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Robotic Versus Video-Assisted Thoracoscopic Lobectomy (VATS) for Lung Cancer

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Abstract
Purpose of Review Video-assisted thoracoscopic (VATS) lobectomy has been demonstrated to be a safe procedure, and it is known to provide less postoperative pain, similar lymph node dissection capabilities, decreased length of postoperative stay, less complications, reduced mortality, and similar oncologic outcomes compared with open lobectomy lung cancer operations.
Recent Findings A recently developed approach for lobectomy is robotic surgery. Although both techniques are minimally invasive, there are differences between the approaches. The most important question is "could robotic-assisted surgery cover the limitations of video-assisted thoracoscopic lobectomy at a similar cost in the near future?"
Summary This article discusses the concerns of both techniques and the future expectations.

Keywords VATS · Robotic surgery · Lung cancer · Lung resections · Advantages · Survival · Complications · Outcomes

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Introduction

Video-assisted thoracoscopic (VATS) lobectomy has become a well-established surgical technique during the last decade. VATS includes a videoscopic surgery in which the surgeon directly controls and manipulates the tissue, from outside the patient, as opposed to open surgery, through one to three incisions in the chest wall, and performs the operation by looking at a monitor, without placing a rib spreader.

Robotic surgery is different, where the surgeon is not at the operation table but is sitting at a console outside the sterile area, directing and controlling the surgery with two or more robotic arms and a camera. However, the control of the operation is indirect. "Robotic surgery" has become a commonly used and a generally accepted term. The term refers to the surgical technology that has the ability to carry out the surgeon's capabilities inside the patient through "remote tele-manipulators." A sterile table surgeon assists the console surgeon at the table. In this article, robotic surgery is defined as a surgical procedure that involves a computer technology interaction between a surgeon and a patient. The aim of this article is to compare VATS and robotic surgery in lung cancer patients.

An Established Technique: VATS Lobectomy

A decade ago, VATS lobectomy was at its infancy after a difficult delivery in the academic platform of thoracic surgery. Debates, discussions, presentations, case–control studies, trials, and meta-analyses have placed this technique in its valuable position today. VATS lobectomy has been demonstrated to be a safe procedure, with a very low conversion rate [1•, 2–4]. Thoracoscopic lobectomy provides less postoperative pain, similar lymph node dissection capabilities, decreased length of postoperative stay, less complications, reduced mortality, and similar oncologic outcomes compared with open lobectomy lung cancer operations [5, 6, 7•, 8]. Several thoracic surgeons had concerns about major bleeding and operative mortality at the beginning of VATS era, but these concerns were dismissed by multiple large-volume studies [1•, 2, 9, 10].

Moreover, the VATS's recurrence rate in case appears to be equivalent to that for thoracotomy, which further proves the oncological principles of VATS [11]. In the last few years, the above-mentioned studies concluded that VATS should be considered as a gold standard technique in stage 1 and 2 lung cancer patients.

Concerns and Disadvantages of VATS Lobectomy

Although, currently, lymph node dissection has been accepted as a standard technique in VATS, concerns remain about the systematic approach to nodal dissection. Several studies showed no difference in the number of dissected lymph nodes and lymph node stations, compared to thoracotomy [12–14]. On the contrary, other surgeons have demonstrated that dissection of the lymph nodes with VATS may be less satisfactory [15]. The extent of the dissection was not related to the oncologic outcomes; however, less experienced surgeons in VATS might not provide similar lymph node dissection as thoracotomy [16]. The Cancer and Leukemia Group B study showed that 15 % of the patients did not have any lymph node removed, and more than 50 % of the patients had almost two stations explored during VATS lobectomies [17•]. For a complete lung cancer resection, the number of removed or sampled mediastinal lymph nodes is one of the important quality measures [14]. Despite the development of the instrumentation, optical systems, and teaching platforms, this technique still needs standardization, particularly in lymph node dissection. Limited and unequivocal adoption of VATS has been well demonstrated in a STS database study [18]. In this study, patients who underwent VATS lobectomy were demonstrated to have 1.6 times more intraoperative complications than patients who underwent open lobectomy [18]. The short-term mortality, lengths of stay, and hospitalization costs were shown to be similar between the two groups [18]. These results are not similar to those of the experienced centers and surgeons. Although VATS has been considered as the "standard-of-care" for the treatment of early-stage malignancies, the findings do not support the results [19]. The majority of the lung cancer operations are performed by thoracotomy, despite demonstration of the safety and advantages of VATS [19]. A large and nationally representative hospital database demonstrated that thoracic surgeons have better VATS outcomes than non-thoracic surgeons, and a greater experience with open thoracic surgery procedures is not an advantage for better VATS outcomes [20]. This implies that established, experienced thoracic surgeons might not disseminate their capabilities to the VATS platform. These educated surgeons with oncological surgical experience, knowledge, analytic minds, and capabilities to solve catastrophic intraoperative events might not adopt VATS technique. Thus, this is a disadvantage of the technique.

The author believes that catastrophic intraoperative complications may occur in every clinical setting. Although several surgeons experience these complications, they are rarely reported. One important study reported concerns regarding the safety of VATS lobectomy procedures [21]. Flores et al. [21] have demonstrated that these events are rare (13 major intraoperative complications in 633 VATS lobectomies). In this article, a catastrophic complication was defined as an event that ends up with an unplanned major surgical procedure. These injuries frequently include vascular trauma and stapling of main pulmonary artery or bronchus.

VATS lobectomy has been reported to have a vaguely defined learning curve for the development of competency and proficiency [22•]. It has been reported that 100–200 operations are required to achieve efficiency, and more cases may be required for consistency [22•]. This should be considered as a high volume and difficult to achieve by a single surgeon in one or two years.

The duration of postoperative stay with VATS lobectomy is 5.3 days in the STS database, different from the 2 or 3 days as reported by experienced VATS surgeons [1•]. The associations between hospital volume and operative mortality are mostly related to surgeon volume [23]. It has been reported that the surgeon volume has a greater influence on the outcomes than the total hospital volume [24•]. Surgeons are the key factors for making preoperative patient selection and intraoperative decisions. There is evidence that the high-volume cancer surgeons have a lower rate of operative mortality [25]. Not only the duration of the postoperative stay but also the morbidity, which is a reflection of postoperative stay, is related to surgeon's volume of surgery. Better outcomes which were provided by high-volume surgeons and centers could not be generalized.

In summary, there are important concerns that need to be highlighted: (1) difficulties in adoption, efficiency, and consistency; (2) although the established open surgeons have no advantage in learning VATS, or could not easily disseminate their capabilities to the VATS community, their experience is highly valuable for the treatment of catastrophic intraoperative complications; and (3) the differences in the efficiency of nodal dissections in different studies [16].

The above-mentioned findings demonstrate that surgeons are still struggling with the VATS platform, and the outcomes of VATS in the learning period in the general thoracic surgery platform are not equivalent to those of the surgeons who are experienced in VATS.

The Future of VATS Lobectomy

Dissemination of technology and knowledge has never been as easy in the history of medicine as it has been in the past 10 years. Video sharing through video channels and courses supported by important national and international bodies provided this educational platform. Consequently, VATS lobectomy became a popular approach throughout the world. Even the number of ports decreased to single port, and resections in awake patients were performed. The author believes that the adoption of VATS may reach a plateau in the next few years. The limitations described above may prevent it from reaching a higher rate of adoption. Although complicated extended resections are claimed to be performed safely by several individual surgeons, such as carinal resection and double sleeve resection, standardization of the basic surgical technique, including a good lymph node dissection, is the current need of both the surgeons and patients. Providing a faster return to daily activities and long-term survival are the ultimate endpoints of a high-quality lung cancer surgery. Both aims should be provided by either of the techniques.

Robotic Lobectomy

Initially, robotic surgeons believed that the robotic platform should have at least similar advantages compared to VATS. These surgeons claimed that the three-dimensional optics and the articulations provided by the robotic instrumentations could increase the capabilities of the minimally invasive surgery and thus could cause less conversions to open, less catastrophes, and more radical oncological resections. However, they were not embraced by the VATS community, and most of the time VATS surgeons did not want to change their position and shift to robotic surgery. Robotic studies are performed to compare robotic lobectomies with open or muscle-sparing lobectomies [26]. The results demonstrated superior early outcomes with prolonged duration of operations. In fact, robotic lobectomy should have been compared to VATS lobectomy in a randomized study, which is currently about to be launched by the author with the collaboration of other eminent minimally invasive/robotic operators. Surgeons adopted robotic surgery unequivocally throughout the world and most of the time presented only case series to prove feasibility.

The data suggest that robotic lobectomy offers advantages similar to VATS, in terms of postoperative morbidity and recovery, compared to thoracotomy. A study compared 106 patients undergoing robotic lobectomy to 318 patients undergoing muscle-sparing lobectomy [26]. Robotic surgery patients had reduced postoperative morbidity (27 % vs. 38 %), improved mental quality of life, shorter chest tube duration (1.5 vs. 3 days), and shorter hospital stay [26]. Three different centers analyzed their experiences on 325 patients undergoing robotic lobectomy and reported a median length of stay of 5 days, with a perioperative morbidity rate of 25 %, a mortality rate of 0.3 %, and a conversion rate of 8 % [27••]. The long-term outcomes showed similar results at similar stages [27••].

Robotic Safety and Feasibility

It is a common belief that open surgeons are more convinced that robotic resection may be feasible in their hands, with reproducible results and similar outcomes. Published documents demonstrated that anatomic lung resections, especially lobectomy and segmentectomy, via the robotic platform are feasible and safe [27••, 28, 29]. Several case series [26, 30–32] and comparative studies [33–36] reported similar results demonstrating superiority in several outcome parameters, with the most important being the number of the mediastinal lymph nodes dissected. The reported mortality rates changed from 0 % in most series to 4.9 % in one series [37]. Deaths were not related to the robotic technology, but were mostly related to patient selection. The results were similar to those of VATS lobectomy [35].

Conversion to open surgery from robotic surgery might be higher than expected compared to VATS in the experienced hands of VATS users. On the other hand, it must be remembered that these outcomes are generally the first robotic experiences of the robotic cases of either the clinics or the authors. Another important issue is that several authors have described predefined time frames during their early robotic experiences for planned conversions [32, 33]. The most important difference in robotic surgery is the reason for conversions to open surgery compared to VATS. It has been claimed that there were no conversions that resulted from massive bleeding. Most conversions were reported to be the result of adhesive disease, advanced T-stage, or lung isolation problems [26]. Basically, the higher conversion rate may be explained by the scrutiny of the robotic surgeon and the robotic thoracic community.

Non-demonstrable Advantages of Robotic Surgery

The author of this article has been performing VATS and robotic lung cancer surgery in the same minimally invasive lung surgery program. The author believes that robotic surgery is feasible and safe, and agrees that it is associated with comparable morbidity and mortality to that of open surgery and VATS [3]. Robotic thoracic surgery proponents believe that the technological progression provided by the robotic surgery over VATS will be validated soon. The miniaturized instruments having the capabilities of a wrist and the high-definition, three-dimensional camera could carry the surgeon's fundamental surgical abilities to the inside the thoracic cavity and could provide advantages over conventional VATS. As it has been originally described, the robotic platform provides an enhanced exposure in a narrow operative space, with abilities to perform precise maneuvers around vital organs and vessels. These abilities facilitate the safety of the dissection around the vessels. Pardolesi et al. [28] and Toker et al. [29] showed that the robotic anatomic segmentectomy was easier to adopt compared to VATS. In Dylewsky's study, published at 2011 [30], 200 consecutive patients underwent surgery with robotic surgery, and 197 of them (98.5 %) successfully completed without conversion to open surgery. This series is one of the earliest studies demonstrating that a broad population of patients, including early-stage, locally advanced disease, and complex cases, requiring pneumonectomy, chest wall resection, and sleeve resection, can be reliably managed using a robotic-assisted minimally invasive approach.

Several robotic surgeons believe that with the robotic approach, one could replicate the surgeon's preferred open surgery technique while using a minimally invasive approach. According to the author, the primary advantage of the robotic platform is the presence of alternative options when dissection is difficult or dangerous during complex surgery. Using a robot, the surgeon has the option to choose a different approach for a determined operation (e.g., In case of right open lobectomy, through anterior approach, fissure, posterior approach, or superior approach). The surgeon has even a chance to shift from one approach to another during the dissection. For a more specific description, while working with the robot, the order of operation (almost always) allows the surgeon to work in the interlobar fissure by directly dissecting the hilar and peribronchial nodes located around the pulmonary artery and the bronchus, particularly the station 11 nodes, before the division of the fissure. This is similar to the traditional open surgery. These technical options provided by the robot may allow some of the open surgeons to feel confident with the robot. On the other hand, there are several techniques that can be used during a VATS resection. One popular technique is a fissureless lobectomy, which is aimed at avoiding a dissection around the pulmonary artery [37, 38]. The fissureless technique is accomplished by stapling through the fissure after dividing the hilar structures, which may cause a less effective hilar nodal dissection, since the intralobar lymph nodes are not removed [37, 38].

Developments made in surgical multimedia and simulation should decrease the duration of the learning curve. A wider adoption would be inevitable as the economic benefits are provided.

Nodal Upstaging and Lymph Node Dissection in VATS and RATS

Usually, nodal upstaging demonstrates the quality of the surgery. However, it is very difficult to identify the reason for upstaging. This mostly depends on the surgeon's dedication to lymph node dissection. On the other hand, the extent of preoperative investigation such as endobronchial ultrasonography, endoesophageal ultrasonography, mediastinoscopy, or even video-assisted mediastinal lymph node dissection may alter the degree of lymph node dissection. The author of this article believes that regardless of the approach, the surgeon is likely to be a key factor in the nodal upstaging, as claimed earlier. In one important study, robotic anatomic lung resection was performed in 302 patients [39••]. The majority were right sided (192; 63.6 %) and of the upper lobe (192; 63.6 %). Most were clinical stage IA (237; 78.5 %). Pathologic nodal upstaging occurred in 33 patients [10.9 % (pN1 20, 6.6 %; pN2 13, 4.3 %)]. Hilar (pN1) upstaging occurred in 3.5, 8.6, and 10.8 %, respectively, for cT1a, cT1b, and cT2a tumors. Comparatively, historic hilar upstage rates of video-assisted thoracoscopic surgery (VATS) versus thoracotomy for cT1a, cT1b, and cT2a were 5.2, 7.1, and 5.7 %, versus 7.4, 8.8, and 11.5 %, respectively. However, the technical advantages, such as the dissection and visional capabilities provided by the robot, definitely enhance lymph node dissection. Most of the time, during a robotic surgery, lymph nodes are completely removed without rupturing their capsule, unlike VATS. In our study, we compared open, video-assisted and robotic-assisted thoracoscopic surgical techniques in the dissection of N1- and N2-level lymph nodes during surgery for lung cancer [40]. This retrospective analysis is based on prospectively collected data of patients (excluding those with N2 or N3 diseases, and sleeve resections) undergoing mediastinal lymph node dissection via open ($n = 96$), video-assisted thoracoscopy ($n = 68$), and robotic-assisted thoracoscopy ($n = 106$).

The groups are compared according to the number of lymph node stations dissected, the number of lymph nodes dissected, and the number of lymph nodes dissected by stations. Three techniques had similar results based on the number of the dissected N1- and N2-level lymph node stations. Robotic-assisted thoracoscopic surgery yielded significantly more lymph nodes in total ($p = 0.0007$), and in the number of dissected N1-level nodes ($p < 0.0001$). All techniques yielded similar number of mediastinal lymph nodes, whereas robotic-assisted thoracic surgery (RATS) yielded more station #11 and #12 lymph nodes compared to the other groups. The robotic-assisted thoracoscopic surgery has been shown to dissect more lymph nodes at N1 level. However, taking the open approach as standard, we could claim that currently both robotic- and video-assisted techniques may provide similar number of dissected N1- and N2-level lymph node stations [40].

Survival

Two of the most important measures of the surgical quality are the outcomes, such as the overall survival and disease-free survival. The 2-year overall survival in a multicentric study [41] was 87.6 %, which is similar to the 5-year overall survival of 80 % in another multicentric study reported by Park [27••]. The overall survival rates with VATS have been reported to be 76.5 % at 5 years and 89.9 % at 3 years; with thoracotomy, the overall survival rates were 77.5 % at 5 years and 84.7 % at 3 years [41]. A recent study reported a higher overall disease-free survival rate of 70.2 % at follow-up [39••]. This rate is superior to the 5-year disease-free survival rates of 60 % and 70.3 % with VATS and thoracotomy, respectively [41], and similar to follow-up data published in robotic series that reported a rate of 90 % [27••].

VATS versus RATS Comparisons in the Literature

A recent study, based on a propensity-matched analysis, analyzed patients who underwent an open, VATS, or robotic lobectomy [42]. The authors observed that the case volumes for robotic resections increased from 0.2 % in 2008 to 3.4 % in 2010. Robotic resections demonstrated significant reductions in mortality (0.2 vs. 2.0 %), length of stay (5.9 vs. 8.2 days), and overall complication rates (43.8 vs. 54.1 %), compared to open thoracotomy. Although the results were not significant, robotic resection was also associated with reduced mortality (0.2 vs. 1.1 %,), length of stay (5.9 vs. 6.3 days), and overall complication rates (43.8 vs. 45.3 %) compared to VATS. This study demonstrated that robotic resection appeared to be an appropriate alternative to VATS [42].

A very recent study used The Society of Thoracic Surgeons General Thoracic Surgery (STS-GTS) Database to evaluate quality metrics for VATS and robotic surgery lobectomy techniques [43••]. Primary non-small-cell lung cancers (NSCLCs) with clinical stage I or stage II disease at high-volume centers from 2009 to 2013 were identified, and 1220 robotic lobectomies and 12,378 VATS procedures were analyzed. Patients undergoing robotic lobectomy were older, less active, less likely to be an ever smoker, and had higher body mass index. Robotic lobectomy operative times were longer (median 186 vs. 173 min). All postoperative outcomes were similar, including complication and 30-day mortality rates (0.6 vs. 0.8 %). Median length of stay was 4 days with both the techniques, but a higher proportion of patients undergoing robotic lobectomy had hospital stays less than 4 days (48 vs. 39 %). Overall, nodal upstaging was similar ($p = 0.6$), with trends favoring VATS in the cT1b group and robotic lobectomy in the cT2a group. This study concluded that patients undergoing robotic lobectomy had more comorbidities, and robotic lobectomy operative times were longer, but quality outcome measures, including complications, hospital stay, 30-day mortality, and nodal upstaging, suggested that robotic lobectomy and VATS were equivalent [43••].

Cost

The associations between VATS or Robotic lobectomy and adverse events, hospital costs, surgery time, and length of stay were examined in a study based on a premier database in the United States [44]. Out of 15,502 patient records analyzed, 96 % were performed without robotic assistance. Using robotic assistance was associated with higher average hospital costs per patient. The average cost of inpatient procedures with Robotic surgery was $25,040.70 versus $20,476.60 with VATS for lobectomies and $19,592.40 versus $16,600.10 for wedge resections, respectively. Operating times were longer for Robotic lobectomy than VATS lobectomy (4.49 vs. 4.23 h) and for wedge resections (3.26 vs. 2.86 h). The length of stay was similar, with no differences in adverse events. Robotic lobectomy and wedge resections seemed to have higher hospital costs and longer operating times, without any differences in adverse events [44]. Cost analyses are different in different countries. Each organization should calculate and estimate the cost–benefit ratio of robotic surgery to those of VATS.

Learning Curve and Education in Robotic Surgery

The term ''learning curve'' has been frequently used in publications about surgical procedures as a reference to the process of gaining experience and improving skills in performing such procedures [45]. The da Vinci System has been shown to have a rapid learning curve [46]. The shorter operative time is regarded as a reference in several reports, mostly in robotic lobectomies. Although operative times vary with the complexity, it appears that the decrease in operative times is highly correlated with the learning curve [47]. Melfi et al. [48] suggested a minimum of 20 operations to acquire new skills for the whole surgical team. Gharagozloo et al. [49] and Veronesi et al. [50] separately observed that the first 20 patients had longer operative times. Based on operative times, Meyer et al. [47] proposed a learning curve of 18 ± 3 cases and Lee et al. [51] of 15–17 cases. Based on the operative times (docking, console, and total) in our current analyses, we calculate that 14 cases could be considered as completion of the learning curve for pulmonary resections [45]. However, during the first 14 pulmonary resections, we also performed other thoracic surgical procedures such as thymectomies. Thus, 20 cases may be an appropriate learning period in robotic thoracic surgery [45]. During robotic-assisted lung resections, as in other surgeries, communication and collaboration between the console surgeon, the table surgeon, or the anesthesiologist, and all nurses on the team are essential. Thus, team training is also important in addition to surgical training of the console surgeon. Simulation training can be an effective tool in both VATS and robotic surgeries, but it is more appropriate and developed for robotic surgery since haptic feedback is not present in the VATS simulation. Certainly, simulation should not take the place of proctored procedures. In addition to receiving basic training, all the team members need to develop their skills through frequent use of the robotic surgery system. This is also true for VATS resections. If the case load for a particular procedure is insufficient for both surgical techniques, simulation training would continue in order to not to lose the skills. Although robot-assisted surgery has become an established alternative to lobectomy operations, it is still an evolving technology, and it will likely develop faster than the VATS operations. Thus, continuous training will be needed as the technology advances.

Conclusions

VATS lobectomy has been an established surgery and remains to be the gold standard in early-stage lung cancer. Robotic surgical devices have developed beyond the investigational stage and are now unequivocally used in lung resections throughout the world. New robotic devices continue to develop and will probably become less expensive and more widely disseminated. Thus, they will likely be more frequently utilized [52].

The thoracic surgical community would benefit from a consensus statement on robotic lung cancer surgery education, which also includes guidelines for training and credentialing.

Compliance with Ethics Guidelines

Conflict of Interest Dr. Toker declares no conflicts of interest relevant to this manuscript.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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