Original Article

Single-port inflatable mediastinoscopy combined with laparoscopic esophagectomy via right cervical auxiliary operating port and sternal lifting: a safe and reliable surgical method

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Background: Minimally invasive esophagectomy (MIE) has revolutionized esophageal cancer treatment, but limitations in mediastinal exposure and lymph node dissection remain significant challenges. This study aimed to explore the application and safety of an improved surgical method combining single-port inflatable video-assisted mediastinoscopic transhiatal esophagectomy (SP-IVMTE) with a right cervical auxiliary operating port and sternal lifting.

Methods: This study reviewed data from 304 patients who underwent esophagectomy from January 2022 to June 2024. Patients were divided into 274 who underwent video-assisted MIE (VAMIE) and 30 who underwent SP-IVMTE. Propensity score matching (PSM) minimized selection bias, resulting in 120 VAMIE and 30 SP-IVMTE patients being analyzed. Surgical and postoperative data were collected.

Results: All SP-IVMTE surgeries were successfully completed without significant intraoperative injuries. The use of auxiliary ports and sternal lifting significantly increased operating space and improved the visual field, reducing the difficulty of subcarinal lymph node dissection. After PSM, there were no significant differences between the groups in terms of operation time, number of lymph nodes dissected, or postoperative hospital stay. The SP-IVMTE group required fewer fiber-optic bronchoscopy (FOB) suctions, indicating better postoperative recovery and safety.

Conclusions: The combination of auxiliary operating ports and sternal lifting in SP-IVMTE provides a safe and reliable surgical method, with enhanced operability and a stable surgical field, offering potential for widespread application in esophageal cancer patients.

Keywords: Esophageal cancer; mediastinoscopic esophagectomy; minimally invasive surgery; sternal lifting

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Introduction

Esophageal cancer is a highly aggressive malignancy with increasing incidence and mortality rates worldwide. Surgical resection remains the primary treatment for esophageal cancer. However, traditional esophagectomy is associated with significant trauma and high complication rates, including respiratory distress, infections, and delayed recovery, thereby imposing substantial physical and psychological burdens on patients (1). Recently, minimally invasive esophagectomy (MIE) has gained widespread acceptance. Despite this, surgeons must still operate separately in the cervical, thoracic (thoracoscopic), and abdominal (laparoscopic) regions (2-4). Fujiwara *et al.* were the first to apply inflatable mediastinoscopy for radical esophagectomy, thereby advancing its development and global dissemination (5). In 2016, Professor Qingdong Cao performed this surgery for the first time in China (6). Since its introduction, single-port inflatable video-assisted mediastinoscopic transhiatal esophagectomy (SP-IVMTE) combined with laparoscopy has gradually gained attention. SP-IVMTE has demonstrated potential advantages by reducing chest wall trauma and improving postoperative recovery (7). However, SP-IVMTE surgery is highly challenging due to the limited operating space, particularly in patients with a narrow mediastinum. This limitation not only increases surgical risk but also restricts its broader clinical application (8-10). To address the issue of inadequate operating space, several scholars have proposed modifications to surgical techniques and instruments (11,12). At Fujian Medical University Union Hospital, we have enhanced the surgical method by combining a right cervical auxiliary operating port with sternal lifting. This approach significantly expands the operating space, providing a larger surgical field and greater operational flexibility. Therefore, this study aimed to explore and verify the application and safety of this improved surgical method in esophageal cancer surgery, offering new methods and insights for clinical practice to improve surgical outcomes for esophageal cancer patients. We present this article in accordance with the STROBE reporting checklist (available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-1380/rc).

Highlight box

Key findings
- The study introduces an innovative single-port inflatable video-assisted mediastinoscopic transhiatal esophagectomy (SP-IVMTE) technique, combining a right cervical auxiliary port and sternal lifting (Fujian union model), which enhances the surgical field and facilitates lymph node dissection. This method demonstrates improved safety and operability, offering a reliable alternative for esophageal cancer surgery.

What is known and what is new?
- Minimally invasive esophagectomy reduces trauma and enhances recovery, but limitations exist in operating space, especially in conventional mediastinoscopy.
- This manuscript introduces an innovative approach combining SP-IVMTE with auxiliary ports and sternal lifting (Fujian union model), providing improved operability and broader application potential in esophageal cancer surgery.

What is the implication, and what should change now?
- The improved SP-IVMTE technique offers a promising alternative to conventional methods, reducing postoperative complications and improving patient outcomes.
- This approach should be considered for wider clinical application, especially in patients with poor respiratory function or severe pleural adhesions, to optimize esophagectomy outcomes.
- Further prospective studies are needed to validate long-term benefits and integrate this method into standard surgical protocols.

Methods

Study population

This study reviewed the database of patients who underwent esophagectomy for esophageal cancer at the Department of Thoracic Surgery, Fujian Medical University Union Hospital, from January 2022 to June 2024. The inclusion criteria were: (I) histologically confirmed esophageal squamous cell carcinoma by preoperative endoscopy; and (II) no distant metastasis detected in preoperative examinations or intraoperatively. The exclusion criteria were: (I) history of previous malignancy or concomitant malignancies in other locations; (II) esophagectomy performed via thoracotomy or laparotomy; and (III) incomplete data. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Ethics Committee of Fujian Medical University Union Hospital (No. 2024KY037), and informed consent was obtained from all patients.

The study enrolled 304 patients, with 274 patients undergoing video-assisted MIE (VAMIE) and 30 patients in the SP-IVMTE group. Clinical baseline data and surgical outcome data were collected, including operation time, blood loss, extent of lymph node dissection, and postoperative complications. The diagnosis of anastomotic

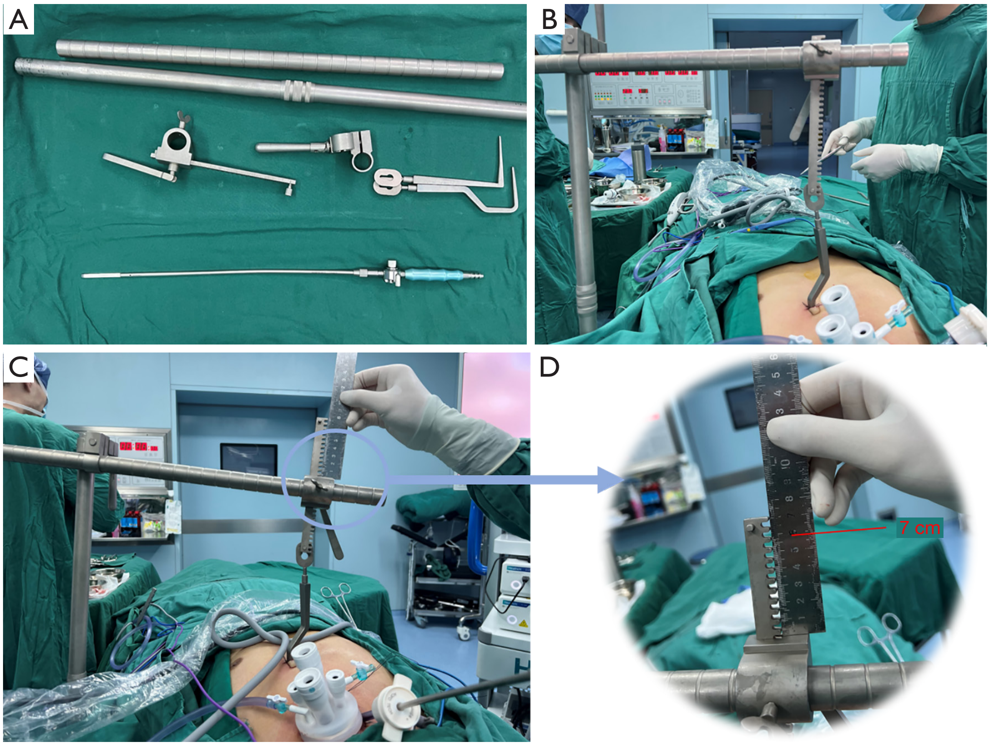

Figure 1 The structure of the sternum retractor and its application during use. (A) Sternum suspension retractor. (B) Before the sternum is raised. (C) The state after sternal lifting. (D) A magnified view of (C), showing the sternum elevated by approximately 7 cm.

leak was based on: (I) clinical presentation of apparent gastrointestinal content leakage into the wound; and (II) radiographic evidence of contrast medium extravasation from the gastrointestinal tract into the wound, neck, or mediastinal tissues on upper gastrointestinal series or computed tomography (CT) scan.

Surgical procedure

This innovative surgical technique is referred to as the "Fujian union model", which integrates single-port inflatable mediastinoscopy, a right cervical auxiliary port, and sternal lifting. Under general anesthesia, the patient was placed in the supine position with bilateral lung ventilation. The fixation rod of the sternal retractor was installed on the left side of the operating table. A 0.5 cm incision was made at the second or third intercostal space at the left sternal border. After minimal dissection, the retractor hook was inserted behind the sternum, connected to the fixation rod, and the sternum was elevated by 5–8 cm (*Figure 1*). Following this, a right cervical auxiliary operating port was used for mediastinoscopic esophagectomy, laparoscopic gastric mobilization, transhiatal esophageal mobilization, and complete mediastinal lymph node dissection.

Cervical approach

A 4 cm longitudinal incision is made along the anterior edge of the left sternocleidomastoid muscle. Subsequently, the cervical esophagus is mobilized, and the left recurrent laryngeal nerve is identified and mobilized. Lymph nodes adjacent to the left recurrent laryngeal nerve are also dissected. A 5 mm incision is made approximately 1 cm medial to the right sternocleidomastoid muscle, followed by the insertion of a wound protector into the cervical incision to seal the gap. Carbon dioxide (6–10 mmHg) is used to create an enclosed mediastinal operative space (*Figure 2*). A conventional thoracoscope is utilized for auxiliary operations, and instruments are used to elevate the trachea while assisting in smoke evacuation. The primary surgeon should mobilize the esophagus as distally as possible, reaching the level of the inferior pulmonary vein or the diaphragmatic hiatus. Lymph nodes adjacent to the esophagus, tracheobronchial region, and subcarinal area are

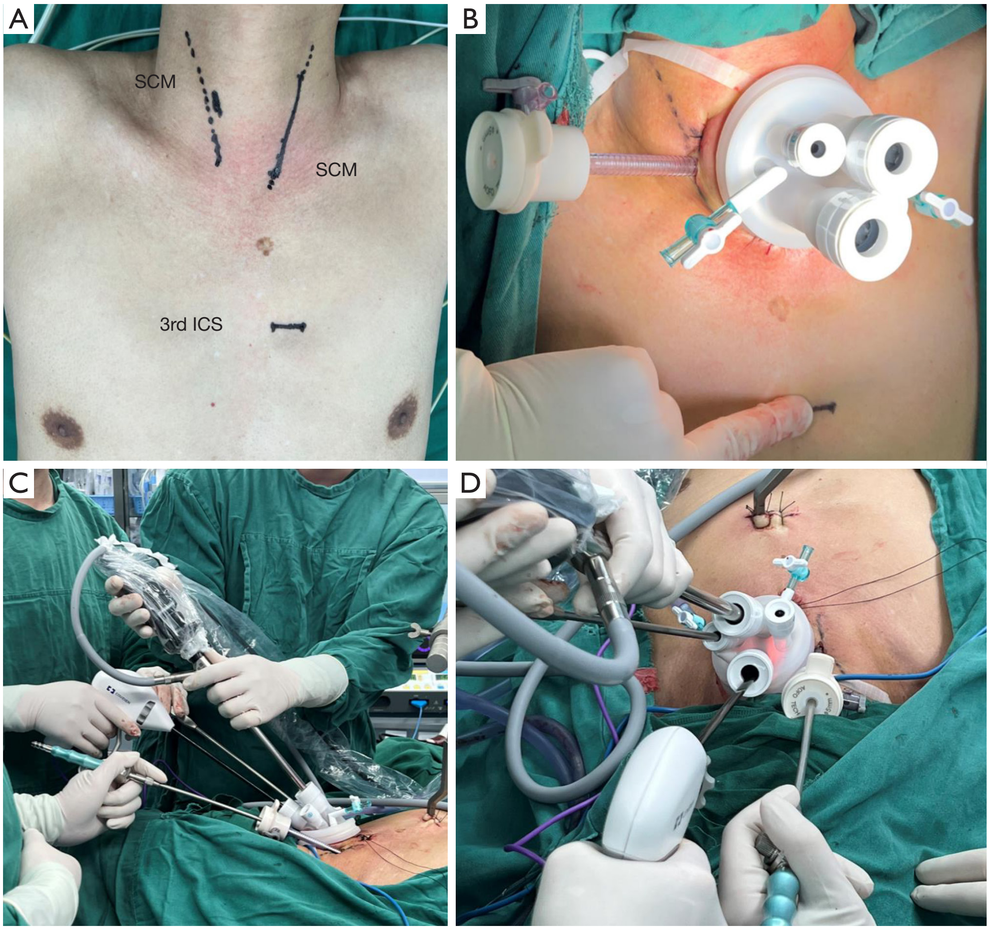

Figure 2 The cervical incision and intraoperative views during the procedure. (A) Surgical incision and the sternal suspension retractor Schematic diagram of incision preoperatively. (B) Wound protector and right auxiliary operating port. (C) Lateral view during surgery. (D) Overhead view during surgery. 3rd ICS, third intercostal space; SCM, sternocleidomastoid muscle.

dissected. All intraoperative lymph nodes are sent for frozen section analysis to determine the presence of metastasis. If lymph node metastasis is detected intraoperatively, the procedure should be converted to a conventional thoracoscopic surgery to perform a radical three-field lymphadenectomy.

Abdominal procedure

The abdominal and cervical surgeries are performed sequentially by a single primary surgeon. A 1 cm exploration port is located to the right of the umbilicus. The first auxiliary port (0.5 cm) is positioned 1 cm below the intersection of the right midclavicular line and the subcostal margin. The main operating port (1.2 cm) is located at the midpoint between the umbilicus and the first auxiliary port. The second auxiliary port (0.5 cm) is placed 4 cm below the intersection of the left midclavicular line and the subcostal margin. Pneumoperitoneum is established with carbon dioxide (8–10 mmHg). The Maryland dissector or ultrasonic scalpel is used to mobilize the greater and lesser curvatures of the stomach and the abdominal esophagus. The left gastric vessels are ligated.

Statistical analysis

To minimize selection bias, 1:4 propensity score matching (PSM) with a caliper value of 0.02 was performed using a logistic regression model. Categorical variables were expressed as frequencies and percentages, and continuous variables as mean ± standard deviation or median (interquartile range). Categorical variables were compared

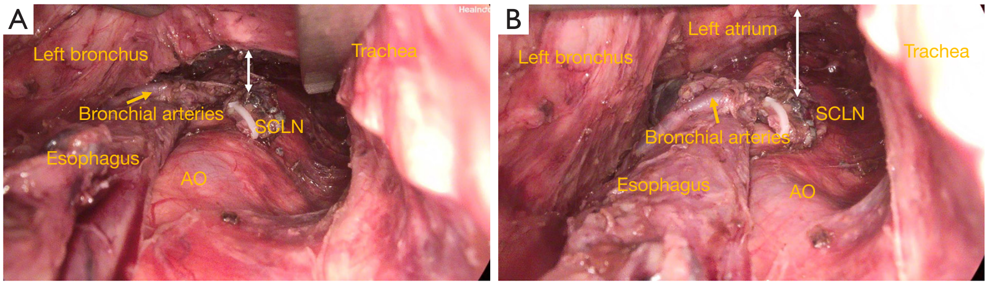

Figure 3 Compares the surgical operating space with and without the use of instruments for tracheal elevation and sternal retraction. (A) Anatomical situation without the trachea being elevated by instruments through the auxiliary operating port and without the application of force by the sternal retractor. (B) The anatomical situation with the trachea elevated by instruments through the auxiliary operating port and the application of force by the sternal retractor. The white lines in the figure indicate the same spatial position, demonstrating a significant expansion of the surgical operating space. AO, aorta; SCLN, subcarinal lymph node.

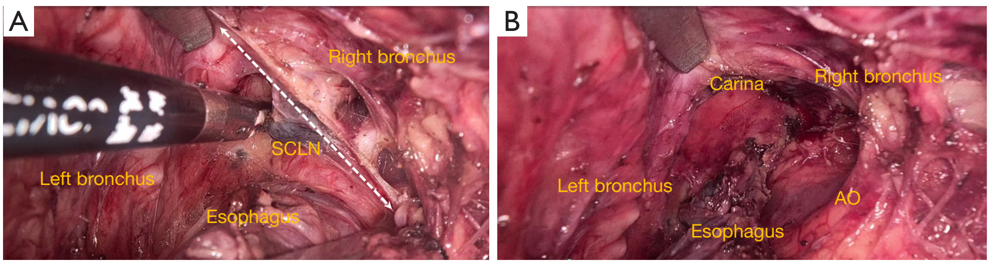

Figure 4 The dissection of subcarinal lymph nodes. (A) Schematic diagram of subcarinal lymph node dissection. The dashed lines indicate the counter-traction formed by the instruments through the auxiliary operating port and those of the primary surgeon, exerting a downward pulling force on the subcarinal lymph nodes. During this process, the Maryland dissector is used to separate the lymph node spaces in the subcarinal region and perform the dissection. (B) A schematic diagram after subcarinal lymph node dissection, clearly showing the anatomical region following the successful removal of the lymph nodes. AO, aorta; SCLN, subcarinal lymph node.

using the Chi-squared test, Fisher's exact test, or Mann-Whitney *U* test, and continuous variables using the Student's *t*-test. All statistical analyses were performed using SPSS v.26.0 (SPSS Inc., Chicago, IL, USA) for Windows. All reported P values were two-sided, with P values <0.05 considered statistically significant.

Results

All surgeries planned for the SP-IVMTE group were successfully completed without any observed intraoperative injuries, such as damage to the intercostal nerves, blood vessels, heart, or intrathoracic vessels. During the postoperative observation period, no bleeding, infection, or pain was reported at the intercostal incision for sternal suspension. Sternal elevation enhanced the visual field by increasing the available workspace and working angles for the mediastinoscopy port. Elevating the upper edge of the manubrium raised the corresponding side of the cervical incision protector, successfully expanding the operative space within the mediastinum. Additionally, the right auxiliary operating port allowed for tracheal elevation, further expanding the operative space (*Figure 3*) and facilitating esophageal dissection. The use of the auxiliary port significantly reduced the difficulty of subcarinal lymph node dissection (*Figure 4*). This approach also facilitated the identification of critical structures, including the azygos arch, thoracic duct, trachea, carina, and bronchi, thereby avoiding damage to these structures. When separating the esophagus from the lower mediastinum through the diaphragmatic hiatus under laparoscopy, the suspension technique expanded the mediastinal space, reducing compression of the left atrium by the mediastinal retractor.

Table 1 presents the detailed clinicopathological

Table 1 Comparison of baseline characteristics of patients in VAMIE and SP-IVMTE

Variables	Unmatched cohort			Marched cohort		
	VAMIE (n=274)	SP-IVMTE (n=30)	P	VAMIE (n=120)	SP-IVMTE (n=30)	P
Sex (male)	208 (75.9)	21 (70.0)	0.62	87 (72.5)	21 (70.0)	0.96
Age (years)	62.0 [56.0, 66.0]	63.0 [58.0, 69.0]	0.14	63.0 [59.5, 68.0]	63.0 [58.0, 69.0]	0.84
Smoking history (+)	154 (56.2)	14 (46.7)	0.42	56 (46.7)	14 (46.7)	>0.99
Alcohol consumption (+)	97 (35.5)	9 (30.0)	0.70	34 (28.3)	9 (30.0)	>0.99
Weight (kg)	60.0 [53.8, 66.8]	60.0 [53.6, 62.4]	0.79	60.0 [53.0, 67.1]	60.0 [53.5, 62.4]	0.78
Body mass index (kg/m^2)	21.8 [20.1, 23.7]	21.6 [20.0, 23.7]	0.89	21.9 [20.2, 23.8]	21.6 [20.5, 23.7]	0.74
ASA (I/II/III)	15/225/34	2/25/3	0.86	9/97/14	2/25/3	>0.99
MVV (L/min)	105 [91.5, 114]	99.8 [95.4, 109]	0.22	105 [88.6, 114]	99.8 [95.4, 109]	0.33
FEV1 (L)	2.72±0.63	2.38±0.61	0.006	2.49±0.59	2.38±0.61	0.37
Comorbidities hypertension (+)	45 (16.4)	9 (30.0)	0.11	27 (22.5)	9 (30.0)	0.84
Diabetes (+)	21 (7.7)	4 (13.3)	0.30	9 (7.5)	4 (13.3)	0.89
Cardiovascular diseases (+)	7 (2.6)	2 (6.7)	0.22	4 (3.3)	2 (6.7)	0.76
COPD (+)	14 (5.1)	5 (16.7)	0.03	13 (10.8)	5 (16.7)	0.36
Cancer location (U/M/L)	25/149/100	6/14/10	0.19	17/69/34	6/14/10	0.49
Clinical stage (I/II/III/IV)	90/55/128/1	16/10/4/0	0.002	76/24/20/0	16/10/4/0	0.32

Data are presented as median [range], n (%), n, or mean ± SD. +, positive. ASA, American Society of Anesthesiologists; COPD, chronic obstructive pulmonary disease; FEV1, forced expiratory volume in 1 second; MVV, maximal voluntary ventilation; SD, standard deviation; SP-IVMTE, single-port inflatable video-assisted mediastinoscopic transhiatal esophagectomy; U/M/L, upper/middle/lower; VAMIE, video-assisted minimally invasive esophagectomy.

characteristics of patients in the transthoracic and transcervical groups before (n=304) and after (n=150) PSM. Before matching, there were significant differences between the groups in forced expiratory volume in 1 second (FEV1) (P=0.006), chronic obstructive pulmonary disease (COPD) (P=0.03), and clinical staging (P=0.002). To reduce bias, a 1:4 PSM was performed, resulting in the inclusion of 120 patients in the VAMIE group and 30 patients in the SP-IVMTE group. Post-matching, no significant differences were observed in the clinical characteristics, indicating comparability between the groups. After matching, the majority of patients in both groups were male [VAMIE group: 87 (72.5%) *vs.* SP-IVMTE group: 21 (70.0%)], with a mean age of 63 years. Most patients had stage I disease [VAMIE group: 76 (63.3%) *vs.* SP-IVMTE group: 16 (53.3%)].

There were no statistical differences between the two groups in terms of operation time (P=0.97), the number of lymph nodes dissected (P=0.07), cervical drainage tube removal time (P=0.15), and postoperative hospital stay (P=0.46). Similarly, no significant differences were observed between the groups in postoperative neural invasion (P=0.96) and vascular invasion (P=0.73). In the VAMIE group, one patient required a second surgery for hemostasis due to thoracic bleeding, while no reoperations were needed in the SP-IVMTE group. Regarding postoperative complications, the SP-IVMTE group had fewer instances of fiber-optic bronchoscopy (FOB) suction compared to the VAMIE group (P=0.02). However, there were no statistical differences between the groups in esophagogastric anastomotic leak (EGAL) (P=0.80), recurrent laryngeal nerve paralysis (RLNP) (P=0.74), hepatorenal dysfunction (P=0.43), arrhythmia (P>0.99), pleural effusion (P=0.96), and chylothorax (P=0.36) (*Table 2*).

Discussion

Minimally invasive techniques have become the primary approach for treating esophageal cancer, aiming to achieve radical resection while minimizing postoperative

Table 2 Comparison of perioperative data and postoperative complications between VAMIE and SP-IVMTE

Variables	VAMIE (n=120)	SP-IVMTE (n=30)	P
Operation time (min)	302 [272, 348]	304 [266, 381]	0.97
Lymph node dissection count	33.0 [24.8, 42.0]	27.5 [21.2, 36.5]	0.07
Vascular invasion (+)	13 (10.8)	2 (6.7)	0.73
Nerve infiltration (+)	18 (15.0)	5 (16.7)	0.96
Neck extubation time (days)	6.00 [4.00, 8.00]	5.00 [4.00, 6.75]	0.15
Hospitalization days	9.0 [8.00, 11.0]	10.00 [8.00, 11.0]	0.46
Reoperation (+)	1 (0.8)	0 (0.0)	>0.99
EGAL (+)	3 (2.5)	1 (3.3)	0.80
FOB suction (+)	47 (39.2)	5 (16.7)	0.02
RLNP (+)	14 (11.7)	2 (6.7)	0.74
Hepatorenal dysfunction (+)	23 (19.2)	7 (23.3)	0.43
Arrhythmia (+)	24 (20.0)	6 (20.0)	>0.99
Pleural effusion (+)	21 (17.5)	6 (20.0)	0.96
Chylothorax (+)	1 (0.8)	1 (3.3)	0.36

Data are presented as median [range] or n (%). +, positive. EGAL, esophagogastric anastomotic leak; FOB, fiber-optic bronchoscopy; RLNP, recurrent laryngeal nerve paralysis; SP-IVMTE, single-port inflatable video-assisted mediastinoscopic transhiatal esophagectomy; VAMIE, video-assisted minimally invasive esophagectomy.

complications (13). Currently, VAMIE is the main method of minimally invasive surgery (2-4). In recent years, there has been increasing discussion about the potential use of the mediastinal approach as an alternative for esophagectomy (5,10). Compared to VAMIE, IVMTE ensures the relative integrity of the thoracic cavity, results in less interference with the heart and lungs, reduces blood loss, and lowers postoperative morbidity, while ensuring tumor safety and the reliability of lymph node dissection (14). Several comparative studies have confirmed the feasibility of IVMTE, demonstrating that its therapeutic outcomes are similar to those of VAMIE during long-term follow-up (15,16).

Although IVMTE boasts numerous advantages, its limitations cannot be ignored. The proximity of the esophagus to critical structures such as the aorta, trachea, heart, azygos arch, bronchial arteries, and thoracic duct increases the risk of damaging these adjacent structures during surgery within the narrow mediastinal space (17,18). Additionally, systematic lymph node dissection is crucial in radical esophagectomy for cancer. Concerns have been raised about the dissection of right recurrent laryngeal nerve lymph nodes and subcarinal lymph nodes, as this might compromise the oncological principles of surgery. Consequently, IVMTE has strict indications, being suitable only for T1 or T2 patients without invasive tumors or mediastinal lymph node metastasis. Due to its extrathoracic approach, IVMTE is also suitable for patients with severe pleural adhesions or poor respiratory function (19,20). However, these limitations have restricted the widespread adoption of IVMTE (5,10).

Nevertheless, due to the advantages of IVMTE, numerous researchers have sought to refine this technique for broader application. In 1993, Bumm *et al.* introduced mediastinoscopy for esophageal cancer, and in 2004 Japanese scholar Tangoku reported the short-term outcomes of mediastinoscope-assisted transhiatal esophagectomy (MATHE) (21,22). However, the extent of resection in MATHE, especially concerning upper mediastinal lymph node dissection, remains contentious. In 2017, Fujiwara *et al.* first applied IVMTE for radical esophagectomy, significantly advancing and popularizing the technique globally (5). Yet, the challenge of poor exposure in patients with flat chests persists, complicating lymph node dissection (23). In response, Zhu proposed using a sternal retractor to lift the sternum, thereby increasing the working space for mediastinoscopic esophagectomy, making IVMTE easier and safer (11). Similarly, Hiroyuki Daiko performed bilateral transcervical mediastinoscopy-assisted transhiatal laparoscopic esophagectomy (BTCMATLE) to enhance exposure (12). Hua Tang reported reducing incision size by employing a single-incision plus one-port technique, albeit requiring special instruments such as the 5-mm Olympus flexible endoscope (20).

At Fujian Medical University Union Hospital, drawing from the experiences of other centers and leveraging our resources, we innovatively employed sternal elevation combined with a right cervical auxiliary port. This significantly increased the operational space, allowing the use of conventional thoracoscopic instruments and avoiding the constraints of special instruments, thereby enabling more centers to perform IVMTE. We initially tried using a wound protector for the auxiliary port instruments, but the proximity of the main operative instruments caused interference, hindering the procedure. The addition of the right cervical port facilitated better dissection and allowed smoother transitions between operative tools. We understand that subcarinal and peribronchial lymph node dissection is challenging via the cervical approach due to their superior location, making complete dissection difficult. However, the sternal elevation and auxiliary port assistance allowed more conventional instruments to be used, making dissection easier. Thanks to sufficient exposure, we found no significant difference in mediastinal lymph node dissection between Fujian Medical University Union Hospital IVMTE and thoracoscopic surgery. Our propensity score-matched analysis demonstrated no significant difference in short-term postoperative complications between the two groups, with fewer patients requiring sputum aspiration in the transcervical group. This reduced need for sputum aspiration could be attributed to less lung injury from avoiding thoracic invasion and the absence of thoracic drainage tubes, which might encourage patients to cough more freely. This study has certain limitations. First, it is a retrospective study with a relatively small sample size, which may introduce selection bias. Due to the limited indications for transcervical mediastinal surgery, 86.7% of the patients were in stages I and II, with 53.3% in stage I. Additionally, a higher proportion of patients undergoing transcervical mediastinal surgery had COPD, reaching 16.7%, which inevitably introduces selection bias. Second, the current research primarily focuses on the short-term outcomes of mediastinoscopic esophagectomy, such as surgical results and postoperative complications, lacking long-term follow-up on surgical prognosis. However, according to studies from other centers, mediastinoscopic esophagectomy appears to yield clinical outcomes similar to traditional three-field surgery. In this study, the modified method improved exposure of the mediastinal field, potentially providing some advantages for this procedure. Nevertheless, further prospective studies are needed to gather more postoperative data and long-term follow-up results.

Conclusions

The combined use of an auxiliary operating port and sternal elevation in inflatable transcervical mediastinoscopic esophagectomy provided good operability and a stable surgical field, making it a safe and reliable MIE technique with promising potential for esophageal cancer patients.

Acknowledgments

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-1380/rc

Data Sharing Statement: Available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-1380/dss

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Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-1380/coif). The authors have no conflicts of interest to declare.

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 (as revised in 2013). The study was approved by the Ethics

Committee of Fujian Medical University Union Hospital (No. 2024KY037), and informed consent was obtained from all patients.

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