzed	12

side of the trachea wall on the same plane. The recurrent laryngeal nerve and parathyroid gland should be dissected and identified during resection. If the recurrent laryngeal nerve and parathyroid glands were involved, they were removed together. Tracheal reconstruction: The remaining trachea was cut off from the middle of the healthy side of the trachea defect, and then the trachea was separated from the esophagus by 2 cm to make the upper and lower tracheal flaps, and the upper and lower ends were properly separated. The upper and lower tracheal flaps were reversed separately and then performed end-to-end anastomosis to achieve tracheal reconstruction. A schematic representation of the reconstruction is shown in Fig. 1. The strap muscles were then used to cover the anastomosis for reinforcement. The surgical area was rinsed and negative pressure drainage was placed. The wound was sutured. The patient retained the nasotracheal tube and was lying flat with a high pillow. All patients were treated with postoperative anti-infective therapy, and nasotracheal tubes were removed under fiberoptic bronchoscopy 72 h later. The surgical procedure is shown in Fig. 2. The lateral margin of the cricoid cartilage was invaded in three patients, so it was removed simultaneously. The lower trachea was then rotated 180 degrees and anastomosed to the lower edge of the thyroid cartilage.

Results

All the 15 patients underwent total thyroidectomy, tracheal window resection, and torsional tracheal reconstruction. The length of tracheal defect was 5–7 cm (mean 6 cm), and the tracheal defect accounted for 40-60% of the circumferential area. The tracheal reconstruction time was 30–60 min (mean, 41.33 min). All patients underwent cervical lymph node dissection of II, III, IV area on the affected side and VI area on both sides. Four patients underwent additional contralateral II, III, IV area cervical lymph node dissection. Among the 15 patients, 3 patients had cricoid cartilage and recurrent laryngeal nerve invasion on the affected side and were resected simultaneously, of which 1 patient underwent tracheotomy at the first stage, and the other patient underwent tracheotomy after re-intubation because of dyspnea during extubation 72 h after operation.

For postoperative complications, two patients with bilateral vocal cord paralysis were found to have been invaded by tumors at the site of laryngeal entry, and the tumor lesions involved the cricoid cartilage. It is difficult to preserve the recurrent laryngeal nerve during resection of the involved cricoid cartilage, and bilateral vocal cord paralysis occurs postoperatively. Among the three patients with unilateral vocal cord paralysis, two of them had tumor invasion of the right cricoid cartilage, resulting in postoperative right vocal cord paralysis. In

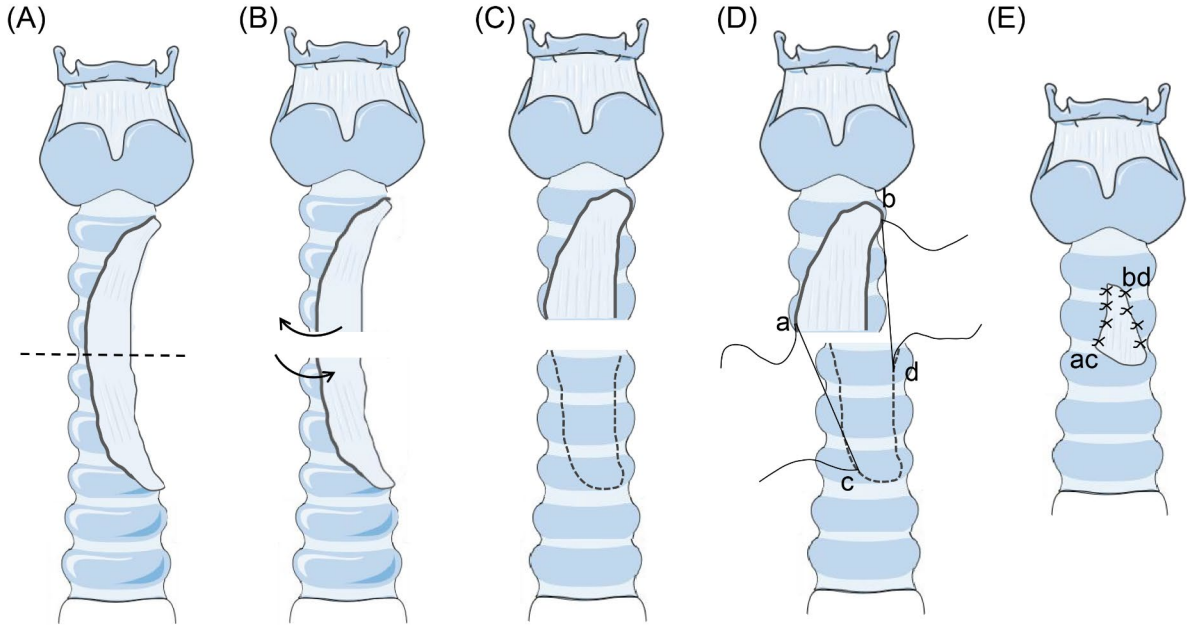

Fig. 1 Schematic diagram of modified spiral tracheoplasty. **A**: Tracheal defect. The residual tracheal wall on the healthy side was transected. **B**: The upper and lower tracheal valves were rotated 90 degrees in the opposite direction. **C**: Rotation of the upper and lower tracheal valves was completed. **D**: Anastomosis after torsion of the trachea. **E**: Tracheal remodeling completed

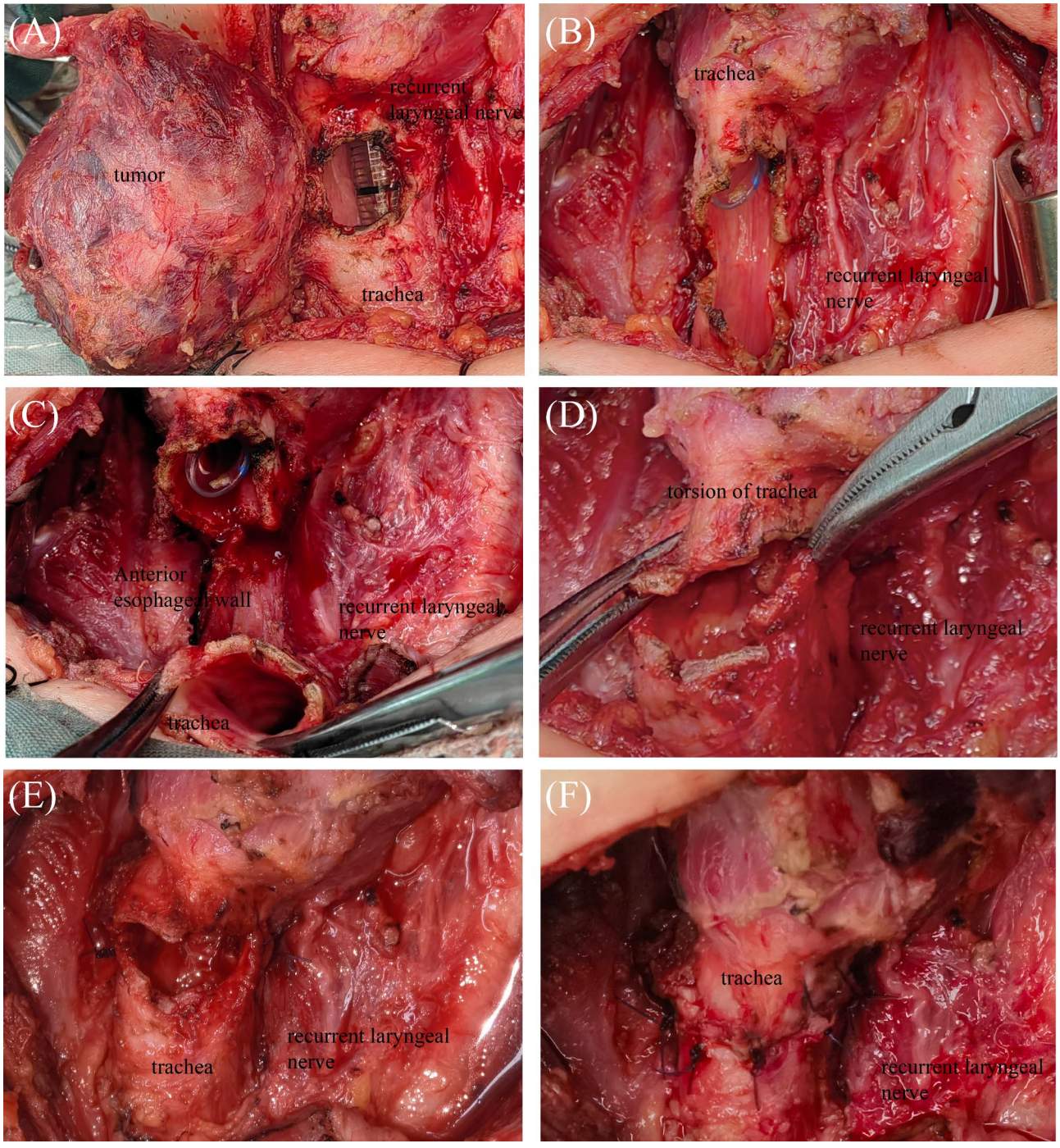

Fig. 2 Surgical procedure. **A**: Tracheal defects after tumor tissue isolation. **B**: Cut the residual trachea from the middle of the tracheal wall on the unaffected side of the tracheal defect. **C**: Separate the trachea from the esophagus to make the upper and lower tracheal valves. **D**: The two broken ends of the trachea are twisted in the opposite direction by about 90 degree. **E**: The incision in the posterior part of the trachea is sutured after tracheal torsion. **F**: Anastomosis after torsion of the trachea was completed

one patient, the tumor directly invaded the left recurrent laryngeal nerve, resulting in left vocal cord paralysis after surgery. 4 patients developed hypoparathyroidism, hypocalcemia and intermittent hand and foot convulsion within 1 month after operation. The symptoms were relieved after calcium supplementation, and the levels of parathyroid hormone returned to normal after 1 month. The symptoms of hypocalcemia occurred after stopping calcium supplementation. One of the 2 patients with tracheotomy showed right vocal cord paralysis and vocal cord edema by laryngoscopy after tracheotomy. Three months later, the laryngoscope showed that the glottic

fissure was unobstructed, and the tracheotomy tube was removed. One patient with bilateral vocal cord paralysis was treated with arytenoid cartilage resection 2 months after iodine-131 treatment, and decannulation was performed 3 months later.

Postoperative follow-up: 15 patients were followed up for 24 to 60 months. Nine patients were followed up for 24 months and no tumor recurrence was found. One patient had recurrence in the left VI area lymph node after 16 months of follow-up, and no tumor recurrence was found after the second operation and additional iodine 131 treatment. One patient developed lung metastasis after 17 months of follow-up, and then received iodine-131 and targeted therapy again, and died after 24 months of follow-up. The follow-up results are shown in Table 1.

Discussion

At present, surgery is still the first choice of treatment for differentiated thyroid cancer. The prognosis of differentiated thyroid carcinoma is good, but tracheal invasion is considered to be one of the important reasons affecting the prognosis of THCA [20]. Complete resection of THCA and invaded tissues can improve the survival rate of patients. Therefore, one-stage surgery for thyroid cancer invading the trachea has been approved to remove the involved organs simultaneously [11, 21]. For THCA with trachea invasion, whether tracheal reconstruction can be completed in one stage after the involved trachea resection is the most important technical issue of surgery. Especially for deep or full-thickness tracheal lesions, adequate tracheal resection and one-stage reconstruction can improve the survival rate and quality of life of patients. The most common reconstruction methods after tracheal resection are end-to-end anastomosis repair and tissue flap repair and so on. End-to-end anastomosis repair after tracheal sleeve resection has been recognized to help preserve the tracheal function of patients. Tracheal window resection can be used if the tumor invading from the lateral or anterior wall of the trachea does not exceed 50% of the circumferential, and the tracheal ring invading does not exceed 4 rings. After tracheal window resection, sternocleidomastoid muscle, banded myohyoid bone flap, clavicular membrane flap, pectoralis major myocutaneous flap or supraclavicular island flap can be used for repair [22, 23]. If the tumor invasion is more than 50% of the circumferential, then tracheal sleeve resection and end-to-end anastomosis can be performed. The sleeve resection trachea is generally 4 to 5 rings, and the longest can be 6 to 7 rings. In clinical practice, it may be encountered that the tracheal defect is close to 50%, and the tracheal ring defect is more than 5 rings. In such cases, tissue flap repair after window resection may cause postoperative airway collapse, while end-to-end anastomosis after sleeve resection may cause ischemic rupture of the anastomosis due to excessive tension [24, 25]. In this study, we analyzed the application of modified spiral tracheoplasty in the repair of large scale tracheal defects. Modified spiral tracheoplasty not only reduced the tension of the anastomosis, but also had no obvious airway collapse and stenosis after operation.

According to the Shin [26] classification, the depth of tracheal involvement can be divided into 5 grades. Grade 0: tumor confined to the thyroid gland. Grade I: the tumor had penetrated the thyroid capsule adjacent to but not invaded the tracheal cartilage. Grade II: tracheal cartilage destruction caused by tumor invasion; Grade III: the tumor invaded the tracheal lumen but the tracheal intima was intact. Grade IV: The tumor penetrates the full thickness of the tracheal wall. Tumor shaving can be considered for grade I and some grade II cases, while most grade II, III and IV cases must undergo involved trachea resection, including window resection and sleeve resection. In the cases included in this study, the tumors invaded the tracheal lumen and the depth of tracheal involvement was grade IV, so we chose to perform a total resection of the involved trachea. In addition to the depth of involvement, the width at the circumference of the defect also determines the method of tracheal resection. When the defect exceeds 50% of the circumference, the window defect is difficult to repair, and sleeve resection and end-to-end anastomosis are often required. In our case, the defect accounted for 40–60% of the circumferential area, and the risk of tracheal stenosis was high for simple window resection repair, but the end-to-end anastomosis was limited by the length of the defect. According to our experience, the length of the defect can be sutured directly within 4 cm, but if the length of the defect is too long, the tension of the anastomosis can be reduced by separating the lower trachea and the upper laryngeal body. All patients included in this study had a defect length of more than 5 cm, and the longest was 7.5 cm. Simple end-to-end anastomosis required the dissection of the upper larynx and the lower trachea. The risk of recurrent laryngeal nerve injury is increased during dissection. In 2009, Wu [17] reported a case of spiral tracheoplasty for repair after resection of window tracheal wall. Spiral tracheoplasty is to transection the remaining healthy trachea, rotate the upper and lower ends by 90 degrees in the opposite direction (one clockwise and the other counterclockwise), and perform preliminary anastomosis to reduce anastomotic tension. The subsequent reports on this technique were all case reports. Otsuki [27] reported two cases of reconstruction of large tracheal defects by modified spiral tracheoplasty. On the basis of Wu's spiral tracheoplasty, he separated the trachea and esophagus by 2 cm, and only rotated the lower trachea by 90 degrees to reconstruct. Inspired by

this technique, we performed repair after extensive tracheal defects by further improving spiral tracheoplasty. The residual trachea on the healthy side was transected in the middle, separated from the posterior esophagus, and designed as a tracheal valve. The upper and lower ends were twisted about 90° in the opposite direction and anastomosed up and down. This method can reduce the distance between the upper and lower trachea and reduce the tension of the anastomosis. Due to the elastic action of the tracheal wall, the lumen formed by the upper and lower tracheal valves has a rebound force to the original position when it is twisted. Under the action of the rebound force, the lumen is easy to expand, so tracheal stenosis almost does not occur. Moreover, because the trachea and esophagus are separated to a certain extent, the lower trachea can be twisted about 180° and anastomosed with the affected thyroid cartilage in the case of cricoid cartilage invasion. In the cases included in this study, we used simple modified spiral tracheoplasty without dissection of the laryngeal body. Combined with the results of endoscopy and airway CT after operation, no airway stenosis occurred in all cases. In conclusion, we conclude that modified spiral tracheoplasty is suitable for reconstruction of defects with 6 to 8 tracheal rings of length and 40–60% of the width of the tracheal lumen.

We summarized the details of the operation based on the analysis of 15 cases of large tracheal defects repaired by modified spiral tracheoplasty. (1) When making a tracheal flap by transection of the residual trachea on the healthy side, it is necessary to separate the esophagus and trachea properly to reduce the tension caused by esophageal traction during tracheal torsion; (2) In cases where the cricoid cartilage is invaded by THCA, tracheal torsion can also repair the partial loss of the cricoid cartilage. In this study, 3 cases invaded the cricoid cartilage and underwent partial resection of the cricoid cartilage. During reconstruction, the cartilage part of the lower tracheal valve was sutured with the lower edge of the thyroid cartilage. However, it is difficult to preserve the recurrent laryngeal nerve during the resection of the affected cricoid cartilage. In this study, 3 cases were found to have the invasion of the recurrent laryngeal nerve into the larynx during the operation, and both were resected. (3) Due to the total thyroidectomy in these cases, the tracheal anastomosis lacks tissue reinforcement, so we generally use the strap muscle to wrap the anastomosis to strengthen and increase blood supply. (4) The choice of tracheotomy. Preventive tracheotomy is recommended for predicting recurrent laryngeal nerve involvement during operation. One patient in this study underwent tracheotomy during resection of thyroid cancer. The main reason was that the patient had undergone unilateral thyroidectomy and had developed vocal cord immobilization. In this case, the tumor invaded the cricoid cartilage, and the recurrent laryngeal nerve was found to be involved during the operation, which was resected at the same time. Postoperative bilateral vocal cord paralysis could already be predicted during the operation, so tracheotomy was chosen during the operation. One patient was extubated 72 h after surgery and developed obvious laryngeal obstruction, so tracheotomy was performed after re-intubation. The patient was re-evaluated as having unilateral vocal cord paralysis with laryngeal cavity edema. The tracheal cannula was extubated 1 month later.

Recurrent laryngeal nerve injury is the main complication after modified spiral tracheoplasty. The recurrent laryngeal nerve is easily injured when making the tracheal flap and performing the tracheoesophageal separation. Therefore, the recurrent laryngeal should be fully dissociated and protected during the whole operation. In this study, recurrent laryngeal nerve palsy occurred in three patients after surgery. In addition, there is the possibility of rupture and stenosis of the tracheal anastomosis in both window-based tracheal resection and end-to-end tracheal anastomosis, which is related to the large scope of window-based resection and the excessive tension of the anastomosis [28, 29]. There was no tracheal anastomotic rupture and stenosis after operation.

The oncologic outcome of patients with THCA who use modified spiral tracheoplasty to repair the defective trachea is also of concern. Ebihara [27] et al. conducted a retrospective analysis of 41 patients with THCA invading deep trachea after window resection. The 5-year and 10-year survival rates were 78.9% and 74.5%, respectively, and the 5-year and 10-year local control rates of tumor and invaded trachea were 92.4% and 73.4%, which fully confirmed the therapeutic effect of window resection. For THCA involving the cervical trachea, the 3-year and 5-year survival rates of tracheal sleeve resection and end-to-end anastomosis were 93.8% and 70.3% respectively. In this study, the follow-up time was from 24 to 60 months. The 2-year survival rate was 100%, the 2-year tracheal local control rate was 100%, and the 2-year tumor-free survival rate was 81.8%. The survival rate and local control rate were similar to those reported in the literature. For THCA with tracheal involvement, iodine 131 has a role in the diagnosis and treatment, which is beneficial to the control of local recurrence and distant metastasis. All 11 cases in this study had complete tumor resection, and all patients were treated with iodine-131. One patient received a second iodine-131 therapy and targeted therapy because of lung metastasis at 17 months after surgery.

Conclusions

When the trachea is invaded by THCA, it is difficult to maintain the stability of the tracheal framework after resection of the trachea more than 5 cm with simple reconstruction or end-to-end anastomosis. The results of this study indicate that the modified spiral tracheoplasty is a safe and effective method. Modified spiral tracheoplasty can not only reduce the tension of the tracheal anastomosis, but also enlarge the tracheal lumen and prevent stenosis through the retraction force of the trachea after torsion. Modified spiral tracheoplasty can be effectively applied to tracheal reconstruction after wide tracheal resection for locally advanced THCA with tracheal invasion.

Abbreviations

THCA Thyroid carcinoma

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Author contributions

M.L. edited the manuscript and analyzed data. Q. T. and X. Y. provided clinical samples. Q. Y., M. Z., Y. Z. and P. H. collected data. S. L. and D. Y.designed experiments. All authors read and approved the final manuscript.

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Data availability

The data and materials that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

All participants provided informed consent for their participation and for the publication of images and any accompanying data. This research was comprised of human participants and was approved by the Second Xiangya Hospital Ethics Committee (No. LYG2022010), and all procedures were performed in accordance with relevant guidelines and regulations. Informed consent was obtained from all participants.

Consent for publication

Informed consent to participate was obtained from all patients. And all participants provided informed consent for the publication of their images and any accompanying case details.

Competing interests

The authors declare no competing interests.

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