Technical Aspects of Lung Volume Reduction Surgery Including Anesthetic Management and Surgical Approaches

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KEYWORDS

• LVRS • Minimally invasive thoracic surgery • Subxiphoid

KEY POINTS

- Lung volume reduction surgery (LVRS) can be offered to a carefully selected subset of chronic obstructive pulmonary disease patients.
- Bilateral LVRS is recommended.
- Minimally invasive approaches improve outcomes.
- Extrathoracic subxiphoid incision with subcostal ports decrease postoperative pain to improve spontaneous breathing and early mobilization.

INTRODUCTION

Initially described in the 1950s by Brantigan and colleagues,[1] lung volume reduction surgery (LVRS) was highly controversial until the completion of the National Emphysema Treatment Trial (NETT) in the late 1990s.[2] This study demonstrated that patients with both upper-lobe predominant emphysema and low baseline exercise capacity benefited from surgery in terms of survival and quality of life. It also demonstrated this benefit was durable.[2] Patients assigned to LVRS in the NETT underwent bilateral stapled lung volume reduction through either a median sternotomy (MS) or a video-assisted bilateral thoracic surgery (VATS). With stringent selection criteria being adopted after the NETT trial, the subsequent era saw a transition from maximally invasive resections carried out via sternotomy toward bilateral VATS surgeries. For these procedures, the intraoperative general anesthesia was complemented by an epidural catheter to improve postoperative pain management and allow for early patient mobilization. In this article, the authors review the historical evolution of surgical techniques used to perform LVRS, including the recent development of subxiphoid surgery, especially when coupled with subcostal port placement further reduced postoperative pain.

ANESTHETIC MANAGEMENT

LVRS is routinely performed under intubated general anesthesia using a left-sided double-lumen endotracheal tube (ET). A single lumen tube can first be placed to perform flexible bronchoscopy for evaluation of the bronchial tree and to assess and clear secretions. A microbiology sample should be obtained to help guide antibiotic management should the patient develop postoperative infectious complications.

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Ventilation must be protective during surgery, as the major risk faced by chronic obstructive pulmonary disease (COPD) patients during positive pressure ventilation is a further increase in air trapping resulting in hemodynamic instability. Low tidal volumes (5–8 mL/kg) to achieve low plateau pressures (<15–20 cm H_2O) and low to no positive end-expiratory pressure at a slower rate (10–12 breaths per minute) to increase in the inspiratory-to-expiratory ratio (1:3) are strategies to prevent air trapping. Nevertheless, disconnecting the ET from the vent will drop ventilator tension-related life-threatening situations. If the patient remains hypotensive upon ET tube disconnection, the alternative diagnosis of tension pneumothorax must be evoked and addressed. Soon after positioning, ventilation to the first addressed side must be stopped to allow enough time for the lung to deflate.

The major downside of protective ventilation in these patients is hypercapnia, which will be tolerated in a “permissive” strategy as long as pH is kept greater than 7.25. This permissive strategy also includes oxygenation, as Fio_2 is kept as low as possible to achieve saturations greater than 90%. Before extubation, the permissive hypercapnia must be recognized and fully reversed to avoid and exacerbate the drowsiness associated with higher $Paco_2$ after extubation. For the same purpose, the authors very cautiously use opioids for pain management during LVRS, as their undesirable effects (eg, prolonged respiratory depression) may greatly impact the early postoperative period. Short-acting synthetic opioids (eg, fentanyl or remifentanil) are therefore definitively preferred intraoperatively in these patients.[3] Opioids should be used very cautiously postoperatively and avoided in the epidural in the early postoperative period.

Over time, refinements in the authors’ surgical techniques have resulted in less surgical pain, which, on the one hand, decreases pain management requirements, and on the other hand, improves early patient mobilization postoperatively. By using the fully extrathoracic approach depicted in later discussion, the authors have now moved away from using epidural catheters in LVRS patients. Ultimately, the goal is to improve the patient’s respiratory drive after extubation and in the early postoperative period. Extubated, awake, and alert patients are then transferred to the intensive care unit (ICU) for 24 to 48 hours of monitoring. Patients failing this strategy are placed on bilevel positive airway pressure (BiPAP) or continuous positive airway pressure (CPAP). The authors favor early tracheostomy for patients who are finally reintubated.

SURGICAL ASPECTS

Strategy

Following the NETT trial and with experience, more data concerning LVRS became available, defining inclusion and exclusion criteria for LVRS. Patient selection is the initial step of the surgical strategy, and these patient characteristics have been shown to accurately predict outcome. The authors therefore recommend diligently respecting these criteria as a critical guide to develop a safe LVRS program[4] (**Table 1**). Next, although unilateral LVRS may produce an excellent result in the highly selected patient, the bilateral procedure has been shown to be the procedure of choice, because it provides improved survival and physiology with no increased morbidity or mortality compared with the unilateral procedure[5] (**Table 2**).

Even if unilateral procedures are staged to yield a bilateral result, the cost of 2 operations and hospitalizations have never been justified.[5] The authors currently always perform bilateral procedures outside of considerations that preclude them from operating on the other side.[6] Conditions allwoing to consider unilateral LVRS include include the rare purely unilateral disease, contralateral pleurodesis, or previous thoracotomy; hemodynamic instability during single-lung ventilation; massive air leaks after first-side LVRS; or contralateral lung transplantation with native lung hyperinflation. It should be noted that prior thoracotomy is not an absolute contraindication to LVRS and can be safely performed under strict guidelines.

The goal of LVRS is to resect by peripheral resection 25% to 35% of the ipsilateral lung volume of the most emphysematous portions of the diseased lung. In most forms of emphysema, destructed areas reside within the upper lobes. Resection targets can be identified preoperatively by perfusion scans and computed tomographic scanning and confirmed by intraoperative observations. Intraoperative lung targeting is performed using the following techniques: (1) the more normal lung retains its elastic recoil and becomes atelectatic faster upon stopping lung ventilation, whereas the more diseased areas become atelectatic more slowly or not at all; (2) more normal lung loses its perfusion during atelectasis and becomes cyanotic, whereas the more emphysematous lung remains pink; (3) reventilating the atelectatic lung results in reexpansion of the more diseased lung first.

Over several decades of performing LVRS, the authors have learned to progressively abandon very aggressive resections and to try to tailor the remaining lung to fill the thoracic cage, still reducing lung volume sufficiently to achieve

Table 1
Inclusion and exclusion criteria for selecting patients for lung volume reduction surgery

Inclusion Criteria	Exclusion Criteria
History and physical examination, chest roentgenogram, and HRCT scan consistent with bilateral emphysema	CT evidence of diffuse emphysema judged inappropriate for LVRS
Severe upper-lobe predominant emphysema	Dysrhythmia or exercise-related syncope that might pose a risk during exercise or training
Severe non-upper-lobe predominant emphysema with low exercise capacity	Resting bradycardia; frequent multifocal PVCs; complex ventricular arrhythmia; sustained SVT
Body mass index $\leq$31.1 kg/m^2 (men) or $\leq$32.3 kg/m^2 (women)	Myocardial infarction within 6 mo and LVEF <45%
Stable with $\leq$20 mg prednisone (or equivalent) each day	Congestive heart failure within 6 mo and LVEF <45%
Plasma cotinine level $\leq$13.7 ng/mL (or arterial carboxyhemoglobin $\leq$2.5% if using nicotine products)	Uncontrolled hypertension (systolic >200 mm; diastolic >110 mm)
Non-smoking for 4 mo	History of recurrent infections with clinically significant sputum production
FEV1 $\geq$45% predicted (15% predicted if age 70 y)	Pleural or interstitial disease that precludes surgery
TLC $\geq$100% predicted postbronchodilator	Clinically significant bronchiectasis
RV $\geq$150% predicted postbronchodilator	Previous lung transplant, LVRS, lobectomy
P_{CO_2} $\leq$60 mm Hg	Pulmonary hypertension: peak systolic PAP $\geq$45 mm Hg or mean PAP $\geq$35 mm Hg
P_{O_2} $\geq$45 mm Hg on room air	Requirement for > 6 L oxygen to keep saturation $\geq$90% with exercise
Postrehabilitation 6-min walk distance of $\geq$140 m	Unplanned weight loss of >10% usual weight in previous 90 d
Able to complete 3 min unloaded pedaling in exercise tolerance test	
Approval for surgery by cardiologist if unstable angina, LVEF <45%, arrhythmia	

Abbreviations: CT, computed tomography; FEV1, forced expiratory volume in 1 second; HRCT, high-resolution computed tomography; LVEF, left ventricular ejection fraction; PAP, pulmonary arterial pressure; PVC, premature ventricular contraction; RV, residual volume; SVT, supraventricular tachycardia; TLC, total lung capacity.

From Seadler B, Thuppal S, Rizvi N, et al. Clinical and Quality of Life Outcomes After Lung Volume Reduction Surgery. Ann. Thorac. Surg 2019;108: 866-872; with permission.

adequate physiologic improvement in ventilation. In the early days of LVRS, overresection resulted in large residual airspaces that predisposed to prolonged and difficult to manage air leaks for a disputable functional benefit. Overresection undoubtedly contributed to the high morbidity and mortality that occurred in the pre-NETT and NETT period. The goal of LVRS is to adequately reduce volume, not to remove all of the diseased lung. Of note, disease can also affect the lower lobes, especially in the context of alpha-1 antitrypsin deficiency, and surgery can be offered in this context with decent outcomes.[7,8]

Although bilateral LVRS was initially carried out via bilateral thoracotomies by Brantigan, Cooper and colleagues[9,10] used MS for this procedure. A less aggressive thoracic approach, VATS, became popular in the 1990s and quickly appeared quite ideally suited for LVRS. With experience, it was shown that VATS LVRS allowed earlier recovery at a lower cost than MS, possibly because of reduced surgical trauma from a minimally invasive surgery.[5,11–13] In the authors' experience, they have performed all LVRS using VATS approaches since 2005.

Last, postoperative management is the closing critical aspect in LVRS. The authors still use an

Table 2
Unilateral versus bilateral lung volume reduction surgery outcomes

Author, Year	*n*	Technique	Mortality (%)	LOS (d)	Change in FEV_1
McKenna,[8] 1996	87	Unilateral	3	11.4	31%
Naunheim,[7] 1996	50	Unilateral	2	13	35%
Keenan,[9] 1996	57	Unilateral	2	17	27%
Cooper,[10] 1996	150	Bilateral	4	13.5	51%
Kotloff,[4] 1996	80	Bilateral	13.8	22	41%
Argentano,[5] 1996	85	Bilateral	7	17	61%
McKenna,[11] 1997	154	Bilateral	4	11	52%
Kotloff,[4] 1996	40	Bilateral	2. S	15	41%
NETT,[18,19] 2003/4	511	Bilateral	2.2	10	NR

Abbreviations: LOS, length of stay; NR, not reported.
From DeCamp MM, Jr., McKenna RJ, Jr., Deschamps CC, Krasna MJ. 2008. Lung volume reduction surgery: technique, operative mortality, and morbidity. *Proc Am Thorac Soc.* Vol 5(4):442-446.

ICU environment for their initial postoperative period but with early mobilization. Every attempt is made to extubate the patient in the operating room, and this has been successful routinely in the post-NETT era. The authors recommend aggressive incentive spirometry, physiotherapy, and mobilization as soon as the patient's clinical condition allows. Chest tubes are connected to low suction until the authors can safely transition to water seal. Pain management is critical, and balancing opioid use with CO_2 levels is important. BiPAP or CPAP can be helpful for the marginal patient to help carry them through the early postoperative period. Awake bronchoscopy for secretions can be helpful in the occasional patient not responding to physiotherapy, suctioning, and steroids. In the face of prolonged air leaks, the authors discharge patients home as soon as they can be safely connected to a Heimlich valve.

The Lateral Video-Assisted Bilateral Thoracic Surgery Approach

The early yet most currently used VATS procedure to achieve bilateral LVRS is to perform 2 lateral approaches starting with the most diseased side. As most surgeons, the authors prefer to position the patient supine with the arms above the head and strapped to a padded bar (Fig. 1). Blanket rolls placed under the shoulders, hips, and along the spine, or a beanbag, elevate the patient off the operative table to provide more lateral port access. Such positioning avoids the need to reposition and redrape the patient for 2 sequential lateral approaches, which improves surgical efficiency and cost-effectiveness of the procedure and allows for an easy access to the contralateral side in the face of complications.

Technically, the lateral video-assisted bilateral thoracic surgery (LVATS) procedure can be carried out using either 3 ports, 1 port and 1 utility incision, or 1 working incision alone. In general, ports or incisions should be placed as anterior as possible to take advantage of the wider intercostal interspaces on the anterior chest wall, thus decreasing torsion injury to the intercostal nerves and postoperative pain. Port placement posterior to the scapula should therefore be avoided. All sites are preemptively locally injected with a solution of bupivacaine 0.25% with epinephrine 1:200,000 (Sensorcaine; Fresenius Kabi, Lake Zurich, IL, USA), which enhances pain control and reduces the nuisance of blood dribbling from the ports during the surgery.

For a 3-incision approach, the chest is usually entered with a 5-mm port placed in the eighth intercostal space on the anterior axillary line, and a 30-degree angled camera is used to place the other ports under direct vision. The authors then place a 12-mm port anteriorly in the sixth intercostal space, as this location offers the widest space to accommodate such larger "stapler" port. Last, the triangle is completed by placing a second 5-mm port in the seventh or eighth intercostal space more posteriorly. When using only 2 incisions, a 5-cm utility incision can be placed in the fifth intercostal space just anterior to the anterior axillary line. The authors use a small Alexis O-Ring (Applied Medical, Rancho Santa Margarita, CA, USA) to keep this access open. For the uniportal procedure, only the fifth intercostal space incision is used (Fig. 2).

Fig. 1. Patient positioning with arms above the head and padding. The patient is positioned supine with the arms above the head and strapped to a padded bar. Blanket rolls placed under the shoulders, hips, and along the spine, or a beanbag, elevate the patient off the operative table to provide more lateral port access. (*Courtesy of* Linda Capello, Sag Harbor, New York, USA.)

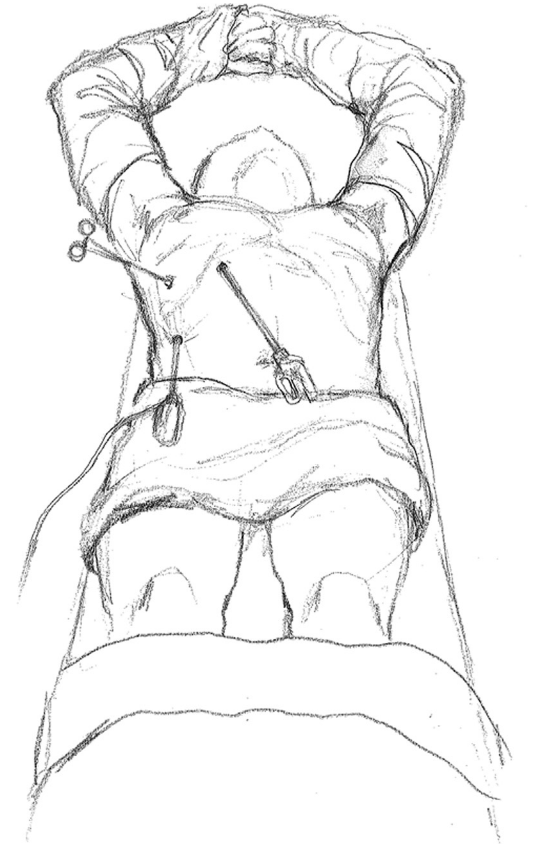

Fig. 2. Port placement for LVATS approach. For a 3-incision approach, the chest is entered with a 5-mm port placed in the eighth intercostal space on the anterior axillary line, and a 30-degree angled camera is used to place the other ports under direct vision. The second port (12 mm) is placed anteriorly in the sixth intercostal space. The third port (5 mm) is placed in the seventh or eighth intercostal space more posteriorly. (*Courtesy of* Linda Capello, Sag Harbor, New York, USA.)

The LVATS approach offers great benefit in that it replicates the exact same visual orientation as that of open surgery. Less-experienced surgeons will therefore find it comforting to use. Following port placement, the pleural cavity is fully explored to rule out any condition that could prevent proceeding. Adhesions are taken down if needed using gentle dissection, as this maneuver is a definitive risk factor for air leaks. Use of CO_2 can at times substantially improve exposure, and the extrapleural route can be used in unsafe areas. When carrying out these dissections, the authors cannot emphasize enough the importance of avoiding the phrenic nerve injury, as this is an even more dreadful complication in LVRS than in other thoracic conditions. It can therefore be helpful to divide the lung first, then dissect adhesions, or even leave a rim of lung attached to the phrenic area. Of note, surgical judgment regarding adherences is critical. The goal is to allow the healthy lung to expand and slide to fill the pleural cavity; this requires the freeing of all adherences.

When the lung is completely mobilized and free, the visual difference between atelectatic healthy and the still inflated diseased lung together with the preoperative imaging-based LVRS plan allow identification of the diseased areas. Manipulating these fragile areas is prone to tearing and must therefore be avoided. In this perspective, the authors first recommend operating on a deflated lung, which can be rapidly accomplished by using the cautery to fenestrate the most bullous areas: the marked collateral ventilation leads to prompt collapse. Next, the authors recommend grasping exclusively the diseased areas that will then be resected.

The NETT trial mandated a bilateral stapled approach to LVRS.[14] Initially designed for bowel resections, staplers evolved over time and are nowadays the most common way to divide the lung. Specifically, buttressed staple lines became popular for LVRS following early reports showing reduced air leaks, even if this idea was subsequently challenged.[15–17]

The authors currently use linear polyglycolic acid buttressed staplers (Endo GIA Reinforced Reload with Tri-Staple technology; Medtronic, Minneapolis, MN, USA) with the addition of surgical glues as sealants at the discretion of the surgeon. Other buttressing compounds include strips of bovine pericardium or polytetrafluoroethylene, but the material does not seem to affect aerostasis.

The staple line is created from anterior to posterior. On the right side, the authors start straight across the middle lobe beginning medially above the hilum and ending up just above the posterior aspect of the oblique fissure (Fig. 3). On the left side, the upper half to two-thirds of the upper lobe is excised following a line that is nearly parallel to the oblique fissure. On both sides, respecting the posterior aspect of the fissure avoids damaging or tethering the superior segment of the lower lobe. Either could indeed prevent the superior segment from fully expanding and filling the apex of the chest. Care is taken to create a straight and single staple line. The resected specimen is then placed in an Endobag (EndoCatch Gold; Medtronic, Minneapolis, MN) and exteriorized through the utility incision or the 12-mm port, which may have to be enlarged in the face of a large resection.

With experience, the authors moved away from placing 2 chest tubes postoperatively to only one 24 or 28F straight tube with multiple additional holes whenever possible. This tube is exteriorized through the lowest port site. At the end of the procedure, the lung is reinflated under direct vision. Following this, the authors apply the lowest amount of suction possible that would keep the lung up, usually starting at −10 cm H_2O in the immediate postoperative period and rapidly moving to water seal. Indeed, minimal, if any, chest tube suction appears to decrease the severity and duration of postoperative air leaks.[10] Using the Pa_{CO_2}-lowering strategy mentioned above, all the authors' patients are currently extubated in the operating room and then transferred awake to the ICU.

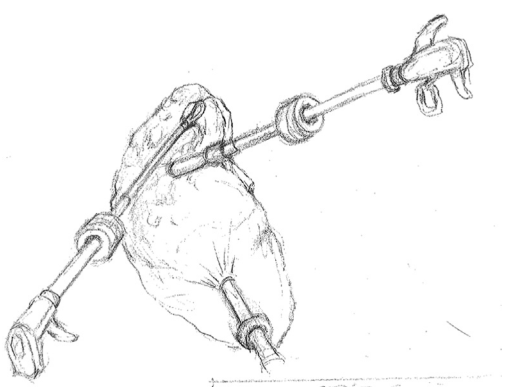

Fig. 3. Intrathoracic view of LVATS LVRS. On the right side, the staple line is started straight across the middle lobe beginning medially above the hilum. (*Courtesy of* Linda Capello, Sag Harbor, New York, USA.)

The Subxiphoid Video-Assisted Bilateral Thoracic Surgery Approach

Subxiphoid incisions have been used for decades by cardiothoracic surgeons to create pericardial windows. Reports dating back the late 1990s also demonstrated this approach was suitable to access the anterior mediastinum, especially for thymic resections.[18,19] As thoracic surgeons became more comfortable with the lateral uniportal approach for lung resections, the subxiphoid uniportal incision became more popular for thymic resections as well and proved suitable for pneumothorax surgery and lung resections, including segmentectomy and lobectomy.[20] It was therefore a quite natural evolution of the lateral uniportal VATS technique to move the incision subxiphoid for LVRS as well.[21,22] This midline incision is indeed ideally located to provide a minimal invasive bilateral pleural access. Since early 2019, the authors have adopted the subxiphoid video-assisted bilateral thoracic surgery (SVATS) access for all LVRS procedure at Columbia.

Technically, the authors perform a 2- to 3-cm incision on the midline below the xiphoid process. The subcutaneous fat is dissected, and the rectus muscles are spared by opening the linea alba. The substernal plane is then developed bluntly to create a working space, and the pleura is entered on the right side first. The authors do minimal substernal mobilization to avoid increasing postoperative pain. When the lung is fully freed, and in the absence incidental finding precluding to proceed with the procedure, the authors then place a 5-mm port laterally (Fig. 4). In the authors' early subxiphoid experience, they placed that port in the eighth or ninth intercostal space on the anterior axillary line, but they more recently moved the incision caudally to place the port totally subcostal. Subcostal port placement is then best achieved using 1 finger inside the chest to depress the diaphragm and place the port safely above the finger. The port should be placed at least 2 cm below the costal arch to avoid costal arch trauma, which can be painful, and should be aimed laterally during initial placement to avoid cardiac injury. The combination of this port with a 30-degree angled camera allows wide view and easy manipulation of the lung. LVRS can be thereafter carried out by inserting the lung retractor together with the stapler via the subxiphoid incision. The resection achieved through the subxiphoid incision is exactly the same as depicted using LVATS. At the end of the procedure, a single 24F or 28F straight chest tube is oriented apically in the pleural cavity and exteriorized through the subcostal port site (Fig. 5).

The left side is carried out similarly to the right. The major difference relates to the heart position that mandates a more lateral subcostal port placement and more careful port insertion to avoid any cardiac injury. Because of the heart position, the left side is technically somewhat more challenging than the right, and instruments must be entered cautiously. Heart compression during the procedure may generate some arrhythmias or hemodynamic instability. It is the authors' practice to operate on the easier right side first, as it further decreases compression to perform the left side in a more comfortable physiology.

The combination of subxiphoid midline incision and subcostal port placement allows fully extrathoracic access to further reduce the patient's pain. Similar to reports showing decreased pain with SVATS compared with LVATS,[23] the authors' experience reveals an average 2.3-fold decrease in patient's pain scores during the first 3 postoperative days when using the subxiphoid approach (Mark E. Ginsburg, MD, unpublished data). Such significant decrease in pain improved early mobilization and allowed the authors to move away from epidural requirements.

COMPLICATIONS OF LUNG VOLUME REDUCTION SURGERY

As the principal surgical complication, air leaks develop in most LVRS patients and are prolonged in half, which inevitably leads to a more complicated and longer hospital course. Their prevalence and duration are associated with certain patient characteristics, such as the use of inhaled steroids, worse pulmonary function, and distribution of disease (less common and shorter in lower lobe disease), and are more common and longer when extensive pleural adhesions are present. In contrast, surgical technique, such as choice of staple line buttressing material, use of pleural tents, or pleurodesis, does not seem to significantly prevent air leaks.[17] Some recent internal unpublished data also suggest that multiple resection lines, rather than the resected volume itself, are an independent risk factor for prolonged air leaks (Mark E. Ginsburg, MD, unpublished data). As depicted above, the most linear and therefore shortest staple line represents the ideal LVRS plan. Regarding space management, the authors do not perform pleural tents and no longer divide the pulmonary ligament. Infections are the second major complication following LVRS. Pneumonia is the most serious of these and is avoided by aggressive management of secretions and early mobilization. Although low-grade pleural contamination may help to promote pleural fusion, empyema is rare but may be severe.

Fig. 4. Subxiphoid incision and lateral subcostal port placement for SVATS LVRS. A 2- to 3-cm midline subxiphoid access allows bilateral resections. A lateral 5-mm port is placed subcostal on each anterior axillary line to allow full extrathoracic approach. (*Courtesy of* Linda Capello, Sag Harbor, New York, USA.)

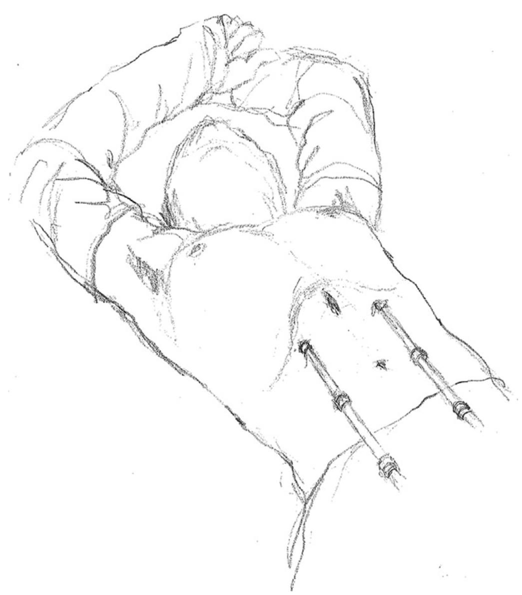

Fig. 5. Postoperative SVATS illustration. At the end of the procedure, a single 24F or 28F straight chest tube is oriented apically in the pleural cavity and exteriorized through the subcostal port site. (*Courtesy of* Linda Capello, Sag Harbor, New York, USA.)

SUMMARY

As a palliative treatment option, LVRS can be offered to a selected subset of COPD patients. Careful adherence to established inclusion and exclusion criteria is critical to achieve good outcomes. The evolution of surgical techniques toward minimally invasive VATS approaches has improved patient outcomes.[4] In addition, the authors have moved toward less aggressive surgical resections, and better match for the size of the hemithorax, and this has contributed to a short-term reduction in morbidity as well as to continued improvements in overall cardiopulmonary function. Recently, the fully extrathoracic access combining a midline subxiphoid incision with subcostal port placement allowed the authors to further decrease postoperative pain and favor early postoperative mobilization. With these techniques, the authors' patients experience improved pulmonary function tests, effort capacity, and dyspnea scores out to 5 years post-LVRS. Outcome at 1 year showed 99% survival; 5-year survival is 78%, and the authors' median survival is 9 years.

CLINICS CARE POINTS

- Fenestrate bullous areas to operate on a deflated lung and minimize manipulation of the fragile diseased lung to reduce air leaks.
- Avoid excessive volume reductions to minimize postoperative spaces.
- Before extubation, the permissive hypercapnia must be recognized and fully reversed to avoid and exacerbate the drowsiness associated with higher $Paco_2$ after extubation.
- Patients are best monitored in the intensive care unit for the first 24 to 48 postoperative hours.
- Chest tubes are connected to low suction until transition to water seal.
- Early aggressive incentive spirometry, physiotherapy, and mobilization are recommended.
- Early tracheostomy should be performed in patients who require reintubation.

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