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Chapter

# Advances in Minimally Invasive Surgery for Lung Cancer

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## Abstract

Over the last 25 years, improvement in instrumentation and surgical techniques has led to widespread adaptation of thoracoscopic (VATS) surgery in the field of thoracic oncology. What once was a niche operation like VATS wedge resection to now hybrid VATS chest wall resections, and advanced surgeries like bronchoplasty and sleeve resections are done with VATS. This has led to improved surgical outcomes for our patients and increased use of surgery in the treatment of chest disease. We review the history of VATS and its current state with most recent changes and upgrades in the technique in this chapter. We review the advancement in uniportal VATS, robotic assisted resection, complex VATS resection, and awake lung surgery with VATS.


**Keywords:** VATS, uniportal, robotics, awake VATS, hybrid resections

## 1. History of thoracoscopy

While the modern era of thoracoscopy begins in the early 1990s and includes Giancarlo Roviaro's report of the first thoracoscopic lobectomy as a major milestone [1], the term thoracoscopy dates back to a procedure performed by Francis Richard Cruise and Samuel Gordon in 1865 [2]. Using a device similar to the "Leichtleiter" used by Bozzini with a light source improved by Antonin Jean Desormeaux, Cruise examined the pleural space of an 11 years old suffering from an empyema and a pleurocutaneous fistula. Several years later, in 1882, coincidentally the year Robert Koch discovered *Mycobacterium tuberculosis* [3], Carlo Forlanini observed that spontaneous pneumothorax could collapse cavitary lesions and lead to their resolution [4]. From this observation, he introduced a procedure of inducing artificial closed pneumothoraces by inserting a needle in the anterior axillary line and forcing air into the pleural space, the first minimally invasive thoracic procedure.

Though he is considered by many to be the father of thoracoscopy, Hans Christian Jacobeus published his eponymous Jacobeus Operation in 1910; this operation involved inducing pneumothorax, inserting a thoracoscope through one incision, and introducing an galvanocautery instrument in through a separate incision for the purpose of releasing adhesions to allow the lung collapse to treat pulmonary tuberculosis [5]. Subsequently, antibiotics, improved anesthetics, and intraoperative oxygen delivery, thoracoscopy was neglected as a therapeutic option for most of the twentieth century until the modern era.

Attributed in large part to fiber optics for light transmission, enhanced image processing and rendering, and the advent of the surgical staplers, interest in VATS was piqued. The classic three-port technique focused the camera from hip-to-head while increased experience determined that a modified approach should focus from umbilicus-to-shoulder. Aside from traditional three-port VATS technique, some procedures, including thoracic sympathectomy, have been performed via needlescopic VATS as well as two-port and uniportal VATS. Additionally, robotic assisted thoracic surgery (RATS) can serve a role in thoracic surgery, particularly for mediastinal procedures. Each of these different techniques has the potential to serve an important role as part of the thoracic surgeon's armamentarium [6].

## 2. VATS lobectomy

As mentioned in the previous section, Roviaro reported the first VATS lobectomy in 1991. However, in 1993, only 2% of the cases reported by the Video Assisted Study Group were VATS lobectomies while 49% were wedge resections. As reports continued to show the feasibility of VATS lobectomies as well as possible advantages, familiarity with the procedure improved technique. Even so, skepticism remained for the use of VATS for the treatment of non-small cell lung cancer (NSCLC). The results of a randomized control trial by Kirby et al. [7] failed to demonstrate the superiority of VATS though it also failed to demonstrate inferiority. In this study, 30 patients were randomized to the traditional muscle-sparing thoracotomy while 24 were put into the VATS group. No difference was found between the duration of chest tube drainage, hospital length of stay, pain score, or time prior to returning to work. The study specifically expressed concerns about the adequacy of lymph node dissection for an operation intended for malignancy.

McKenna et al. reviewed 298 cases of patients that underwent VATS lobectomy and lymph node dissection for NSCLC with the intent of determining adequacy of resection [8]. Their multi-institutional review included patients with stage I to IIIA and featured a 6% conversion rate with a single report of an incisional recurrence. In this study, the survival rate at 4 years for patients with stage I disease was 70%. Comparatively, Li and Wang [9] retrospectively evaluated outcomes for 76 patients that underwent lobectomies with lymph node dissection via VATS or thoracotomy for clinical N0 disease that was discovered to be pathologic N2 NSCLC. In their study, the number of lymph nodes recovered and the number of stations sampled were similar. The survival and disease-free survival rates are presented in **Table 1**. In addition to these reported survival and disease-free survival rates, VATS patients had shorter operative times and less blood loss.

A subsequent larger study was performed by Onaitis et al. [10] on VATS lobectomies for benign and malignant disease including 500 patients. Of these lobectomies, 83.2% were performed for NSCLC with an overall conversion rate of 1.6% (8 of 500). The pathologic stage of the patients included in this study were stage I (55.3%), stage II (9.6%) and stage III or greater (10.6%). The overall 2-year survival rate in the patients with stage I NSCLC and stage II was comparable to those undergoing thoracotomy (85% vs. 77%). Additionally, perioperative mortality for benign pathologies was 0% while it was 1% for malignant pathologies.

| | 1-year disease-free survival | 3-year disease-free survival | 1-year survival | 3-year survival |
|---|---|---|---|---|
| VATS | 82.6% | 49.3% | 84.9% | 64.0% |
| Thoracotomy | 72.0% | 51.3% | 71.2% | 42.7% |

**Table 1.**
*Comparative survival rates.*

Whitson et al. [11] analyzed 147 patients who underwent lobectomies for stage I NSCLC (59 by VATS and 88 by thoracotomy). In this particular study, patients who underwent thoracotomy had a larger yield of nodes and shorter time in the ICU, potentially because of the additional comorbidities reported in the VATS patients. However, no significant differences were found in operative times, length of hospital stay, or median survival.

## 3. Long-term outcomes of VATS lobectomy for NSCLC

To justify the continued use of VATS for lobectomies as treatment for NSCLC, data continues to be collected and reported by many groups. Multi-institutional experience of 145 patients with clinical stage IA NSCLC less than or equal to 2 cm was reported by Shigemura et al. [12]. For this study, three approaches were utilized: complete thoracoscopic technique without any rib spreading, assisted VATS, which included VATS with a mini-thoracotomy and open thoractomy. The overall 5-year survival rates did not differ significantly between techniques (VATS—96.7%, assisted VATS—95.2%, and open—97.2%). Higuchi et al. [13] also reported their experience of 160 patients with stage IA NSCLC with patients who underwent VATS lobectomy and open thoracotomy. The reported 5-year disease-free survival was equivalent with 88% in the VATS group and 77.1% in the thoracotomy group. The 5-year overall survival for pathologic stage IA NSCLC was 94.8% in the VATS group and 96.2% in the thoracotomy group, showing no statistical difference in survival. Lee et al. [14] performed a retrospective review of patients who underwent lobectomy for NSCLC, from their institution using propensity-matched scores in 416 patients. The review included clinical stage I to III with the majority being stage IA. The 3- and 5-year overall survival for the patients with clinical stage IA who underwent VATS lobectomy were 87.4 and 76.5%, respectively, and 81.6 and 77.5% for thoracotomy. Their analysis also showed no inferiority of VATS lobectomy for early stage NSCLC. Murakawa et al. [15] also evaluated survival outcomes in patients with early stage NSCLC and found VATS and open thoracotomy to be equivalent. Yang et al. [16] queried the national cancer database to evaluate the national survival outcomes following VATS versus open lobectomy for stage I NSCLC. After propensity score matching 2928 patients were included in the final analysis. In the matched patients there was no difference in 5-year survival between VATS and open thoracotomy, 66.3 and 65.8%, respectively. Data published by Flores et al. [17], which included intent to treat analysis in 741 patients (398 VATS and 343 open thoracotomy) demonstrating similar 5 year survival. The majority of their patients treated with lobectomy were clinical stage IA and demonstrated 79% 5-year survival in the VATS group and 75% in the open thoracotomy group (**Table 2**).

| Reference | Year | # of patients | VATS | Open |
|---|---|---|---|---|
| Shigemura et al. [12] | 2006 | 145 | 96.7% | 97.2% |
| Flores et al. [17] | 2009 | 741 | 79% | 75% |
| Higuchi et al. [13] | 2014 | 160 | 94.8% | 96.2% |
| Lee et al. [14] | 2013 | 416 | 76.5% | 77.5% |
| Yang et al. [18] | 2017 | 2928 | 66.3% | 65.8% |

**Table 2.**
*Five-year overall survival.*

## 4. Mediastinal lymph node dissection (MLND) via VATS

An essential component of each complete pulmonary resection for NSCLC is an adequate mediastinal lymph node dissection (MLND). With the advent of VATS lobectomy particularly for NSCLC, the efficacy of a VATS MLND has been evaluated in comparison to MLND via thoracotomy. The National Comprehensive Cancer Network's (NCCN) NSCLC Database was evaluated by D'Amico et al. [19] to compare VATS MLND to MLND via thoracotomy. The number of lymph node stations evaluated by both techniques was at least 3 and the number of N2 nodes evaluated by both techniques was not significantly different. A single institution randomized control trial reported by Palade et al. [20] included 66 patients with stage 1 NSCLC. In this study, there was no statistically significant difference in the overall number of lymph nodes sampled or the number of lymph nodes in each station. Because VATS MLND has comparable efficacy to open dissection, adequate lymph node dissection can be performed thoracoscopically.

## 5. Clinical advantages of VATS lobectomy vs. thoracotomy

Multiple studies have documented several advantages of VATS lobectomies including improved quality of life, decreased postoperative pain, and shorter hospital stays. A retrospective study by Villazmizar et al. [21] evaluated 1097 patients that underwent lobectomies with 697 lobectomies via VATS and 382 lobectomies via thoracotomy. In reviewing these cases, the incidence of postoperative complications, including atrial fibrillation, atelectasis, prolonged air leak, transfusion requirements, pneumonia, renal failure death, and shorter hospital stay, were all found to be less common in the VATS lobectomy group. Paul et al. [22] found similar results in evaluating the STS database and reviewing 6323 lobectomies, 5024 via thoracotomy and 1281 via VATS. Propensity matched analysis of these cases found that 73% of VATS patients experienced no complications while 65.3% of thoracotomy patients had no complications. Furthermore, patients undergoing VATS lobectomy in this review had a lower incidence of arrhythmias, reintubations, and blood transfusion as well as shorter duration of chest tube drainage and length of stay.

Predictably, patients requiring pulmonary resections for management of NSCLC often suffer from decreased pulmonary function, which makes them high risk. Because VATS has reduced the risks associated with lobectomy, patients previously considered prohibitive risks are potentially resectable. Donahoe et al. [23] evaluated a cohort of 608 patients (including 72 high risk and 536 standard risk) that underwent lobectomy for NSCLC. For those patients who underwent a VATS lobectomy, there was no difference in complication rate or overall survival between high risk and standard risk patients. Another study by Bertani et al. [24] found that VATS lobectomy patients with reduced preoperative FEV1 had similar outcomes as those with normal preoperative FEV1, despite a longer hospital stay. Patient with a predicted postoperative FEV1% of less than 60% had an average length of stay of 8.7 days while those with a predicted postoperative FEV1% of greater than 60% was 6.8 days (8.7 vs. 6.8 days, $p = 0.05$) (**Table 3**).

In light of these advantages, it is important to establish not only efficacy but cost effectiveness as a measure of quality. Swanson et al. [25] evaluated the costs of open versus VATS lobectomy for 3961. In this study, patients who underwent a VATS lobectomy had a shorter length of stay, less adverse events, and cost the hospital less than an open lobectomy.

| Ppo FEV1% | n | Grade I | Grade II | Grade IIIa | Grade IIIb | p-value† | LOS, Mean (±SD) | p-value‡ |
|---|---|---|---|---|---|---|---|---|
| <40% | 2 | 0 (—) | 1 (100.00) | 0 (—) | 0 (—) | n.s | 5.90 (±2.23) | n.s |
| ≥40% | 98 | 22 (45.83) | 24 (50.00) | 1 (2.08) | 1 (2.08) | | 7.18 (±3.83) | |
| <50% | 4 | 1 (50.00) | 1 (50.00) | 0 (—) | 0 (—) | n.s | 9.18 (±6.31) | n.s |
| ≥50% | 96 | 21 (44.68) | 24 (51.06) | 1 (2.13) | 1 (2.13) | | 7.10 (±3.72) | |
| <60% | 18 | 4 (40.00) | 4 (40.00) | 1 (10.00) | 1 (10.00) | 0.067 | 8.74 (±4.79) | 0.05 |
| ≥60% | 82 | 18 (46.15) | 21 (53.85) | 0 (—) | 0 (—) | | 6.80 (±3.52) | |

*LOS, overall hospital length of stay; n.s., not significant; ppo-FEV1, predicted postoperative forced expiratory volume in 1 s; SD, standard deviation.*
*†Fisher's exact test.*
*‡t-test with equal or unequal variance.*

**Table 3.**
*Complications of patients undergoing video-assisted thoracic surgery lobectomy based on different ppo-FEV1 cut-offs [24].*

## 6. Clinical advantages of VATS lobectomy vs. thoracotomy

As a direct result of the advantages and similar survival rates for patients after VATS lobectomy for NSCLC, many institutions have adopted this surgical approach. In addition to VATS lobectomies, other anatomic resections have been performed via VATS.

Recent data have indicated that an anatomic segmentectomy can be considered an acceptable operation to obtain an R0 resection for small stage I NSCLC lesions. In a study reviewing 225 anatomic segmentectomies by Schuchert et al. [26], VATS segmentectomies were compared to those performed via thoracotomy demonstrating similar overall mortality, complications, recurrence rates, and overall survival.

Liu et al. [27] difference was seen in transfusion rates, number of lymph nodes dissected, estimated blood loss, duration of chest tube drainage, overall complication rates, or length of hospital stay. Operative time was longer in the VATS group while postoperative mean pain scores were higher in the higher in the thoracotomy group. From their data, they conclude that VATS pneumonectomy is a safe technique for either benign or malignant disease.

## 7. Development of single port VATS

The first description of single port VATS by Rocco et al. [28] was published in 2004. Initially used for diagnosis or treatment of primary spontaneous pneumothorax, the uses of single port VATS expanded to include management of pleural effusions, nonanatomic wedge resections, and diagnostic thoracoscopy for lung cancer during this study's 10 year experience. The conversion rate to a 2 or 3 port VATS or mini thoracotomy was 3.7%. Xie et al. [29] reported their single-institution experience of single port VATS in 1063 cases with a conversion rate of 4.6%. Institutional data reported by Shih et al. [30] comparing single port VATS to multiport VATS for anatomic segmentectomies in treating primary lung cancer indicated similar operative outcomes in the two propensity matched groups.

Single port VATS has been evaluated for safety and efficacy in the treatment of NSCLC. Comparing VATS and single port VATS lobectomy patients, Dai et al. [31] reported that single port VATS patients reported a higher satisfaction score, less postoperative pain, and less blood loss. Fan et al. [32] reported a similar operative time and number of lymph nodes dissected in both single port VATS and open lobectomies for locally advanced NSCLC. In this study, single port patients had a shorter period of chest tube drainage and length of hospital stay but a higher complication rate than thoracotomy. The complications studied included prolonged air leak, atrial fibrillation, bleeding, pneumonia, bronchopleural fistula, chylothorax, death, and 30-day mortality. However, neither study reported data on recurrence rates of overall survival.

## 8. Development of robotic-assisted VATS

With data indicating that VATS is safe and efficacious for the resection of NSCLC as well as having a variety of advantages over open surgery, it has been established as the preferred technique. However, with the availability of the robotic assistance, techniques for robotic procedures have been developed and examined. Utilizing three robotic ports as well as an assistance port, Melfi et al. [33] reported their early experience using the Da Vinci platform, describing lobectomies, enucleations, excisions, and bulla stitching. Single institution experiences have reported safety and shown similar outcomes in robotic resection when compared to VATS with improvement in postoperative pain. Other experiences with larger cohorts found higher incidence of operative injury, and bleeding compared to VATS. Robotic-assisted operations are also significantly more costly [34]. Park et al. [35] reported the long-term oncologic outcomes from three institutions and found them to be similar to VATS lobectomies.

Rajaram et al. [36] evaluated the use of robotic surgery for stage I to IIa NSCLC in the National Cancer Database from 2010 to 2012. They found 62,206 patients who underwent lobectomies including the open (n = 45,427), VATS (n = 12,990), and robotic (n = 3689) techniques. They found that the over the two-year period the use of the robotic lobectomy technique increased by 6%. Patients who underwent a robotic lobectomy had a lower length of stay compared to open lobectomy but had a higher rate of prolonged length of stay compared to VATS. The number of lymph nodes examined was significantly higher in the VATS group compared to robotic, with no difference in number of lymph nodes in the robotic and open groups. The resection status, margin positivity, was comparable between all groups. The evaluation of this data and the known increase in cost for the robotic technique did not show any potential advantages to the use of robotic surgery for a lobectomy compared to VATS. With the use of robotic techniques in treatment for NSCLC, early outcomes have been evaluated. Mungo et al. [37] found no negative effect on outcomes in patients who underwent robotic resection.

Park et al. [38] reported long-term outcomes to be similar in robotic assisted lobectomies compared to VATS and open thoracotomy. Yang et al. [18] compared the use of robotic, VATS, and open thoracotomy in patients treated with lobectomy for stage I NSCLC. An advantage of the robotic approach they report is a higher number of mediastinal lymph node stations dissected compared to the other techniques. The patients treated with the minimally invasive approach, robotic and VATS, had shorter hospital stays. The long term outcomes were similar in all the groups with 5 year overall survival reported for robotic, VATS and open thoracotomy as 77.6%, 73.5%, and 77.9%, respectively.

Cerfolio et al. [39] demonstrated the efficacy of robotic segmentectomies. For 100 planned robotic segmentectomies, 7 converted to lobectomies though every case was completed robotically. In this cohort, there were no mortalities at 30 or 90 days. Only 2 patients suffered major morbidity, each of which were postoperative pneumonias. Of the 79 patients that underwent robotic segmentectomy, there were only 3 recurrences (3.4%) with median follow up of 30 months while overall survival was 95%.

## 9. Development of awake VATS

Optimal visualization for a VATS is typically achieved with general anesthesia for double lumen tube intubation. However, awake VATS under regional anesthesia may be appropriate for selected patients. Potential anesthetic approaches include intercostal nerve block, paravertebral block, thoracic epidural block, peripheral field block, or ipsilateral stellate ganglion block [40].

A randomized study of 43 patients by Pompeo et al. [41] assessed the feasibility and efficacy of awake VATS in patients with spontaneous pneumothoraces that require intervention. Patients were randomized to undergo VATS bullectomy and pleural abrasion with either thoracic epidural anesthesia or general anesthesia. The patients undergoing awake VATS had shorter operating room times, improved pain scores, and shorter hospital stays compared to the general anesthesia group. Awake VATS patients did suffer minor complications including vomiting and transient urinary retention though there was no difference in morbidity and mortality between groups. Recurrences at 12 months were similar in each group. Tacconi et al. [42] reported satisfactory lung reexpansion in 95% in 19 patients that underwent awake VATS for pleural decortication. A single institution study by Chen et al. [43] reported 285 cases of awake VATS for pathologies such as primary lung cancer, metastatic lung cancer, benign lung tumors, and pneumothorax. Operative interventions included lobectomies, wedge resections and segmentectomies with a 4.9% intubation rate.

Additionally, Chen et al. [44] examined outcomes for patient undergoing awake VATS in stage I and II NSCLC. For 30 patients undergoing awake VATS lobectomy under epidural anesthesia and intrathoracic vagal block with sedation and 30 patients undergoing VATS lobectomy under general anesthesia with single lung ventilation, there was evidence that each group had comparable pathologic stages and number of lymph nodes resected. Additionally, no statistical difference was seen in postoperative complication though the awake VATS group had shorter hospital stays and decreased need for chest tube drainage.

## 10. Conclusion

At this point in the development of minimally invasive thoracic surgery, there is evidence that there are advantages as well as proof of non-inferiority. Additionally, robotic-assisted minimally invasive surgery has been proven safe in the hands of those adept in it on selected patients but carries the burden of additional cost. Follow up data from some studies show that long term outcomes are equivalent. Additional study is still required to fully establish if the costs of robotic surgery are justified.

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