Robotic Lobectomy: Experience with 638 Consecutive Cases

Farid Gharagozloo, MD
Professor of Surgery, Surgeon-in-Chief
Center for Advanced Thoracic Surgery, Global Robotics Institute, Advent Health
University of Central Florida
Celebration, FL

Mark Meyer, MD
Chief of Surgery
Wellington Regional Medical Center
Wellington, FL

Barbara Tempesta, CRNP
Chief Nurse Practitioner
Center for Advanced Thoracic Surgery, Global Robotics Institute, Advent Health
University of Central Florida
Celebration, FL

ABSTRACT

BACKGROUND: Robotic lobectomy has been evolving over the past decade and has been shown to be an oncologically acceptable procedure. We evaluated our experience with robotic lobectomy for the treatment of early-stage lung cancer.

METHODS: We performed a retrospective review of prospectively accrued patients at our institution who underwent robotic lobectomy for early-stage lung cancer from February 2004 to July 2019.

RESULTS: Of 3304 consecutive patients who underwent a robotic operation by a single surgeon, 638 underwent robotic lobectomy for early-stage primary non-small cell lung cancer (NSCLC; stages I and II). The 427 (67%) men and 211 (33%) women had a median age of 69 y (range 41-86), and 567 (89%) were former or current smokers. The median operative time was 176 minutes (range 160-456), the median chest tube time was 3 days (2-8), the median air leak time was 0 days (0-3), and the median length of stay was 3 days (1-26). The median tumor size was 2.6 cm (range 0.6-3.4). The mean number of nodes recovered was 14 ± 3. Pathologic upstaging was noted in 121 patients (19%). Minor complications were observed in 133 patients (21%). Conversion to thoracotomy occurred in 11 (1.7%) patients. Mortality was 0.5%.

CONCLUSION: Robotic lobectomy is a safe, minimally invasive procedure that replicates the oncologic and technical principles of thoracotomy for the treatment of lung cancer.
The most common indication for lobectomy is lung cancer. Approximately 228,150 new cases of lung cancer (116,440 men and 111,710 women) were diagnosed in the United States in 2018. During the same time period, 142,670 patients died from lung cancer (76,650 men and 66,020 women). Lung cancer is by far the leading cause of cancer death among both men and women. Each year, more people die of lung cancer than of colon, breast, and prostate cancers combined. The overall 5-year survival for lung cancer is approximately 23%. This dismal outlook is largely due to the fact that over 50% of patients are in stage III or IV at the time of diagnosis. On the other hand, the 5-year survival for patients with stage I disease is 80-95%. It is estimated that, at any one time, approximately 650,000 patients with early lung cancer are undiagnosed. Thus, the number of early-stage lung cancers appropriate for surgical resection should be increasing.

Lobectomy performed by minimally invasive video-assisted thoracic surgery (VATS) has become oncologically acceptable for isolated non-small cell lung cancer (NSCLC). However, VATS lobectomy is hampered by 2-dimensional visualization and limited instrument maneuverability in a highly complex anatomic environment. The surgical robot (da Vinci; Intuitive Surgical, Sunnyvale, CA) has offered the promise of overcoming these shortcomings by providing three-dimensional visualization, instruments with “wrist-like” action, and ease of fine dissection in a confined space. A small number of series have reported acceptable perioperative results. In addition, in a large multi-institutional cohort of patients, long-term stage-specific survival has been shown to be consistent with prior results for VATS and thoracotomy.

The aim of the present report is to present our experience with robotic lobectomy for early-stage lung cancer.

PATIENTS AND METHODS

A retrospective review was conducted of patients with early-stage lung cancer (stages I and II) who underwent robotic lobectomy between February 2004 and July 2019.

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 or 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 was reviewed and determined to be exempt from institutional review board approval under 45 CFR 46.101 (b).

Operative technique

Due to the evolution of robotic techniques and the introduction of new instruments and techniques during the study period, two robotic lobectomy techniques were used.

From 2004 to 2012, a hybrid robotic dissection and VATS bronchovascular division technique were used. From 2012 to 2019, a completely port-based robotic lobectomy procedure was used.

VATS robotic lobectomy

This technique has been described previously. The patient is placed in a full lateral decubitus position. The table is flexed to open the intercostal spaces. The position of the double-lumen tube is reconfirmed after final patient positioning. The patient is then prepared and draped as in routine VATS procedures. The superior portion of the drape is allowed to cover the patient’s head. The table is unlocked and rotated 30° from its normal position to facilitate the positioning of the robot over the patient’s head. The operation is performed in 5 Stages: Stage I, Routine VATS and retractor placement for the robot; Stage II, Robotic subcarinal, paratracheal and posterior mediastinal dissection; Stage III, Robotic dissection of the pulmonary artery in the fissure; Stage IV, Robotic dissection of the pulmonary veins and the anterior mediastinum; and Stage V, Division of vascular and bronchial structures by VATS.

Port-based robotic lobectomy

The operating room table is reversed so that the pedestal does not interfere...
with the docking of the robot over the head of the patient.

A double-lumen tube is placed and the patient is positioned in a full lateral decubitus position. The right arm is placed over pillows and positioned high enough such that access to the 4th intercostal space in the anterior axillary line is readily attained. The table is flexed to move the hip down and to open the intercostal spaces. The lung is deflated and placed on suction. The position of the double-lumen tube is rechecked after the patient is prepped and draped.

Figures 1 and 2 show port placement. A line is drawn from the tip of the scapula to the costal arch. This delineates the highest point in the chest and the mid-scapular line (posterior axillary line). Pleural entry is with a Hassan needle. Saline is infused and care is taken to look for easy egress of the saline from the needle. If there is any question of pleural adhesions, we use a Visiport Instrument (Medtronic Inc., Norwalk, CT) for entry into the pleural space under direct vision. If the Visiport is used, a purse string is placed in the muscle layer and tied around the robot camera port to prevent CO₂ leakage.

Port #1 is the camera port. Warm, humidified CO₂ is insufflated through this port at 6 L/min to a pressure of 6-8 mmHg to push the lung and diaphragm away. The other ports are placed under direct vision. Port #2 (8 mm) is placed in the 7th intercostal space in the posterior or scapular line. This port is 9 cm posterior to Port #1 and accommodates da Vinci arm #2. Prior to the placement of Port #3, a 21-gauge needle is inserted into the 7th intercostal space at the costovertebral junction from the patient’s back and injected a 10-ml subpleural bubble of 0.25% bupivacaine with epinephrine near the intercostal nerve. Next, Port #3 is placed 10 cm posterior to Port #2 in the 7th intercostal space just medial to the spine. This port accommodates da Vinci arm #3. Port #4 is placed 9 cm anterior to Port #1 in the 7th intercostal space at the anterior scapular line. This port accommodates da Vinci arm #1. The assistant Port #5 uses a 10-12 Versisport trocar and is placed in the 9th intercostal space, triangulated between Ports #1 and #4. It should be two or three ribs lower than, and as far as possible from, the da Vinci ports to maximize assistant workspace. Keeping this port off the trajectory lines for those ports will facilitate the patient-side assistant’s access for retraction and other maneuvers.

After lobectomy is complete, the specimen is retrieved through the anterior incision using a lubricated double-bag consisting of a 1500-mL size LapSac® (Cook Medical, Bloomington, IN) placed inside an Endopouch™ (Ethicon Endo-Surgery, Cincinnati, OH). Subpleural intercostal pain catheters (on-Q; iFlow, Inc., Lake Forest, CA) are used for postoperative analgesia, and staple lines are sealed with a fibrin sealant (Evicel™; Johnson & Johnson, Somerville, 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 post-discharge visits, interviews, tumor registry data, and regular radiographic and clinical follow-up. A 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. It was difficult to distinguish second primaries from distant recurrence. These cases were recorded as distant recurrence unless specific criteria were met.

RESULTS

During the period of the study, 3,304 consecutive patients underwent a robotic operation by one surgeon (FG). Of 638 patients who underwent robotic lobectomy, 204 (32%) underwent robotic lobectomy by a hybrid robotic dissection and VATS bronchovascular division technique (2004-2012) and 434 (68%) underwent a completely port-based robotic lobectomy (2012-2019). The 427 (67%) men and 211 (33%) women had a median age of 69 y (range 41-86) and 567 (89%) were former or current smokers.

The median operative time was 176 minutes (range 160-456). The median chest tube time was 3 days (2-8), the median air leak time was 0 days (0-3), and the median length of stay was 3 days (1-26).

The median tumor size was 2.6 cm (range 06-3.4), and the tumor distribution was RUL 197 (31%), RML 51 (8%), RLL 133 (21%), LUL 159 (25%), and LLL 95 (15%). Tumor type was adenocarcinoma in 497 (78%) patients and squamous cell carcinoma in 121 (19%) patients.

Four nodal stations were dissected in patients with right-sided disease, and five nodal stations were dissected in patients with left-sided disease. The mean number of nodes recovered was 14 ± 3. Pathologic upstaging was noted in 121 patients (19%). As the result of disease discovered in the resected nodes, 71 patients with clinical stage I disease were upstaged to stage II, and 25 patients with clinical stage I and 35 patients with clinical stage II disease were upstaged to stage IIIA.

Minor complications were observed in 133 patients (21%). The most common complication was atrial fibrillation, which was seen in 13% of patients. Thirteen (2.1%) patients had major complications, including bronchopleural fistula (3), pulmonary embolism (5), acute renal insufficiency (3), and hemorrhage (2). Conversion to thoracotomy occurred in 11 (1.7%) patients; 6 conversions were for bleeding and the remaining 5 were due to anatomic or oncologic reasons.

There were 3 deaths (0.5%). All 3 deaths occurred in the first 20 patients and during the learning curve of the procedure. There have been no deaths in the last 618 robotic lobectomy procedures.

DISCUSSION

One of the shortcomings of the VATS lobectomy technique stems from the fact that the instruments are introduced through ports or small incisions, which amount to holes in the chest wall. The instruments pivot at the entry hole and can be moved in four directions. The limited mobility of conventional endoscopic instruments, whether in the abdomen or the chest, has been referred to by some investigators as “chopstick surgery.” The chopstick nature and the limited maneuverability of the effector instruments stem from the rigid shaft axis fixed to the thorax by the entry
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hole. This technical shortcoming limits the surgeon in performing fine dissection and complex three-dimensional maneuvers. Pivoting instruments on the chest wall results in a large radius of curvature for the tip of the instrument and makes fine dissection in deep spaces such as the mediastinum very difficult and even dangerous. Indeed, it is this fact which has necessitated the need for a utility thoracotomy. Using the utility thoracotomy, the surgeon is able to utilize conventional instruments and his or her own wrist to provide additional degrees of freedom.

Another shortcoming of the VATS lobectomy technique is the lack of three-dimensional visualization. The surgeon has to use two-dimensional information from the video monitor to create a three-dimensional mental image. This fact requires significant experience and can be a source of fatigue for the surgeon. Most importantly, the use of such indirect means of judging depth perception is rarely equivalent to binocular vision. In the thoracic hilum, binocular vision is paramount for lymphadenectomy and individual vascular and bronchial dissection.

Surgical robots have offered the promise of overcoming these limitations. With the EndoWrist® (Intuitive Surgical, Sunnyvale, CA), a cable-driven wrist at the end of a robotic arm is positioned to provide downscaling from the surgeon’s head, eyes and hands in providing optimal hand-eye coordination and, because it is mounted on the chest wall results in a large radius of curvature for the tip of the instrument and makes fine dissection in deep spaces such as the mediastinum very difficult and even dangerous. Indeed, it is this fact which has necessitated the need for a utility thoracotomy. Using the utility thoracotomy, the surgeon is able to utilize conventional instruments and his or her own wrist to provide additional degrees of freedom.

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confined pleural space. As a result, for these patients, the operative times were longer and may have contributed to the postoperative complications and poor outcome.

Appropriate nodal staging plays a significant role in the implementation of adjuvant therapy. We do not use mediastinoscopy routinely. Instead, 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. One-hundred-twenty-one patients with clinically understaged disease were upstaged after robotic mediastinal nodal dissection. These patients underwent adjuvant therapy.

Conversion to thoracotomy occurred in 11 (1.7%) patients, and 6 (overall 1%) of these conversions were for bleeding. The overall incidence of major vascular injury during all elective robotic thoracic operations has been reported to be 1.2% (16 of 1,304 operations) by Cerfolio et al. These authors reported that the incidence of major bleeding complications with robotic lobectomy was 2.6%. Major vascular injury most commonly occurs during left upper lobectomy and is associated with dissection, isolation and division of the truncus branch. Cerfolio and colleagues described the "4 P's" for the control of major vascular injury: Poise, Pressure, Preparedness, and Proximal Control. We have added a 5th P to the overall management of major vascular injuries during robotic lobectomy:

Prevention.

Thus, our approach to major vascular injuries during robotic lobectomy encompasses the "5 P's":

1. Prevention: First and foremost is Prevention. Prevention of major vascular injury entails complete and methodical dissection of the perivascular structures, as outlined above. The completion of mediastinal nodal dissection allows for mobilization of the bronchial and vascular structures. Dissection and removal of perivascular N1 nodes allows for full visualization of the PA branches and allows for a safer approach to the isolation and division of the vessel. The use of vessel loops for elevation of the vascular branch and the use of staplers with guide catheters further decreases the chance of vascular injury. As a general rule, the branch of the pulmonary artery and the proximal portion of the artery that gives rise to the branch should be completely dissected before any attempt is made to encircle the branch. Decreasing tension on the branch point is an excellent technique for avoiding injury to the artery. As a rule, greater dissection leads to safer control of the pulmonary artery branches and prevention of catastrophic bleeding. Furthermore, following these principles facilitates proximal control and control of bleeding in the event of injury to the pulmonary artery. In our view, every step of robotic lobectomy should be designed to build a foundation of safety for the prevention of vascular injury.

Conversion to a thoracotomy is the safest approach. As Cerfolio et al. pointed out, the most conservative and safest route is to open, perform a safe and elective thoracotomy, and fix the injury. In the event of vascular injury, the goal of the operation needs to change from performing an R0 resection with complete lymph node resection through a minimally invasive technique to saving the patient's life and performing an R0 resection with complete lymph node resection. Although conversion to a thoracotomy is always possible and should be anticipated by having the appropriate trays, etc., in the room, in our experience, thoracotomy takes too long and is associated with significant blood loss. With greater experience, we prefer to control the bleeding using robotic techniques.

2. Preparedness: The anesthesia and surgical teams need to prepare by running drills such that each team member is totally ready for their function in the event of vascular injury. This requires a dedicated anesthesia and nursing team. Thoracotomy trays must be in the room, and possibly opened and counted depending on the experience of the surgeon. Blood needs to be available, dictating the need to type and cross-match blood for patients who undergo robotic lobectomy.

3. Poise: The primary surgeon must remain as relaxed as possible to create a calm and methodical approach to the problem. The primary surgeon needs to impart an attitude of confidence and calmness to all members of the surgical and anesthesia teams. This is only possible when there is a specific anesthesia and OR team, and if the team has prepared for the emergency by running regular disaster-readiness drills.

4. Pressure: Since the pulmonary artery is a low-pressure and high-flow vessel, bleeding can be controlled with pressure. Attempts at grabbing the artery should be discouraged as this maneuver, which works best for high-pressure vessels, will tend to enlarge the tear. The best approach is to have a tightly rolled sponge in the field. In the event of bleeding, the rolled sponge is placed over the bleeding point with the left robotic instrument (usually a Cadherie forceps) and pressure is maintained. Next, the assistant introduces a tightly rolled sponge that is covered with EVARREST™ fibrin sealant patch (Ethicon, Somerville, NJ)(Fig. 3). The patch attached to a tightly rolled sponge is grasped by the right robotic instrument (usually a curved bipolar). In a swift motion, the sponge in the left hand is removed and replaced with the sponge carrying the EVARREST™ patch. The
patch is held over the bleeding point for exactly 3 minutes. Following this, the patch should be left in place and the fourth arm should be used to continue applying pressure on the sponge/patch composite. The tendency to assess the state of the tear should be absolutely avoided. The patch should be left in place until proximal control is obtained.

5. Proximal Control: Once the vessel is hemostatic, the surgeon should obtain proximal control by passing a vessel loop around the pulmonary artery proximally, double-looping around it, and gently pulling up to completely stop its blood flow. At this point, the patch sponge composite should be removed. The injury can be seen because the blood flow is stopped, and can be sewn using 4-0 nonabsorbable suture that is cut to a length of 12 cm or stapled if there is room proximally.

If conversion to thoracotomy is chosen, the robotic instruments need to be completely removed, the robot undocked and moved completely away from the operative field, and the bleeding stopped by sponges alone without outside instruments holding pressure. We believe it is a mistake to leave one arm of the robot in to compress a vessel. It is critical to completely remove the robot from the operative field. If a vessel is still bleeding, pressure needs to be held by means of a nonrobotic instrument through the access port by a bedside assistant while the chest is safely and calmly opened.

With greater experience, a minimally invasive technique is used to control pulmonary artery bleeding. However, until greater experience is gained, and even then only under certain circumstances, an orderly conversion to a thoracotomy should remain the procedure of choice.

**CONCLUSION**

In a large series of patients who underwent robotic lobectomy for early-stage lung cancer, the procedure was associated with excellent results. Robotic lobectomy represents a minimally invasive, oncologically sound procedure, with acceptable results in patients with early-stage lung cancer.

**The authors declare that they have no competing interests.**

**REFERENCES**