Review Article

Modern impact of video assisted thoracic surgery

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Abstract: With advancement in technology, experience and training over the last two decades, video assisted thoracic surgery (VATS) has become widely accepted and utilized all over the world. VATS started as a diagnostic tool in the early 1990s, technique of VATS lobectomy evolved and became safer over the next 10-15 years and now it is being used for more advanced and hybrid operations. VATS has contributed to the development of minimally invasive surgical interventions for other thoracic disorders like mediastinal tumors and esophageal cancer as well. This article looks at the advantages of VATS, technique advancements and its applications in other thoracic operations and its influence on the present and future of thoracic surgery.

Keywords: Video assisted thoracic surgery (VATS); lobectomy; esophagectomy; minimally invasive esophagectomy (MIE); uniportal VATS

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Introduction

The tremendous success of laparoscopic surgery in the late 1980s and early 1990s gave impetus to thoracic surgeons to adapt and apply this technology on the other side of the diaphragm. Thoracoscopy or more correctly termed video assisted thoracic surgery (VATS) became possible with advancement in endoscopic video systems and endoscopic surgical staplers. In 1993, a VATS study group was formed and a review of more than 1800 cases was published (1). Wedge resection for solitary pulmonary nodule and interventions for pleural disorders were the most commonly performed VATS procedures in this study and the conversion rate was 24%. During these early years of adaptation VATS was primarily used for basic procedures like drainage of pleural effusion, biopsy of pleura or lung and pleurodesis. With time and experience thoracic surgeons started to master more advanced and technically challenging cases.

VATS lobectomy

About 2% of patients in the VATS study group had thoracoscopic lobectomy. Over the next 10 years several authors described the technique of VATS lobectomy and reported on its safety, efficacy and reproducibility. Walker *et al.* reported 158 cases of VATS lobectomy with 11% conversion rate, 1.8% mortality and 3-year survival comparable to lobectomy with thoracotomy (2). McKenna *et al.* (3) reported in 1998 of 298 VATS lobectomy cases with 6% conversion rate and 0.3% mortality rate. Port site tumor recurrence was reported in 1 (0.3%) case. In a subsequent paper of 1,100 patients who underwent VATS lobectomy, McKenna and colleagues (4) reported a 2.5% conversion rate, 0.8% mortality, 0.57% local recurrence, and a mean length of hospital stay of 4.78 days. Onaitis *et al.* (5) reported 500 VATS lobectomy cases with 1.6% conversion rate, 1% 30-day mortality and there were no operative mortality. Two year survival for stage 1 and stage 2 NSCLC was 85% and 77% respectively.

Mediastinal lymph node dissection (MLND) during VATS lobectomy has shown to be equally efficacious to open lobectomy by D'Amico *et al.* (6). In this National Comprehensive Cancer Network's database review, close to 400 patients undergoing VATS and open lobectomy were reviewed and there was no difference in the number of N2 stations and mean lymph nodes harvested. In two large meta-analyses, VATS lobectomy has been shown to be safe with a conversion rate of 1-2% and oncologic outcomes equal to open lobectomy (7,8). These reports along with training of thoracic surgery residents and adaptation by existing surgeons have led to increase in the number of lobectomy performed by VATS across the world. In a recent review of the Society of Thoracic Surgeons (STS) General Thoracic Surgery Database, 45% of lobectomies were performed with VATS techniques (9).

Advantages of VATS lobectomy

In a prospective database evaluation, Villamizar *et al.* (10) evaluated 1,079 patients undergoing VATS and open lobectomy over a ten year period. Compared to open lobectomy, VATS lobectomy patients were shown to have less major complications like atrial fibrillation, atelectasis, prolonged air leak, pneumonia and renal failure. Duration of chest tube and length of hospitalization were shorter in the VATS lobectomy group. Similar findings were reported by Paul *et al.* (11) in a review of more than 6,000 patients undergoing lobectomy for NSCLC. VATS lobectomy has also been shown to facilitate deliver of adjuvant treatment. Petersen *et al.* (12) reported a higher percentage of patients undergoing VATS lobectomy receiving 75% or more of their planned adjuvant regimen without delayed or reduced doses compared to patients who had open lobectomy (61% versus 40%, P=0.03). Cost of VATS lobectomy has been reviewed in a study of close to 4,000 lung resections (13) and found to be less compared to open lobectomy ($20,316 *vs.* $21,016, P=0.027). This study also found the risk of adverse events was significantly lower in the VATS group, odds ratio of 1.22 (P=0.019). There is growing evidence to suggest that the body's immune function is better preserved after VATS compared to thoracotomy, as documented by the release of pro-and anti-inflammatory cytokines, innunomodulatory cytokines, circulating T cells (CD4) and natural killer (NK) cells, and lymphocyte function (14). In patients with forced expiratory volume in 1 second (FEV1) of less than 60%, Ceppa and coauthors (9) reported a much less incidence of pulmonary complications (P=0.023) in patients undergoing VATS lobectomy versus lobectomy with thoracotomy.

VATS lobectomy—Impact on other pulmonary resections

As the technique, experience and comfort with VATS lobectomy grew, thoracic surgeons employed its principles in various subsets of patients of lung cancer who would have not received a curative resection or would have required a thoracotomy. In patients with poor pulmonary function, advanced age and small peripheral tumors who cannot tolerate a lobectomy or a thoracotomy, VATS wedge resection can be an attractive option. Linden and colleagues (15) performed VATS wedge resection in patients with a mean FEV1 of 26% and reported a 1% mortality rate. To decrease the risk of local recurrence after VATS wedge resection, Santos and coworkers (16) reported the use of brachytherapy mesh placement over the stapled lung margin which led to reduction of local recurrence from 18% to 2%.

Technical principles of VATS lobectomy, namely individual ligation of artery, vein and bronchus, lymph node dissection and resection of lung parenchyma with surgical staplers have been applied to VATS segmentectomy as well. Schuchert *et al.* (17) reported on 225 cases of anatomic segmentectomy performed by VATS or thoracotomy. Length of stay (5 *vs.* 7 days, P<0.001) and pulmonary complications (15.4% *vs.* 29.8%, P=0.012) were significantly improved in patients undergoing VATS segmentectomy. Similar outcomes have been reported by multiple other authors with acceptable survival and local recurrence rates.

Berry *et al.* (18) reported on a hybrid technique of VATS lobectomy with en-bloc chest wall resection without rib spreading or scapula retraction. In this series, technique of VATS lobectomy was used to achieve lung resection which was followed by a small counter incision to remove the involved ribs en-bloc. They reported a shorter length of stay (P=0.03) in 12 patients with this hybrid approach compared to 93 patients who had a thoracotomy.

Further advanced VATS techniques like bronchoplasty and sleeve resections have also been reported over the last 5 years. Agasthian (19) reported a case series of 21 patients, 9 had simple bronchoplasty, 8 patients had sleeve lobectomy and 4 patients had extended bronchial resection. All patients underwent hand-sewn closure of the bronchus with interrupted sutures. One patient developed bronchopleural fistula. There was no operative mortality and no local recurrence was reported at 6 months. Yu and colleagues (20) reported on nine cases from China undergoing VATS lobectomy and sleeve resection without any major intra-operative or post-operative complications.

VATS lobectomy—Impact on minimally invasive esophagectomy (MIE)

Emergence of VATS lobectomy led to increasing interest among thoracic surgeons to employ similar techniques to develop VATS assisted esophagectomy. The goal would be to mobilize the esophagus and eventually perform an intra-corporeal thoracoscopic anastomosis. From late 1990s, several authors have reported on VATS mobilization of the esophagus as part of McKeown esophagectomy and VATS mobilization and intra-corporeal anastomosis as part of Ivor Lewis esophagectomy. Luketich *et al.* (21) reported their first series of 222 patients undergoing MIE. Operative mortality was 1.4% and anastomotic leak was seen in 11.7%. In the subsequent paper of over 1,000 MIE cases by the same group (22), 481 McKeown and 530 Ivor Lewis esophagectomies were reported with 1.68% mortality and median length of stay of 8 days. The Ivor Lewis MIE was associated a decrease in 30-day mortality (0.9%). In a randomized trial from Netherlands (23), authors reported a significant decrease in pulmonary complications in patients undergoing MIE *vs.* open transthoracic esophagectomy (9% *vs.* 29%, RR 0.30, 95% CI: 0.12-0.76, P=0.005).

VATS lobectomy—Impact on other thoracic procedures

For resection of thymoma and other mediastinal tumors, sternotomy remained the preferred approach until late 1990s. VATS thymectomy over the years has become an accepted method for resection of the thymus in non-thymomatous myasthenia gravis (MG) and early-stage thymoma (with or without MG). VATS resection is often used for thymomas less than 5 cm in diameter, but it has also been reported for larger tumors. Multiple studies have demonstrated decreased blood loss, shorter length of hospital stay, and equivalent symptomatic outcomes in patients with MG undergoing VATS thymectomy, compared with thymectomy via sternotomy (24-26). Both bilateral and unilateral VATS thymectomy techniques have been reported with good symptomatic results in MG patients (24).

Authors have also reported on the feasibility and efficacy of diaphragm plication by VATS approach for unilateral diaphragm paralysis. Freeman *et al.* (27) reported 22 cases of VATS diaphragm plication. All patients showed improvement in dyspnea score and pulmonary function on follow-up. Hospital stay for patients with VATS plication was shorter compared to plication by thoracotomy (3.7 *vs.* 5.4 days).

VATS lobectomy—Impact on technical advances

The widespread use and advancement of VATS and other minimally invasive techniques can be attributed to the endoscopic stapling device that has enabled rapid and safe resection of major hilar structures as well as lung parenchyma. In a study of 713 patients undergoing stapled vascular division of 2,567 vessels, vascular complications included five cases of minor intimal fracture, one arterial avulsion, and one stapler misfire, with an overall adverse event rate during stapler application of 0.27% (28). But cost has been a major issue with each VATS lobectomy requiring several loads of stapler cartridges. Energy based coagulation and tissue fusion technology has been applied in laparoscopic procedures over the last two decades. Several energy-based fusion devices are currently available. Schuchert *et al.* (29) in 2012 reported their experience with application of the Ligasure device (Valleylab, Boulder, CO) for sealing and division of pulmonary vasculature, at the time the only FDA approved sealant for thoracic use. First 12 cases were done with Ligasure Impact device with a seal width upto 4.7 mm. Bleeding from a branch of pulmonary vein was seen in two cases that were controlled intraoperative without any major complications. In the next 300 cases a larger Ligasure Atlas device with a seal width up to 6 mm was used and there was no immediate or late bleeding noted. The authors used the device twice before cutting the vasculature and applied it on vessel diameter up to 7 mm. Sakuragi and colleagues (30) reported use of BiClamp technology for division of lung parenchyma in patients with fused fissures during VATS lobectomy in 60 patients and compared them to patients in whom fissure was divided with staplers. Incidence rates of prolonged air leak and pneumonia were not significantly different between the two groups [6.9% and 3.4% in the staple group *vs.* 10.6% and 9.1% in the BiClamp(®) group].

In a randomized controlled trial, Marulli *et al.* (31) evaluated the safety and efficacy of laser use for division of incomplete fissures. Forty four patients were randomized to stapling or laser application (Thulium laser 2010 nm, Cyber TM, Quanta System, Italy). Duration of air leak and chest tube was slightly improved in the laser group but not statistically significant. Overall complications (P=0.006), length of stay (P=0.03), hospital cost (P=0.01) and procedure cost (P<0.0001) were lower in the laser group. Total procedure time was longer in the laser group (197 *vs.* 158 minutes, P=0.004).

VATS lobectomy—Development of uniportal VATS

Over the years, technique of VATS lobectomy has evolved and various modifications with 2-4 incisions have been reported by various leading surgeons across the world. Similar to single incision laparoscopic surgery, thoracic surgeons have evolved and the technique of VATS lobectomy has been modified into a single incision access with no rib spreading. From wedge resections to complex pulmonary resections have been reported. Over a 10-year period, Rocco *et al.* (32) performed more than 600 uniportal VATS cases. Majority of these cases were for pleural disorders and wedge resections for pulmonary nodules. The authors reported excellent outcomes without any major intraoperative complications. Gonzalez-Rivas reported their first 100 cases over a two year period with impressive results (33). Majority (96%) of lobectomy were accomplished with uniportal technique with no operative mortality. Mean chest tube duration and length of stay was 2 and 3 days respectively. Average 14.5 lymph nodes were harvested per resection with 154 minutes of mean operative time. Tam *et al.* (34) reported similar results in 38 uniportal VATS lobectomy. Six patients required thoracotomy. Ninety-seven percent of patients did not require intravenous analgesia and mean time to return to full normal activities was 7 days. Gonzalez-Rivas and colleagues (35) have also reported uniportal right pneumonectomy without any major complications.

VATS lobectomy—Development of robotic assisted VATS

Advancement in the robotic technology has generated interest among thoracic surgeons to its suitability for VATS pulmonary resections and other thoracic operations. It has been proposed that 3-dimensional optics and the articulation provided by robotic instruments may allow for increased use of a minimally invasive approach for pulmonary resection. The learning curve for robotic prostatectomy has been shown to be the same among laparoscopic trained fellows and experienced open surgeons who are not familiar with minimally invasive skills (36). Can this experience be replicated in thoracic surgery where surgeons not trained in VATS lobectomy are able to perform robot assisted VATS resection? More recently, the dual console systems, infrared technology for better anatomic visualization and tissue perfusion as well as improved simulation and training have made surgeons experienced in VATS lobectomy techniques interested in including robotics in their practice. Louie *et al.* (37) compared directly robotic and thoracoscopic pulmonary resection in a case-control analysis of anatomic robotic and VATS lung resections: 46 robotic resections (40 lobectomies, 5 segmentectomies, 1 conversion to VATS included in this group for intention-to-treat analysis) were compared with 34 VATS resections (27 lobectomies, 7 segmentectomies). Length of stay, major and minor postoperative morbidity and operative times were comparable. In a multi-institutional retrospective cohort study of 325 patients who underwent robotic lobectomy (38), median chest tube duration and length of stay was 3 and 5 days respectively. Major peri-operative complications were seen in 3.7% of patients and surgical mortality was 0.3%. Estimated 5-year survival was 80%. Implementation of robotic surgery programs carry a high capital cost and require expensive maintenance protocols. In a recent study, Nasir *et al.* (39) evaluated 862 robotic lung resections. 30-day mortality was 0.25% and major morbidity was seen in 9.6%. The authors estimated a profit of $4,750 per patient after factoring in the operative and hospital cost. Median length of stay in this study was 2 days.

VATS lobectomy—Development of awake thoracoscopy

Traditionally, intubation with a double-lumen tube and single lung ventilation has been considered mandatory for VATS to obtain optimal visualization. This is tolerated well in most cases but adverse effects of general anesthesia and airway trauma from double-lumen tube placement are inevitable. Many thoracic surgery patients have pre-existing cardio-pulmonary compromise which makes anesthesia riskier. These issues have led some thoracic surgeons to explore the idea of an awake thoracoscopy. Pleuroscopy with drainage of effusion and pleural biopsy with local anesthesia has been routinely performed with flexible scopes in an outpatient setting for many years, mostly by pulmonologists. Anesthesia for a more complex thoracoscopic intervention, termed 'awake VATS' includes a regional block with or without conscious sedation. This consists of one of the following—local anesthesia, intercostal nerve blocks, paravertebral blocks and thoracic epidural anesthesia. In this set up, open pneumothorax after trocar insertion leads to gradual collapse of the non-dependent lung and leads to spontaneous one-lung ventilation (40).

In a small randomized trial performed by Pompeo *et al.* (41), 43 patients with spontaneous pneumothorax underwent VATS bullectomy and pleurodesis under a thoracic epidural anesthesia. Their results showed safety and efficacy of this technique of VATS along with shorter hospital stay and reduced cost. The same group has also reported 19 cases of empyema treated with awake VATS decortication (42). Three patients developed mild hypercapnia that resolved with time and four patients required general anesthesia as thick pleural peel required a non-emergent thoracotomy. Chen *et al.* (43) reported their single institution experience of doing awake VATS in 285 cases. Of these, 137 were VATS lobectomy, 132 were VATS wedge resection and 16 were VATS segmentectomy. Conversion to general anesthesia was required in 4.9% of cases and one patient required thoracotomy for bleeding. There was no operative mortality. Anesthesia consisted of thoracic epidural, sedation and temporary intra-thoracic vagal blockade for inhibition of cough reflex.

Conclusions

Over the last 20 years, VATS lobectomy has developed into a safe and effective treatment for lung cancer and is superior to lobectomy with thoracotomy in many regards. Development and further refinement of its technique has allowed other thoracic procedures to be done in a minimally invasive fashion. With future improvement in optics, energy devices and anesthesia management, this technique will continue to serve as the pillar for development of newer thoracic surgical interventions.

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