Investigating Clinical Significance of 3D Single-hole Thoracoscopy Surgery for Mediastinal Tumor Resection With Artificial Pneumothorax

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AIM: This study aims to analyze and compare the clinical efficacy and safety between single-hole approach and two-hole video-assisted thoracoscopic surgery (VATS) for mediastinal tumor resection.
METHODS: This study included 62 patients who received VATS mediastinal tumor resection in the Thoracic Department of the Affiliated Hospital of Xuzhou Medical University, between March 2020 and March 2022. Patients were divided into a single-hole VATS group (27 cases) and a two-hole VATS group (35 cases). The two groups were compared for their clinical characteristics (such as age, gender, tumor size, body mass index (BMI), comorbidities, and pathological findings), postoperative outcomes (such as operation time, intraoperative bleeding, transfer to open surgery, drainage volume, extubating time, and hospital stay), postoperative complications, and pain score.
RESULTS: There were no significant differences in operation time, introperative bleeding volume, and postoperative complication rates between the two groups ($p > 0.05$). However, extubating time and hospital stay were significantly shorter in the single-hole VATS group than the two-hole VATS group ($p < 0.05$). Moreover, drainage volume was decreased in the single-hole VATS group compared to the two-hole VATS group ($p < 0.05$). The pain score was significantly lower on days 1 and 3 post-surgery in the single-hole VATS group than in the two-hole VATS group ($p < 0.05$).
CONCLUSIONS: In conclusion, 3D single-hole VATS mediastinal tumor resection is a safe and feasible option for treating mediastinal tumors compared to the traditional approach. Furthermore, it significantly reduces postoperative pain, lowers drainage duration and volume, as well as extubating time, promotes faster recovery, and reduces hospital stays.

Keywords: 3D single-hole thoracoscopy; artificial pneumothorax; mediastinal tumors

Introduction

The majority of mediastinal tumors are benign and can be effectively resected. Consequently, reducing surgical trauma, alleviating pain, and accelerating recovery have become primary concerns for thoracic surgeons. While traditional open-chest surgery provides a clear visualization, it is associated with significant surgical trauma, substantial scarring, considerable postoperative pain, prolonged recovery, and various other complications. In contrast, video-assisted thoracoscopic surgery (VATS) for mediastinal tumor resection minimizes these limitations by offering a minimally invasive approach, resulting in aesthetically favorable incisions and minimal physiological disruption, which has contributed to its increasing adoption in mediastinal tumor management [1–3].

Thoracoscopic surgery for mediastinal tumors is now well established, and surgical techniques are generally categorized into multiple incisions with double-lumen endotracheal intubation or single-incision surgery and multiple incisions with artificial pneumothorax under single-lumen endotracheal intubation. While single-incision thoracoscopy results in less trauma compared to conventional muti-port thoracoscopy, it presents significant technical challenges and demands more advanced equipment. Undoubtedly, single-lumen endotracheal intubation alleviates patient trauma and eliminates the issue of inadequate ventilation often associated with double-lumen tubes. Under single-lumen ventilation, most surgeons prefer the three-hole technique to conduct the procedure [4–6].

We have optimized the existing surgical technique by employing a specialized single-hole puncture device and artificial pneumothorax to conduct 3D single-hole mediastinal tumor resection under single-lumen endotracheal intubation. This procedure, which we called 3D single-hole inflatable thoracoscopic mediastinal tumor resection, ensures optimal mediastinal exposure—particularly the thoracic gland tissue—through controlled inflation while maintaining the benefits of minimal incision trauma inherent to single-hole procedure. Furthermore, single-lumen endotracheal intubation is simple, minimizing the challenges associated with single-lung ventilation for the surgeon, and reducing lung

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tissue damage. The surgical outcomes have proven consistently reliable. However, there are limited reports on this surgical approach. Therefore, we present our experience with this approach, including a clinical review and comparative analysis of several patients undergoing routine two-port thoracoscopic mediastinal tumor resection to evaluate its clinical efficacy.

Materials and Methods

Recruitment of Study Participants

This study included 62 patients who underwent thoracoscopic mediastinal tumor resection in the Thoracic Surgery Department of the Affiliated Hospital of Xuzhou Medical University between March 2020 and March 2022. Patients were divided into single-hole and two-hole VATS groups. The study was reviewed and approved by the Ethics Committee of the Affiliated Hospital of Xuzhou Medical University (ethical approval number: XYFY2023-JS025-01) and conducted in compliance with the principles of the Declaration of Helsinki. Additionally, an informed consent form was signed by each patient.

The inclusion criteria for patient selection were as follows:
(a) Preoperative chest Computed Tomography (CT) or Magnetic Resonance Imaging (MRI) confirming an anterior mediastinal mass with a maximum diameter of 6 cm, no evident extra thoracic invasion, and patient age <80 years.
(b) Preoperative evaluation by a thoracic surgeon and anesthesiologist confirming surgical tolerance without any significant contraindications.

The exclusion criteria adopted during patients' recruitment were as follows:
(a) Patients who received neoadjuvant chemotherapy before surgery.
(b) History of previous chest surgery or medical condition causing thoracic adhesions.
(c) Patients with incomplete clinical and follow-up data.

Surgical Procedures

Single-hole group: Patients were positioned supine under general anesthesia with single-lumen endotracheal intubation. A single 3-cm incision was developed in the 4th or 5th intercostal space along the anterior axillary line (Figs. 1,2). The surgery was conducted using 3D thoracoscopy with artificial pneumothorax. The equipment used during the procedure included a 3D High Definition Camera Control Unit (TC200, TC302, Karl Storz SE, Goleta, CA, USA), a TIPCAM 1 S 3D (26605AA, 26605BA, Karl Storz SE, Tuttlingen, Germany), and a Cold Light Fountain Insufflator (U1400, U1500, Karl Storz SE, Tuttlingen, Germany), which were all obtained from Karl Storz.

Single-lumen endotracheal intubation with single-lung ventilation was used to reduce the impact of single-lung ventilation on the surgery, minimizing lung injury, and reducing the risk of postoperative pulmonary complications. A special single-hole puncture device was utilized to insufflate CO_2 at a pressure of 8–10 cmH_2O (Fig. 3), improving the surgical field visibility. For patients with mediastinal tumors, especially those with myasthenia gravis and solid thymic tumors, a total thymectomy was conducted. The procedure progressed from the right to the left side, gradually separating the tumor and thymus tissue. The upper margin was carefully dissected to expose the ring vein (Fig. 4), with careful hemostasis and handling of thymus veins, which were cut off using an ultrasonic scalpel. The resection included the thymus and surrounding adipose tissue, extended to both sides of the thymus angle, inferiorly to the pericardial diaphragm fat, and laterally to the medial edge of the diaphragmatic nerve. All thymic tumors were accessed through the right thoracic cavity. A 10-mm, 30-degree endoscope was employed for visualization.

The single-hole strategy was used with the incision (3–4 cm) located at the 4th or 5th interrib along the anterior axillary line. Surgical instruments were selected flexibly during the operation, with real-time adjustment to the endoscopic approach. A chest drain was placed through the same incision after surgery. Surgical specimens were obtained using an extraction bag and sent for pathological examination. Due to the relatively large single-hole aperture, specimen removal was smooth, even for larger masses, eliminating the need for prolonged incision.

Two-hole group: Patients were placed in the lateral decubitus position under general anesthesia with double-lumen endotracheal intubation. The procedure involved two surgical incisions and was conducted using common thoracoscopy through Karl Storz DR.-Karl-Storz-SE 34 equipment (Karl Storz, Tuttlingen, Germany).

A 1-cm incision was made at the 7th intercostal area along the axillary midline for thoracoscope insertion, while a 3-cm incision was made at the 4th intercostal space along the axillary line for surgical procedure. The electrocautery or an ultrasonic knife was used to incise the mediastinal pleural overlying tumor surface. The tumor was excised completely with careful dissection and suction assistance. Furthermore, the extra pleural fat, prepericardial fat, and lymph nodes were thoroughly removed to avoid damage to the innominate vein, diaphragmatic nerve, and intrathoracic vessels to ensure a safe and effective resection.

Postoperative Management

All patients received standardized postoperative management. SpO_2, electrocardiogram (ECG), and blood pressure were routinely monitored during the early postoperative period. A chest X-ray was routinely performed on postoperative day 1 and again on the first day after drain removal to evaluate the pleural effusion or gas accumulation. Early postoperative chest drain removal was performed if the following criteria were met: (1) stable hemodynamics, (2) stable spontaneous breathing (respiratory rate <30 times/min), (3) arterial blood gas analysis within normal limits low-flow oxygen inhalation (such as PaO_2 >80 mmHg, $PaCO_2$

<40 mmHg, pH >7.30, and SpO_2 >90%), and (4) full consciousness.

Additionally, early postoperative chest drain was encouraged if there was no air leakage, drainage was less than 200 mL within 24 hours, and the normal chest X-ray and vital signs remained stable. All patients had their chest drains removed before discharge.

Postoperatively, under the guidance of a neurologist, patients were given the same medication as before surgery once myasthenia gravis (MG) symptoms were controlled. However, the dose and timing of pyridostigmine and prednisone were adjusted in critically ill patients based on clinical symptoms. If necessary, plasmapheresis or intravenous immunoglobulin (IVIG) therapy was considered. For critically ill patients who had undergone endotracheal intubation, assisted ventilation with new endotracheal intubation was provided if necessary. Opioid analgesics were avoided due to the risk of respiratory depression and induction of an MG crisis. As a general practice, painkillers were not routinely used after surgery unless necessary. In cases of intolerable pain, low-dose non-steroidal anti-inflammatory drugs (NSAIDs), such as diclofenac sodium, were preferred.

Postoperative Pain Score

Postoperative pain was evaluated using the visual analog scale (VAS), which ranges from 0–10 points [7], where 0 points indicate no pain, 1–3 points show mild pain (generally tolerable), 4–6 points represent moderate pain, which may affect sleep, but still tolerable, and 7–10 points denote severe pain.

Statistical Analysis

Statistical analysis was performed using SPSS 17.0 (SPSS, Chicago, IL, USA). All laboratory tests were independently performed in triplicate. The Shapiro-Wilk test was employed to evaluate the normality of the data, and if $p > 0.05$, the data were considered to follow a normal distribution. Continuous variables following a normal distribution were expressed as mean ± standard deviation. Normally distributed continuous variables were analyzed using the *t*-test. Categorical variables were represented as counts and percentages, and group comparisons were performed using the Chi-square test or Fisher's precision probability test, with a *p*-value < 0.05 considered statistically significant. Moreover, Fisher's exact test was applied when any expected frequency in a contingency table was less than 5; otherwise, the Chi-square test was employed.

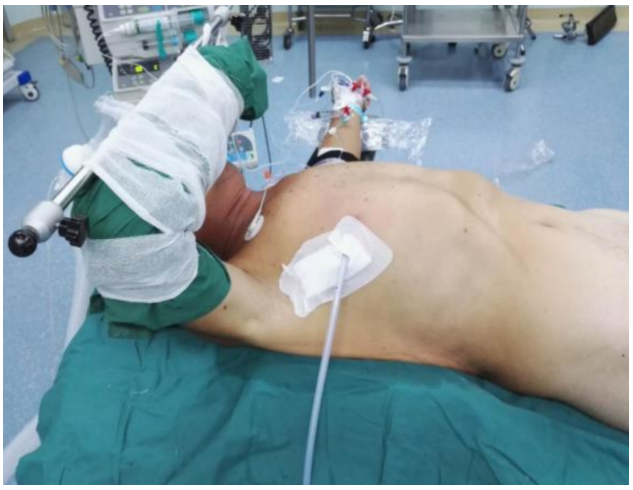

Fig. 1. Patient position during the procedure.

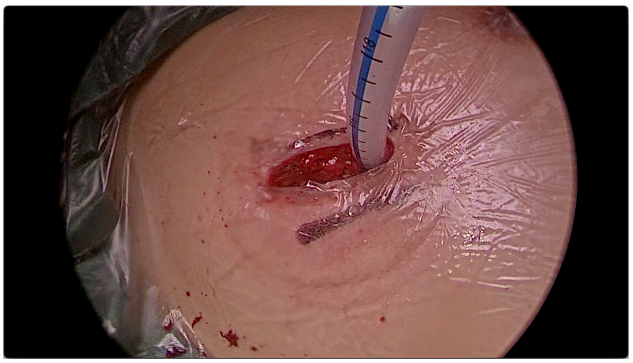

Fig. 2. 3 cm incision: 4th/5th intercostal space (anterior axillary line).

Fig. 3. Single-hole puncture device used during the procedure.

Results

Clinical Features of the Patients

Patients (n = 62) were divided into two groups based on the surgical approach: the single-hole group (n = 27) and the two-hole group (n = 35). There were no statistical differences between the two groups regarding clinical data, including age, gender, body mass index (BMI), tumor size, pathological classification, and concurrent diseases. The clinical characteristics of the patients are summarized in Table 1.

Furthermore, no significant differences were observed between the two groups regarding operation time, intraopera-

Table 1. Baseline characteristics of the study participants.

Variables	Single-hole VATS (n = 27)	Two-hole VATS (n = 35)	t/χ^2	p-value
Age (years)	57.6 ± 14.6	55.3 ± 12.1	0.678	0.5003
Gender (male/female)	16/11	19/16	0.154	0.695
Tumor size (cm)	4.2 ± 1.4	3.8 ± 1.3	1.16	0.250
Body mass index (BMI) (kg/m^2)	24.7 ± 3.4	23.5 ± 2.3	1.66	0.103
Comorbidities (n, %)				
Hypertension	5 (18.5%)	7 (20.0%)	0.021	0.884
Diabetes	3 (11.1%)	5 (14.2%)		1.000
Chronic obstructive pulmonary disease (COPD)	2 (7.4%)	1 (2.8%)		0.575
Coronary heart disease	1 (3.7%)	3 (8.5%)		0.626
Myasthenia gravis (MG)	3 (11.1%)	5 (14.2%)		1.000
Others	13 (48.1%)	14 (40.0%)	0.412	0.521
Pathology				
Thymoma	10 (37.0%)	14 (40.0%)	0.056	0.812
Thymic Cyst	7 (25.9%)	8 (22.8%)	0.078	0.780
Mediastinum Cyst	4 (14.8%)	8 (22.8%)		0.526
Pericardial Cyst	3 (11.1%)	4 (11.4%)		1.000
Schwannoma	3 (11.1%)	1 (2.8%)		0.309

VATS, video-assisted thoracoscopic surgery.

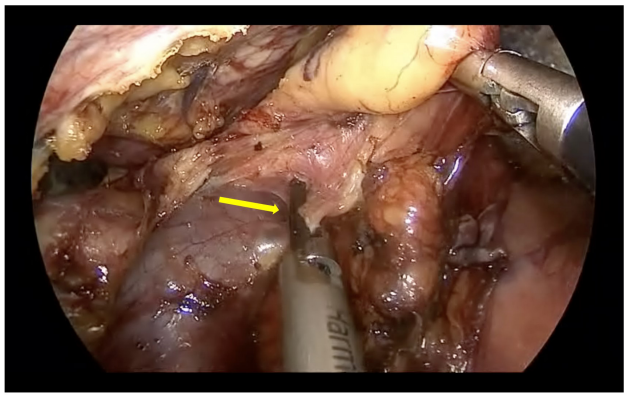

Fig. 4. An illustration of a representative thymic vein (yellow arrow).

tive bleeding, and postoperative complications ($p > 0.05$). However, the drainage volume, extubating time, and hospital stay in the single-hole group were substantially lower than in the two-hole group ($p < 0.05$). Postoperative mortality and phrenic nerve palsy were 0 in both groups, with no statistical difference ($p > 0.05$). Moreover, a significant difference was found in the VAS pain score between the two groups on postoperative days 1 and 3 ($p < 0.05$). Additionally, postoperative drainage, hospital stay, and pain levels were significantly better in the single-hole group than the two-hole group, with no disadvantage in operation time or postoperative complications (Table 2).

These results suggest that the safety of the 3D single-hole VATS group was comparable to that of the traditional two-hole VATS group. Furthermore, the 3D single-hole group had shorter drainage duration and reduced postoperative hospital stays compared to the traditional two-hole group.

Follow-up Results

All patients were followed up through outpatient visits or telephone calls, with a mean follow-up duration of 12 months. During the follow-up duration, all patients reported substantial symptom improvement, and none experienced death or recurrence.

Discussion

Over the past decade, single-port thoracoscopy technology has gradually advanced. In 2011, Gonzalez *et al.* [8] was the first to report single-port thoracoscopic lobectomy, making a significant milestone in the advancement of this technique. Compared to traditional thoracoscopy techniques, single-port thoracoscopy has introduced significant differences in visual field, instrument selection, and operating angle. Traditional thoracoscopy usually requires 2–3 intercostal access points, which facilitates the procedure but leads to greater postoperative pain and incision extension for larger specimens [9]. In contrast, our approach employs a single-port surgical technique, effectively addressing operational requirements while minimizing incision-related trauma.

Single-lumen endotracheal intubation simplifies the anesthesia process and minimizes airway injury. A significant advantage of single-port thoracoscopy is its reliance on a single incision, thereby avoiding damage to the chest wall muscles, reducing postoperative pain and numbness around the incision site, and accelerating postoperative recovery. The incidence of complications remains low, with no reported perioperative deaths. While a single-incision approach is feasible for simple resections of mid-posterior mediastinal tumor and chest wall lesions, conducting a total thymectomy poses greater challenges. These challenges

Table 2. Intraoperative and postoperative clinical conditions of patients with mediastinal tumors.

Variable	Single-hole VATS	Two-hole VATS	t/χ^2	p-value
Operation time (min)	92.5 ± 30.1	85.5 ± 25.3	0.99	0.324
Intraoperative bleeding (mL)	71.6 ± 26.2	80.4 ± 30.5	–1.20	0.236
Transfer to open surgery (n, %)	0	0		
Drainage volume (mL)	284.5 ± 78.4	350.8 ± 91.2	–3.01	0.004
Extubating time (h)	44.3 ± 16.8	64.1 ± 25.1	–3.53	0.001
Hospital stay (d)	3.5 ± 1.4	5.1 ± 1.9	–3.67	0.001
Postoperative complication (n, %)				
Chylothorax	0	0		1.000
Pulmonary infection	2 (7.4%)	1 (2.8%)		0.575
Incision infection	1 (3.7%)	2 (5.7%)		1.000
Urinary tract infection	1 (3.7%)	0 (0%)		0.436
Pleural effusion or pneumothorax	3 (11.1%)	5 (14.2%)		1.000
Arrhythmia	1 (3.7%)	2 (5.7%)		1.000
Postoperative mortality	0	0		1.000
Diaphragmatic paralysis	0	0		1.000
VAS pain score				
1st day	4.3 ± 1.1	6.2 ± 1.3	–6.09	<0.001
3rd day	3.2 ± 0.6	5.3 ± 0.8	–11.38	<0.001

VAS, visual analog scale.

include accessing the thymic angles bilaterally, working around the anterior portions of the phrenic nerves, and eliminating adipose tissue near the pericardial and diaphragmatic muscles. Successful execution of the procedure requires close collaboration between the assistant and primary surgeon, along with flexible and adjustable instruments and endoscope positioning.

For patients with concurrent myasthenia gravis, a total thymectomy is performed. Following a right thoracotomy, the right thymus and surrounding adipose tissue are excised first, and the innominate vein is carefully dissected through the superior vena cava. Specifically, special attention is required when dissecting the thymic vein, which is typically present on the right thymus [10–13]. In the 27 total thymectomy cases in our study, tumor diameter did not exceed 6 cm, and contralateral tissue was well exposed with minimal respiration impact during the procedure.

The primary limitation of traditional thoracoscopic surgery utilizing a two-dimensional (2D) endoscopic system is its flat surgical field visualization, lacking a sense of three-dimensionality. This makes it challenging to accurately distinguish bronchial and vascular structures, potentially increasing the risk of related injuries due to limited precision in dissection and maneuvering. However, advancements in technology have led to the development of three-dimensional (3D) endoscopic systems, which significantly improve depth perception and spatial awareness. By wearing 3D glasses, surgeons can achieve a three-dimensional view of the surgical field, making complex procedures such as bronchial reconstruction more precise.

The 3D endoscopic system offers several advantages:

• **Improved operability and comfort**: Compared to 2D conventional thoracoscopes, where the light source and thoracoscopic instrument shaft often form a 90° angle, resulting in interference, 3D thoracoscopic instruments align the optical fibers with the thoracoscope body, thereby minimizing interference between the operator and surgical instruments. Furthermore, the mirror holder enables one-handed operation, reducing surgeon fatigue and enhancing overall surgical comfort.

• **Image magnification and clarity**: While traditional 2D thoracoscopy offers up to fourfold image magnification, the 3D thoracoscopy system can achieve a twentyfold magnification, substantially enhancing surgical anatomy visualization and procedure accuracy.

• **Enhanced stereoscopic vision and depth perception**: The 3D imaging closely resembles direct surgical vision, which ensures more precise surgical incisions and reduces unnecessary tissue injury.

• **Autofocus functionality**: The 3D lens has an autofocus feature, which eliminates the need for frequent lens wiping, thereby enhancing surgical efficiency.

• **Dual-mode compatibility**: The 3D thoracoscopic surgery system supports both 3D and 2D modes, allowing surgeons to select the appropriate mode based on intraoperative preferences, ensuring optimal visualization for varying surgical requirements.

The trajectory of surgical advancement continues towards minimally invasive techniques, with single-port thoracoscopy representing the pinnacle of this innovation in thoracic surgery. However, the evolution of minimally inva-

sive thoracic surgery has reached a bottleneck phase. Future advancements are likely to rely on breakthroughs in surgical instruments and artificial intelligence (AI) integration. Among the latest innovations, the Da Vinci robotic system stands as the most sophisticated surgical platform available today, gaining increasing traction in thoracic surgery. This system offers enhanced accuracy and stability, providing surgeons with high-definition 3D imaging and a robotic arm system capable of replicating complex manual surgical maneuvers under magnification. These features facilitate hand-eye coordination and enable remote operations, making the system beneficial for complex thoracic procedures, such as certain chest tumor resections.

However, despite its unparalleled precision and advantages, the De Vinci system has certain limitations:

• The equipment requires significant spatial allocation. Preoperative preparation is lengthy and complex.

• The system is costly, including start-up, maintenance, and consumable expenses, which poses a significant barrier, limiting its widespread adoption, particularly in China.

• The Da Vinci endoscopic system currently needs multiple operating ports, which limits its utility in single-port thoracoscopic surgery, further hindering its integration into thoracic procedures.

Traditional 2D thoracoscopy presents flat imaging devoid of depth perception, making it challenging to manage complex cases or procedures such as lung cancer procedures or bronchial sleeve resections due to its incision constraints. In contrast, the 3D endoscopic system offers significant visualization advantages to the Da Vinci system while being compatible with single-port thoracoscopy. Additionally, it maintains a comparable overall cost to conventional endoscopes, making it a practical alternative to overcome the current challenges.

The development and widespread adoption of 3D single-hole thoracoscopy technology can redefine the future of minimally invasive thoracic surgery. Integrating single-port thoracoscopy with 3D visualization technology, minimizes damage to intercostal nerves and blood vessels, alleviates postoperative pain, and enhances cosmetic outcomes with concealed incisions. Furthermore, this technology enhances stereoscopic depth perceptions, bringing the surgical field closer to direct vision and ensuring greater precision in surgical operations, reducing the risk of surgical injuries [14–16] (Table 2).

Since the implementation of 3D single-hole inflatable mediastinal tumor resection, the author has summarized the following insights:

(1) Proper patient positioning is crucial, particularly for thymoma cases. The right 30-degree oblique position with the head elevated and feet exposed offers optimal surgical access. If necessary, the operating table can be adjusted to optimize the field of view. It is essential to avoid the indiscriminate use of electric hooks or ultrasonic scalpers without direct visualization, as this may lead to phrenic nerve or major blood vessel injury. In cases of accidental injury to critical vessels, this position facilitates rapid midline or lateral thoracotomy to ensure patient safety.

(2) Single-hole surgery requires considerable surgical experience and a strong rapport with surgical assistants. A primary challenge during the procedure is the interference of instruments, which can be reduced through extensive procedural familiarity. Additionally, using longer, specialized elbow instruments effectively mitigate instrument crowding and enhance maneuverability.

(3) Careful dissection of the inferior margin of the innominate vein is crucial to prevent thymic vein injury during thymic tumor excision. An ultrasonic knife is recommended for thymic vein detachment, and a vascular clamp may be employed for safer treatment if necessary. Furthermore, during the removal of the contralateral fat and thymic tissue, careful handling of the contralateral pleura is essential, as it is susceptible to damage. While some experts suggest contralateral pleura removal, the surgeon preserved the pleural intact in this cohort, excising only adipose tissue adjacent to it to maintain structural integrity.

In this group of cases, the surgical duration for thymic tumor patients was relatively prolonged due to the fixed sheath tubes in the single-hole puncture device, which often interfered with the endoscopes and surgical instruments. To overcome this issue, the operator proposed redesigning the single-hole puncture device or utilizing specialized instruments. Additionally, enhancing the operator's surgical skills are essential, necessitating close collaboration between the endoscope holder and the primary surgeon, and a thorough understanding of thoracoscopic techniques. Compared to traditional two-hole surgery, the operation time for the 3D single-hole group was comparable to that of the traditional surgery group. However, it demonstrated significant advantages in terms of exposure and safety, specifically:

(1) The artificial pneumothorax created in 3D sing-hole surgery provided substantially superior exposure compared to traditional approaches, allowing for clearer dissection.

(2) In cases of accidental bleeding, extending the original incision into the chest is not feasible. Instead, a midline opening is preferred, minimizing the surgical burden on both patients and surgeons. This limitation highlights the need for a robust surgical approach to reduce bleeding risk (Table 2).

(3) Modern thoracic surgery employs artificial pneumothorax to enhance field exposure and expedite the procedure by inducing lung collapse. However, this practice also changes intraoperative physiology, posing significant challenges for anesthesiologists in perioperative management. To overcome these complexities, anesthesiologists must optimize oxygenation, implement protective lung ventilation strategies, and maintain circulatory stability, necessitating a balance between surgical requirements and patient safety.

The combination of flat single-lung ventilation and artificial pneumothorax requires a precise balance between hemodynamics, ventilation, and surgical field exposure. Establishing minimum positive end expiratory pressure (PEEP) values is crucial to optimize lung compliance, minimize ventilatory driving pressure, and ensure adequate oxygenation and circulatory stability. Due to the increased risk of pulmonary complications associated with artificial pneumothorax and single-lung ventilation, optimizing intraoperative protective ventilation strategy is particularly critical. Based on our operational experience, literature review, and the vital signs of patients during anesthesia, we propose that maintaining an artificial pneumothorax pressure between 8–12 mmHg provides an optimal balance between surgical field exposure and patient safety.

The learning curve is primarily used in 3D single-port thoracoscopy to evaluate a surgeon's proficiency by analyzing perioperative outcomes, which reflect both the technical skill and inherent procedural complexity. Current evidence suggests that mastering single-hole thoracoscopic lobectomy generally needs 25 to 40 cases, with 30 cases being the typical recommendation. However, considering the experience gained in single-port thoracoscopic surgery and the surgeon's prior expertise, we estimate that the learning curve for 3D inflatable single-port thoracoscopy is approximately 15 cases [17].

Limitations and Future Directions

This study is a single-center retrospective analysis, which inherently introduces selection bias and is limited by a small sample size. Furthermore, the incidence of thymoma is rare, requiring longer case accumulation and follow-up duration, which may lead to incomplete follow-up data. Additionally, the study primarily involved patients with early-stage thymoma and good overall health, raising concerns regarding the safety and feasibility of this procedure in patients with multiple comorbidities or locally advanced thymoma. Given these limitations, there is an urgent need for a multicenter prospective randomized controlled trial with a larger sample size and extended follow-up to thoroughly evaluate the safety, efficacy, long-term oncological outcomes, and prognostic factors of 3D single-hole VATS thymectomy for thymoma. Furthermore, future research should focus on extending multi-center studies and advancing single-hole thoracoscopic approaches. Additionally, developing robotic-assisted single-hole thoracoscopic surgery through the xiphoid approach represents a promising future direction [16].

Conclusions

In conclusion, 3D single-port inflatable thoracoscopic mediastinal tumor resection is a safe and reliable approach for treating mediastinal tumors with no significant external invasion and a lesion size of <6 cm. This approach provides several advantages over conventional two-hole techniques, such as shorter drainage duration, reduced postoperative hospital stays, and reduced drainage volume. Furthermore, it minimizes postoperative pain and promotes faster recovery, making it a promising minimally invasive surgical technique for mediastinal tumor treatment.

Availability of Data and Materials

The datasets generated and analyzed during the current study are not publicly available due to patient privacy restrictions, but are available from the corresponding author upon reasonable request. The imaging and histopathology materials are archived in the Affiliated Hospital of Xuzhou Medical University database under the accession code of the author.

Author Contributions

QPL, conceptualization, data curation, writing–original draft, finish operation, project administration, and funding acquisition. BP, formal analysis, methodology, software. JJP, conceptualization, investigation, validation. YYL, formal analysis, resources, supervision, writing–review & editing. WMQ, medthodoly, guide operation. All authors have been involved in revising it critically for important intellectual content. All authors gave final approval of the version to be published. All authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

Ethics Approval and Consent to Participate

The study was reviewed and approved by the Ethics Committee of the Affiliated Hospital of Xuzhou Medical University (ethical approval number: XYFY2023-JS025-01) and conducted in compliance with the principles of the Declaration of Helsinki. Additionally, an informed consent form was signed by each patient.

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Conflict of Interest

The authors declare no conflict of interest.

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