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DOI: 10.1016/j.athoracsur.2009.04.039

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Robot-Assisted Lobectomy for Early-Stage Lung Cancer: Report of 100 Consecutive Cases

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Background. Robotics can facilitate dissection during video-assisted thoracoscopic (VATS) lobectomy. This study describes a hybrid minimally invasive lobectomy procedure consisting of two phases: robotic vascular, hilar, and mediastinal dissection, and then VATS lobectomy.

Methods. Over a 54-month period, 100 consecutive patients with stage I and II (T1 or T2N0, and T1 or T2N1) lung cancer (42 men, 58 women; mean age 65 ± 8 years) underwent robotic VATS lobectomy.

Results. Lobectomies were right upper (29), right middle (7), right lower (17), left upper (31), and left lower (16). Mean operating room time was 216 ± 27 minutes. Tumor type was adenocarcinoma (57), squamous cell carcinoma (25), 7 adenosquamous carcinoma (7), bronchoalveolar (3), large cell (1), poorly differentiated (3), carcinoid (2), mucoepidermoid (1), spindle cell (1). Pathologic upstaging was noted in 17 patients (10 to stage IIB, 7 to stage IIIA). There was no emergent conversion to a thoracotomy. Median hospitalization was 4 days. Complications included atrial fibrillation (13), atelectasis (5), prolonged air leak (4), pleural effusion (3), pulmonary embolus (3), incisional bleeding (1), hydropneumothorax (1), dural leak (1), liver failure (1), pneumonia (1), respiratory failure (1), and cardiopulmonary arrest (1). There was no intraoperative death. Postoperative mortality was 3%. There were no deaths among the last 80 patients. At a median follow-up of 32 months (range, 1 to 59), 1 patient (1%) died of his cancer, 6 (6%) had distant metastases, and 2 (2%) had a second lung primary cancer. There was no local recurrence.

Conclusions. Robotics are feasible for mediastinal, hilar, and pulmonary vascular dissection during VATS lobectomy.

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Video-assisted thoracoscopic (VATS) lobectomy has emerged as a safe and effective technique for the treatment of early stage lung cancer [1–3]. During this procedure, the dissection of the pulmonary artery and mediastinal nodes is difficult using conventional videoendoscopic instruments. It has been hypothesized that, as the result of three-dimensional visualization, the “wristlike” action of the instruments, and ease of fine dissection in a confined space, the surgical robot (daVinci; Intuitive Surgical, Sunnyvale, CA) may facilitate the dissection phase of the VATS lobectomy procedure.

This study was undertaken to assess the feasibility of robotic mediastinal, hilar, and vascular dissection during VATS lobectomy for early stage lung cancer.

Patients and Methods

Patients

A retrospective review was conducted of the first 100 consecutive patients with early stage lung cancer (stages I and II) who underwent robotic mediastinal and vascular dissection during VATS lobectomy between January 2004 and July 2008.

Preoperative evaluation included comprehensive history and physical examination, computed tomographic scans, positron emission tomography, cardiac evaluation, pulmonary function testing, and peripheral venous ultrasound examination. Inclusion criteria were clinical stage I and II lung cancer (T1 or T2N0, and T1 or T2N1), predicted ability to achieve resection by lobectomy, and the physiologic state of the patient. Exclusion criteria were chest wall invasion, endobronchial tumors visible at bronchoscopy, a central tumor, and induction therapy. The study received Institutional Review Board approval in February 2008, with individual patient consent being waived.

Operative Technique

Single-lung ventilation is established, and the patient is placed in a lateral decubitus position. Three 2- to 3-cm incisions are used (Fig 1). The scapula and the lower border of the rib cage are marked. A line is drawn between the tip of the scapula and the lower border of the rib cage in the midaxillary line. The camera incision (incision 1) is placed on this line in the eighth intercostal space. The video-endoscope is introduced through this incision, and the oblique fissure is visualized. The anterior incision (incision 2) is placed over the anterior part of the...
the oblique fissure in the anterior axillary line (usually the sixth intercostal space). The posterior incision (incision 3) is made in the posterior part of the fissure in the posterior axillary line (usually the fifth intercostal space). An additional 1- to 2-cm incision is made in the anterior axillary line in the seventh intercostal space (incision 4) and used for an endoscopic paddle retractor (Endo Pad Retract 12 mm; Autosuture, Mansfield, MA) during the robotic dissection. This incision is used for the chest tube at the end of the operation.

The operation replicates the open lobectomy technique and has been described previously [4, 5]. It is divided into the robotic dissection phase and the VATS lobectomy phase.

Robotic Dissection
This phase consists of three steps: (1) robotic posterior mediastinal, subcarinal, and hilar dissection; (2) robotic pulmonary artery dissection; (3) robotic pulmonary vein and anterior hilar dissection.

ROBOTIC POSTERIOR MEDIASTINAL, HILAR, AND SUBCARINAL DISSECTION. An atraumatic paddle retractor is used to retract the lung anteriorly and medially and is fixed to the operating table. The surgical robot is brought over the patient’s head, and the camera arm and two additional arms are used. The camera arm is introduced through incision 1, and the right and left arms are introduced through incisions 2 and 3, respectively. Complete mediastinal dissection is performed with the removal of the subcarinal, paratracheal, paraesophageal, and inferior pulmonary ligament nodes. In addition, aortopulmonary nodes are dissected in patients with left-sided disease.

ROBOTIC PULMONARY ARTERY DISSECTION. Next the retractor is removed, and the oblique fissure is exposed. The robot is positioned over the fissure, and the pulmonary artery branches are dissected.

ROBOTIC PULMONARY VEIN AND ANTERIOR HILAR DISSECTION. The lung is retracted posteriorly, and the robot is used to dissect the anterior hilum and the pulmonary vein.

VATS Lobectomy
After the dissection phase, the robot is removed, and the surgeon returns to the operating table. During this phase, vascular, parenchymal, and bronchial division is performed using standard VATS techniques.

The specimen is retrieved through the anterior incision using a lubricated double bag consisting of a 1,500-mL size Lap Sac (Cook Medical, Bloomington, IN) placed inside an Endocatch (Ethicon Endo-Surgery, Cincinnati, OH). Wedge excision of the tumor before the lobectomy decreases the bulk of the specimen and facilitates retrieval. Subpleural intercostals pain catheters (on-Q; i-Flow, Inc, Lake Forest, CA) are used for postoperative analgesia, and staple lines are sealed with a fibrin sealant (Evicel; Johnson & Johnson, Sommerville, NJ). Patients are extubated in the operating room.

Follow-Up
Length of postoperative stay, all major and minor complications, and mortality were recorded for each patient. Patients were seen in the clinic 2 weeks after discharge. Subsequent follow-up was at 6, 12, 18, and 24 months, and annually thereafter. Computed tomography scans and positron emission tomography scans were obtained at the time of follow-up. Follow-up data were obtained from records of postdischarge visits, interviews, tumor registry data, and regular radiographic and clinical follow-up.

Diagnosis of recurrent disease was made by radiographic and pathologic confirmation. Recurrence was defined as local when disease recurred at the pulmonary hilum, or in the subcarinal space. Recurrence was defined as distant when disease developed in a separate lobe, in the contralateral lung, in N3 nodes, or in an extrathoracic site. Distinguishing second primaries from distant recurrence was difficult. These cases were recorded as distant recurrence unless specific criteria were met [6].

Results
During the period of study, a total of 128 VATS lobectomies with robotic vascular and mediastinal dissection were performed. One hundred patients underwent this procedure for early stage lung cancer and are included in this study. There were 42 men and 58 women with a mean age of 65 ± 8 years. Preoperatively, 82 patients were in clinical stage I (T1N0 or T2N0), and 18 patients were in clinical stage II (T1N1 or T2N1). There were 29 right upper lobectomies, 7 right middle lobectomies, 17 right lower lobectomies, 31 left upper lobectomies, and 16
left lower lobectomies. Pathologic cell type of the resected tumors was adenocarcinoma in 57 cases, squamous cell carcinoma in 25, adenocarcinoma in 7, large cell carcinoma in 1, bronchoalveolar carcinoma in 3, poorly differentiated carcinoma in 3, carcinoid tumor in 2, mucoid tumor in 1, and spindle cell carcinoma in 1. Mean operative time was 216 ± 27 minutes (range, 173 to 369). There was no emergent conversion to thoracotomy. In 1 patient with severe kyphosis, a dural leak was suspected after attempts at controlling intercostals bleeding from the posterior port. This patient underwent a thoracotomy and exploration. The presumed dural defect was patched and sealed, and the patient recovered without further complication. Hospitalization ranged from 3 to 42 days with a median of 4 days.

Pathologic Staging
Four nodal stations were dissected in patients with right-sided disease, and five nodal stations were dissected in patients with left-sided disease. Mean number of nodes recovered was 12 ± 3. Pathologic upstaging was noted in 17 patients (17%). As the result of disease discovered in the resected nodes, 10 patients with clinical stage I disease were upstaged to stage II, and 2 patients with clinical stage I and 5 patients with clinical stage II disease were upstaged to stage III. These patients were included in the survival and recurrence analysis.

Complications
Thirty-five complications were observed in 21 patients (21%) and are noted in Table 1. The most common complication was atrial fibrillation, in 13% of patients.

Mortality
There were 3 deaths (3%). No deaths were attributable to the robotic technique. The first death was of a 68-year-old man with forced expiratory volume in 1 second (FEV₁) of less than 800 cc who underwent a left upper lobectomy for stage IA adenocarcinoma. Postoperative unsuspected liver failure developed, and he died on the 12th postoperative day. The second death was of a 75-year-old woman with preserved pulmonary function who underwent a left lower lobectomy for stage IIA adenocarcinoma. The patient died of unexplained cardiopulmonary arrest while undergoing a radiographic procedure on the fourth postoperative day. The third death was of a patient with FEV₁ less than 800 cc who underwent a right upper lobectomy for bronchoalveolar carcinoma. The patient had postoperative pneumonia and respiratory failure and died on the 42nd postoperative day.

Early Versus Late Experience
Based on the retrospective analysis, the series could be divided into two groups: the first 20 patients, and the last 80 patients. The last 80 patients had shorter operating times (186 ± 16 minutes versus 337 ± 31 minutes for the first 20 patients) and hospitalization (range, 3 to 5 days versus 5 to 42 days). The complications were similar in the two groups. However, all 3 deaths occurred in the first 20 patients.

Survival
At a median follow-up of 32 months (range, 1 to 59), 1 patient (1%) had died of his cancer, there were 6 distant metastases (6%), and 2 patients (2%) had a second new lung cancer. There was no local recurrence.

Comment
Although the da Vinci surgical robot has been used in a number of thoracic surgical applications, at present, the role of robotics in the minimally invasive surgical treatment of lung cancer remains unclear. Theoretically, by virtue of three-dimensional visualization, increased instrument maneuverability and dexterity, and downsizing, the robot should represent an ideal tool for minimally invasive lobectomy. However, a number of published small series have failed to demonstrate the added value of robotics [7–9].

In addition, a number of shortcomings have been identified when the robot is used for the entire procedure. (1) The robot is designed for fine dissection. Manipulation of the lung with the robot is cumbersome and results in parenchymal tears, bleeding, and loss of visualization. (2) Lobectomy requires a wide-angle view of the entire thoracic cavity. This view is inherently impossible with the robot. (3) Introducing staplers and instruments through the same port as the robotic arm hampers their mobility and can lead to catastrophic bleeding and emergent conversion to thoracotomy. (4) This technique removes the surgeon from the field and requires a highly trained assistant at the operative field. This requirement necessitates a highly organized and rehearsed approach to the conduct of the operation, especially in the event of complications such as catastrophic bleeding. Furthermore, in the event of a catastrophic event, the response by the surgeon is delayed.

We view the robot as an instrument for dissection, and we have incorporated it solely as an “instrument” during the dissection phase of a hybrid VATS lobectomy technique. Our technique is based on the VATS lobectomy

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Table 1. Postoperative Complications in 100 Patients

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<th>Number</th>
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<td>Atrial fibrillation</td>
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<td>Atelectasis</td>
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<td>Prolonged air leak</td>
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<td>Pleural effusion requiring drainage</td>
<td>3</td>
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<tr>
<td>Pulmonary Embolism</td>
<td>3</td>
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<td>Incisional bleeding requiring exploration</td>
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<tr>
<td>Hydropneumothorax</td>
<td>1</td>
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<tr>
<td>Dural leak</td>
<td>1</td>
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<tr>
<td>Liver failure</td>
<td>1</td>
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<tr>
<td>Pneumonia</td>
<td>1</td>
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<tr>
<td>Cardiopulmonary arrest</td>
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<td>Respiratory failure</td>
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platform and consists of two phases. In phase 1, the robot is used for dissection of the posterior mediastinum and the subcarinal, para-tracheal and paraesophageal space. Next, the robot is used to dissect the pulmonary artery. Finally, the robot is repositioned to dissect the anterior hilum and the pulmonary vein. This approach to dissection replicates our operative approach during an open procedure. In phase 2, the robot is removed, and the structures are divided by the primary surgeon utilizing all the advantages of multiple ports and the VATS lobectomy technique.

The VATS lobectomy technique is an accepted oncologic approach to the treatment of early stage lung cancer. The safety, feasibility, and oncologic efficacy of VATS lobectomy have been demonstrated in both single and multi-institutional series [10–12]. However, although patient selection varies among surgeons, many have limited the application of this technique to patients with smaller and peripherally located tumors with no preoperative evidence of pathologic lymph nodes. Furthermore, except for a few reports, VATS lobectomy has been avoided in patients with stage II disease owing to concerns about the difficulty of hilar, mediastinal, and pulmonary artery dissection [13]. The daVinci surgical robot can be used to dissect the subcarinal space, the pulmonary artery in the fissure, and the pulmonary veins. Robotic dissection of the pulmonary artery and its branches is facilitated by the magnified three-dimensional visualization and “wristlike” action of the instruments. The robot enables easier pulmonary artery dissection in the presence of nodal disease in the fissure and the hilum, and in patients with incomplete fissures. As a result of these potential advantages, the robot may expand the application of VATS lobectomy to patients with higher stage disease and complex anatomy.

Appropriate nodal staging plays a significant role in the implementation of adjuvant therapy. The routine use of mediastinoscopy in patients undergoing VATS lobectomy has been shown to be an effective approach for mediastinal nodal staging [9]. We do not use mediastinoscopy routinely. We reserve mediastinoscopy for patients with N2 disease as diagnosed by preoperative staging computed tomography and positron emission tomography scans. Given this approach, robotic mediastinal and hilar nodal dissection enabled complete nodal staging in this series. Seventeen patients with clinically understaged disease were upstaged after robotic mediastinal nodal dissection. These patients underwent adjuvant therapy. Seven patients were found to have pathologic N2 disease. In these patients, microscopic metastases were seen. The presence of microscopic disease may explain the unusually low negative predictive value of 83% for the preoperative positron emission tomography and computed tomography staging.

In the patient with the dural leak, the complication occurred at the time of closure of the posterior incision, and was not related to the robotic phase of the procedure. During the period of this study, 327 robotic thoracic surgical procedures were performed at our institution. This series represents 100 consecutive VATS lobectomies with robotic dissection for early stage lung cancer. Retrospectively, longer operating room times, longer hospitalizations, and higher mortality rates were seen with the first 20 patients. That may represent the steep learning curve for the robotic technique. The 3 deaths in this series occurred among the first 20 patients. Although the deaths occurred in the postoperative period and were not the result of the robotic technique, they represent poor patient selection for this procedure. We have observed that in patients with poor FEV1 and diffusion capacity of the lung for carbon monoxide, the lung does not collapse, and the robotic and endoscopic VATS maneuvers are hindered by the confined pleural space. As the result, for these patients, the operative times were longer and may have contributed to the postoperative complications and the poor outcome. After that initial experience, for the last 80 patients, the hybrid technique was offered to patients with FEV1 more than 1 L. In highly selected cases, when lobectomy is offered to patients with FEV1 less than 1 L, it should be performed by VATS with a utility thoracotomy. As Demmy and Curtis [14] have observed, a utility thoracotomy may be instrumental in applying VATS lobectomy in high-risk patients with poor pulmonary reserve.

While robotics has the promise of greater instrument maneuverability, dexterity, and three-dimensional visualization, it is hampered by a number of shortcomings. Incorporation of the robot into the VATS platform increases the complexity and length of the procedure. The cost of the robotic procedure is inherently higher than VATS and encompasses longer operating room times, the cost of the robot, the cost of the disposable components, and the steep learning curve. The exact cost analysis is beyond the scope of this report and will be the subject of a future study. This study illustrates the feasibility of robotic dissection of the mediastinum, hilum, and pulmonary vasculature. As there does not seem to be an advantage in terms of operating times and hospitalization with the hybrid procedure, patients with stage I lung cancer may best be approached by the less expensive, more expeditious, and equally efficacious VATS lobectomy procedure. The value of the hybrid robotic procedure may be realized in patients with complex hilar anatomy and higher stage disease.

Based on this experience, we would conclude that Robotics is feasible for the dissection phase of VATS lobectomy. The learning curve for the use of robotics is steep. However, after the initial experience, this procedure is associated with low morbidity, low mortality, short hospital stay, and low local recurrence rate. The role of robotics as an adjunct to VATS lobectomy and in the minimally invasive surgical treatment of lung cancer remains to be studied.

References


INVITED COMMENTARY

Gharagozloo and colleagues [1] report a single institutional experience of a combined robotic (RATS) and video-assisted thoracoscopic surgical (VATS) approach for pulmonary lobectomies in 100 consecutive patients with early-stage non-small cell lung cancer. This large series on RATS lobectomies demonstrates the feasibility and safety of a hybrid technique using the robot for hilar and vascular dissection.

The concept of hybrid procedures, combining the specific advantages of the conventional and robotic minimally invasive approaches, is forward-looking and may represent the future for the robot in general thoracic surgery, where it has turned out that indications for completely robotic procedures are rare.

The question remains, however, whether a combined RATS-VATS approach for pulmonary lobectomy provides any benefit and thus should be used in this specific operation. Complete VATS lobectomies and complete RATS lobectomies were both shown to be feasible and safe [2, 3], and this study fails to demonstrate an added value of the robot when compared with a complete VATS lobectomy. Operative times, rates of complications and mortality, and length of stay were comparable or worse than in reported VATS series [4]. Oncologic lymph node dissection of N1 and N2 levels was also shown to be feasible by conventional VATS [5, 6] and the authors’ conclusion that the robot enables a more accurate mediastinal lymph node dissection represents a personal appraisal rather than a proven fact.

In most RATS lobectomies, the surgeon has a tablesided assistant perform some steps of the procedure, including the control of the main hilar structures with conventional stapler devices or the repeated repositioning of the lung. Thus, strictly speaking, any robotic lobectomy is a kind of hybrid procedure.

Although a RATS-VATS hybrid approach does not seem to provide relevant advantages for simple lobectomies, this may be different for advanced procedures like sleeve lobectomies. In a recently performed VATS right upper lobe sleeve lobectomy, the robot was used for the bronchial anastomosis only. The main characteristics of the robot—superior maneuverability of the instruments and 3-dimensional vision—significantly facilitated this critical step of the operation.

The introduction of robotic technology does have the potential to revolutionize minimally invasive surgery. Innovative, forward-looking surgeons like Gharagozloo and his group are trying to overcome current limitations of both VATS and RATS by performing hybrid procedures. This is an important step in the right direction and is meritorious. However, transducing the hybridization from the procedure to the instrument by implementing robotic micromechanical technology into hand-held, conventional VATS instruments might be even more effective.

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References
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*Ann Thorac Surg* 2009;88:380-384
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