Original Article

Single-port thoracoscopic surgery for pneumothorax under two-lung ventilation with carbon dioxide insufflation

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Background: The development of single-port thoracoscopic surgery and two-lung ventilation reduced the invasiveness of minor thoracic surgery. This study aimed to evaluate the feasibility and safety of single-port thoracoscopic bleb resection for primary spontaneous pneumothorax using two-lung ventilation with carbon dioxide insufflation.

Methods: Between February 2009 and May 2014, 130 patients underwent single-port thoracoscopic bleb resection under two-lung ventilation with carbon dioxide insufflation. Access was gained using a commercial multiple-access single port through a 2.5-cm incision; carbon dioxide gas was insufflated through a port channel. A 5-mm thoracoscope, articulating endoscopic devices, and flexible endoscopic staplers were introduced through a multiple-access single port for bulla resection.

Results: The mean time from endotracheal intubation to incision was 29.2±7.8 minutes, the mean operative time was 30.9±8.2 minutes, and the mean total anesthetic time was 75.5±14.4 minutes. There were no anesthesia-related complications or wound problems. The chest drain was removed after a mean of 3.7±1.4 days and patients were discharged without complications 4.8±1.5 days from the operative day. During a mean 7.5±10.1 months of follow-up, there were five recurrences (3.8%) in operated thorax.

Conclusions: The anesthetic strategy of single-lumen intubation with carbon dioxide gas insufflation can be a safe and feasible option for single-port thoracoscopic bulla resection as it represents the least invasive surgical option with the potential advantages of reducing operative time and one-lung ventilation-related complications without diminishing surgical outcomes.

Keywords: Pneumothorax; thoracoscopy/video-assisted thoracoscopic surgery (VATS); minimally invasive surgery; anesthesia; ventilation

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Introduction

A pneumothorax is a collection of air in the pleural space between the lung and chest wall. Primary spontaneous pneumothorax is a common disease that usually occurs in tall, thin young men as a result of the rupture of emphysematous subpleural bullae or blebs in the apical lung (1,2). The goal of surgical therapy is to reduce the likelihood of a recurrence, which can exceed 50% if not managed appropriately (3). Video-assisted thoracoscopic surgery (VATS) is the preferred surgical method of resecting bullae or blebs and creating a pleurodesis (4,5).

Recently, the surgical technique for VATS has evolved

into single incisional thoracoscopic surgery (SITS) performed through 2- to 3-cm incisions (6,7). In addition, some groups, including ours, reported on the feasibility and safety of SITS for minor to major lung resection in benign or malignant thoracic disease (8-11). The potential benefits of SITS in thoracic surgery reportedly include reduced intercostal pain (12,13), reduced surgical trauma (14), and surgeon hand-eye coordination similar to that of open thoracotomy (15). The single-port approach also promises improved ergonomics through the development of SITS endoscopic devices and their combination with robotics (16).

Despite recent improvements in surgical technique, one-lung ventilation anesthesia (OLVA) is still indicated in most thoracic surgeries and can be performed with double-lumen endotracheal intubation or with bronchial blockers through single lumen endotracheal intubation (17). During VATS for pneumothorax, OLVA is used for the identification and resection of bullous lesions in a non-ventilated state since bullae are most commonly treated with endoscopic stapling. Many physiological disadvantages of OLVA have been reported including overventilation of a non-collapsed lung resulting in a postoperative ventilation/perfusion mismatch, hypoxemia, sputum retention, consolidation, and edema in the operative lung (18,19). Moreover, fiberoptic bronchoscopy is essential for confirming the proper location of the endotracheal tube or blocker (20). These OLVA-related problems can be minimized with adequate intraoperative management and postoperative care. However, even minor adverse events after VATS for pneumothorax in patients with poor pulmonary function and lung manipulation during surgery can increase postoperative lung problems such as pulmonary edema or atelectasis, resulting in prolonged hospital stays (21).

Since 2007, we have been using a two-lung ventilation anesthesia (TLVA) strategy with low tidal volume during VATS for pneumothorax (22). We previously reported that TLVA was cost-effective and time-saving compared with OLVA (23). In 2009, we started performing SITS for pneumothorax under TLVA with carbon dioxide (CO_2) gas insufflation using a special multiple-access single port (SILS^{TM} port, Covidien, Mansfield, MA). The SILS port has multiple channels including a three-way stopcock for gas infusion, which enabled the performance of SITS under TLVA with gas infusion to achieve acceptable surgical views. To our knowledge, there are no reports on SITS under TLVA. This was the first study to evaluate the feasibility and safety of SITS performed using a SILS port under TLVA with CO_2 gas insufflation for pneumothorax.

Table 1 Characteristics of the study population (N=130)

Characteristics	Value
Sex, n (%)	
Male	121 (93.1)
Female	9 (6.9)
Age, mean ± SD* (years)	22.6±8.3
Laterality, n (%)	
Right	58 (44.6)
Left	54 (41.5)
Bilateral	18 (13.9)

*SD, standard deviation.

Methods

Patients

A consecutive series of 130 patients with primary spontaneous pneumothorax underwent single-port thoracoscopic bleb resection using a SILS port under TLVA with CO_2 gas insufflation between February 2009 and May 2014 at our institution. The study was approved by our institution's Ethics Committee, and written informed consent was obtained from all patients in accordance with the Declaration of Helsinki (institutional review board no. KUGH14263-001). Initially, all patients were managed with a tube thoracostomy. Chest computed tomography was performed to identify subpleural bullae or blebs. Our hospital's surgical indications were reported previously (22). Patients with a first episode of bullae or blebs on chest computed tomography, combined hemothorax, an air leak lasting more than 5 days, an unexpanded lung, bilateral pneumothorax, tension pneumothorax, or recurrent attack were included in our study. Patients with secondary pneumothorax with severely emphysematous lungs or pneumothorax caused by traumatic injury and moderate-to-severe adhesions on computed tomography scans were excluded (*Table 1*).

Anesthesia

The TLVA protocol used during single-port surgery was the same as that described in our previous report (24). After general anesthesia induction, patients were intubated with a single-lumen endotracheal tube (Sheridan/CF Tracheal Tubes, ID 7.0 for women and ID 8.0 for men; Hudson RCI, Durham, NC) and ventilated with a volume of 10 mL/kg,

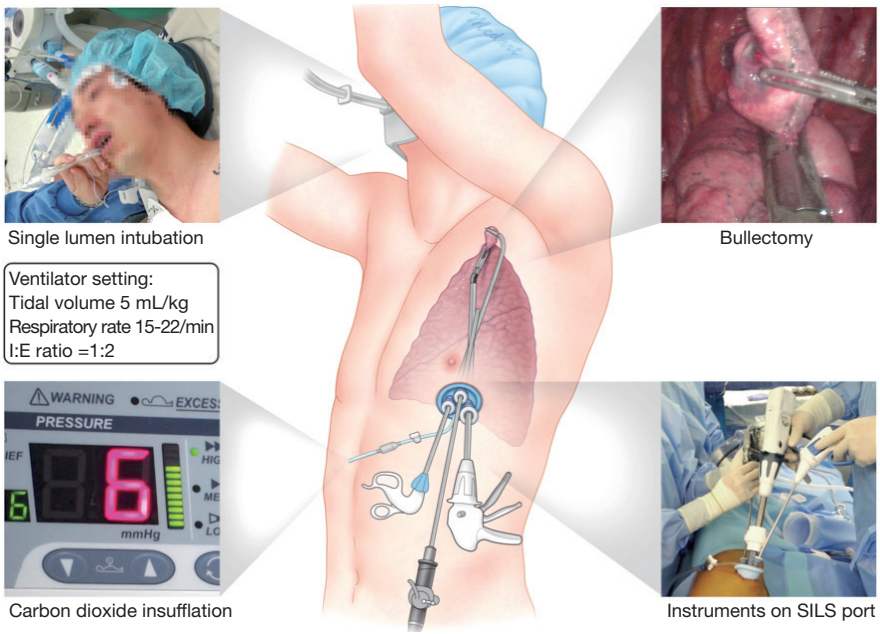

Figure 1 Operative setting and procedures for single-port thoracoscopic bleb resection through a multiple-access single port under two-lung anesthesia with carbon dioxide insufflation.

a respiratory rate of 12 breaths/min at a 0.5 fraction of inspired oxygen, a 1:2 inspiratory-to-expiratory ratio, and a 1.5 L/min flow rate for oxygen and nitrous oxide without positive end-expiratory pressure. Immediately before surgical incision, the tidal volume was reduced to 5 mL/kg and the respiratory rate was increased to 15 breaths/min (*Figure 1*). CO_2 retention and intrinsic positive end-expiratory pressure were monitored using end-tidal CO_2 and a manometer with a ventilator (S/5 Avance with monitor; Datex-Ohmeda, Madison, WI). To minimize the potential for hypoxia and a barotrauma event, the anesthesiologist adjusted the ventilator setting when pulse oximetry was lower than 90% or the peak inspiratory pressure was higher than 25 mmHg. We recorded the time from intubation to surgical incision, operation time, and total anesthesia time.

Operation

Patients were placed in the lateral decubitus position. A 2.5-cm surgical incision was made at the 6th or 7th intercostal space using the hole through which the chest tube was inserted. We installed the SILS port at this incision, and 6 mmHg of CO_2 gas was continuously insufflated into the thoracic cavity via the SILS port channel to achieve a better operative field under TLVA (*Figure 2*). Initially, a 5-mm thoracoscope connected to a light cable at right angles to prevent instrumental conflicts was introduced to identify pleural adhesions and bullae or blebs. After inspecting the location and extent of bullae or blebs, we used one or two flexible endoscopic staplers to resect the apical lung lesion along with an articulating Endo Grasper. Finally, the CO_2 gas insufflation was stopped and the SILS port was removed; a resected lung specimen was retrieved through the incision. The stapler line was reinforced with surgical mesh and fibrin glue. To facilitate pleural symphysis, we performed mechanical pleurodesis using medical sandpaper and chemical pleurodesis using powdered minocycline (*Figure 3*). In all patients, a 24-french chest drain was inserted into the lung apex.

Postoperative course

We routinely applied 15 to 20 cmH_2O of thoracic suction and checked the daily chest PA or AP images. In case of a positive air leak with an unexpanded lung, we performed additional bedside chemical pleurodesis with powdered minocycline. The chest drain was removed if the drain amount was reduced to less than twice the weight (kg*mL) after a daily 5 cm step-by-step pullback of the chest drain. The day following chest drain removal, patients were discharged if their chest PA image showed no pneumothorax. All patients were followed up at 1 week,

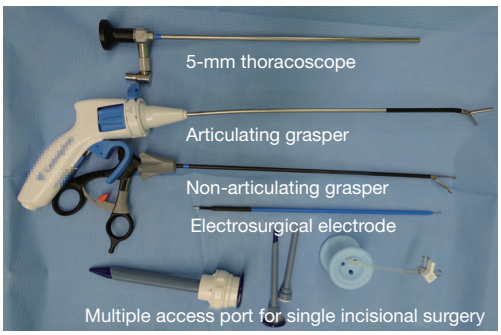

Figure 2 Endoscopic instruments and multiple-access port used for single-port thoracoscopic bleb resection.

Figure 3 Single-port thoracoscopic surgery for pneumothorax under two-lung ventilation with carbon dioxide insufflation (25). Available online: http://www.asvide.com/articles/985

1 month, and 3 months postoperatively.

Results

The study included 121 men and nine women aged 22.6±8.3 years (range, 13–56 years). The indication for surgery was a recurrent pneumothorax in 130 patients who showed bullae or blebs on chest computed tomography. There were 18 bilateral surgeries. All patients successfully underwent SITS under TLVA with CO_2 gas insufflation through a SILS port. No conversions to a conventional three-port VATS or CO_2-related intraoperative adverse events occurred. The time from endotracheal intubation to incision was 29.2±7.8 minutes (range, 15–55 minutes) and the operation time was 30.9±8.2 minutes (range, 11–57 minutes). The total time under anesthesia was 75.7±14.4 minutes (range, 30–126 minutes). Chest drains were removed 3.7±1.4 days (range, 2–11 days) from the day of operation. Fifteen patients showed prolonged air leaks (longer than 5 days) postoperatively and were treated with additional bedside pleurodesis with minocycline. Eventually, chest drains were removed successfully in these patients without complications. Patients were discharged after a mean of 4.8±1.5 days (range, 3–15 days) (*Table 2*). During 7.5±10.1 months (range, 4.3–43.9 months) of follow-up, no wound or TLVA-related problems occurred. There were five ipsilateral (3.8%) and nine contralateral (6.9%) recurrences. Ipsilateral recurrences were treated conservatively by reinserting a chest drain in three patients and with oxygen inhalation in two patients.

Comments

In this study, we infused CO_2 gas into the thoracic cavity to collapse the lung during TLVA based on a similar method used in needlescopic sympathetic surgery for hyperhidrosis (26). To our knowledge, there have been no reports of SITS under TLVA with CO_2 gas insufflation for pneumothorax.

The standard VATS procedure utilizes three or four ports that are 1 or 2 cm in size (utility incision, thoracoscope, one or two ports per instrument). However, the feasibility of performing VATS using two ports or a single port has been described in many thoracic diseases along with the benefits of better cosmetic results and tolerable postoperative pain. A 2- to 5-mm thoracoscope is preferred over the 10-mm thoracoscope as it reduces the torque on the intercostal nerves even through a small incision. There have been many modifications of the SITS technique, including SITS performed using a 2-mm needlescope (23) or a 5- to 10-mm thoracoscope with or without any trocar or scope guide to maximize instrumental maneuverability (27). Various incisional lengths measuring between 2 and 4 cm can be created during the procedure. In addition, a subxiphoid incision was introduced for bilateral lesions (28). Recently, the most minimally invasive VATS, non-intubated surgery using a single port, has been reported in limited numbers (29,30). Avoiding airway trauma and general anesthesia can be more advantageous than our strategy, although uncontrollable lung movement and spontaneous breathing can lead to a difficult surgical procedure and fatal events.

Some clinicians have reported the feasibility and safety of SITS performed using a SILS port (13,31). The SILS port was originally designed for single-port laparoscopic surgery; its application to VATS has enabled a more accurate lining up of instruments and improved reticulating endoscopic

Table 2 Operative data for single-port thoracoscopic bulla resection with two-lung ventilation and carbon dioxide gas insufflation

Operative data	Value, mean ± SD*
Time from intubation to skin incision	29.2±7.8 min
Operative time	30.9±8.2 min
Total anesthetic time	75.7±14.4 min
Chest tube indwelling time	3.7±1.4 d
Time to discharge from operative day	4.8±1.5 d

*SD, standard deviation.

device ergonomics and performance through port channels. Moreover, the three-way stopcock in the SILS port was originally designed for pneumoperitoneum induction during laparoscopic surgery. Carbon dioxide gas insufflation has been used to create a pneumoperitoneum in laparoscopic surgery (32) and has also been used in sympathetic or mediastinal surgery (33). In pediatric thoracic surgery (34), where double lumen tubes are not available, a low flow and pressure (<8 cmH_2O) infusion of CO_2 into the thoracic cavity helps partially compress the lung and increases the visualization of intrathoracic structures, as in our series. In thoracic surgery, the optimal endoscopic surgical view can usually be achieved by insufflating carbon dioxide during the procedure. However, there have been few reports of lung resection under two-lung anesthesia with the exception of drainage for pleural effusion or biopsy for a pleural lesion (35). Our consecutive 130 cases of single-port VATS for primary spontaneous pneumothorax utilized a SILS port under TLVA with low tidal volume and CO_2 gas infusion into the thoracic cavity. OLVA may be indicated in most thoracoscopic surgeries for better visualization of the surgical field after proper collapse of the lung (17). However, OLVA requires a double endotracheal tube or a Univent with a blocker, which is costly compared with a single lumen endotracheal tube (23). It also requires additional time for confirming the proper positioning of the endotracheal tube by intraoperative bronchoscopy. Anesthesiologists may also have concerns regarding unexpected complications related to double lumen tube intubation such as hypoxia that can result from improper tube positioning whereas the VATS procedure for pneumothorax is short and simple. Some clinicians have reported that low tidal volume with high frequency can be a feasible option in simple thoracoscopic procedures (35). Despite the availability of TLVA for simple thoracoscopic procedures, pneumothorax requires VATS to ensure an adequate surgical field for the stapling of bullae or blebs or the inspection of additional fissural blebs. This technique was well-tolerated in most patients in our series (22). However, some other series reported potential complications including CO_2 embolism and hypotension resulting from impaired venous returns (36). Stopping the gas infusion and relieving the pneumothorax can promptly reverse hypercarbia and hypoxia.

Initially, we did not use CO_2 gas during multiport VATS for pneumothorax under TLVA because it is possible to identify the apical bullous lesion with low tidal volume without CO_2. However, in single-port VATS, the apical bullous lesions can be missed due to the limited thoracoscopic view when using a previous improper chest drain site under TLVA. CO_2 insufflation may not be a mandatory component of this procedure for experienced surgeons, but represents a useful technique for beginners performing SITS with a SILS port for pneumothorax. Nevertheless, our two-lung anesthetic strategy for SITS using a SILS port has several potential advantages such as reduced postoperative pain compared with single-port surgery using a uniportal trocar and reduced anesthetic and operative times compared with one-lung ventilation. The limitation of this study is that a disposable SILS port is mandatory to our surgical strategy, increasing surgical cost. However, the benefits of our surgical strategy may outweigh the high instrument cost inherent in most minimally invasive surgeries.

We routinely performed mechanical and chemical pleurodesis in all our cases. Although there was no early (<30 days) recurrence of ipsilateral thorax and no need to reoperate, additional pleurodesis during surgery for pneumothorax for the prevention of recurrence remains controversial (37,38) and may be considered in select recurrent cases. In our series, TLVA strategy had a little impact on the postoperative outcomes compared to historical papers (13). Our relatively longer chest drain indwelling time (3.7±1.4 days) may have been caused by the strict criteria for chest drain removal (less than twice the body weight) in our center. In addition, the relatively longer hospital stay (4.8±1.5 days) noted in our series is due to patients' reluctance to leave the hospital early as a result of the comprehensive national insurance coverage in our country.

In conclusion, our anesthetic strategy using two-lung ventilation with low tidal volume and CO_2 infusion through a SILS port was a technically feasible and safe procedure for simple thoracoscopic bulla resection. Using a SILS port provides the additional benefits of improved instrumental

maneuverability and procedural performance in single-port thoracoscopic surgery during two-lung ventilation. This procedure can represent a safe alternative to VATS for the treatment of primary spontaneous pneumothorax with the advantages of reduced anesthetic and operative times.

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Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

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