Original Article

Perioperative outcomes of median sternotomy for intrathoracic tracheal malignancies: a 15-year retrospective analysis

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Background: Tracheal resection and reconstruction is a complex thoracic surgery procedure. Posterolateral thoracotomy (PLT) is the standard approach for intrathoracic tracheal resection; however, research on the median sternotomy (MST) approach is limited. This study evaluated the surgical outcomes of MST in treating intrathoracic tracheal malignancies.

Methods: A 15-year retrospective analysis of the data of patients with primary intrathoracic tracheal malignancies who underwent "trachea + carina" resection and reconstruction at a single center was conducted.

Results: A total of 62 patients were included in the analysis. Among the patients, 27 (43.55%) underwent tracheal resection only, while 35 (56.45%) underwent combined carinal and main bronchial resection. The mean length of the resected tracheal segment was 35.00±8.15 mm, and 13 (20.97%) patients had a resection length of at least 40 mm. Negative surgical margins were achieved in 33 patients (53.23%), unilateral positive margins in 15 patients (24.19%), and bilateral positive margins in 14 patients (22.58%). The logistic regression analysis identified adenoid cystic carcinoma (ACC) pathology and extraluminal tumor growth as independent risk factors for positive surgical margins. No postoperative sternotomy site infection case was observed, and postoperative pain was generally well tolerated. Complications requiring medical intervention occurred in 16 patients (25.8%), including excessive granulation tissue formation at the anastomosis in 14 patients (22.58%) and an anastomotic fistula in 2 patients (3.23%). Notably, no instances of recurrent laryngeal nerve injury were reported.

Conclusions: The MST approach offers several advantages in the management of tracheal tumors, including better exposure, blood supply preservation, and left recurrent laryngeal nerve protection. Thus, it should be the preferred approach for long-segment resection and reconstruction.

Keywords: Tracheal malignancies; tracheal resection and reconstruction; median sternotomy (MST); complications

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Introduction

Intrathoracic "trachea + carina" resection has long been one of the most challenging thoracic surgeries procedures. Postoperative complications following tracheal surgery are primarily due to anastomotic issues, mainly resulting from anastomotic high tension and ischemia (1,2).

Though the implementation of minimally invasive techniques and non-intubated surgery have made it possible to apply robotic procedures in neoplastic tracheobronchial surgery in strictly selected sets of patients (3-5). There is still a lack of standardization regarding surgical approach for complex intrathoracic "trachea + carina" resection and reconstruction due to malignancies. Because of the rarity of the disease, surgical preferences vary across institutions and are up to thoracic surgeons' preferences. The earliest data reported by Grillo *et al.* showed that of 90 cases of thoracic tracheal surgery performed at their center, only 4 (4.4%) used the median sternotomy (MST) approach (6). A report from Massachusetts General Hospital revealed that among 45 cases of "trachea + carina" resection, 33% were performed via MST, while 58% were performed via right posterolateral thoracotomy (PLT) (7). Similarly, de Perrot *et al.* reported that among 119 cases of carinal resection, 81% employed right PLT, and only 0.5% employed MST (8). Early data from Shanghai Chest Hospital revealed that 17.0% (9/53) of patients with primary tracheal adenoid cystic carcinomas (ACCs) underwent surgery using MST (9). These differences highlight the variability in lesion locations and the influence of surgeons' preferences and clinical experience. Notably, other studies on this subject lack specification of the surgical approaches employed (10-12).

Right PLT remains the preferred approach for intrathoracic "trachea + carina" resection and reconstruction. This approach is valued for simplicity and ability to precisely visualize the lower trachea and right main bronchus, making it an optimal choice for lesions confined to these areas (13). Conversely, the left-sided approach is rarely used due to limited surgical visibility caused by the aortic arch and pulmonary arteries. It has been reported that MST, while less frequently used, has potentially higher morbidity rates than thoracotomy (14). Additionally, the middle and lower segments of the thoracic trachea are covered by major blood vessels at the base of the heart, and thus intuitively do not provide ideal surgical visualization.

Despite these challenges, MST has advantages in managing complex malignant tumors involving the carina, left main bronchus, upper thoracic trachea, or long tracheal segments requiring extensive resection and reconstruction. The restricted visibility and limited maneuverability associated with the right PLT can hinder effective mobilization and increase the risk of anastomotic complications in such cases. While more invasive, MST provides superior visibility of the thoracic trachea, carina, and both main bronchi, facilitating mobilization and

Highlight box

Key findings

- This study used the largest single-center dataset to evaluate the perioperative outcomes of median sternotomy (MST) in treating intrathoracic tracheal malignancies. The MST approach was safe and feasible in a retrospective analysis of 62 patients with complex "trachea + carina" malignancies. No postoperative infections or extensive complications were observed, and pain was well tolerated. Notably, the superior surgical visibility provided by MST preserved vascular integrity, protected the left recurrent laryngeal nerve, and achieved a longer resectable tracheal length.

What is known, and what is new?

- Surgery remains the primary treatment for tracheal malignancies, but resection and reconstruction, particularly of the long-segment intrathoracic segment, are technically challenging. Posterolateral thoracotomy (PLT) is the most commonly used approach in these scenarios. Despite its prevalence, data on the use of MST in malignant tracheal resection and reconstruction remain limited.
- The MST approach is advantageous for patients requiring extensive tracheal resections—an area not extensively addressed in previous research.

What is the implication, and what should change now?

- Our findings significantly contribute to the existing body of knowledge by demonstrating that MST is a viable alternative to PLT that provides superior surgical exposure and results in fewer complications in long-segment tracheal resections. This evidence supports the use of MST for more complex cases and may influence future surgical strategies for managing tracheal malignancies. Incorporating these findings into clinical practice could improve patient outcomes, particularly those requiring extensive resections and reconstructions.

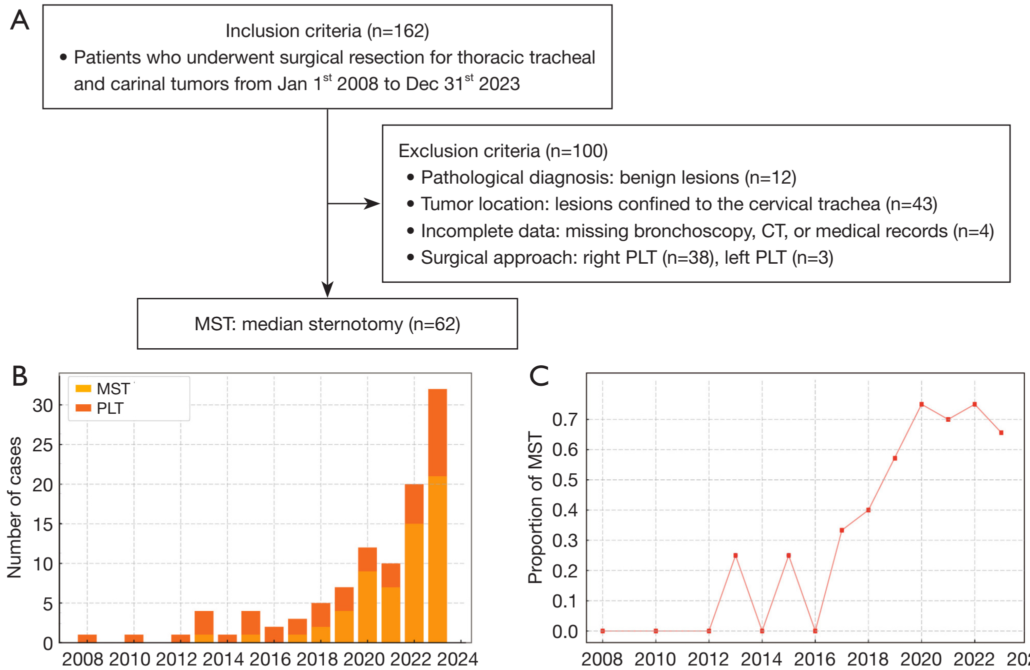

Figure 1 Study design and temporal trends in surgical approaches for tracheal tumors. (A) Study inclusion and exclusion criteria. (B) Bar chart showing the number of cases per year for MST and PLT. (C) Line graph showing the annual change in the proportion of MST cases. CT, computed tomography; MST, median sternotomy; PLT, posterolateral thoracotomy.

reducing anastomotic tension (15). Recent research has also reported on the advantages of MST in managing complex tracheal diseases (15,16). Nevertheless, there is a lack of evidence reporting the perioperative outcomes of the MST approach in these scenarios.

In recent years, the Shanghai Chest Hospital has gained substantial experience using MST for complex tracheal diseases. This study retrospectively analyzed the data of 62 patients with intrathoracic malignancies who underwent thoracic "trachea + carina" resection and reconstruction over the past decade and showed that this approach has certain advantages. We present this article in accordance with the STROBE reporting checklist (available at https://jtd.amegroups.com/article/view/10.21037/jtd-2025-773/rc).

Methods

Patients inclusion and exclusion criteria

We retrospectively identified patients who underwent thoracic "trachea + carina" resection and reconstruction for tracheal tumors at the Thoracic Surgery Department of Shanghai Chest Hospital from January 2008 to December 2023. Patients were excluded from the study in case of missing data, benign postoperative definitive pathology, and PLT surgical approach. Sixty-two patients were included in our study following the workflow shown in *Figure 1A*. The study was conducted in accordance with the Declaration of Helsinki and its subsequent amendments. The study was approved by Ethics Committee of Shanghai Chest Hospital (approval No. IS23098) and informed consent was taken from all the patients.

Preoperative evaluation

Each patient underwent enhanced chest computed tomography (CT) and bronchoscopy preoperatively to rule out distant metastasis and confirm surgical indication. Cardiopulmonary function assessment was planned as a routine work-up.

Measurements

The tracheal length parameters and the tumor length on CT were measured by two senior radiologists using preoperative enhanced thin-slice (1-mm) CT images. Considering the average measure, the cervical tracheal length was defined as the distance from the cricoid cartilage plane to the thoracic inlet. The intrathoracic tracheal length was defined as the distance from the thoracic inlet to the carina level. The total tracheal length was obtained by summing these two distances. The tumor length on CT was defined as the longitudinal length of the tumor on the CT images. Enhanced thin-slice CT was selected over bronchoscopy for preoperative tumor length assessment due to its superior ability to detect submucosalinvolvement, as indicated by tracheal wall thickening, and its ability to accurately evaluate tumors with extraluminal growth, which may not be adequately visualized by bronchoscopy. Additionally, the distances from the upper and lower margins of the tumor to the carina, respectively, were measured on CT images. For carina neoplasms, the lower margin distance was recorded as zero (Figure S1).

Anesthesia and intraoperative ventilation

All patients received general anesthesia and mechanical ventilation. Tracheal intubation was performed under bronchoscopic view to avoid the endotracheal tube (ETT) from coming into contact with the tumor mass. Mechanical ventilation and peripheral oxygen saturation monitoring above 95% were the standard. During surgery, the ETT tube was advanced into the distal trachea to ensure ventilation. In patients undergoing carinal resection, high-frequency jet ventilation was used (17). Veno-venous extracorporeal membrane oxygenation was implemented in cases of severe tracheal obstruction and respiratory impairment.

Surgical approaches and intraoperative resection margins considerations

The MST approach has been frequently employed in recent years, primarily due to the extensive segmental involvement observed in tracheal malignancies. The patient is positioned supine, under general anesthesia and ETT ventilation. A standard midline vertical incision is made, from the sternal notch to the xiphoid process. The sternum is then divided with a sternal saw, and the halves are retracted to access the mediastinum. The thymus and anterior mediastinal tissue are dissected, and the anterior pericardium is opened. The posterior pericardium is then opened between the superior vena cava and ascending aorta. The pulmonary artery trunk is dissected for mobilization, and the brachiocephalic vessels are retracted to expose the lower trachea and carina. Tumor resection is guided through a bronchoscopy view, followed by the trimming of the resection margins. Adequate mobilization of trachea and bronchi reduces anastomotic tension, ensuring healthy tissue margins for optimal resection, and reducing risk of recurrence. Muscle flaps or thymus tissue cover the anastomoses, and an air leak test is performed.

For carinal reconstruction, the trachea and left main bronchus were typically approximated and anastomosed with 3-0 Prolene sutures in a continuous fashion for the posterior and lateral walls and an interrupted fashion for the anterior wall. A tracheal incision was made to anastomose the right main bronchus in an end-to-side fashion. In our clinical practice of MST approach, we often use thymus tissue covering at anastomotic sites. For the PLT approach, we do not routinely implement additional coverage (e.g., omental wrapping, synthetic patches, or biological membranes) at anastomotic sites.

In tracheal surgery, determining the appropriate resection range requires careful consideration of multiple factors. While the primary objective is to remove as much of the tumor as possible to minimize recurrence, increasing the resection length substantially raises the complexity of tracheal anastomosis and the risk of anastomotic complications. It is thus critical to consider the patient's overall condition, including factors such as body height, total tracheal length, the proportion of the trachea being resected, and elements affecting anastomotic tension. For example, older patients typically have reduced tracheal elasticity, which limits the safe resection range. Tumor pathology also plays a key role in determining resection range, particularly in cases of ACC, which is prone to significant longitudinal submucosal invasion. Achieving a negative microscopic margin is often challenging in ACC, and surgical practice usually focuses on obtaining a macroscopic negative margin, followed by postoperative adjuvant radiotherapy. Therefore, decisions regarding tracheal resection must strike a careful balance between maximizing tumor removal and minimizing the risk of anastomotic complications. At Shanghai Chest Hospital, based on preoperative examination results and intraoperative visual assessment of the tracheal tumor's growth, we initially determine the resection range for the first surgery. The resected specimen is sent for frozen section pathology, and the margin status is evaluated under the microscope. The resected specimen was sent for frozen section pathology. The margin closer to the pharynx, glottis, or larynx was labeled as the "upper margin to the carina", while the margin closer to the pulmonary hilum or main bronchi was labeled as the "lower margin to the carina". If the margin is positive, further tracheal tissue is resected, ensuring surgical safety, until the margin becomes negative or no further tissue can be safely removed.

Postoperative management and postoperative complications

Complications were determined through medical history records, postoperative bronchoscopy and chest CT examination results, and follow-up records. In this study, complications were defined as cases requiring medical interventions. For example, patients with temporary recurrent laryngeal nerve injury who needed enteral nutrition due to impaired oral intake caused by vocal cord paralysis, as well as those with persistent or irreversible vocal cord paralysis, were included in the complication group. Those requiring bronchoscopic interventions for observed tissue granulation at the anastomotic site were described as complicated patients. Other patients requiring transfer to the intensive care unit (ICU) for treatment due to postoperative complications were also included in the complication group.

Most patients were transferred to the ICU for monitoring after surgery, having an average ICU length of stay (LOS) of 3.7 days. They received routine airway management and symptom treatments, including anti-inflammatory medications. Once their clinical stabilization, they were moved to a regular ward for further observation, with an average LOS of 4.7 days before being discharged for home recovery.

During the perioperative period, a pain pump was used for pain control within the first 48 hours, in combination with an intravenous parecoxib injection. Pain was assessed using the Numeric Rating Scale (NRS), a widely used tool for assessing pain intensity in clinical practice. Nurses assessed pain intensity using the NRS, asking the patients to rate their pain on a scale ranging from 0 (no pain) to 10 (the worst possible pain). When the NRS score exceeded 4, temporary interventions were initiated in accordance with the World Health Organization's three-step analgesic ladder for cancer pain. This simple tool helps clinicians quickly assess pain severity and tailor pain management strategies.

Bronchoscopy was routinely performed on postoperative days 3 and 14 to assess anastomotic healing and clear tracheal secretions. Additionally, it was used to check for the occurrence of over-granulation 2–3 months postoperatively. For cases with positive surgical margins, postoperative adjuvant radiotherapy was generally required.

Statistical analysis

The continuous variables were analyzed using the Student's *t*-test, while the categorical variables were analyzed using the χ^2 test, with Monte Carlo simulated P values used when appropriate. Grouped analyses and three-line tables were calculated and output using the "table1" package (version 1.4.2) in R 4.1.0. All the statistical tests were two-sided, and a P value <0.05 was considered statistically significant.

Univariate and multivariate logistic regression analyses were conducted to identify risk factors. Prior to the logistic regression, the continuous variables were standardized using the "StandardScaler" function from the Python "sklearn" package (version 1.3.0) to ensure consistent scales and comparable distributions across features. Each variable was individually subjected to univariate logistic regression with the selected outcome variable, using Python 3.10.0 and the "statsmodels" package (version 0.14.0). Variables with a P value <0.05 in the univariate logistic regression were selected for further analysis.

A stepwise-regression method, based on the Akaike information criterion (AIC), was employed to select the optimal combination of variables and to reduce multicollinearity. To avoid bias, all possible variable combinations were iterated using the "itertools. combinations" function from the "itertools" module (version 3.10.x) in Python Combinations were classified according to the number of included variables, and for each variable set size, the combination with the smallest AIC value was selected as the optimal model. An AIC curve was plotted to visualize the selection process. The final model was chosen by considering the AIC values and multicollinearity among the variables. Multicollinearity was assessed using variance inflation factors (VIFs), and variables with VIF values greater than 10 were excluded from the final model. This optimal variable combination was then included in the multivariable logistic regression analysis. A forest plot was generated using the "subplots" function from the "Matplotlib" package (version 3.8.0) to visualize the results.

Results

Trends in the choice of surgical approaches

From January 2008 to December 2023, the total number of patients undergoing intrathoracic tracheal or carinal resection at our tracheal surgery center increased (*Figure 1B*), along with a corresponding rise in the proportion of cases involving MST (*Figure 1C*).

Table 1 Baseline characteristics of patients with MST

Variables	Value (n=62)
Age (years)	52.08±11.66
Gender	
Female	25 (40.32)
Male	37 (59.68)
Height (cm)	163.45±5.42
Smoking status	
Never	27 (43.55)
Current	19 (30.65)
Former	9 (14.52)
Unknown	7 (11.29)
Comorbidities	
Diabetes	7 (11.29)
Hypertension	10 (16.13)
COPD	11 (17.74)
CAD	2 (3.23)
CVD	0 (0.00)
Lung surgery history	8 (12.90)
Length of trachea (mm)†	
Cervical segment	57.52±5.59
Intrathoracic segment	62.21±5.63
Entire trachea	119.32±8.48
Intrathoracic segment/entire	0.52±0.03
Distance from the tumor's margin to carina (mm)†	
Upper margin	15.68±18.14
Lower margin‡	3.67±5.42

All the continuous variables are presented as the mean ± standard deviation, and the categorical variables are presented as the sample size and proportion, unless otherwise stated. †, measured on preoperative enhanced thin-slice (1-mm) CT. ‡, for tumors invading the carina, the lower margin distance was recorded as zero. CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease; CT, computed tomography; CVD, cardiovascular disease; MST, median sternotomy.

Baseline characteristics of patients

During the 15-year study period, 62 patients underwent "trachea + carina" resection and reconstruction by MST (*Table 1*). The patients had a median age of 52 years (range, 16–80 years), and the majority were male (59.68%). A history of smoking was noted in 35 patients (56.45%). The most common presenting symptoms were cough and dyspnea, followed by hemoptysis. The prevailing comorbidities included chronic obstructive pulmonary disease (n=11, 17.74%) and hypertension (n=10, 16.13%), and 8 patients (12.90%) had a history of prior lung cancer surgery via right PLT. The average distance from the upper margin to the carina was 15.68±18.14 mm, while the average distance from the lower margin to the carina was 3.67±5.42 mm.

Pathology and surgery

Postoperative pathology revealed that the most common pathology type was ACC (n=39, 62.90%), followed by mucinous epidermoid carcinoma (n=310, 16.13%). The average tumor length measured intraoperatively was 24.32±6.91 mm, and the average length of the intraoperatively resected trachea was 35.00±8.15 mm. Among the patients, 13 (20.97%) underwent long-segment (≥4 cm) tracheal resection. Tumor involvement was confined to the trachea in 27 patients (43.55%), while the invasion of the carina and main bronchi was observed in 35 patients (56.45%) (*Table 2*).

Margin status

Postoperative pathological evaluations demonstrated that completed (R0) resection was achieved in 33 patients (53.23%), while 29 patients (46.77%) presented with positive surgical margins, of whom, 15 (24.19%) had unilateral involvement and 14 (22.58%) had bilateral involvement. The ACC histological subtype accounted for the most positive margins, representing 25 cases (86.21%). There were also two cases of squamous cell carcinoma and two cases of small cell carcinoma. The univariate logistic regression analysis identified tumor growth site, growth pattern, and pathological subtype as significant factors affecting margin status (Table S1). The multivariate analysis (*Figure 2A*) further established membranous-origin tumors and extraluminal growth patterns as independent risk factors for positive surgical margins.

Postsurgical pain evaluation and complications

The overall mean LOS was 8 days (range, 3–29 days). Notably, over the 15-year study period, the ICU stay remained relatively stable, while the total length of

Table 2 Surgical details and pathological diagnosis of patients with MST

Variables	Value (n=62)
Resection length (mm)	
Resected trachea	35.00±8.15
Resected trachea/total trachea	0.29±0.07
Resected trachea/intrathoracic segment	0.57±0.15
Tumor size (mm)	
Measured by CT†	27.10±6.93
Measured by pathologists	24.32±6.91
Resection type	
Trachea alone	27 (43.55)
Trachea + carina	35 (56.45)
Pathology	
ACC	39 (62.90)
SqCC	6 (9.68)
MEC	10 (16.13)
SmCC	2 (3.23)
Sarcoma	2 (3.23)
Others	3 (4.84)
Margin status	
Negative	33 (53.23)
Positive	29 (46.77)
Growth pattern	
Non-extra-lumen growth	30 (48.39)
Extra-lumen growth	32 (51.61)
Growth sites	
Cartilaginous part	39 (62.90)
Membranous part	23 (37.10)

All the continuous variables are presented as the mean ± standard deviation, and the categorical variables are presented as the sample size and proportion, unless otherwise stated. †, tumor longitudinal length measured on preoperative enhanced thin-slice (1-mm) CT. ACC, adenoid cystic carcinoma; CT, computed tomography; MEC, mucinous epidermoid carcinoma; MST, median sternotomy; SmCC, small cell carcinoma; SqCC, squamous cell carcinoma.

stay showed a gradual reduction in more recent years. Postoperative pain was well tolerated; patients' NRS scores were steadily less than 4 (mean ± standard deviation, 3±1.47). No cases of postoperative sternotomy site infection were observed.

A total of 16 patients (25.8%) experienced postsurgical complications that required medical interventions. The most represented was anastomotic complications in 14 patients (22.58%), which included excessive granulation tissue formation in 14 patients (22.58%) and anastomotic fistula in 2 patients (3.23%) (Table S2). The two patients with anastomotic fistula were managed by reoperation and stent placement, respectively, and both developed mild tracheal stenosis during follow-up. Notably, the limited surgical visibility inherent to PLT may increase the risk of recurrent laryngeal nerve injury. In contrast, no patients experienced recurrent laryngeal nerve injury that requiring medical interventions.

A logistic regression analysis was conducted to investigate the factors associated with postoperative complications. The results of the univariate logistic regression analysis are presented in *Table 3*. A further multivariable logistic regression analysis (*Figure 2B*) identified older age [odds ratio (OR): 1.14; 95% confidence interval (CI): 1.04–1.25], the length of the trachea within the thoracic segment (OR: 0.86; 95% CI: 0.75–0.98), and the extent of tracheal resection (OR: 1.13; 95% CI: 1.02–1.25) as significant factors contributing to an increased risk of postoperative complications.

Discussion

Tracheal malignancies are frequently diagnosed at an advanced stage, necessitating extensive resection. In recent years, the MST approach has been increasingly adopted at our tracheal surgery center. MST offers advantages over PLT in some instances, particularly those requiring long-segment tracheal resection with carinal reconstruction. Based on our own practical experience, we have observed that MST has four advantages: (I) it provides excellent visibility, allowing exposure of the entire trachea from the cricoid cartilage to the main bronchi; (II) it enables the combination of laryngeal release with bilateral pericardial and hilar release, offering sufficient mobilization and release for safer anastomosis and amore extended resection range; (III) it has little effect on the blood supply to the membranous part of the trachea, facilitating better postoperative anastomotic healing; and (IV) it reduces the risk of damaging the left recurrent laryngeal nerve by providing a direct operative view (*Figure 3*).

The unique anatomical configuration of the lower

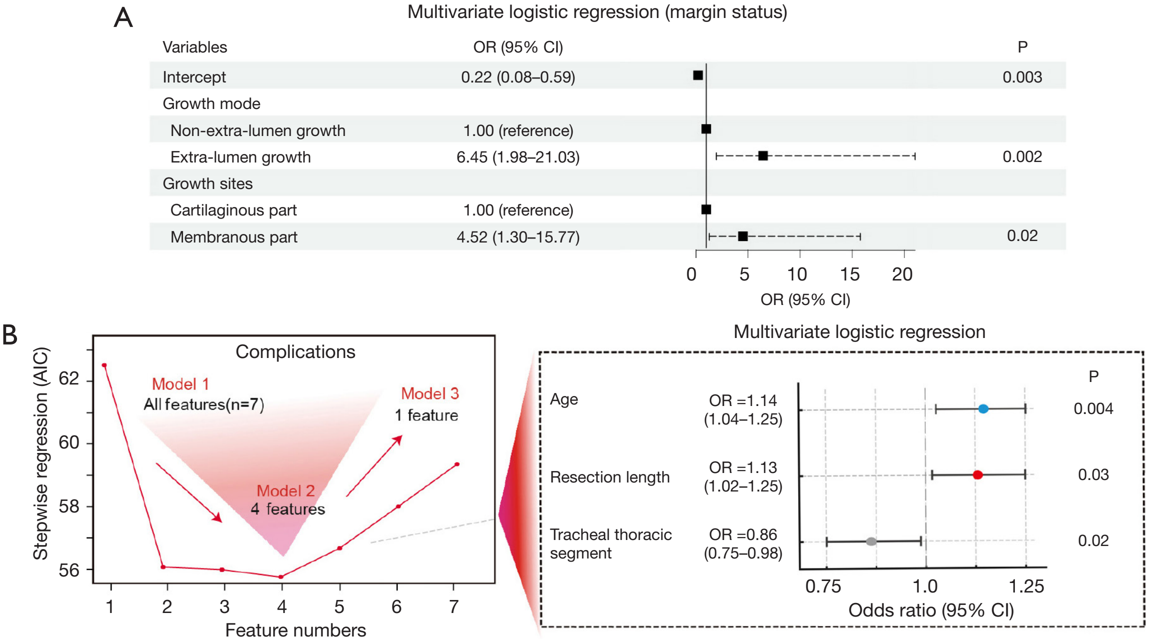

Figure 2 Multivariate analysis of factors affecting complications and margin status. (A) Multivariable logistic regression analysis identifying the potential factors affecting margin status. (B) Stepwise-regression and multivariable logistic regression analysis identifying the potential factors affecting complications. The AIC selection curve shows the stepwise selection of variables based on minimizing the AIC. The variables with the lowest AIC values were selected for the final multivariable logistic regression model. AIC, Akaike information criterion; CI, confidence interval; OR, odds ratio.

trachea and carina creates significant challenges related to restricted mobility. These limitations are attributed to constraints imposed inferiorly by the pericardium, and the left and right hila, and superiorly by the major blood vessels and hyoid muscles situated at the heart's base. Conversely, intraoperative release maneuvers for the lower trachea are notably restricted. When the extent of tracheal resection exceeds 40 mm, the significant tension at the anastomotic site may substantially hinder wound healing (18,19). Therefore, extensive tracheal resection often requires bilateral hilar and pericardial mobilization to relieve tension at the anastomosis.

Right PLT enables the relatively easy mobilization of the right hilum and right lower pulmonary ligament. However, due to limited visibility, the mobilization of the left hilum and left lower pulmonary ligament is challenging. Conversely, MST enables optimal exposure, providing excellent visibility of the left hilum and lower pulmonary ligament. Additionally, MST facilitates laryngeal and hyoid release, further reducing anastomotic tension (15,20). Wright *et al.* conducted a single-center retrospective review of 901 patients who underwent tracheal resection and

Table 3 Factors associated with occurrence of postsurgical complications

Variables	P value	OR (95% CI)
Margin status		
Negative		1.00 (reference)
Positive	>0.99	1.00 (0.32–3.12)
Gender		
Female		1.00 (reference)
Male	0.39	1.69 (0.51–5.66)
Pathology		
Other		1.00 (reference)
ACC	0.11	0.39 (0.12–1.25)
Smoking		
Never		1.00 (reference)
Current	0.17	2.57 (0.67–9.86)
Former	0.36	2.20 (0.41–11.95)
Unknown	0.79	0.73 (0.07–7.53)

Table 3 *(continued)*

Table 3 *(continued)*

Variables	P value	OR (95% CI)
Comorbidities		
Diabetes	0.47	0.44 (0.05–4.01)
Hypertension	0.65	0.68 (0.13–3.59)
COPD	0.90	1.10 (0.25–4.76)
CAD	>0.99	0.00 (0.00–Inf)
Growth mode		
Non-extra-lumen growth		1.00 (reference)
Extra-lumen growth	0.88	0.92 (0.29–2.86)
Growth sites		
Cartilaginous part		1.00 (reference)
Membranous part	0.97	1.02 (0.32–3.32)
Extent of excision		
Trachea alone		1.00 (reference)
Trachea + carina	0.23	0.50 (0.16–1.58)
Age	0.006*	1.10 (1.03–1.18)
Height	0.03*	0.87 (0.78–0.99)
Length of trachea†	0.78	0.99 (0.89–1.09)
Cervical segment		
Tracheal thoracic segment	0.03*	0.88 (0.79–0.99)
Total tracheal length	0.15	0.95 (0.89–1.02)
Segment/entire	0.09	0.00 (0.00–18.27)
Tumor margin to the carina distance†		
Upper margin to the carina distance	0.09	1.03 (1.00–1.06)
Resection length	0.01*	1.10 (1.02–1.18)
Tumor size		
Measured by CT scan‡	0.03*	1.10 (1.01–1.20)
Measured by pathologists	0.17	1.06 (0.97–1.16)
Margin distance from the carina	0.05	1.10 (1.00–1.22)

*, indicates P value <0.05, which was considered statistically significant. †, measured on preoperative enhanced thin-slice (1-mm) CT. ‡, tumor longitudinal length measured on preoperative enhanced thin-slice (1-mm) CT. ACC, adenoid cystic carcinoma; CAD, coronary artery disease; CI, confidence interval; COPD, chronic obstructive pulmonary disease; CT, computed tomography; Inf, infinity; OR, odds ratio.

found that resections exceeding 40 mm were significantly associated with higher failure rates. The surgical approaches included cervical (676, 75%), mediastinal (180, 19.97%), and thoracic (45, 4.99%) techniques (21). In Gaissert *et al.*'s study of 190 surgically treated tracheal tumor patients, the reported resection lengths ranged from 21 to 35 mm, but the specific surgical approach was not described (22). Similarly, Refaely *et al.* conducted a retrospective analysis of 22 tracheal tumor surgeries, and reported resection lengths between 20 and 50 mm, and that most procedures were performed via unilateral or bilateral thoracotomy (23). Further, in surgical teams that predominantly employ the PLT approach (33% MST, 62% PLT), it is generally advised that tracheal resections with PLT should not exceed 40 mm, a view supported by previous studies (7,24).

Although R0 resection remains the preferred treatment for tracheal tumors, it is often challenging to achieve due to the tumor's insidious onset, frequent invasion of adjacent vessels and nerves, and the technical difficulty of long-segment tracheal resection. In ACC, positive surgical margins are particularly common owing to its infiltrative growth pattern. Numerous studies (22,25) have shown that patients who undergo complete resection have significantly better survival outcomes than those with incomplete resection. Therefore, the application of MST to extend the resectable length of the trachea may improve R0 resection rates and ultimately enhance patient prognosis. In the present study, 13 (20.97%) cases had a tracheal resection length of at least 40 mm, and 9 (14.52%) cases had a length of 50 mm. Therefore, MST enables more extended tracheal resections. Although recent reports such as Liu *et al.*'s (26) study of long-segment tracheal ACC resection via dual-port thoracoscopy with bilateral hilar and pericardial mobilization, have shown promising results, the efficacy and safety of this approach have yet to be verified.

Anastomotic complications are primarily related to blood supply and anastomotic tension. The lower trachea-carina region is supplied by branches of the bronchial arteries from the front and back (27). Right PLT typically disrupts the blood supply of the membranous part, while MST does not involve dissection, preserving more blood supply to the membranous part. Adequate blood supply is crucial for anastomotic healing, and its disruption can lead to poor healing and fistula formation (28). According to previous

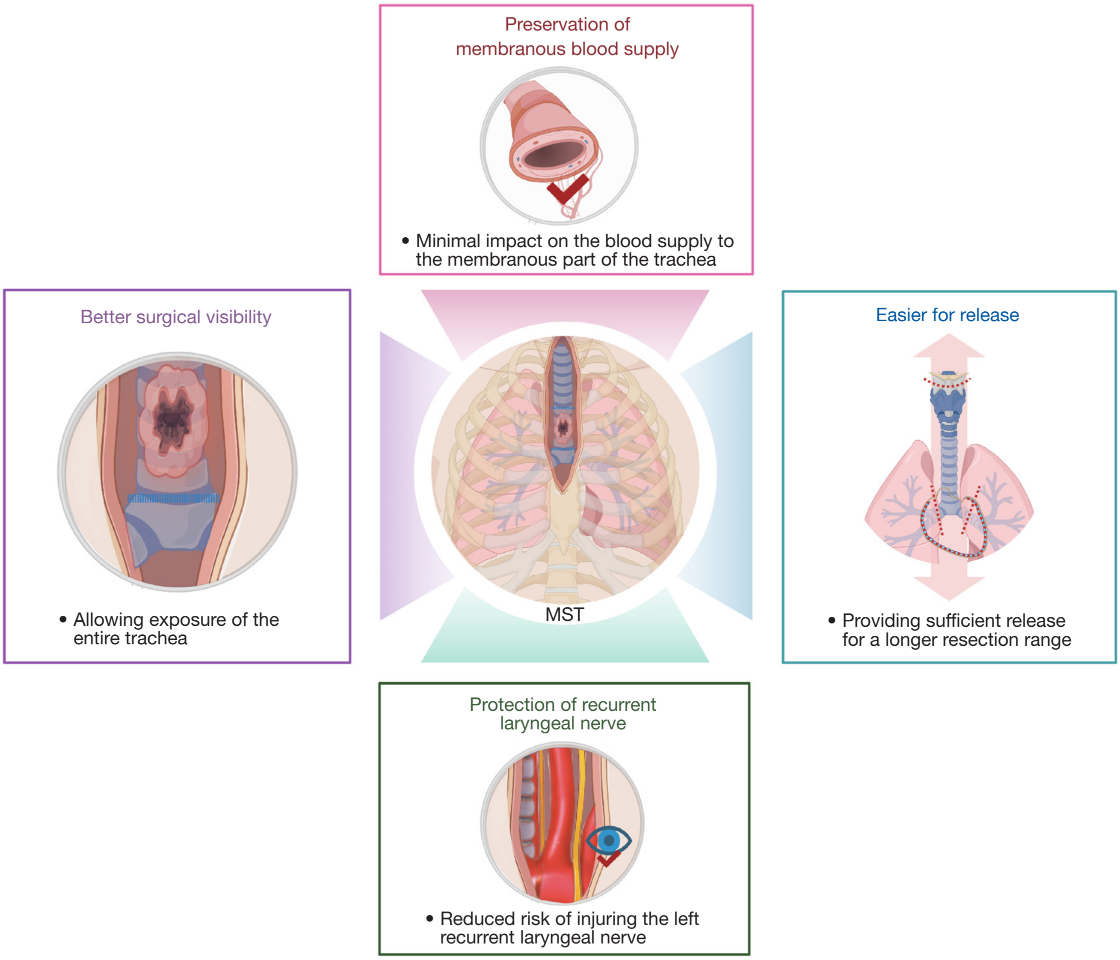

Figure 3 Main advantages of MST. MST, median sternotomy.

reports (7,8), the incidence of anastomotic leakage or necrosis after PLT is 10–11%. However, in our study, only 2 cases (3.23%) developed anastomotic leakage. Despite the longer resections associated with MST, the incidence of anastomotic complications in MST does not appear to be higher than that in PLT. This evidence is likely related to the tension relief achieved through sufficient mobilization and blood supply preservation. Additionally, the limited visibility in the right and left PLT increases the risk of recurrent laryngeal nerve injury, leading to postoperative hoarseness, coughing, and, in severe cases, the need for parenteral nutrition (29). MST provides a better surgical view, reducing the risk of recurrent laryngeal nerve injury. Although MST might be more invasive and is associated with a slower recovery than PLT, we recommend it as the primary choice for patients requiring extensive lower "trachea + carina" resection and reconstruction.

While MST offers excellent visibility and safety, emerging minimally invasive techniques, such as bilateral thoracoscopic pericardial release, are gaining attention due to their potential for reduced morbidity and faster recovery. These approaches focus on minimizing tissue damage with smaller incisions, leading to less postoperative pain. However, MST remains valuable in complex cases, especially in centers with extensive surgical expertise. Future studies comparing MST with these emerging techniques will help determine the optimal approach for different patient populations.

This study has several limitations. As a retrospective, single-center analysis, it may be subject to selection bias and limited generalizability. Additionally, the lack of long-term survival data and incomplete information on postoperative adjuvant therapies constrain the evaluation of oncological outcomes. Further prospective, multicenter studies with extended follow-up are needed to validate these findings.

Conclusions

Overall, this large-sample case study summarized the perioperative outcomes of the MST approach. The results showed the effectiveness of MST as a routine surgical approach for sectioning intrathoracic tracheal malignancies. It has several advantages, particularly in cases requiring extensive resection and reconstruction. However, further comparative studies between MST and PLT need to be conducted to comprehensively evaluate their respective benefits and limitations, ultimately contributing to the standardization of tracheal surgery protocols.

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Footnote

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki and its subsequent amendments. Ethics approval was obtained from the Ethics Committee of Shanghai Chest Hospital (approval No. IS23098). Written informed consent was obtained from all patients for the use of their clinical examination data and imaging.

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