Complex Thoracoscopic Pulmonary Resections for the Treatment of Lung Cancer—A Review

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Abstract Minimally invasive surgery is increasingly being used in cancer resections. Benefits attributed to minimally invasive surgery include improved functional and oncological outcomes. In keeping with this trend, thoracoscopic lung resections are gaining acceptance amongst thoracic oncologic surgeons. As surgeons become more comfortable with these approaches, more complex resections are being performed through these techniques. This review article summarizes the current state of the art with respect to complex thoracoscopic resections.

Keywords VATS · Lung resection · Lung cancer

Introduction

Since the first successful thoracoscopic anatomic lung resection in 1992 [1], minimally invasive operations took a long time to gain acceptance for bronchogenic carcinoma. Now more and more surgeons adopt thoracoscopic lobectomy and adapt existing techniques to optimize their learning curves. Specific maneuvers and instruments have evolved or been replaced to overcome technical challenges faced during thoracoscopic lung resections [2]. Currently, minimally invasive lung cancer resections are accepted widely for the treatment of early stage lung cancer, especially in old or frail patients with limited functional reserve [3]. Thoracoscopic lung resections have several advantages over open resections such as decreased post-operative pain, less inflammatory

response, decreased incidence of atrial fibrillation, early ambulation, and shorter convalescence [4–6]. If needed, adjuvant therapy is given sooner and with fewer dose reductions. Such approaches preserve immune responses better against residual tumor [7].

Most promising, new surgical techniques evolve from routine to complex case selections and Video-Assisted Thoracoscopic Surgery (VATS) is no exception. Here, we summarize the results of these enhanced thoracoscopic resections under three general categories—locally advanced lung cancer, en-bloc pulmonary and chest wall resection and thoracoscopic pneumonectomy. In this article, the terms thoracoscopic and VATS will be used interchangeably.

Thoracoscopic Resection of Locally Advanced Lung Cancer

The early indications for thoracoscopic lung resections were peripheral tumors less than 3 cm in greatest dimension. Over time, some centers expanded their indications to more advanced tumors: sizes greater than 4 cm, T3–T4 stages, preceding neo-adjuvant therapies and central locations [8].

Our approach emulates what we use for early stage lung cancer [2, 8]. The patient is placed in lateral decubitus position, and the table is tilted slightly posteriorly to enhance access to the anterior thorax. The table is also flexed to widen the intercostal spaces. Port sites follow a general pattern that may be altered somewhat based on patient chest wall anatomy and where the most challenging dissection is anticipated. The surgeon's most ergonomic stance may be anterior to the patient. Generally the first 1–2 cm incision is made for the camera in the 7th or 8th intercostal space perpendicular to the mid-axillary line. It allows multiple angle views of hilum both anteriorly and posteriorly and a good inspection of thoracic cavity. An open, flexible port

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reduces lens-smearing, intercostal nerve injury and suction-related lung reinflation. We prefer a flexible-tip thoracoscope with high-definition picture quality. The second (work) incision is made in 6th intercostal space as anteriorly as possible, in-line with major fissure. This helps to keep the stapler perpendicular to the hilum facilitating its entry during the division of hilar structures. We have found that the use of articulated and curved tip staplers lessen the chance of vascular injury. A site of third access incision (4–8 cm in length) may differ depending on which lobe or part of the lung needs to be excised. For upper lobectomies, 4th intercostal space in anterior axillary line and for lower lobectomies, 5th or 6th intercostal space in mid-axillary line (avoiding the long thoracic nerve) is our site of preference. The advantage of the former is a better exposure of superior arterial branches and veins while the latter helps to clearly visualize the pulmonary artery in the fissure. The above arrangement serves only as a general guide. The locations and functions of the ports need not be rigid, as one can take the role of other, as the need arises. Frequently, moving the access incision 1–2 interspaces higher or slightly more anterior results in a much larger working space. This can be judged during the initial thoroscopic inspection. The larger access incision space greatly improves dissection maneuvers and reduces the chance of rib fracture during lung extraction. Some surgeons prefer to hold open the access incision with a self-retaining wound protector or Weitlaner retractor. If a rib-spreader is used, the operation is considered converted to something more invasive than VATS. Additional port sites may be created if the clear view of structures is obstructed particularly in case of large tumors. The narrow posterior intercostal spaces should be avoided to prevent nerve injury. The pleura is then mobilized from hilum and hilar structures are divided using endoscopic staplers starting with vascular structures, either the vein or the arterial branches. Once vascular structures are divided, the fissures are completed. Often, identification of the interlobar pulmonary artery facilitates the definition of the fissures, which are then divided. We prefer that the bronchus be the last structure to be transected. This serves two purposes—first, with large tumors, this prevents torque on small pulmonary arterial branches that decreases the probability of inadvertent injury. Second, in case a bronchoplasty needs to be performed for a central tumor, such an approach enhances exposure for the airway division. Clips can tear the vessels during their application or can dislodge during later tissue manipulations. Some experienced surgeons use locking clips in locations well removed from upcoming stapler or dissection maneuvers.

A sleeve resection is carried out in a similar manner except that a long handle (occasionally angled) 15-blade scalpel introduced through the access incision is used to divide the bronchus [9]. After specimen extraction, the

bronchial anastomosis is performed. The two bronchial ends are approximated by stay sutures and the anastomosis is carried out using interrupted 3–0 polyglycolic or 4–0 polydioxanone sutures completing the posterior layer first followed by the anterior layer. In order to facilitate suture management, the posterior layer is tied down before the anterior layer is placed. Sutures may be tied down on the inner aspect of the bronchus. Releasing the inferior pulmonary vein by a relaxing incision on the pericardium and Rummel tourniquets on some of the cartilaginous sutures can make it easier to approximate the airway.

An important consideration during surgery for large tumors is appropriate manipulation and traction on different structures. This can be improved by using newer thoracoscopic instruments, like low profile 5 mm round shaft lung graspers that can be easily and quickly adjusted even at difficult angles [2, 8]. Another problematic point can be the extraction of a large specimen. This can be facilitated using large extraction sac (8×10 in.), aspirating all the fluid and allowing all the air to escape from the sac before closing it. The specimen in the sac is oriented so that its thinner portion (lead point) comes out first and also the seams of the sac should be parallel to the ribs. The incision may also need to be extended if the need arises [2], but division of the rib or insertion of a chest wall retractor is almost never necessary.

In our previous retrospective study [10], 95 patients had been selected to undergo thoracoscopic lobectomy for locally advanced lung cancer between 2002 and 2007. Of these, 73 (77 %) patients safely completed the procedure while 22 (23 %) were converted to open. The most common reason for conversion was unsafe continuation for anatomic reasons ($n=7$) especially a tumor involving or in close vicinity of major vessels. This was followed by bleeding ($n=5$) and dense adhesions ($n=5$). Other causes included the need for extended resection to clear positive margins ($n=2$), large tumor size ($n=1$) and stapler misfire ($n=1$). When compared to patients who underwent planned open resection for locally advanced tumors during the same time, majority of the intra-operative parameters and post-operative outcomes like operative blood loss, operation time and length of ICU/hospital stay were similar. However, a significantly higher number of patients in the thoracoscopic group received adjuvant therapy (37.3 % vs. 5.2 % in open group, $p=0.0006$). In addition, no significant difference was demonstrated in overall and disease free survival between the two groups. Mahtabifard et al. [9, 11] have demonstrated the safety of VATS sleeve lobectomy. In a case series of 13 patients, thoracoscopic sleeve lobectomy was carried out without any conversions and there were no deaths within 30 days post-operatively. The patients had the diagnosis of non-small cell lung cancer or NSCLC ($n=8$), carcinoid ($n=4$) and metastatic sarcoma ($n=1$). One patient suffered from an anastomotic stricture and another required repair of the bronchial tear. Although no comparisons

were drawn with open sleeve resection, the various intra-operative parameters like blood loss and operative time were acceptable. Also the number of post-operative complications was not increased and length of ICU/hospital stay was not prolonged. As a variation, Nakanishi [11] recommended the use of a utility mini thoracotomy (about 8 cm long) anteriorly in 4th intercostal space. Other ports, each about 1.5 cm long, were placed in 6th intercostal space in posterior axillary line for the camera, 6th space in anterior axillary line for lung manipulation and in 3rd space in anterior axillary line for handling the needle holder used in bronchial anastomosis. The majority of work in bronchial anastomosis was done through the mini thoracotomy incision under direct vision after the removal of specimen. A 5 mm flexible-tip camera view was also used through either the access incision or traditional thoracoscopic port if the direct visualization was unclear during the course of the procedure. The bronchial resection was done either in form of a wedge (wedge-plasty) or circumferentially (sleeve resection). The wedge was closed using interrupted absorbable monofilament starting from the cartilaginous portion and ending at the membranous part. The end-to-end anastomoses were performed using continuous suturing and reinforcement with interrupted sutures after each bite. Then, the end of each interrupted suture was tied to the end of continuous suture along the way to prevent it from slipping or loosening up. In this technique of anastomosis, the silk sutures were used to hold up and tighten the monofilament loops from inside the bronchial lumen. Five patients having NSCLC were operated using this technique in which four underwent wedge bronchoplasty and one underwent sleeve resection. The post-operative results were acceptable with no mortality or major morbidity; only one patient developed chylothorax. Kamiyoshihara et al. [12], in a retrospective study, published their results of VATS lobectomy plus wedge bronchoplasty in 1 metastatic and 6 primary lung cancer patients without any serious complications. In these patients, 6–10 cm working incisions in 4th or 5th intercostal spaces were used with suturing under direct vision. The other 12 mm ports, either in the 7th space (along anterior axillary line) or 9th space (in posterior axillary line), were utilized for camera or insertion of other thoracoscopic instruments as an aid in the procedure. The anastomosis was done using interrupted 3–0 or 4–0 monofilament, starting from the lower to upper edge of the deepest portion of the bronchial anastomosis. The instruments, particularly needle holders, were manipulated in a back-handed fashion to provide clearer views.

Thoracoscopic En-bloc Pulmonary and Chest Wall Resection

Intuitively, thoracoscopic chest wall resection may seem to offset the advantages minimally invasive procedures.

However, the precise dissection, transection of minimal number of intercostal nerves and avoidance of open wound and rib retraction may decrease local inflammation and centrally propagated nociception. Such interventions can decrease post-operative analgesic requirements [8, 13].

The technique of en-bloc anatomic pulmonary and chest wall resection has been described in detail previously [13]. The patient and surgeon positioning and sites of port incisions remain more or less the same as for lobectomy. The important difference is the placement of the access incision, which varies with the location of the tumor. As a general guideline, the access incision should not be in close proximity to or exactly over the involved segment of chest wall to avoid delayed wound healing and chances of infection to underlying structures especially if prosthetic material is used in chest wall reconstruction. An anterior position with respect to involved area is our preferred site for access incision as it facilitates the division of medial ends of the ribs. However, if the access incision is not able to provide an optimal view for pulmonary or hilar dissection, a different site can be chosen that is more useful for a safer continuation and completion of surgery. Additional ports can also be placed if there is no alternative. Therefore, it is always preferable to do a thorough inspection of the pleural cavity and location of tumor on the lung and chest wall before deciding the port sites. After completing the incisions, the parietal pleural surface is scored with electrocautery to mark the planned resection. The ribs closest to the access incision are divided using a standard rib cutter. This is followed by dissection of intercostal muscles and neurovascular bundles with an energy-sealing device like the Ligasure™ (Covidien, Boulder, CO). The rib block is mobilized from overlying muscles and lateral/posterior portion of the ribs are divided using an endoscopic bone cutter or high-speed drill. The pulmonary and hilar dissections are performed and the specimen is placed in a large sturdy nylon extraction sac. With the ribs oriented perpendicularly to the incision, the specimen is extracted. If a large defect is created at the tumor site, then a prosthetic patch can be used to prevent port site herniation. The prosthetic patch (polytetrafluoroethylene) is pre-punched with small holes inside the rim before being introduced in the pleural cavity and held against the defect with a fair overlap. The sutures are placed through 2 mm stab incisions using suture-passing devices that are passed through chest wall and the punched-out holes in the prosthetic patch. This can be done from an inside-out or outside-in direction and knots placed externally below the incision or internally facing the pleural cavity. The chest wall reconstruction can also be carried out using muscle flaps (like latissimus dorsi) that can also be mobilized video-endoscopically. In a case presentation, by Widmann et al. [14], a 60-year-old man underwent VATS en-bloc pulmonary and chest wall resection for a more posterior left upper lobe lesion. The patient had previously

completed neo-adjuvant external beam radiation therapy. The involved segments of 3rd and 4th rib (each 2 cm long) were circumferentially excised together after completing the pulmonary resection and mediastinal lymphadenectomy. The ribs were divided anteriorly by a long-handled osteotome while neurovascular bundles were divided using a harmonic scalpel. Posteriorly the rib heads were disarticulated from the corresponding vertebral bodies to remove this portion of chest wall en-bloc with the pulmonary specimen. The specimen extraction was completed without rib spreading through a 5 cm anterior incision. The chest wall defect was under the scapula and therefore, reconstruction was not required. The patient had a rapid convalescence and returned to baseline physical activity in 3 weeks without any significant peri-operative complications. In our case presentation [15], a 69-year old white male underwent en-bloc resection of right upper lobe along with wedge resection of right middle lobe and sub-scapular portion of chest wall involving 3rd, 4th and 5th ribs. The patient had previously undergone neo-adjuvant radiation. The total duration of anesthesia was 146 min. On 1st post-operative day, the patient underwent thoracoscopic evacuation of retained hemothorax largely thought to be caused by the early use of heparin and antiplatelet therapy for cardiovascular co-morbidities. The patient suffered respiratory failure on 3rd post-operative day (POD) due to retained secretions and had to be re-intubated. Extubation was done on POD 5 and the patient was discharged on 9th POD. At 3 week follow up visit, the patient had regained near normal activity and required minimal pain medications. In a small case series of 3 patients [16] (which included the above mentioned patient), en-bloc pulmonary and chest wall resection was performed for stage IIA to IIIB NSCLC. Two patients had received neo-adjuvant therapy prior to surgery. The only patient that developed any post-operative complication is the one already mentioned above as a case presentation. At the 3 week outpatient visit, all patients either required no or minimal pain medications. At 6, 16 and 26 months follow-up, all patients were alive with no evidence of recurrence. Although not entirely in the realm of pure thoracoscopic resections, a hybrid procedure by D'Amico et al. deserves mention [17]. The procedure of thoracoscopic pulmonary resection was followed by en-bloc chest wall resection through a counter incision over the involved area avoiding rib spreading and scapular mobilization. Twelve patients completed this hybrid procedure without any conversion. There were no peri-operative deaths and other post-operative outcomes were similar to open procedure except for a significantly shorter hospital stay ($p=0.03$).

Thoracoscopic Pneumonectomy

The technique of VATS pneumonectomy has been described previously [18]. After double-lumen endobronchial

intubation for selective ventilation, the patient and surgeon positions remain similar as in VATS lobectomy. The location of 1.5 cm camera and working port incisions also remain the same whereas an access incision, which can later be extended to a length of 4–7 cm is placed directly above the hilum with the aid of a finder needle. Using the access incision, the pulmonary veins are dissected and encircled. It may be useful to delay division of the first dissected vein until the other is prepared to prevent lung congestion. Proximal control of the pulmonary artery is obtained not so much by encircling the pulmonary artery, but by encircling the firmer main-stem bronchus first (especially on the left side). As the veins are already divided, all the soft tissue apart from the encircled bronchus contains the main pulmonary artery. Such an approach minimizes the probability of potentially catastrophic main pulmonary arterial injury. The vessels are divided using a roticulating endoscopic linear cutting vascular stapler. Division of main bronchus by a 4.8 mm or other thick tissue stapler follows, taking care to divide the bronchus at the carina. This often involves proximal dissection that is facilitated by control of the lung itself using the Snowden-Pencer Diamond-Flex™ triangular liver retractor (Cardinal Health Inc, Dublin, OH) as previously described [19]. The specimen is delivered into a large 5×8 or 8×10 in. sac, which is then taken out through the access incision using a rocking motion. In our initial experience, 7 pneumonectomies were performed in a 20-month period until the end of December 2004 [18]. Among these patients, one was an emergent procedure and remaining six were elective that underwent mediastinoscopy as well. Five patients had central lesion or bulky hilar adenopathy compressing the pulmonary artery while the other two patients had lesions involving the secondary carina. After thoracoscopic inspection, the patients were not found to be suitable candidates for sleeve resection and therefore, underwent pneumonectomy. There was one conversion in this initial series. The final pathology of one patient reported positive bronchial margins and therefore, received adjuvant radiotherapy. The immediate post-operative outcome was acceptable. However, two patients died 3 months later, one due to radiation pneumonitis and other due to liver metastasis. The remaining patients had no evidence of recurrence at median follow up of 21 months. In an effort to include more number of cases and evaluate any long-term benefits of thoracoscopic pneumonectomy, a subsequent retrospective study was done to include patients who underwent the procedure between 2002 and 2008 [20]. Out of 32 elective cases, 8 (25 %) were converted to open. The reasons for conversion included tumor extension ($n=5$), bleeding ($n=1$) and adhesions involving hilar structures or proximal pulmonary vessels ($n=2$). The patients who completed thoracoscopic pneumonectomy had less operative blood loss and also shorter hospital stay. The converted patients suffered a

Table 1 Summary of published VATS pneumonectomy experience

Study	Sample size (n)	Tumor size/stage	Surgical technique	Intra-operative parameters/outcomes	Post-operative outcomes	Other comments
Craig and Walker [21]	6	T2 (<6 cm)	3 ports, pulmonary A. divided after bronchial transection	Mean op. time 233 mins., mean blood loss 294 ml	A fib. ($n=1$), Readmission ($n=1$) for suspected empyema, better pain score	2 patients developed metastasis at 7 months
Conlan and Sandor [22]	1	T2 left hilar mass	3 ports, pulmonary A. divided after bronchial transection	Op. time 180 mins., blood loss 200 ml	A fib.	Essential criteria for thorascopic pneumonectomy were laid down in the article
Cadière et al. [23]	1	3 cm left lower lobe mass with concurrent cervical esophageal tumor	3 ports, prone position, specimen extraction through trans-hiatal route during laparoscopic phase of esophageal surgery.	Op. time 146 min., blood loss 30 ml	Not described	Prone position facilitated better visualization and access to aortopulmonary window
Oparka et al. [24]	1	T4, left upper lobe	3 ports, Edinburgh posterior approach, pulmonary A. divided after bronchial transection	Not mentioned	Uneventful	The posterior approach was claimed to provide better view of posterior hilum, mediastinal nodes and instrument tips
Nakanishi et al. [25]	1	New T2 lesion in left upper lobe, left lower lobectomy done previously	Completion pneumonectomy, 3 ports, bronchus being the last hilar structure to be divided	Op. time 350 mins., blood loss 241 ml	Uneventful	The pulmonary veins were divided intra-pericardially because inferior pulmonary vein stump could not be identified.
Piwkowski et al. [26]	1	T2 left hilar mass	3 ports, bronchus being the last hilar structure to be divided	Op. time 130 mins., blood loss 150 ml	Uneventful	Difficulty in deflating the involved lung was experienced despite properly placed double lumen endobronchial tube
Gonzalez-Rivas et al. [27]	1	5 cm right lower lobe lesion	Single 4 cm incision in 5th intercostal space	Op. time 210 mins.,	Uneventful	Chest-tube was placed in the posterior part of the incision

significantly higher operative blood loss. However, other peri-operative outcomes were similar in thoracoscopic, converted and open groups. The overall survival, at median follow-up of 47 months, was also similar in all the three groups, especially, when adjusted for the tumor stage. Other experiences of thoracoscopic pneumonectomy are summarized in Table 1.

Conclusions

Although it has been more than a decade since complex thoracoscopic pulmonary resections have been reported, the practice is largely limited to only a few centers around the world. Accumulating evidence suggests that thoracoscopic approaches to these resections are oncologically sound and safe and have the usual benefits of minimally invasive surgery—quicker recovery and lesser morbidity. However, further adoption and study of these techniques is required before wide deployment. These cases should be attempted by surgical groups proficient in straightforward VATS resections. Excellent anesthesia and intensive care support significantly augments the ability of surgeons to keep the case thoracoscopic. As confidence is gained by performing increasing number of surgeries, we believe that more complex resections will find their practitioners and proponents in more and more operating rooms.

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