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ORIGINAL ARTICLE

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ORIGINAL ARTICLE

Single-port video-assisted thoracic surgery in 1063 cases: a single-institution experience[†]

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Abstract

OBJECTIVES: Single-port video-assisted thoracic surgery (VATS) technique has been used for thoracic diseases. There was no report about single-port VATS in large series. Outcomes following single-port VATS were analysed to determine its efficacy and safety.

METHODS: From June 2012 to June 2014, 1063 single-port VATSs were performed by four surgeons. Patient demographics, perioperative parameters, histopathology and outcomes were analysed.

RESULTS: There were 1063 patients (524 men and 539 women). The median age was 56.1 ± 8.7 years (range, 15–86 years). Lobectomy was performed in 569 patients, segmentectomy in 162, wedge resection in 264, pleural biopsy in 7, drainage of effusion in 20, pleural tumour resection in 5, mediastinal tumour resection in 54, mediastinal tumour biopsy in 2, bilobectomy in 7, sleeve lobectomy in 3 and pneumonectomy in 2. Synchronous bilateral single-port VATS was performed in 27 cases, whereas metachronous bilateral single-port VATS was performed in 5 cases. Pathological diagnoses included primary lung cancer in 635 cases, metastatic lung cancer in 19, mediastinal tumour in 56, pleural disease in 32 and benign pulmonary conditions in 353. Fifteen intraoperative vascular injuries were identified in 15 patients. The total conversion rate was 4.6%. The average operation time was 135 ± 31 min (range, 30–230 min), and the average blood loss was 117 ± 47 ml (range, 50–2000 ml). The median intensive care unit stay was 1 day (0–4 days). The postoperative hospital stay was 6.2 ± 2.6 days on average. There was no operative death, and operative complications occurred in 59 patients (5.6%). The 1-year overall survival and 1-year disease-free survival for the primary lung cancer group were 98 and 96%, respectively.

CONCLUSIONS: Our findings indicate that single-port VATS for thoracic diseases is safe and feasible.

Keywords: Video-assisted thoracic surgery • Single-port • Minimally invasive surgery

INTRODUCTION

The single-port video-assisted thoracic surgery (VATS) technique was first reported by Rocco *et al.* [1]. Since 2004, Rocco has published several articles on the single-port VATS technique for diagnostic and therapeutic purposes [2–5]. Gonzalez-Rivas *et al.* developed the single-port technique for VAT major pulmonary resections in 2011 [6–9], and reported the first series for major pulmonary resections in 2013 [10]. Hsu *et al.* [11] reported the first multi-institutional single-port VATS study in anatomical resection for primary lung cancer. Ng *et al.* [12] reported that the early survival outcomes after single-port VATS were satisfactory. Wang *et al.* [13] reported that the perioperative outcomes in single-port approach were comparable with those of the multiple-port approach in a propensity-matched study.

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The potential advantages of the single-port VATS include less postoperative pain, fewer paraesthesias and better cosmetic results [10–15]. However, there are still controversies regarding the safety, mortality and morbidity of single-port VATS. This study was designed to assess the safety and feasibility of single-port VATS.

MATERIALS AND METHODS

The study protocol was reviewed and approved by the Ethics Committee of Shanghai Pulmonary Hospital, and the informed consent was obtained from all patients. Between June 2012 and June 2014, 1063 single-port VATSs were performed by four senior surgeons at the Thoracic Department of Shanghai Pulmonary Hospital, Shanghai, China. In the same period, 2476 thoracic surgical procedures were performed by the same surgeons; hence, in a 2-year period, single-port VATS was performed in 42.9% of the patients. A full medical record review was conducted to obtain demographics, history of tobacco exposure, operative time, operative blood loss, postoperative complications, length of postoperative hospital stay, lung cancer, pathological type, clinical staging and treatment.

Preoperative evaluation

The preoperative work-up included chest CT scan, spirometry, arterial gas analysis and fibre-optic bronchoscopy. PET scan, brain magnetic resonance imaging and bone scintigraphy were performed if malignant tumour was suspected. Patients with mediastinal lymphadenopathy underwent endobronchial ultrasound-guided trans-bronchial needle aspiration or mediastinoscopy for staging before surgery. Regarding primary lung cancer, patients were staged clinically and pathologically, according to the seventh edition of TNM staging system of the American Joint Committee on Cancer.

Table 1: Demographic and characteristics of patients receiving single-port video-assisted thoracoscopic surgery

Variable	Mean ± SD (range) or no. (%)
Age at diagnosis (years)	56.1 ± 8.7 (15–86)
Gender	
Female	539 (51%)
Male	524 (49%)
Cigarette smoking status	
Never	692 (65%)
Former	44 (4%)
Current	327 (31%)
Pack-years (in smokers)	36.8 ± 21
FEV_1	2.2 ± 0.7
% Predicted FEV_1	79.6 ± 20.3
Operative duration (min)	135 ± 31 (range, 30–230)
Blood loss (ml)	117 ± 47 (range, 50–2000)
Chest drain removal (days)	3.4 ± 2.3
Length of postoperative hospital stay (days)	6.2 ± 2.6

FEV_1: forced expiratory volume in 1 s; $\%FEV_1$: forced expiratory volume in 1 s as a percentage of predicted; SD: standard deviation.

The preoperative indications for surgery included diagnosis and resection of mediastinal masses, diagnosis and management of pleural effusions, drainage and debridement of empyema, lung biopsy for interstitial pneumonia or pleural diseases, management of pulmonary malignancy or benign conditions such as bronchiectasis and pulmonary bullae. Single-port VATS was performed whenever it was found technically feasible by the surgeons. The indications in lung cancer for single-port VAT lobectomy were clinical T1–T3 disease, N0–N1 and tumour size smaller than 4 cm in diameter. The eligibility criteria for VAT segmentectomy were cT1N0M0 lung tumour smaller than 2 cm in diameter, peripheral location, metastatic lung cancer or benign disease. Exclusion criteria include chest wall invasion, invasion of the pericardium, calcified lymph nodes and multiple station N2. Patients with incomplete fissures, extensive adhesions or hilar lymph node involvement were not excluded. No patient underwent neoadjuvant chemotherapy or neoadjuvant radiation. All the patients were actively followed up.

Surgical procedures

The single-port VATS was performed under general anaesthesia with single-lung ventilation with the patient in the lateral decubitus position. The incision, about 3–5 cm long, was made at the fourth or fifth intercostal space along the anterior axillary line. The senior surgeons usually stood in front of the patient, and the assistants on the opposite side. A wound protector was routinely used without rib spreading. A 10-mm, 30° video thoracoscope was routinely used for visualization, and articulated instruments were used for dissection of the vessels and bronchus. Articulated endostaplers were routinely used because they significantly improved the accessibility of all vessels and bronchus. Blood vessels and bronchus were completely dissected and basically sectioned with the use of endostaplers, with fissure last approach whenever possible. Small vessels were severed after ligation or implementation of vascular clips. The resected lung specimen was retrieved through a wound protector. Mediastinal lymphadenectomy was performed in patients diagnosed with a malignancy except for minimally invasive adenocarcinoma and adenocarcinoma *in situ*. Lymphadenectomy (systemic lymph node sampling or systematic mediastinal dissection in at least three lymph node stations including sub-carinal) was facilitated with energy devices. A single chest

Table 2: Comparison of patients receiving lobectomy/segmentectomy and wedge resection

Perioperative data	Lobectomy/segmentectomy	Wedge resection	*P*-value
Number of cases	731[a]	232	–
Age at diagnosis (years)	55.8 ± 8.1	57.7 ± 7.2	0.34
Gender			
Male	337	108	0.90
Female	394	124	
Operative time (min)	143 ± 31	52 ± 14	<0.01
Blood loss (ml)	125 ± 42	57 ± 20	<0.01
Length of postoperative hospital stay (days)	6.7 ± 2.5	3.8 ± 2.1	<0.01
Conversion rate	6.2% (45/731)	0.9% (2/232)	<0.01
Complication rate	7.0% (51/731)	0.9% (2/232)	<0.01

Data are presented as mean ± SD or number (percentage).
SD: standard deviation.
[a]Thirty-two cases were combined lobectomy or segmentectomy with wedge resection.

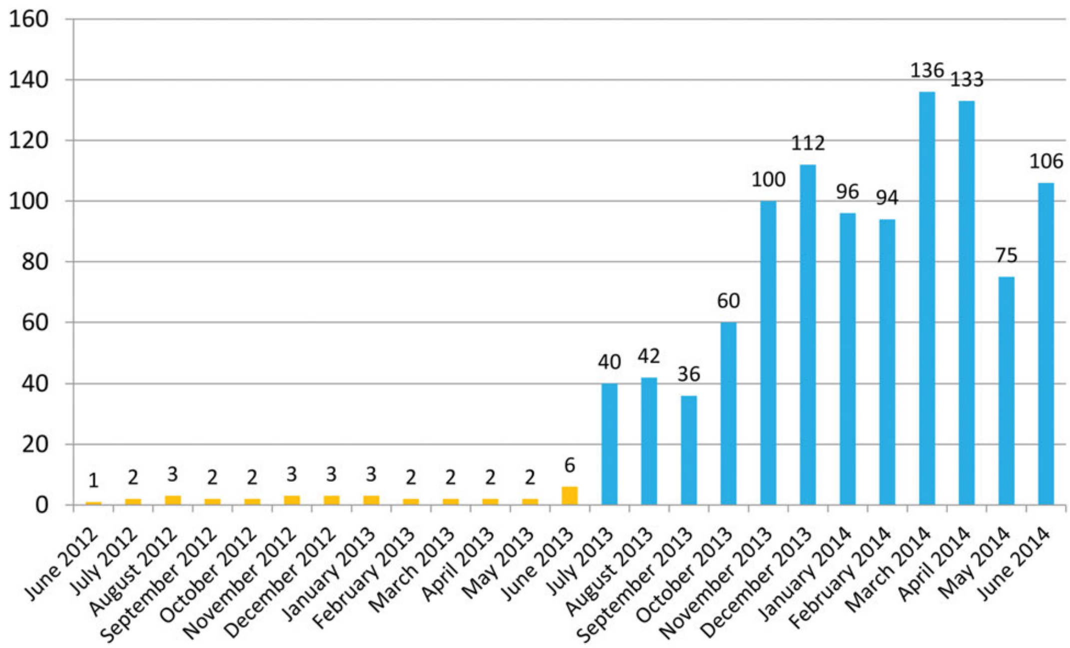

Figure 1: Monthly distribution of cases performed.

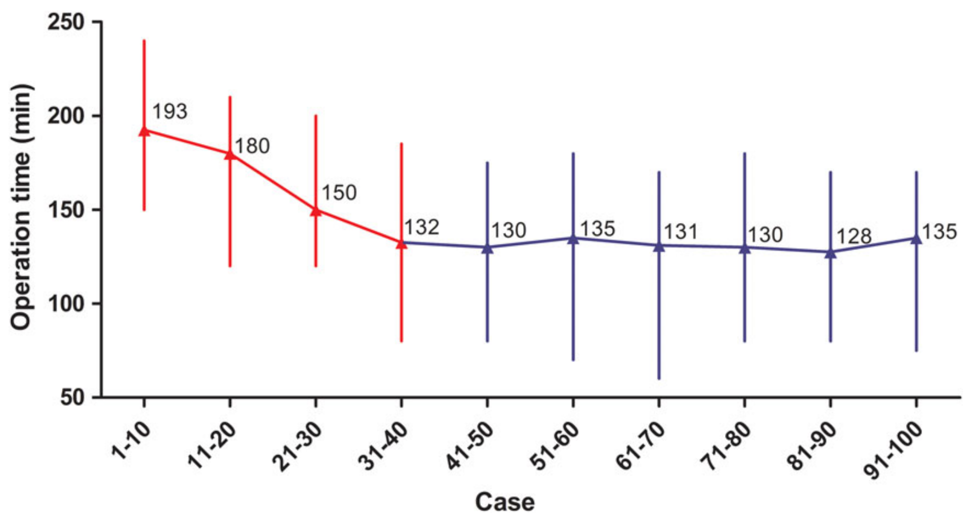

Figure 2: Mean operation time and range in the learning curve. The operation times of the first 100 cases of single-port VAT lobectomy performed by one surgeon were used to evaluate the learning curve. After the first 40 cases, the extent of the reduced time dwindled and the mean operation time reached a plateau. VAT: video-assisted thoracic.

drain (28-F chest tube) was placed at the end of the incision. A patient-controlled analgesia pump was routinely used postoperatively, and oral pain medications were prescribed as needed.

Statistical analysis

A descriptive analysis of the variables studied was carried out. The quantitative variables were expressed as mean ± standard deviation, median and range. Nominal categorical variables were compared using χ^2 tests, and ordinal categorical variables were compared using Wilcoxon rank-sum tests. All statistical analyses were carried out with SAS 9.3 (SAS Institute, Inc., Cary, NC, USA). All *P*-values were two-tailed.

RESULTS

The demographic and perioperative patient characteristics are summarized in Tables 1 and 2. A total of 524 men and 539 women were enrolled in the study. The median age was 56.1 ± 8.7 years (range, 15–86 years). Figure 1 shows the monthly distribution of cases performed. Figure 2 shows the learning curve of the first 100 cases of single-port VAT lobectomy performed by one surgeon. After the first 40 cases, the extent of the reduced time dwindled and the mean operation time reached a plateau. Before July 2013, only one surgeon performed the single-port VATS. Three other thoracic surgeons adopted single-port approach after July 2013.

Table 3: Histological types

Histological types	*n* (%)
Lung cancer	654 (61.5)
Adenocarcinoma	560 (52.7)
AIS	64 (6.0)
MIA	68 (6.4)
IA	427 (40.2)
Squamous cell	50 (4.7)
Adenosquamous	4 (0.38)
Large cell	12 (1.1)
SCLC	4 (0.38)
Sarcomatoid	3 (0.28)
Lymphoma	2 (0.18)
Metastatic lung cancer	19 (1.8)
Benign pulmonary disease	353 (33.2)
Pulmonary tuberculosis	52 (4.9)
Pulmonary bullae	80 (7.5)
AAH	39 (3.7)
Hamartoma	19 (1.8)
Bronchial cyst	12 (1.1)
Bronchiectasis	19 (1.8)
Organizing pneumonia	27 (2.5)
Interstitial pneumonia	39 (3.7)
Pulmonary sclerosing haemangioma	11 (1.0)
Pulmonary sequestration	6 (0.6)
Pulmonary cryptococcosis	13 (1.2)
Intrapulmonary lymph nodes	6 (0.6)
Inflammatory consolidation	14 (1.3)
Others[a]	16 (1.5)
Mediastinal disease	56 (5.3)
Thymoma	39 (3.7)
Thymic cyst	5 (0.47)
Lipoma	3 (0.28)
Schwannoma	4 (0.38)
Lymphoma	2 (0.18)
Pericardial cyst	1 (0.09)
Bronchogenic cyst	2 (0.18)
Pleural disease	32 (3.0)
Empyema	26 (2.4)
SFTP	5 (0.47)
MPM	1 (0.09)

AIS: adenocarcinoma *in situ*; MIA: minimally invasive adenocarcinoma; IA: invasive adenocarcinoma; SCLC: small-cell lung cancer; AAH: atypical adenomatous hyperplasia; SFTP: solitary fibrous tumour of the pleura; MPM: malignant pleural mesothelioma.
[a]Include lung abscess, right middle lobe syndrome, broncholithiasis, amyloidosis, pulmonary lymphangioleiomyomatosis.

Synchronous bilateral single-port VATS was performed in 27 cases, whereas metachronous bilateral single-port VATS was performed in 5 cases. A total of 1063 patients underwent 1095 procedures, which are detailed in Table 3. A lobectomy was performed in 569 patients, segmentectomy in 162, bilobectomy in 7, sleeve lobectomy in 3, pneumonectomy in 2, wedge resection in 264, pleural biopsy in 7, drainage of effusion in 20, pleural tumour resection in 5, mediastinal tumour resection in 54 and mediastinal tumour biopsy in 2.

The median intensive care unit stay was 1 day (0–4 days), and the mean duration of chest tube placement was 3.4 ± 2.3 days and the postoperative hospital stay was 6.2 ± 2.6 days on average.

Diagnoses of all these lesions were proved by pathology including primary lung cancer in 635 cases, metastatic lung cancer in 19, mediastinal tumour in 56, pleural disease in 32 and benign pulmonary conditions in 353 (Table 4). For pulmonary lesions (n = 975), the most common histological type was adenocarcinoma (57.4%), and the most frequent location was the right upper lobe (34.3%), followed by the left upper lobe (22.4%), right lower lobe (18.3%), left lower lobe (16.5%) and right middle lobe (8.6%). Among the 635 patients with primary lung cancer, the clinical stage evaluation was Stage 0 in 15 cases (2.4%), Stage Ia in 346 (54.5%), Stage Ib in 259 (40.8%), Stage IIa in 8(1.3%) and Stage IIb in 7(1.1%). A summary of pathological stages is detailed in Table 5. Mediastinal lymphadenectomy was performed in 493 cases (77.6%). Regarding mediastinal lymphadenectomy, the median number of lymph node stations sampled was four (range, 4–6 stations), the mean number of lymph nodes resected was 16.5 ± 5.2.

Table 4: Type of single-port VATS performed

Surgical type	Number
Lobectomy	569
RUL	211
RML	59
RLL	104
LUL	106
LLL	89
Sleeve lobectomy	3
Bilobectomy	7
RML and RLL	6
RUL and RML	1
Pneumonectomy	2
Segmentectomy	162
LUL apicoposterior	5
LUL trisegmentectomy	18
LUL lingulectomy	18
LLL superior	16
LLL basal	14
Left other segments	11
RUL posterior	24
RUL apicoposterior	8
RLL superior	23
RLL basal	16
Right other segments	11
Wedge resection	264
Pleural biopsy	7
Pleural tumour resection	5
Drainage effusion	20
Mediastinal tumour resection	54
Mediastinal tumour biopsy	2

LLL: left lower lobectomy; LUL: left upper lobectomy; RLL: right lower lobectomy; RML: right middle lobectomy; RUL: right upper lobectomy; VATS: video-assisted thoracic surgery.

Intraoperative vascular injury

Fifteen intraoperative vascular injuries were encountered in 15 patients, including 1 case of injury at the main pulmonary artery, 6 cases of injury at the first branch of pulmonary artery, 6 cases of injury at the other pulmonary arterial branches, 1 case of injury at the azygos vein and 1 case of injury at the inferior pulmonary vein. Among these, 8 were converted to thoracotomy, and 7 were repaired by single-port VATS approach.

Conversion rate

The total conversion rate was 4.6%. Twenty-seven operations (2.5%) were converted to open surgery, 14 (1.3%) needed one additional

Table 5: Pathological stage of patients receiving single-port VATS for primary lung cancer (*n* = 635)

Classification	Number	Percentage
T stage		
Tis	64	10.1
T1	310	48.8
T2	252	39.7
T3	7	1.1
T4	2	0.3
N stage		
N0	583	91.8
N1	22	3.5
N2	30	4.7
M stage		
M0	633	99.7
M1a	2	0.3
Pathological stage		
0	64	10.1
Ia	310	48.8
Ib	209	32.9
IIa	12	1.9
IIb	10	1.6
IIIa	26	4.1
IIIb	2	0.3
IV	2	0.3

VATS: video-assisted thoracic surgery.

incision and 8 (0.8%) were converted to three-port VATS. The reasons for conversion to thoracotomy were pleural adhesions in 14 cases, bleeding in 8 cases and resection of centrally located tumours requiring vascular control in 5 cases.

Morbidity and mortality

There was no intraoperative or 30-day mortality. One patient required reoperation because of bleeding, and 3 patients (0.3%) had to be readmitted in the intensive care unit. Blood transfusion was required in 39 of 1063 patients (3.7%), one unit on average. Postoperative complications occurred in 59 patients (5.6%), as given in Table 6. With a median follow-up time of 15 months, the 1-year overall survival and 1-year disease-free survival for the lung cancer group were 98 and 96%, respectively.

DISCUSSION

Single-port VATS has a history spanning over more than 1 decade [1–5] and, more recently, has become an increasingly popular approach for surgical treatment of thoracic diseases [12, 13]. With increasing experiences, the indications for single-port VATS have been expanded to lobectomy, sleeve lobectomy, pneumonectomy and rib resection [6–10, 16]. The potential advantages of the single-port VATS include less postoperative pain, fewer paraesthesias and better cosmetic results [10–15]. Nevertheless, single-port VATS remains very much a minority interest, as there are still some controversies regarding the safety and mortality and morbidity associated with this approach.

As the largest series of single-port VATS, this study confirms previous findings regarding the safety of single-port VATS [1, 2, 6, 8, 10, 11, 13, 15, 17–19]. It is evident that this procedure can be accomplished in selected patients with minimal in-hospital mortality and morbidity.

Table 6: Postoperative complications (*n* = 59 patients)

Complication	Number
Atrial fibrillation	15
Prolonged air leak lasting >7 days	16
Atelectasis	14
Pulmonary complications[a]	8
Pulmonary embolism	2
Deep venous thrombosis	1
Haemothorax required re-exploration	1
Chylothorax	1
Gastrointestinal system[b]	2

[a]Pneumonia and its consequences, i.e. ARDS or respiratory failure.
[b]Gastroparesis or ileus.

One area of concern is the risk of blood loss with a single-port VATS procedure. In a propensity-matched study, Wang and co-workers compared patients who underwent lobectomy and segmentectomy by single-port VATS (46 patients) with those by multiple-port VATS (46 patients). Single-port approach was associated with shorter operative time ($P = 0.029$), and less intraoperative blood loss ($P = 0.017$) than multiple-port approach. In this study, the average operative blood loss was 116.7 ± 47.2 ml, similar to that in Hsu's study (99.1 ml) [11]. Single-port VATS performed by experienced VATS surgeons does not carry an increased risk of bleeding.

Among possible clinical advantages, the single-port approach has the potential of reducing postoperative chest pain because only one intercostal space is involved and the use of trocar is avoided, which in turn spares the intercostal nerve from compression. Several authors have reported fewer paraesthesias and less postoperative pain in patients operated through single-port approach, in comparison with the multiport approach [20, 21]. However, this advantage lacks a high-quality prospective randomized evidence [22].

The conversion rate was 4.6% in this series, which was higher than those in Gonzalez-Rivas's (2.9%) [10] and Hsu's studies (2.5%) [11], but much lower than that in Tam's study (15.8%) [23]. However, only 27 cases (2.5%) were converted to open surgery in this series, and 22 cases (2.1%) were converted to two- or three-port VATS. If needed, we will first convert to two- or three-port VATS. There was no intraoperative or 30-day mortality. In this study, the morbidity (5.6%) was lower than that in Gonzalez-Rivas's study (13.7%) [10].

The length of the learning curve has been suggested to consist of 50 VAT lobectomies [24]. The single-port VATS requires more skills than conventional VATS. However, with skills acquired in VATS, conversion from three- or two-port VATS to single-port VATS might be easier than the initial conversion from thoracotomy to thoracoscopy. So the learning curve is shorter for single-port VATS in our series.

The current study is limited by its descriptive and retrospective nature. Furthermore, our study lacked analyses of postoperative pain, cosmetic factors, long-term survival outcomes and quality of life. Although pneumonectomy, bilobectomy and sleeve lobectomy were included in our study, which have also been reported in the literature [9, 18], we have not taken the single-port VATS as a routine approach for these challenging procedures.

This series indicates that, in the hands of experienced surgeons, single-port VATS is technically safe and feasible in selected patients, with good postoperative outcomes. In light of potential advantages, the single-port VATS could be applied by the experienced minimally invasive thoracic surgeons.

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