

# Robotic Lung Resection for Non-Small Cell Lung Cancer



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## KEYWORDS

• Robotic • Robot-assisted • Lobectomy • Lung cancer

## KEY POINTS

- Robotic pulmonary lobectomy is becoming an increasingly common modality used for lung resection, and can be done with very low morbidity and mortality.
- Robotic lobectomy offers similar benefits to video-assisted thoracic surgery (VATS) lobectomy in postoperative recovery, and additional advantages in optics, dexterity, and surgeon ergonomics.
- Further comparisons between VATS and robotics in terms of ease of training, long-term oncologic efficacy, and patient outcomes are an area of active study.

## INTRODUCTION

Video-assisted thoracic surgery (VATS) for pulmonary resection, including lobectomy, has become widely used among general thoracic surgeons. However, robotic surgery has certain advantages, such as 3-dimensional visualization, improved camera quality, wristed instruments, and ergonomic ease. As such, the performance of robotic-assisted pulmonary lobectomy has increased since it was first reported in the English literature in 2003.<sup>1</sup> Robotic surgery has certain limitations, including more complex setup time, increased costs, absence of haptic/tactile feedback, and the need for specialized equipment and training. However, results of completely portal robotic lobectomy as done with the 4-arm technique (CPRL-4) similar to or as described by

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The authors have nothing to disclose.

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Cerfolio and colleagues<sup>2</sup> have been shown to yield excellent results in terms of both intraoperative criteria and postoperative morbidity and mortality.

## INDICATIONS

Robotic-assisted pulmonary lobectomy can be considered for any patient that is deemed fit to tolerate conventional lobectomy. In fact, patients have a better functional outcome after minimally invasive compared with open lobectomy; therefore, patients considered marginal or unfit for thoracotomy may still be considered for robotic lobectomy.<sup>3</sup> Burt and colleagues<sup>4</sup> have shown that VATS lobectomy can be performed with predicted postoperative forced expiratory volume in 1 second or diffusion capacity of the lung for carbon monoxide of less than 40% with acceptable morbidity and mortality. We believe that robotic-assisted lobectomy is similarly safe in this group of patients that had traditionally been considered inoperable.

Tumors larger than 7 cm (T3), tumors crossing fissures, and centrally located tumors may all be considered for robotic lobectomy with proper patient selection and increasing surgeon experience, but in general these factors disfavor a robotic approach. Similarly, radiologic evidence of N1 nodes, induction chemotherapy and/or radiation, calcified lymph nodes and prior thoracic surgery are not contraindications to robotic lobectomy but a robotic approach to these patients should not be selected early in one's learning curve.

Chest wall resection with robotic assistance for the parenchymal resection part of the procedure is feasible as well. VATS chest wall resection has been shown to be safe and to decrease the extent of reconstruction necessary.<sup>5</sup> As of yet, however, there are no published series of robotic-assisted combined lung–chest wall resections. The postoperative benefits of minimally invasive chest wall resection remain unclear.

Completely robotic sleeve lobectomy and resection with bronchoplasty have been performed at our institution, but only a single hybrid robotic–VATS case has been published from another center.<sup>6</sup> It is possible that the results from these operations will prove favorable; however, at this time we recommend that only practitioners with extensive experience with robotic thoracic surgery attempt these procedures. Complex vascular reconstruction remains preferentially approached from a thoracotomy.

The typical contraindications for lobectomy that apply to patients undergoing resection via thoracotomy would also apply to patients undergoing robotic lobectomy (eg, prohibitive lung function or medical comorbidities, multistation N2, gross N2 disease, or evidence of N3 disease). Patients with Pancoast tumors, tumors with extensive invasion into the mediastinum or esophagus, and those with contraindications to general anesthesia or single-lung ventilation are also poor candidates for robotic lobectomy. In addition, small nodules that are not tissue diagnosed that require lung palpation for wedge resection are considered by some as a contraindication for robotic lobectomy when a completely portal technique is used because of the inability to palpate the lung; however, lung palpation is possible with a robotic technique when a robotic-assisted technique is used. However, we have used navigational bronchoscopy with methyl blue tattooing of the nodules to help guide wedge resection or a robotic lymph node dissection and then conversion to VATS.

## EQUIPMENT

The Da Vinci Surgical System is currently the only robotic system approved by the US Food and Drug Administration for lung surgery. The surgeon sits at a console some distance from the patient, who is positioned on an operating table in close proximity

to the robotic unit with its 4 robotic arms. The robotic arms incorporate remote center technology, in which a fixed point in space is defined, and about it the surgical arms move so as to minimize stress on the thoracic wall during manipulations. The small proprietary Endowrist instruments attached to the arms are capable of a wide range of high-precision movements. These are controlled by the surgeon's hand movements, via "master" instruments at the console. The master instruments sense the surgeon's hand movements and translate them electronically into scaled-down micromovements to manipulate the small surgical instruments. Hand tremor is filtered out by a 6-Hz motion filter. The surgeon observes the operating field through console binoculars. The image comes from a maneuverable high-definition stereoscopic camera (endoscope) attached to one of the robot arms. The console also has foot pedals that allow the surgeon to engage and disengage different instrument arms, reposition the console master controls without the instruments themselves moving, and activate electric cautery. A second optional console allows tandem surgery and training.

### PREOPERATIVE EVALUATION

Preoperative evaluation including pulmonary function testing should be obtained. Patients who are borderline in terms of overall health and/or respiratory parameters can undergo exercise testing to determine maximal oxygen consumption ( $\text{Vo}_2$  max); patients with a  $\text{Vo}_2$  max of greater than 15 mL/kg\*min are considered moderate risk, 10 to 15 mL/kg\*min are high risk, and less than 10 mL/kg\*min are prohibitive risk. We routinely obtain stress testing to assess for myocardial ischemia especially in patients who have had a significant smoking history. Complete patient-specific staging should also be performed before lung resection. This includes PET-computed tomography scanning in almost all patients and the selective use of brain MRI or computed tomography (those who are symptomatic or who have large central adenocarcinomas), endobronchial ultrasound-guided fine needle aspiration, esophageal ultrasound-guided fine needle aspiration for biopsy of the posterior inferior lymph nodes and adrenals, and/or mediastinoscopy depending on the tumor size, location, radiologic findings, and institutional experience.

### PORT PLACEMENT

Robotic lobectomy is a technique that can be applied to a broad range of patients and tumors. Although small, peripheral tumors in thin patients are the most easily dealt with robotically, obesity, large size of tumor, and central location of tumor are not contraindications for robotic resection.

There are several different techniques used to perform the operation. Veronesi and Melfi in 2010 reported the safety of a 4-arm robotic assisted (not completely portal) lobectomy (using a 3- to 4-cm access incision as used by VATS surgeons) in 54 patients. Ninan and Dylewski<sup>7</sup> in 2010 reported the effectiveness of a completely portal robotic lobectomy using 3 arms (CPRL-3) in 74 patients. Gharagozloo and colleagues<sup>8</sup> in 2009 reported his outcomes using a hybrid technique.

We prefer the CPRL-4 method. The technique with an SI robot is performed in the following manner for a right upper lobe. For a lower lobe the exactly same sequence is used, but the ports are placed over the ninth ribs not the eighth.

The port that is placed first is the camera port. We prefer to use a 5-mm VATS camera as opposed to the 8- or 12-mm robotic camera in case the underlying lung is injured. Once the pleural space is entered over the top of the eighth rib, warm humidified  $\text{CO}_2$  is insufflated into the chest and a 5-mm camera is placed via the camera port and an extensive subpleural paravertebral block is carried out using 0.25% Marcaine

with epinephrine from ribs 3 to 12. The next port that is placed is the 5-mm most posterior port, which is always used for robotic arm 3; this is located 2 to 3 cm lateral to the spinous process of the vertebral bodies. As shown in Fig. 1, which is a right-sided resection, robotic arm 3 represents the second left hand. If you were operating in the left chest robotic, arm 3 would represent a second right-handed instrument.

The next port that is placed is robotic arm number 2, which always serves as the left hand when using an SI robot. We now currently use a 5-mm robotic DeBakey instrument or a Shertell for our left hand and used to use an 8-mm port and use a Caudierre. Once this trocar is placed only 2 trocars are left. They are carefully planned before making any incisions in the skin. The goal of these 2 trocars is to maximize the distance between the access port and the port for robotic arm 1. This affords the greatest working area for the assistant. Using a needle and injecting Marcaine into the chest, these sites are chosen by placing the access port (a 12-mm plastic disposable trocar) as low in the chest as possible and just above the diaphragmatic fibers so as not to injure it. This incision is not made until the site for robotic arm 1 is chosen as well. Note that these ports (the camera, the access port, and the site for robotic arm 1) form an isosceles triangle (see Fig. 1).

We use only a 0° camera to avoid injuring the intercostal nerve. Through the access port we place a 12-mm plastic port and through robotic arm 1 we use an 8-mm metal trocar and place a bipolar instrument.

For the Xi model, there are few changes in the setup. The reusable trocars come currently in 2 sizes; 8 mm is the standard size and a 12 mm, which is used for the robotic stapler. It affords easier docking technology, but one cannot use other trocar models for the robotic arm (Fig. 2). We begin by placing a robotic 8-mm trocar in the camera site, which could be above the eighth or ninth rib. We find that entering the chest cavity a rib space lower on the Xi affords improved visualization and also the arms can reach further on the Xi than Si so there are no downsides in placing the trocars lower when performing upper lobes. For the posterior port, an 8-mm trocar is placed and a double fenestrated tip up instrument is used in lieu of the thoracic 5-mm grasper, which is not available yet for the Xi. Finally, a 12-mm trocar is used for arm number 2 for right-sided resections or arm 3 for left-sided resections, and is used for the robotic vascular as well as thick tissue loads. There is an inner cannula that downsizes the 12-mm trocar to an 8-mm one for use of the other robotic instruments or camera “hopping” if needed. Alternately, 8-mm trocars can be used for all the robotic and camera arms if the robotic stapler is not used. The robot can come

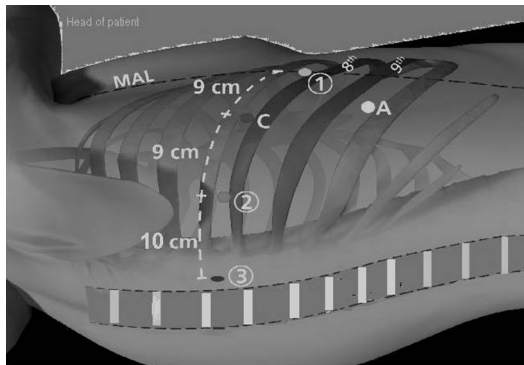


Fig. 1. Port placement for right-sided pulmonary lobectomy (CPRL-4).



**Fig. 2.** New Xi trocar docking mechanism.

from the patient's sides and docked because it has a rotating boom positioned, which affords the anesthesia staff improved access to the airway (**Fig. 3**).

## TECHNIQUE

After the pleural surface is inspected to confirm the absence of metastases, we proceed with mediastinal lymph node dissection.

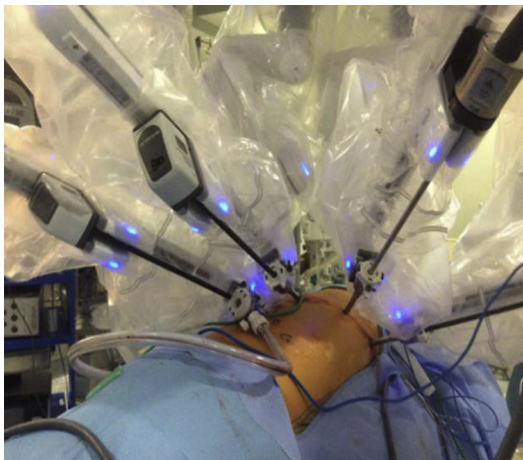


**Fig. 3.** Robotic Xi boom positioned over patient body.

### ***Right Side***

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The inferior pulmonary ligament is divided to get to lymph node station 9. It is removed along with lymph node station 8. Robotic arm 3 is used to retract the lower lobe medially and anteriorly to remove lymph nodes from station 7. Care is taken to control the 2 feeding arteries that make the subcarinal lymph node bloody. Robotic arm 3 is used to retract the upper lobe inferiorly and robotic arms 1 and 2 are used to dissect out stations 2R and 4R, clearing the space between the superior vena cava anteriorly, the esophagus posteriorly, and the azygos vein inferiorly. Avoiding dissection too far superiorly can prevent injury to the right recurrent laryngeal nerve that wraps around the subclavian artery.

### ***Left Side***

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The inferior pulmonary ligament is divided to facilitate the removal of lymph node station 9. The nodes in station 8 are then removed. Station 7 is accessed in the space between the inferior pulmonary vein and lower lobe bronchus, lateral to the esophagus. If still in position, the lower lobe is retracted medially/anteriorly with robotic arm 3 during this process. Absence of the lower lobe facilitates dissection of level 7 from the left. Finally, robotic arm 3 is used to wrap around the left upper lobe and press it inferiorly to allow dissection of stations 5 and 6. Care should be taken while working in the aortopulmonary window to avoid injury to the left recurrent laryngeal nerve. Station 2L cannot typically be accessed during left sided mediastinal lymph node dissection owing to the presence of the aortic arch, but the 4L node is commonly removed.

Once the absence of mediastinal lymph node metastases is confirmed, we then proceed with pulmonary lobectomy. In situations where a confirmatory preoperative biopsy has not been done and the tumor is peripheral, a wedge resection may be done to establish a definitive diagnosis of a cancer before going ahead with lobectomy.

The order of structures to be isolated and divided is not always the same; however, certain patterns emerge depending on the lobe to be removed. A few principles, however, are worth keeping in mind:

- Lymph nodes in interlobar and intersegmental lesions are removed first to facilitate dissection of the vascular structures and bronchi.
- Bipolar cautery may be used to dissect the fissure with minimal air leak. As opposed to VATS, which generally emphasizes stapling of the fissure as one of the last steps of lobectomy, for robotic lobectomies the fissure is often approached first so that vascular structures can be identified and isolated.
- It is helpful to encircle the structures to be divided with vessel loops before attempting to pass the stapler. The stapler should be passed through the port that offers the best angle of attack, whether it is robot arm #1, #2, or the assistant port. If using a robot port, the port itself will have to be removed before putting the stapler through.

### **WEDGE RESECTION**

Wedge resection of a nodule may be necessary to confirm the presence of cancer before proceeding with lobectomy. Because the current iteration of the robot does not offer tactile feedback, special techniques may be necessary to identify a nodule that is not obvious on visual inspection. An empty ring forceps may be used via the assistant port to palpate the nodule. Alternatively, preoperative marking of the nodule

with a dye marker injected via navigational bronchoscopy can facilitate location of the nodule. Preoperative confirmation of a cancer diagnosis with tissue biopsy is helpful to avoid being unable to locate the nodule intraoperatively.

## THE 5 LOBECTOMIES

A certain degree of adaptability is necessary for performance of robotic lobectomy. Structures may be isolated and divided in the order that the patient's individual anatomy permits. What follows is a description of an outline of the typical conduct of each lobectomy.

### *Right Upper Lobectomy*

- Retraction of the right upper lobe laterally and posteriorly with robot arm 3 helps to expose the hilum.
- The bifurcation between the right upper and middle lobar veins is developed by dissecting it off the underlying pulmonary artery.
- The 10R lymph node between the truncus branch and the superior pulmonary vein should be removed or swept up toward the lung, which exposes the truncus branch.
- The superior pulmonary vein is encircled with the vessel loop and then divided (Figs. 4 and 5). The truncus branch is then divided.
- The right upper lobe is then reflected anteriorly to expose the bifurcation of the right main stem bronchus. There is usually a lymph node here that should be dissected out to expose the bifurcation. The right upper lobe bronchus is then encircled and divided. Care must be taken to apply only minimal retraction on the specimen to avoid tearing the remaining pulmonary artery branches.
- Finally, the posterior segmental artery to the right upper lobe is exposed, the surrounding N1 nodes removed, and the artery encircled and divided (Fig. 6).
- The upper lobe is reflected again posteriorly, and the anterior aspect of the pulmonary artery is inspected to make sure that there are no arterial branches remaining. If not, then the fissure between the upper and middle lobes, and the upper and lower lobes, is then divided. This is typically done from anterior to posterior, but may be done in the reverse direction if the space between the pulmonary artery and right middle lobe is already developed. During completion of the

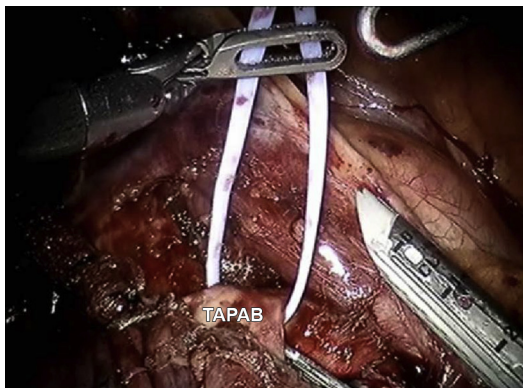


**Fig. 4.** The truncus arterial branch (TAPAB) with vessel loop around it for staple guidance.

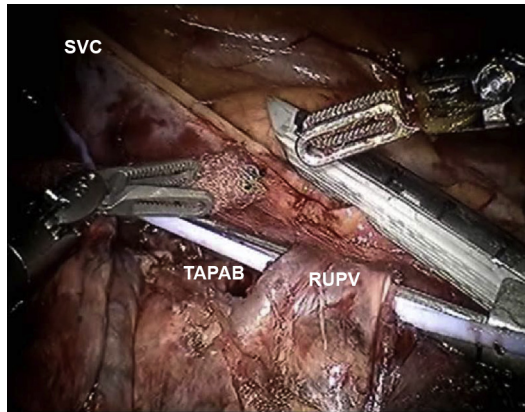


**Fig. 5.** Stapler positioning around the right upper lobe vein branches (RULV) off of the right superior pulmonary vein. Truncus branch (TAPAB) labeled and superior vena cava (SVC) in the left upper corner.

fissure, the right upper lobe should be lifted up to ensure that the specimen bronchus is included in the specimen.

#### ***Right Middle Lobectomy***

- Retraction of the right middle lobe laterally and posteriorly with robot arm I helps to expose the hilum.
- The bifurcation between the right upper and middle lobar veins is developed by dissecting it off the underlying pulmonary artery. The right middle lobe vein is encircled and divided.
- The fissure between the right middle and lower lobes, if not complete, is divided from anterior to posterior. Care should be taken to avoid transecting segmental arteries to the right lower lobe.
- The right middle lobe bronchus is then isolated. It will be running from left to right in the fissure. Level 11 lymph nodes are dissected from around it. It is encircled

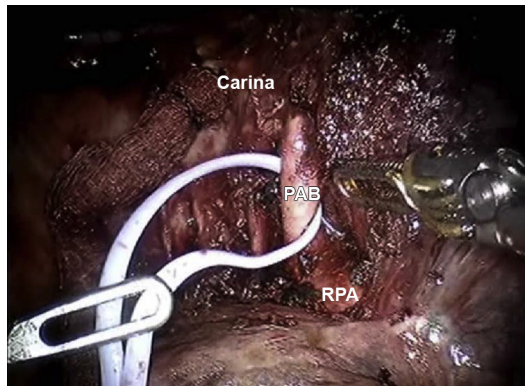


**Fig. 6.** Dissecting in the fissure to expose the posterior ascending branch (PAB) from the right pulmonary artery (RPA). The carina is viewed in the background.

and divided, taking care to avoid injuring the right middle lobar artery that is located directly behind it.

- Dissection of the fissure should continue posteriorly until the branches to the superior segment are identified. Then the 1 or 2 right middle lobar segmental arteries are isolated and divided (**Fig. 7**).
- Stapling of middle lobar structures may be facilitated by passing the stapler from posterior to anterior, to have a greater working distance.
- The fissure between right middle and upper lobes is then divided.

### ***Right Lower Lobectomy***

- The inferior pulmonary ligament should be divided to the level of the inferior pulmonary vein.
- The bifurcation of the right superior and inferior pulmonary veins should be dissected out. The location of the right middle lobar vein should be positively identified to avoid inadvertent transection.
- A subadventitial plane on the ongoing pulmonary artery should be established. If the major fissure is not complete, then it should be divided. The superior segmental artery and the right middle lobe arterial branches are identified. The superior segmental artery is isolated and divided. The common trunk to right lower lobe basilar segments may be taken as long as this does not compromise the middle lobar segmental artery/arteries; otherwise, dissection may have to extend further distally to ensure safe division (**Fig. 8**).
- The inferior pulmonary vein is divided.
- The right lower lobe bronchus is isolated, taking care to visualize the right middle lobar bronchus crossing from left to right. The surrounding lymph nodes, as usual, are dissected and the bronchus divided (**Fig. 9**). If there is any question of compromising the right middle lobe bronchus, the surgeon can ask the anesthesiologist to hand ventilate the right lung to confirm that the middle lobe expands.

### ***Left Upper Lobectomy***

- Retraction of the left upper lobe laterally and posteriorly with robot arm 3 helps to expose the hilum.

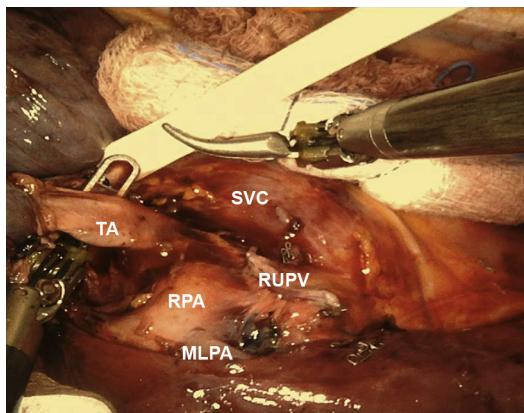


**Fig. 7.** Dissection of the fissure anteriorly showing the middle lobe pa branch (MLPA) off the right pulmonary artery (RPA) and the truncus branch (TA) as well. The superior vena cava (SVC) appears at the top of the image and an already ligated right upper lobe vein (RUPV) staple line is labeled.

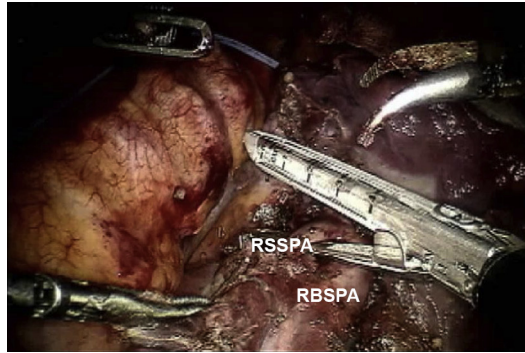


**Fig. 8.** Fissure dissection exposing the right superior segmental pa branch (RSSPA) and the right basilar segmental trunk (RBSPA).

- The presence of both superior and inferior pulmonary veins is confirmed, and the bifurcation dissected.
- The lung is then reflected anteriorly with robotic arm 3 and interlobar dissection is started, going from posterior to anterior.
- If the fissure is not complete, then it will need to be divided. Reflecting the lung posteriorly again and establishing a subadventitial plane will be helpful. The branches to the lingula are encountered and divided in the fissure during this process. The posterior segmental artery is also isolated and divided (**Figs. 10** and **11**). Division of the lingular artery or arteries can be done before or after division of the posterior segmental artery.
- The superior pulmonary vein is isolated then divided (**Fig. 12**). Because the superior pulmonary vein can be fairly wide, it may require that the lingular and upper division branches be transected separately.
- Often the next structure that can be divided readily will be the left upper lobar bronchus, as opposed to the anterior and apical arterial branches to the left upper lobe. The upper lobe bronchus should be encircled and divided, often passing the stapler from robotic arm 1 to avoid injuring the main pulmonary artery (**Fig. 13**).
- Finally, the remaining arterial branches are encircled and divided.

#### ***Left Lower Lobectomy***

- The inferior pulmonary ligament should be divided to the level of the inferior pulmonary vein. The lower lobe is then reflected posteriorly by robotic arm 3.

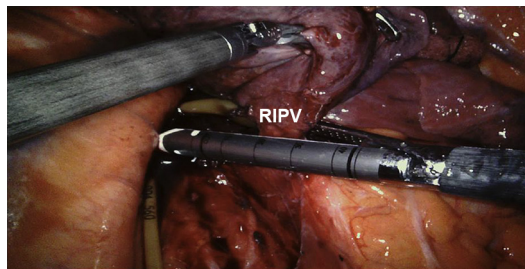


**Fig. 9.** The robotic vascular stapler around the right inferior pulmonary vein (RIPV).

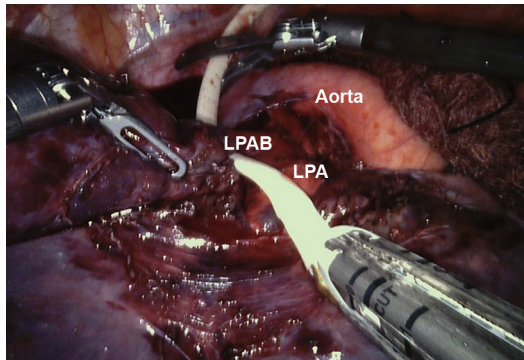


**Fig. 10.** The apical pulmonary artery branch (LPAB) is circumferentially dissected of the main left pulmonary artery (LPA) with the descending aorta in the background. Note the complete AP window lymph node dissection exposing the vagus nerve and the left recurrent laryngeal nerve (not labeled).

- The bifurcation of the left superior and inferior pulmonary veins should be dissected out.
- The lung is reflected anteriorly by robotic arm 3. The superior segmental artery is identified. The posterior ascending arteries to the left upper lobe are frequently visible from this view also. The superior segmental artery is isolated and divided. The common trunk to left lower lobe basilar segments may be taken as long as this does not compromise the middle lobar segmental artery/arteries; otherwise, dissection may have to extend further distally to ensure safe division. If the fissure is not complete, this will need to be divided to expose the ongoing pulmonary artery to the lower lobe.
- After division of the arterial branches, the lung is reflected again posteriorly. The inferior pulmonary vein is divided.
- The left lower lobe bronchus is isolated. The surrounding lymph nodes, as usual, are dissected and the bronchus divided.
- For left lower lobectomy, it may be simpler to wait until after resection is performed before targeting the subcarinal space for removal of level 7 lymph nodes.

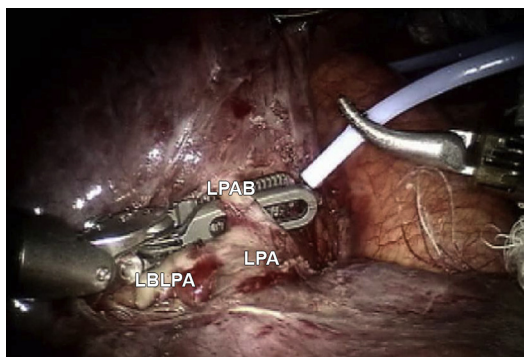


**Fig. 11.** Complete fissure dissection of the left pulmonary artery (LPA) showing accessory posterior pa branch (LPAB) and lingular branch (LBLPA).

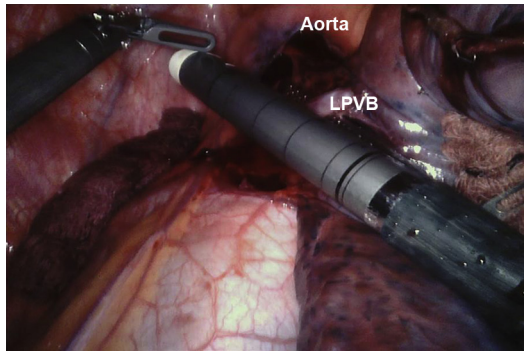


**Fig. 12.** The robotic vascular stapler around the apical branch (LPVB) of the left superior pulmonary vein. The distal arch of the aorta appears at the top of the image.

### AVOIDANCE OF INTRAOPERATIVE COMPLICATIONS/TROUBLESHOOTING

Intraoperative complications can be minimized and managed by following certain rules and guidelines.

- The passing of vascular staplers around fragile structure such as the pulmonary artery and/or vein deserves special attention. Carefully orchestrated moves and clear communication is needed between the bedside assistant and the surgeon. We have developed our own communication system between the bedside assistant and the surgeon to prevent iatrogenic injuries. This uses the anvil of the stapler as the hour hand of a clock and the degree of articulation is also quantified and communicated.
- Robotic instruments should be initially inserted under direct vision during thoracic surgery for their initial placement. Once safely positioned, instruments then can be quickly and safely inserted or changed for other instruments by properly using the memory feature of the robot that automatically inserts any new instruments to a position that is exactly 1 cm proximal to its latest position. However, if this feature is used, it is incumbent on the surgeon to ensure that



**Fig. 13.** The left upper lobe bronchus (LULB) is dissected out showing the trisegmental and lingular divisions with the left pa (LPA) caudad to it.

no vital structure have moved into the path of that newly placed instrument. The most common structure would be the lung.

- A rolled-up sponge should always be immediately accessible when working around vascular structures. If an injury occurs, the first step should be to tamponade the structure with the sponge. A minor injury may respond to this packing alone. If bleeding is massive or persists, a thoracotomy will be necessary. Lap pads should be inserted via the assistant port and packed around the injury to control bleeding. The robot is then dedocked and a thoracotomy made.
- The “drop zone” for the specimen should be well away from the pulmonary artery, which can be injured during this process if care is not taken.
- To remove the specimen, the assistant nonrobotic port is enlarged posteriorly to avoid injuring the diaphragm.
- The robotic arms are removed under direct vision with insufflation discontinued to confirm the absence of bleeding.

**Table 1** shows how to trouble shoot common problems encountered during robotic lobectomy.

## RESULTS

### *Perioperative Morbidity/Mortality*

Robotic lobectomy can be done with very low morbidity and mortality. We have previously demonstrated a 30-day mortality rate of 0.25%, a 90-day mortality rate of 0.5%, and a major morbidity rate of 9.6% in patients undergoing robotic anatomic pulmonary resection (lobectomy and segmentectomy).<sup>9</sup> Robotic lobectomy is associated with decreased rates of blood loss, blood transfusion, air leak, chest tube duration, length of stay, and mortality compared with thoracotomy.<sup>10,11</sup> With experience, conversion rates of less than 1% to thoracotomy may be achieved, although 3% to 5% is more typically reported.<sup>2,10</sup>

### *Oncologic Efficacy*

Park and colleagues<sup>12</sup> showed that the survival of patients undergoing robotic lobectomy to be similar to historical survival data from VATS and open lobectomy series. This multiinstitutional study of 325 patients was characterized by a median follow-up of 27 months, and demonstrated a 5-year survival rate of 80% overall (91% for stage IA, 88% for stage IB, 49% for stage II). The 3-year survival for patients with stage IIIA disease was 43%. Although it is reasonable to hypothesize that robotic lobectomy will demonstrate at least equivalent results to VATS and open lobectomy from an oncologic perspective, more study is needed before this conclusion can be reached.

### *Lymph Node Dissection*

Lymph node dissection with the robot is facilitated by the utilization of wristed instruments and the presence of bipolar cautery on dissectors. Most practitioners of robotic lobectomy perform a dissection of the fissure, with corresponding lymph node resection, although many VATS surgeons perform a “fissureless” technique that may lead to lymph nodes being incorporated in the specimen rather than individually dissected. One study demonstrated that upstaging of early stage lung cancers by robotic lobectomy (clinical T1a, T1b, and T2a) occurred in 10.9% of patients; 6.6% were upstaged owing to hilar (pN1) disease and 4.3% were upstaged owing to mediastinal (pN2) disease. Compared with prior series, this rate of overall nodal upstaging was similar to VATS (8%–12%), but lower than thoracotomy (20%–25%).<sup>13</sup> Other investigators have demonstrated a comparable number of lymph nodes dissected during robotic

| <b>Table 1</b><br><b>Troubleshooting of common problems during robotic lobectomy</b> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|--------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Problems</b>                                                                      | <b>Solutions</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Robotic arms are not responding to hand movement                                     | <ol style="list-style-type: none"> <li>1. Ensure trocar's remote center is in chest.</li> <li>2. Ensure trocar's docked properly to robotic arms.</li> <li>3. Ensure sterile plastic gown covering robotic arms is not interfering with wheeled mechanism of robot.</li> <li>4. Ensure surgeons' hand not maximized at console.</li> </ol>                                                                                                                                                                              |
| The camera is fogging                                                                | <ol style="list-style-type: none"> <li>1. Place humidified CO<sub>2</sub> insufflation through non access port (and not through the camera port).</li> <li>2. Preheat the camera.</li> <li>3. Evacuate smoke from the intraoperative field.</li> </ol>                                                                                                                                                                                                                                                                  |
| There are conflicts between robotic arms 3 and 1 or 2                                | <ol style="list-style-type: none"> <li>1. Ensure <math>\geq 10</math> cm between robotic arm 3 and closest robotic arm (robotic arm 1 or 2).</li> <li>2. Use a 5-mm thoracic lung grasper as the instrument of choice through the most posterior robotic arm.</li> <li>3. After docking, ensure the link 2's of robotic arms are aligned parallel to one another.</li> <li>4. When surgeon toggles between robotic arm 3 and 2 or 1, ensure the nonactive instrument is placed anteriorly toward chest wall.</li> </ol> |
| The bipolar cautery or thoracic dissector is not working.                            | <p>Ensure the bipolar...</p> <ol style="list-style-type: none"> <li>1. ...source is connected to robot,</li> <li>2. ...energy source is functioning, and</li> <li>3. ...cord is not damaged.</li> </ol>                                                                                                                                                                                                                                                                                                                 |
| There is a sudden loss of working space                                              | <ol style="list-style-type: none"> <li>1. Ensure DLET is properly positioned.</li> <li>2. Inflate more air in bronchial cuff.</li> <li>3. Ensure no leaks out of ports if using a completely portal technique.</li> <li>4. Ensure all valves are closed on ports.</li> <li>5. Do not place sucker in chest on suction unless immersed under water or blood.</li> </ol>                                                                                                                                                  |
| You are unable to achieve proper angle of stapler to come across vessels or fissures | <ol style="list-style-type: none"> <li>1. Try placing stapler through robotic access port or robotic arm 1 or 2 to achieve best angle.</li> <li>2. Use a stapler which maximizes the degrees of rotation and articulation.</li> <li>3. Do not force the stapler; tie vessels with suture or use an 8-mm robotic clips on vessel.</li> </ol>                                                                                                                                                                             |
| There is difficulty in bagging specimen                                              | <ol style="list-style-type: none"> <li>1. Use a bag that provides easy opening and closing by bedside assistant.</li> <li>2. Place bag under trocar before deployment.</li> <li>3. Place bag in the most anterior superior aspect of chest to maximize use of gravity, space and keep bag away from stapled hilar structures.</li> <li>4. Use robotic arm 3 to place specimen into bag and then hold back of the bag in place while stuffing specimen into bag with robotic arms 1 and 2.</li> </ol>                    |

*Abbreviation:* DLET, double lumen endotracheal tube.

and VATS lobectomy.<sup>14</sup> Nodal upstaging rates from VATS versus robotic lobectomy have also been shown to be similar in patients with clinical N0 lung cancer (15.2% vs 13.2%;  $P = .72$ ).<sup>15</sup> It is not clear yet whether or not use of the robot for lobectomy will allow surgeons to achieve an equivalent nodal dissection to thoracotomy.

**Table 2**  
Results reported in series of robotic-assisted lobectomies

| Author, Year                         | n   | Conversion Rate (%) | Morbidity (%) | Perioperative Mortality (%) | Median LOS (d) | Other Notes                                                        |
|--------------------------------------|-----|---------------------|---------------|-----------------------------|----------------|--------------------------------------------------------------------|
| Cerfolio et al, <sup>2</sup> 2011    | 168 | 7.7                 | 27            | 0                           | 2              | Decreased morbidity, improved QOL, shorter LOS than open lobectomy |
| Park et al, <sup>19</sup> 2006       | 30  | 12                  | 26            | 0                           | 4.5            | —                                                                  |
| Veronesi et al, <sup>20</sup> 2009   | 54  | 13                  | 20            | 0                           | 4.5            | Shorter LOS than open lobectomy                                    |
| Gharagozloo et al, <sup>8</sup> 2009 | 100 | —                   | 21            | 3                           | 4              | —                                                                  |

Abbreviations: LOS, length of stay; QOL, quality of life.

## Cost

Shorter length of stay and decreased morbidity translate into lower hospital costs, and therefore generally favor minimally invasive pulmonary resection over pulmonary resection via thoracotomy. Robotic lobectomy has been shown to have decreased cost compared with open lobectomy.<sup>9</sup> However, the price of a DaVinci SI Surgical System is \$1.7 million, and the price of a second console is \$450,000. The maintenance cost per year per robot is estimated at \$140,000, and the replacement costs for the instruments that are limited in terms of reusability are significant.<sup>16</sup> When compared with VATS lobectomy, robotic pulmonary lobectomy has a higher overall hospital cost, ranging from an additional \$3000 to \$5000 per case.<sup>17,18</sup> Nevertheless, robotic lobectomy continues to be a profitable endeavor for hospital systems, with an estimated median profit margin of around \$3500 per patient.<sup>9</sup>

## SUMMARY

Robotic pulmonary lobectomy is becoming an increasingly common modality used for lung resection, and can be done with very low morbidity and mortality, as we and other investigators have demonstrated (**Table 2**). Robotic lobectomy is advantageous when compared with open lobectomy with regards to short-term outcomes, both in community and academic settings.<sup>10,11</sup> The modality offers many of the same benefits in terms of perioperative morbidity and mortality that VATS lobectomy, with some additional advantages in terms of optics, dexterity, and surgeon ergonomics. Clearly, robotic assistance can be a safe and useful technology for lung resection when surgeons are properly trained. Further comparisons between VATS and robotics in terms of ease of training, long-term oncologic efficacy, and patient outcomes are an area of active study.

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