Chapter

# Robotic Surgery for Non-Small Cell Lung Cancer

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## Abstract

Pulmonary resection has been a cornerstone in the management of patients with non-small cell lung cancer (NSCLC) for decades. In recent years, the popularity of minimally-invasive techniques as the primary method to manage NSCLC has grown significantly. With smaller incisions and a lower incidence of peri-operative complications, minimally-invasive lung resection, accomplished through keyhole incisions with miniaturized cameras and similarly small instruments that work through surgical ports, has been shown to retain equivalent oncologic outcomes to the traditional gold standard open thoracotomy. This technique allows for the safe performance of anatomic lung resection with complete lymphadenectomy and has been a part of thoracic surgery practice for three decades. Robotic-assisted thoracoscopic surgery (RATS) represents another major advancement for lung resection, broadening the opportunity for patients to undergo minimally invasive surgery for NSCLC, and therefore allowing a greater percentage of the lung cancer population to benefit from many of the advantages previously demonstrated from video assisted thoracoscopic surgery (VATS) techniques. RATS surgery is also associated with several technical advantages to the surgeon. For a surgeon who performs open procedures and is looking to adopt a minimally invasive approach, RATS ergonomics are a natural transition compared to VATS, particularly given the multiple degrees of freedom associated with robotic articulating instruments. As a result, this platform has been adopted as a primary approach in numerous institutions across the United States. In this chapter, we will explore the advantages and disadvantages of robotic-assisted surgery for NSCLC and discuss the implications for increased adoption of minimally invasive surgery in the future of lung cancer treatment.



**Keywords:** non-small cell lung cancer, pulmonary resection, minimally invasive surgery, robotic surgery, robotic-assisted thoracoscopic surgery

## 1. Introduction

Surgical resection for early stage non-small cell lung cancer (NSCLC) (Stage I and II) is associated with the lowest risk for local and distant recurrence and the best 5-year survival compared to other available treatment options [1]. The preferred approach for the surgical management of resectable, early-stage NSCLC has shifted in recent years from open thoracotomy to minimally-invasive surgery (MIS). Although thoracotomy has evolved over several decades to utilize muscle sparing incisions and improved postoperative pain control using epidural and paravertebral catheter systems, this technique is associated with more significant muscle dissection, rib spreading, and increased risk for morbidity and mortality after surgery. This includes a protracted period of recovery following hospital discharge, a slower return to baseline quality of life, and the potential for chronic pain associated with a larger thoracotomy incision.

With fewer perioperative complications and quicker recovery, minimally invasive surgery offers expanded opportunities for surgical resection in patients who otherwise would not tolerate the morbidity of thoracotomy. There are additional benefits to minimally invasive resection, including significantly improved postoperative pain control, shorter hospital length of stay, quicker return to baseline quality of life, and earlier return to work that enhance and support the utilization of this platform for NSCLC [2–4]. These advantages have resulted in a significant shift in the surgical management of NSCLC patients, where formerly open resection and up to a week-long hospitalization were standard even without significant postoperative complications, current expectations for VATS lung resection include discharge to home in the majority of cases within 4–5 days or less [5]. Additionally, in cases where there may be a recommendation for adjuvant therapy, MIS patients are more likely to have recovered and be ready to receive such therapy earlier in their treatment course. Therefore, minimally invasive resection has significant advantages, especially when considering some percentage of thoracotomy patients might not receive adjuvant therapy given a challenging recovery from their index lung resection.

Video-assisted thoracoscopic surgery (VATS) for lung resection has been a part of the thoracic surgeon's toolbox for the past three decades. Lewis et al. first described the use of VATS in 1992 [6]. The technique was quickly adapted to lobectomy in elderly patients with early-stage NSCLC, where some of the first cases were completed with similar or better results to historical controls [7]. Since these initial reports, VATS surgery has become increasingly common, with expanded use in complex lung resections, pneumonectomy, bronchovascular sleeve resections, and tumors that include the chest wall [8–10]. While only 8% of lobectomies in the United States were performed thoracoscopically in 2003, this figure has increased significantly over time, up to 54% as reported in 2014, especially among high-volume surgeons [11–13]. Trends that favor VATS adoption include being a dedicated thoracic surgeon in a high-volume center, performance of lung resection in a larger hospital, and lung resections performed in the Northeast. In one multi-variate analysis, there was a significant association between VATS adoption and surgeon volume (>15 lobectomies performed per year), which is not unexpected given the technical challenges associated with becoming proficient with this technique [11]. Although VATS adoption has significantly improved, there remains a large number of both general, dedicated thoracic, and cardiothoracic surgeons who continue to perform a thoracotomy for NSCLC, limited by both volume challenges and the learning curve associated with VATS lobectomy. Although the percentage of open lung resection has declined over time, this technique still represents a large proportion of early stage NSCLC surgery performed in the United States. As a result, there is an opportunity to expand on the availability of minimally invasive lung resection to patients, and to do so using technology that favors a natural transition for otherwise traditional open surgeons.

This need has led to another major technical innovation in thoracic surgery over the last two decades with the adoption of the Da Vinci robotic system (Intuitive Surgical Inc., Sunnyvale, CA, USA), a platform that is at the forefront of minimally-invasive lung, esophageal, and mediastinal tumor resection. In robotic-assisted thorascopic surgery (RATS), the surgeon is seated at a console adjacent to the sterile field which operates a bedside patient cart with several robotic arms (**Figure 1**). Attached to these arms are robotic instruments that enter the pleural space via keyhole incisions and robotic ports. At the console, the surgeon manipulates the robotic


**Figure 1.**
*Da Vinci XI patient cart with four robotic arms. Image courtesy of © [2020] Intuitive Surgical, Inc.*

arms with three-dimensional controls which translate the surgeon's hand movements to the wristed instruments on each of the robotic arms. A RATS platform aids the surgeon by enhancing visualization with a three-dimensional high-definition view, minimizing hand tremors, and improving dexterity of the instruments by functioning with multiple degrees of freedom. Wristed instruments mimic the surgeon's actual hand movements, simulating open surgery, allowing for the precise dissection of vascular structures and a thorough lymphadenectomy, key steps to success when performing minimally invasive lung resection. While this technique is a dramatic change from either open or VATS procedures as the surgeon is not at the patient's bedside, repetition and the frequency of performing robotic cases helps one's personal comfort as they transition to RATS.

Although the technical advantages of RATS make the platform desirable, the adoption of minimally-invasive robotic surgery is associated with some challenges. While benefits such as reduced postoperative pain, decreased peri-operative morbidity, reduce risk for postoperative air leak, and shorter hospital length of stay have been described, concern over upfront investment and increased cost per operation may be considered a barrier to access. Additional training for operating room staff is required, capital investment into larger operating rooms and to modernize traditional open surgery rooms that might like technological infrastructure, as well as increased operating times impact the opportunity cost of performing other operations and can contribute to some level of adoption apprehension for hospitals that have no robotic experience. Despite any misgivings, there is clear evidence that the adoption of robotic surgery for lung resection is on the rise. In just two years, from 2010 to 2012, robotic surgery increased in popularity by 3-fold, accounting for 9.1% of lung resections annually in 2012 [14]. More recently, an estimated 17.5% of lobectomies were performed robotically in 2017 [15]. Trends in robotic adoption seem to suggest that the technical advantages associated with robotic lung resection outweigh the capital and educational investment needed to make such a program successful. What specific metrics drive robotic adoption and improve outcomes in thoracic surgery are defined in the literature. This chapter will address the advantages and disadvantages of MIS for NSCLC, including the role of robotic surgery, and discuss its future directions in this field.

## 2. Advantages of robotic-assisted and video-assisted thoracoscopic surgery

Minimally-invasive thoracoscopic surgery, and in turn RATS, have several advantages over traditional open surgery. Compared to thoracotomy, VATS and RATS utilize small incisions to access the chest cavity, reducing peri-operative morbidity and enhancing recovery. This allows the surgeon to select a larger range of patients who may otherwise be unable to tolerate open resection. Avoiding the muscle dissection/division and rib spreading associated with thoracotomy, while not compromising on the oncologic efficacy of the procedure, are the key advantages to both VATS and RATS procedures. For the facile VATS surgeon, lung resection and complete lymphadenectomy can be accomplished with a high rate of success, low risk of complication, and an expedited pathway to recovery. There are specific subsets of patients at higher risk for conversion during VATS procedures, particularly in cases where dissection is difficult due to fibrocalcified nodes, large tumor >3 cm, or prior induction therapy [16, 17]. In these cases, the advantages of robotics can be significant. The fundamental benefit of the robotic platform is that it simulates open techniques but with the advantages of smaller incision surgery. RATS procedures utilize insufflation to help maximize exposure, 3-dimensional optics to help define important structures and their relationship to adjacent structures, 10× magnification rather to improve visualization, and the ability to reach farther into the chest with longer instruments while still performing fine dissection work, all without losing out on the ergonomics associated with open surgery. This includes the ability to use robotic stapling devices which are similar to open and VATS variants, bipolar energy devices that articulate, vessel sealing devices that articulate, and fluorescence imaging in cases where tumor localization or performance of segmental resection is preferred. Not only does this provide open-only surgeons with an easier opportunity to incorporate MIS into their technical portfolio but affords a larger number of patients with the opportunity to undergo minimally invasive lung resection when appropriate.

An additional advantage is the ease in which segmental resection can be performed. RATS visualization and the precision in which segmental anatomy can be dissected has helped improve the adoption of segmentectomy in the United States [18]. As new data becomes available regarding the advantage of segmental resection over wedge, and potentially the equivalence of segmentectomy to lobectomy for subsets of early stage NSCLC either <2 cm or in patients with non-solid nodules, the utilization of techniques to improve rates of segmentectomy will become more important. While VATS segmentectomy is both well described and widely performed, it remains a technical challenge for many surgeons to adopt with proficiency required that can be significantly more complex than superior segmentectomy. RATS segmentectomy may be an opportunity for lobectomy only surgeons to increase their success with segmentectomy given these advantages. Previously data has demonstrates that surgical outcomes are comparable between RATS and VATS segmentectomy, both in terms of oncologic outcome and the adequacy of lymph node evaluation [19]. This principle is important to keep in mind as there is no scenario in which the size of an incision is more important than achieving an appropriate and adequate lung cancer resection.

### 2.1 Patient selection

MIS allows surgeons to select patients who would otherwise be unable to tolerate open pulmonary resection. The morbidity of a thoracotomy precludes many patients from benefitting from surgery with otherwise resectable cancers, leading to suboptimal treatments and decreased survival. In these cases, some institutions may turn to a more liberal use of radiation therapy as a means of local control. However, many studies have demonstrated the increased risk of local recurrence and inferior 5-year survival that makes radiation a less desirable choice for subsets of NSCLC patients, even in early stage cancers [1, 20, 21]. The decision to pursue surgery and in what format requires clinical judgment and cannot be determined by looking a one particular clinical parameter (ex. FEV1/DLCO, performance status, specific comorbidities alone). For example, a patient with less than perfect but acceptable pulmonary reserve, a history of cardiac disease who is medically optimized with a negative stress test, and in a motivated patient with reasonable performance status, surgical resection is likely to be well tolerated and preferable to other local therapy options (ex. SBRT or ablation). In this subset, MIS has obvious benefits compared to open resection. For example, in patients who underwent minimally-invasive thoracoscopic surgery, preoperative FEV1 < 60% was noted to be significantly associated with a lower risk for postoperative compilations compared to thoracotomy patients [12]. Although this concept may have seemed novel at the time, there is clearly an association between postoperative pain control, patient ambulation and participation with pulmonary toilet, and risk for postoperative complications following lung resection. Therefore, in patients who might be viewed as medically more marginal, MIS provides these patients with an opportunity for a curative resection and the benefits of lung cancer survival identified in the lung cancer study group with a lower complication profile [22].

Elderly patients are also at risk of receiving suboptimal treatment due to a perception of high-risk associated with surgery. When evaluating the surgical candidacy of this group, it is critical to determine both: 1) preoperative cardiac fitness and performance status as well as 2) competing causes of death. In the current era, it is reasonable to consider MIS as a curative procedure for early stage NSCLC in patients in their 80's or even in their 90's. Without a competing cause of death, it is reasonable to consider surgical resection for early-stage NSCLC in this age group. However, thoracotomy is a physiologically demanding procedure, and in elderly patients, MIS should be strongly considered when possible. Previous reports have demonstrated that post-operative outcomes remain superior in RATS and VATS compared to open thoracotomy for elderly patients. One propensity score-adjusted analysis examining 2,766 patients over the age of 65 with stage I to IIIa NSCLC in the Surveillance, Epidemiology, and End Results (SEER)-Medicare database found lower overall surgical complication rates in RATS versus thoracotomy, as well as lower rates of blood transfusion, shorter ICU stay, and a significant decrease in overall length of stay [23]. In the same study, both VATS and RATS were found to have lower complication rates, adequate lymph node evaluation, and equivalent lung cancer specific survival [23].

Obese patients pose unique challenges for thoracic surgery. While studies show obese patients may have similar risk for complications and long-term outcomes compared to patients with normal body mass index (BMI), severely overweight patients (BMI greater than or equal to 40 kg/m2) face an increased risk of any major postoperative complication, including atelectasis requiring bronchoscopy, pneumonia, ARDS, extended ventilatory support, reintubation, and tracheostomy [24]. In addition to consideration for postoperative pain control, adequate pulmonary toilet, the ability to transfer patients from bed to chair, and the need for postoperative patients to ambulate aggressively, a question that arises is an obese patient's tolerability of a longer surgical case. This may be even more important when for RATS lung resection, especially for surgeons early in their learning curve where operative times may be longer than VATS procedures When we look to literature and evaluate best available data to help develop a recommendation, the use of RATS in obese patients has not been shown to be associated with a significantly higher risk of postoperative complications, longer hospital length-of-stay (LOS), and is associated with similar 5-year survival compared to open lobectomy, suggesting that a robotic approach remains safe in this patient population [25]. While the outcomes of RATS lung resection in the obese population may be similar to VATS, the technical advantages of performing an anatomic lung resection in this population remain significant. To date, no large database or single institution data has defined an association between BMI and inferior outcomes in obese patients that require conversion due to vascular injury or technical challenges associated with lung resection.

### 2.2 Perioperative complications

Patients undergoing RATS experience a similar or lower rate of perioperative complications compared to those who undergo open thoracotomy or VATS. Post-operative complications after robotic lung resection were seen in 10–39% of patients in a review which included five case series and four comparative studies [26]. The most common postoperative complications included prolonged air leaks and atrial fibrillation [26, 27]. Pooled analysis of several studies did not show a prolonged air leak risk that was significantly higher following robotic surgery compared to thoracotomy [28].

Major complications including acute respiratory distress, reoperation for air leak, pulmonary embolism, or arrhythmia requiring pacemaker placement were rare, seen in approximately 2.4% of patients [27]. The rate of major complication in robotic surgery appears lower than thoracotomy, with fewer instances of respiratory failure, hemorrhage, or reoperation [29, 30]. Currently, perioperative mortality at high volume centers where most robotic surgeries are performed is lower in RATS compared to open resection [31]. Although this outcome metric is difficult to interpret as mortality is low for all lung resection regardless of surgical technique, it should be expected than as more centers adopt robotics for minimally invasive resection, the morbidity and mortality of RATS should remain at a comparable level to open and VATS resection.

Conversion from RATS to an open procedure is also low. Recent studies demonstrated a conversion rate of 6.5–9.2% [27, 29, 32]. The most common indications for conversion were technical limitations, inability to achieve an adequate oncologic resection, and bleeding [27]. The learning curve for RATS proficiency appears to be in the range of 20–25 cases, after which the risk for conversion can be expected to go down significantly. Unlike VATS conversions, where the surgeon is present at the bedside and can more easily perform a thoracotomy expeditiously, RATS conversions require a coordinated and well planned 'fire drill' to ensure patient safety. This includes a bedside assist that can hold pressure on a bleeding structure via a non-robot port, that the robot arms can be moved away to allow for better access to the chest, and that the staff in the room are prepared to open instruments that are needed to complete the case. Although these processes may be unfamiliar to the novice robotic surgeon, adequate preparation for case should include discussion of these scenarios with the operating and anesthesia staff. When compared to VATS, there were no differences in conversion rates in recent independent studies or meta-analyses [28, 29].

Robotic surgery holds several key advantages with regards to post-operative outcomes when directly comparing VATS and RATS techniques. In one retrospective propensity score-matched study of 774 patients undergoing anatomical segmentectomy at a single academic institution, there were no significant differences in operative time, blood loss, risk for postoperative complication, or length of stay between RATS and VATS [33]. In another study examining 50 RATS and 80 VATS segmentectomies for patients with stage IA lung cancer at the Shanghai Chest Hospital, there was a shorter mean operative time and lower blood loss with RATS during anatomic resection and mediastinal lymphadenectomy [34]. For centrally located tumors which may be more difficult to access through VATS, robotic surgery was found to be associated with less bleeding, shorter operative times, and reduced volume of chest tube drainage and days with a chest tube, while having comparable oncologic outcomes including disease-free survival [35]. In a meta-analysis of ten studies by Emmert examining perioperative outcomes of minimally invasive thoracic surgery, tube drainage duration, length of hospitalization, and mortality were lower in patients undergoing RATS compared to VATS [36]. Therefore, it is reasonable to consider that the technical advantages associated with the robotic platform, including enhanced visualization and use of articulating instructions, are responsible for the low complication rates seen in RATS lung resection, and that with proficiency the outcomes of this technique can be equivalent to VATS.

### 2.3 Patient outcomes

One important area of scrutiny associated with the adoption of robotic surgery has been that VATS outcomes are already significantly better than open surgery, and that an expensive minimally invasive alternative with surgeon only advantages is a challenge to justify. As with any new technology, are the important outcomes the same or better? This is a fundamental necessity in cancer surgery. These concerns have been expressed since the introduction of the first robot in 2001, particularly with respect to adoption of both VATS and RATS approaches. When studied well, it is clear that both VATS and RATS are associated with excellent oncologic outcomes, equivalent to open surgery particularly with respect to lymph node evaluation and adequacy of resection, and that depending on the platform chosen, a proficient surgeon can be expected to have outcomes that meet or exceed their open surgery experience.

Several studies have examined and compared margin status, recurrence, disease-specific survival, and overall survival in open thoracotomy, VATS, and RATS. A study of the National Cancer Database found similar positive margin status (2%) after robotic surgery as compared to open resection, which is considerable given the lack of haptic feedback associated with RATS [37]. Other series also describe similar R0 resection rates of 97% [38]. Five-year disease recurrence has reported to be from 3% to 24.9% depending on cancer stage, which is also comparable to open surgery for appropriately matched patients [32, 39]. In this series and others, overall and disease-free survival at three and five years did not differ between RATS and either open surgery or VATS [32, 37, 38, 40–43]. These results all suggest that robotic lung resection is a non-inferior alternative to prior surgical options.

The data on nodal evaluation during lung resection is heterogenous for robotic surgery. Some studies report no advantage in nodal stations examined or nodal harvest when compared to open surgery or VATS [28, 29, 44, 45]. One study found that fewer lymph nodes were examined with RATS compared to VATS [14]. Others report improved lymph node examination and retrieval [30, 33, 37, 46, 47]. In particular, one study found N1 (hilar) lymph nodes were better evaluated by robotic surgery as compared to VATS, both in terms of the number (4 vs. 3) and stations (3 vs. 2) examined [33]. The experience of these authors and others are that the technical advantages of robotic surgery allow for an equivalent lymph node dissection to VATS, with some significant advantages including improved hemostasis and thoroughness of lymph node resection performed during mediastinal lymphadenectomy. The use of articulating bipolar instruments allows for complete lymph node packet resection, while improved visualization helps to define lymph node associations to adjacent structures. This is clearly an advantage over VATS, were ring clamps or non-articulating instruments can be used to grasp lymph nodes and non-articulating energy devices are used to free lymph nodes from surrounding structures. Whether these technical advantages translate into differences in short or long-term outcomes is unknown. However, no study to date has demonstrated that taking fewer lymph nodes or an incomplete lymph node evaluation is better than comprehensive lymphadenectomy. Additionally, as surgical outcomes become more heavily scrutinized, particularly with respect to the adequately of lymph node dissection, the use of this platform is likely to help facilitate a comprehensive hilar and mediastinal lymphadenectomy to meet these expectations.

### 2.4 Technical considerations

The true advantage of robotic surgery appears to be the technical advantages conferred to the surgeon, specifically the enhanced visualization and improved dexterity of the instruments. While comparisons between robotic and open thoracotomy appear to have similar rates of complications, outcomes of VATS versus RATS are less uniform. Robotic surgery, in some series, is associated with less bleeding, shorter operative time, and shorter tube drainage duration [35]. These studies are largely retrospective and do not offer a definitive answer as to the causation for these improvements. However, one factor that likely contributes to these perceived results are the ergonomics of the robotic system. Robotic instruments moved with seven degrees of freedom, and as a result the surgeon in control at the console can mimic natural motions of the hand and wrist in the handling of tissue. This allows a surgeon to perform more complex functions in a safer fashion, reducing the risk of inadvertent injury while maintaining the oncologic standards. Important moves during anatomic lung resection, including thorough performance of lymphadenectomy and circumferential mobilization of critical vascular structures, can be performed with improved hemostasis, improved visualization, and reduced risk of injury.

### 2.5 Conclusions

Overall, the literature supports RATS as an alternative to open surgery and VATS. Fewer perioperative complications, improved quality of life, and similar oncologic outcomes have been established following RATS lung resection, bringing minimally invasive surgical options to a wider range of patients. While the advantages of RATS over VATS are certainly up for debate and are more informed by surgeon preference, the ability to improve minimally invasive lung resection availability to patients across the United States helps to drive interest in outcomes related to RATS procedures. The literature clearly demonstrates that surgeons facile with VATS lung resection provide patients with an oncologically sound operation and survival/recurrence expectations that rival results demonstrated in the LCSG. However, this skillset is challenging to learn and the highest standards for technical excellence are not as reproducible as open surgical techniques. In this space, RATS lung resection continues to evolve as adoption of minimally invasive lung resection grows.

## 3. What makes robotic surgery adoption different than VATS?

While robotic surgery has key advantages compared to open and VATS techniques, it has not been uniformly adopted. As compared to VATS, this technology requires a significant capital investment, is associated with its own learning curve, and requires robotically trained support staff for a surgeon to have a successful robotic lung resection practice. All of these characteristics can be overcome but require stakeholders from surgery and the operating room to commit to the success of this platform.

### 3.1 Cost

The cost of robotic surgery is one of its main points of contention. There are two aspects of robotic surgery which contributes to this cost. The first is the initial investment in the robotic system. The second includes intra-operative costs, consisting of the use of consumables and longer operative times associated with RATS [28, 33, 45]. As the second is modifiable, it has garnered more attention in the literature. One study using patients from the SEER-Medicare database found the total cost of lung resection was similar between RATS and thoracotomy ($54,702 vs. $57,104, p = 0.08) [23]. Much of the variability in cost associated with robotic surgery likely stems from the difference in post-operative complications when compared to open resection. In particular, overall length of stay after RATS is significantly shorter than open surgery [29, 31, 38, 47, 48], and may be similar or better than VATS (4 days vs. 5 days) [40]. Therefore, although the cost of the operation may be higher in RATS, the direct associated cost may not be significantly different compared to open or VATS [49]. In time, as familiarity with the robotic platform increases and operating room efficacy is improved to rival VATS procedures, further cost savings can offset the increased initial investment and operative costs.

### 3.2 Learning curve

Another concern for surgeons unfamiliar with robotic surgery is training and familiarization with a new surgical platform. In fact, one of the early difficulties with the transition from VATS to open surgery was the steep learning curve. Laparoscopic instruments are relatively inflexible compared to the dexterity a surgeon is accustomed to during open surgery. Circumferential mobilization of important blood vessels requires dissection facilitated by subtle changes in how one engages the tissue, and these techniques are both important and challenging to learn for a novice VATS surgeon. Additionally, the VATS camera is limited to 3.5x magnification, images are shown in only 2 dimensions, and the camera needs to be held and constantly adjusted by the surgeon assistant. At 10× magnification, with 3D imaging, and a fixed camera that is not subject to fatigue or the concept of 'guess what I am thinking and look where I want you to look', getting used to robotic optics is fairly quick. The learning curve for a robotic lobectomy is approximately twenty cases [26, 50]. In this regard, mastery of robotic surgery appears to easier than VATS, owing to the more natural movements afforded by the robot.

Efficiency of RATS does rely more heavily on the familiarity of supporting operating room staff and the surgeon's bedside assistant than VATS procedures. As the surgeon is seated at a console away from the sterile field, a bedside assistant must assist in exchanging instruments and repositioning robotic arms as needed. Thus, in addition to surgeon training, it is imperative that adequate training be provided to dedicated staff supporting the surgeon in order to maintain a safe working environment and maximum efficiency.

### 3.3 Choosing robotic surgery

In our experience, a surgeon who gains robotic proficiency prefers the robot for a majority of their cases unless the platform is unavailable. Technically, VATS offers little advantage over RATS for the operating surgeon. Few instances exist where cost and time to set up outweighs the benefit. We utilize VATS for short cases such as decortications and pleurodesis, but favor RATS for most pulmonary resections. For technically challenging cases such as pneumonectomies, open surgery may be preferred, however, some case series describe successful RATS applications in pneumonectomy [51, 52].

## 4. Conclusions

In conclusion, robotic surgery represents the latest innovation for lung cancer surgery and an important opportunity for general and thoracic surgeons who still perform open lung resection. RATS procedures are associated with comparable or better outcomes than open surgery or VATS, and over the past two decades has been shown to be a safe platform with which lung cancer procedures can be performed. RATS procedures have significant technical advantages for the surgeon, namely the 3D vision, 10× magnification, and articulating instruments that mimics open surgery and allows for the performance of critical components of an operation safely. Although the advantages of RATS for patients are similar to VATS procedures, the adoption of RATS by open surgeons allows for a larger number of lung cancer patients in the United States to undergo minimally invasive procedures than ever before, which further realizes the patient specific advantages of minimally invasive techniques in this often medically complex population. A lower complication rate and better tolerability increases access to a definitive resection for NSCLC, optimizing 5-year survival. In time, as the volume of robotic surgery increases, the capital investment associated with adoption is likely to decrease. Additionally, with increased surgeon experience, operative times, risks for air leak, and overall hospital length of stay are also expected to decrease, allowing for improved utilization of hospital resources and efficiency.

## Conflict of interest

Justin D. Blasberg, MD MPH is a proctor for Intuitive Surgical.

## Notes/thanks/other declarations

None.



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