

Robotic Lobectomy and Segmentectomy

Technical Details and Results



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KEYWORDS

• Robotic • Lobectomy • Segmentectomy

KEY POINTS

- Robotic lobectomy and segmentectomy are facilitated by thorough knowledge of the anatomy, preparation, proper port placement, and understanding of the conduct of the operation.
- Robotic lobectomy and segmentectomy can be performed with excellent technical and perioperative results.
- The oncologic efficacy of robotic lobectomy is comparable with video-assisted thoracoscopic surgery and open techniques; the role of robotic segmentectomy remains an active area of investigation.
- Advantages of robotic lobectomy and segmentectomy include improved optics, increased dexterity of instrumentation, and better surgeon economics.
- With a completely portal technique, there is the ability to insufflate the chest, leading to improved view and decreased venous bleeding; disadvantages include cost and complexity.

INTRODUCTION

One of the first published reports of pulmonary lobectomy was by Drs Norman Shennstone and Robert Janes from the Toronto General Hospital, in which they describe “a long incision in the general direction of the ribs, passing just below the scapula,” or via a thoracotomy.¹ Since then, practitioners have sought ways to decrease the size of incisions needed and minimize the invasiveness of pulmonary lobectomy and thereby optimize postoperative morbidity, recovery time, and pain. Minimally invasive lobectomy has traditionally been performed using video-assisted thoracoscopic surgery (VATS) techniques. The first robotic lobectomies were reported in 2003 by Morgan and colleagues² and Ashton and colleagues.³ Since then, the use of robotic

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technology for lobectomy has become increasingly common. In 2015, more than 6000 robotic lobectomies were performed in the United States, and more than 8600 were done worldwide.

INITIAL EVALUATION

The evaluation of candidates for robotic lobectomy includes the standard pre-operative studies for patients undergoing pulmonary resection. For patients with suspected or biopsy-proven lung cancer, a whole-body PET-computed tomography scan is currently the standard of care. Pulmonary function testing including measurement of diffusion capacity and spirometry is routine. Mediastinal staging can consist of either endobronchial ultrasound-guided fine-needle aspiration biopsy or mediastinoscopy, depending on expertise. Certain patients may warrant additional testing, including stress test, brain MRI if concern exists for metastatic disease, and/or dedicated computed tomography scan with intravenous contrast or MRI if concern exists for vascular or vertebral/nerve invasion, respectively.

Investigators have shown that thoracoscopic lobectomy is safe in patients with a predicted postoperative forced expiratory volume in 1 second or a diffusion capacity of less than 40% of predicted.⁴ We consider robotic lobectomy feasible in these patients as well. At present, we view vascular invasion, locally invasive T4 lesions, Pancoast tumors, and massive tumor (>10 cm) as contraindications for a robotic approach to lobectomy. The need for reconstruction of the airway, chest wall invasion, presence of induction chemotherapy and/or radiation, prior thoracic surgery, and hilar nodal disease are not contraindications for robotic-assisted lobectomy in the hands of experienced surgeons.

RELEVANT ANATOMY AND PHYSIOLOGY

An intimate knowledge of the pulmonary anatomy and, specifically, the relationship between hilar structures and their potential variations, is needed to perform any lobectomy or segmentectomy, whether via thoracotomy, VATS, or robotic techniques. Although a detailed description of this anatomy is beyond the scope and complexity of this article, suffice it to say that the view of the pulmonary hilum is different depending on the angle of approach. Whereas during a thoracotomy the surgeon is viewing the hilum from either the anterior or posterior direction, typically in VATS and robotic lobectomy, the camera approaches the hilum from an inferior direction. Retraction of the lung can change the orientation of structures considerably. That said, the relationship between structures remains the same regardless of how structures are approached and/or retracted. Knowledge of what risk exists when performing particular steps and moves during an operation is critical to avoid injury. Avoiding misidentification of structures and attention to aberrant or variable anatomy are also of paramount importance during robotic lobectomy or segmentectomy, where an injury can force conversion to an open operation and negate the benefit of attempting minimally invasive surgery.

CONDUCT OF OPERATION

Preparation

A well-trained team that communicates effectively is a priority for the successful performance of robotic lobectomy. Criteria for a well-trained team include documented scores of 70% or higher on simulator exercises, certificate of robotic safety training

and cockpit awareness, weekly access to the robot, familiarity with the robot and the instruments, and a mastery of the pulmonary artery from both an anterior and posterior approach.

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. Da Vinci currently offers both the Xi and Si systems. The Xi system is newer and features an overhead beam that permits rotation of the instrument arms, allowing for greater flexibility in terms of direction of approach of the robot to the patient. Compared with the Si system, the Xi system also has thinner instrument arms, longer instruments themselves, and the option to switch the camera to any arm/port.

Proper location of the robot should be established before the operation. If using an Xi system, the patient can remain with their head oriented toward the anesthesia station, and the robot can be driven in perpendicular to the patient's body. If using the Si system, the robot is driven from over to patient shoulder at a 15° angle off the longitudinal access of the patient. The patient will need to be turned so that the axis of the patient is 90° away from the typical position (ie, head near the anesthesia workstation) to facilitate this. The third robotic arm will need to be located so that it will approach the patient from the posterior. The use of long ventilator tubing and wrapping up this and other monitoring lines with a towel secured to the side of the bed is helpful to minimize interference with the surgeon/assistant.

Patient Positioning and Port Placement

The patient is positioned in the lateral decubitus position. Precise placement of the double lumen endotracheal tube and the ability to tolerate single lung ventilation should be established before draping the patient, because repositioning the tube will be virtually impossible once the robot is docked. Axillary rolls and arm boards are unnecessary (**Fig. 1**). The robotic ports are inserted in the seventh intercostal space for upper/middle lobectomy and in the eighth intercostal space for lower lobectomy. Typical port placement is shown in **Fig. 2** for a right robotic lobectomy. The ports are marked as follows: robotic arm 3 (5-mm port) is located 1 to 2 cm lateral from the spinous process of the vertebral body, robotic arm 2 (8 mm) is 10 cm medial to robotic arm 3, the camera port (we prefer the 12-mm camera) is 9 cm medial to robotic arm 2, and robotic arm 1 (12 mm) is placed right above the diaphragm anteriorly.

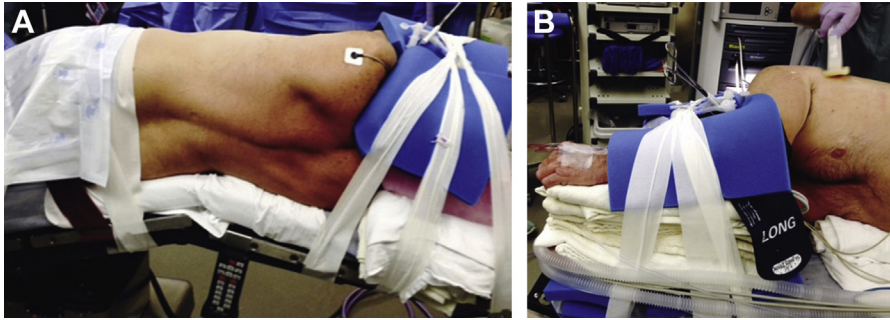


Fig. 1. (A) Posterior view of patient in lateral decubitus positioned with only foam and tape. (B) Anterior view of patient in lateral decubitus positioned with only foam and tape.

The assistant port is triangulated behind the camera port and the most anterior robotic port, and as inferior as possible without disrupting the diaphragm. We use a zero-degree camera for this operation. Insufflation of the camera or assistant port with carbon dioxide is used to depress the diaphragm, decrease bleeding, and compress the lung.

MEDIASTINAL LYMPH NODE DISSECTION

After examining the pleura to confirm the absence of metastases, the next step during our performance of robotic lobectomy is removal of the mediastinal lymph nodes, for staging and also to help expose the structures of the hilum.

- *Right side:* The inferior pulmonary ligament is divided. Lymph nodes at stations 8 and 9 are removed. Robotic arm 3 is used to retract the lower lobe medially and anteriorly to remove lymph nodes from station 7. Robotic arm 3 is used to retract the upper lobe inferiorly during dissection of 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.

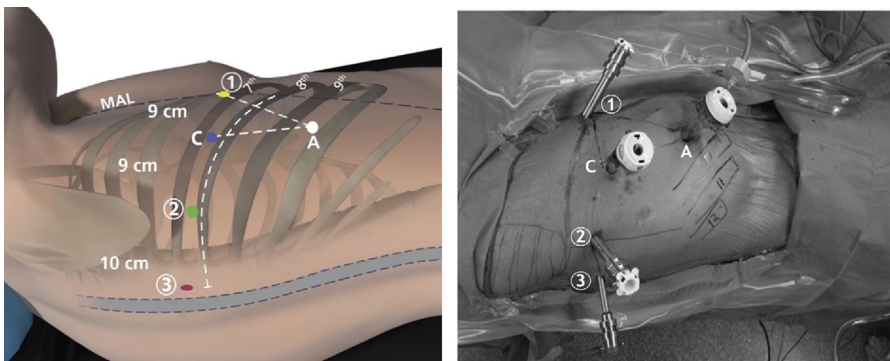


Fig. 2. Total port approach with 4-port placement for right-sided pulmonary lobectomy with da Vinci Si robotic arms 1, 2, 3, camera (C), and access port (A). MAL, mid axillary line.

- *Left side:* 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. 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 pressed it inferior 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.

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 help to 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. In addition, near-infrared imaging of intravenously administered indocyanine green can be used to detect lung nodules; this capability is integrated into the da Vinci Xi platform.⁵

The Five 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. 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.
- 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 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 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 the accessory robot arm 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 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.
- 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 or arteries; otherwise, dissection may have to extend further distally to ensure safe division.
- 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. 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.

- 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. 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. 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.
- 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.
- 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.
- The superior segment may be spared during lower lobectomy. The superior segment artery, vein, and bronchus are isolated as in performance of superior segmentectomy. Instead of dividing those structures, however, the ongoing vein, artery, and bronchus to the remainder of the lower lobe are divided.

SEGMENTECTOMIES

Posterior Segmentectomy of the Right Upper Lobe

- For a posterior segmentectomy of the right upper lobe and for a superior segment of the right lower lobe, the triangle between the bronchus intermedius and the right upper lobe bronchus is identified.
- The No. 11 lymph node is removed and the posterior segmental artery to the right upper lobe is identified. Robotic arm 3 is then used to retract the upper lobe

inferiorly while robotic arms 1 and 2 are used to dissect out stations 2R and 4R, clearing the space between the superior vena cava anteriorly and the azygos vein.

- The 10R lymph node between the right main stem bronchus and the pulmonary artery is then removed.
- The appropriate interlobar lymph nodes are removed, especially the ones that are adjacent to the bronchus to be removed. In patients with non-small cell lung cancer, these are sent for frozen section analysis and, if results are positive, a lobectomy is performed.
- If a posterior segmentectomy is performed, the posterior segmental artery is dissected free, taking care not to injure the posterior segmental vein of the right upper lobe that courses just under the artery in the posterior fissure.
- Once the artery is stapled or ligated, the posterior segmental vein is dissected free, staying superior near the bronchus. It is encircled and then stapled or clipped.
- Now the bronchus can be dissected and the posterior segment and apical and anterior segments easily identified. The posterior bronchus is encircled and stapled and it is then retracted cephalad by robotic arm 3. This affords the pulmonary artery to the middle lobe and the lower lobe to be seen and preserved as the parenchyma is stapled to complete the segmentectomy.

Superior Segmentectomy

- If a superior segmentectomy on the right side is to be performed, the triangle between the bronchus intermedius and right upper lobe is identified. Blunt dissection is carried down on the bronchus intermedius until the No. 11 lymph node is identified and removed.
- The superior segmental artery is seen medially under the No. 12 lymph node. The superior segmental artery is encircled and stapled after the posterior superior segmental bronchus is bluntly dissected.
- Before stapling the superior segmental bronchus, the lung should be retracted medially using robotic arm 3, identifying the inferior pulmonary vein. The superior segmental branch of the inferior pulmonary vein is the most cephalad branch of the inferior pulmonary vein. It can be individually encircled and should be stapled or ligated first.
- The staple can then more easily pass around the superior segmental bronchus and be ligated now that the vein has been ligated.
- On the left side, the superior segmental bronchus is generally accessible after the superior segmental vein (or artery) is isolated and divided. The superior segmental artery can be approached via the fissure. The superior segmental vein is the cranial-most branch of the inferior pulmonary vein, and is isolated while retracting the lung anteriorly.
- There is not infrequently a second superior segmental artery found in the left lower lobe.

Lingula-Sparing Upper Lobectomy

- A lingular artery-sparing trisegmentectomy (lingula-sparing upper lobectomy) is performed by removing the N2 lymph nodes and finding the pulmonary artery posteriorly, just cephalad to the inferior pulmonary vein after removal of the level 9, 8, and 7 lymph nodes.
- A complete fissure can be approached from the back by identifying the posterior segmental artery to the left upper lobe and dividing the artery and then working

along the pulmonary artery to identify the other branches and stapling the posterior fissure along the way.

- The lingular artery is identified and preserved, as is the lingular bronchus.
- The 11L lymph node is removed and sent for frozen section analysis to ensure it is free of cancer.
- The lingular vein is identified and preserved and the remaining pulmonary vein is then stapled. The left upper bronchus is now readily visible and the lingular bronchus is easily identified and preserved. The remaining bronchial branches can be stapled while carefully avoiding the anterior-apical trunk of the pulmonary artery.
- Once the anterior-apical and posterior bronchi are all stapled concomitantly, the anterior-apical pulmonary arterial trunk can be stapled, often with 1 firing. The operation is finished by stapling the pulmonary parenchyma from robotic arm 1.

Lingulectomy

- Lingulectomy can be performed with either a vein-first or artery-first technique.
- If performing a vein-first approach, the lung is retracted posteriorly and the lingular vein is identified and divided. Then the lingular bronchus, which often is located fairly distally, is isolated and divided. Finally, the lingular arteries are then isolated and divided.
- The fissure may also be approached first during a lingulectomy. This provided the advantage of being able to assess the level 11 lymph node first because, if it is positive, a lobectomy is a better oncologic operation if able to be tolerated by the patient. If negative, then the vein-first approach can be taken. Alternatively, the lingular arteries can be accessed via the fissure and divided first. Then the bronchus is divided, and finally the vein.

RESULTS

Robotic lobectomy can be performed with excellent perioperative and long-term outcomes. Our median duration of stay after robotic lobectomy is 3 days.⁶ We have demonstrated a 30-day mortality rate of 0.25%, 90-day mortality rate of 0.5%, and major morbidity rate of 9.6% in patients undergoing robotic lobectomy and segmentectomy.⁷ Similar to VATS, robotic lobectomy is associated with decreased rates of blood loss, blood transfusion, air leak, chest tube duration, duration of stay, and mortality compared with thoracotomy.⁸⁻¹⁰ Conversion rates of less than 1% to thoracotomy may be achieved, although 3% to 5% is reported more typically.⁶ Vascular injury is rare, and when it does occur, can occasionally be repaired without converting to a thoracotomy.¹¹ Lymph node upstaging rates and 5-year survival for robotic lobectomy are comparable with lobectomy via thoracotomy and possibly improved versus VATS.^{12,13} **Table 1** shows results reported in series of robotic-assisted lobectomies.

Robotic segmentectomies have been considered a more demanding technical operation than robotic lobectomy. One investigator found longer operative times (219 minutes vs 175 minutes; $P < .01$) for robotic segmentectomy compared with robotic lobectomy.¹⁵ They found that patients undergoing robotic segmentectomies were more likely to have an effusion or empyema, and pneumothorax after chest tube removal, than patients undergoing robotic lobectomy. We have demonstrated that robotic segmentectomy can be performed with excellent technical and perioperative results (100 patients, 88 minutes median operative time, 7% conversion rate, 10% major postoperative complication rate, 0% 30-day and 90-day mortality rates).²⁰ Two other series of 21 and 17 patients also support the safety and feasibility of robotic segmentectomy; both author groups commented on the subjective advantages of

Table 1
Results reported in series of robotic-assisted lobectomies

Year	n	Conversion Rate	Morbidity	Perioperative Mortality	Median LOS	Notes
Cerfolio et al, ⁶ 2016	520	12% (first 100 cases) → 3.3% (last 120 cases)	50% (first 100 cases) → 4.2% (last 120 cases)	0.19% (30-d), 0.57% (90-d)	3 d	
Yang et al, ¹⁴ 2016	172	9%	26%	0%	4 d	Equivalent OS and DFS at 5 y to VATS
Veronesi et al, ¹⁵ 2009	54	13%	20%	0%	4.5 d	
Gharagozloo et al, ¹⁶ 2009	100	—	21%	3%	4 d	
Echavarria et al, ¹⁷ 2016	208	9.6%	40.4%	1.44% (in hospital)	5 d	
Louie et al, ¹⁰ (STS database) 2016	1220	Not reported	No difference from VATS	0.3% (in hospital), 0.6% (30-d)	4 d	8.44% nodal upstaging
Toker et al, ¹⁸ 2016	102 (53% lobectomy)	4%	24%	2% (60-d)	5 d (mean)	104 min (mean operative time)
Adams et al, ⁸ 2014	116	3.3%	No difference from VATS	0% (30-d)	4.7 d (mean)	
Melfi et al, ¹⁹ 2014	229	10.5% (first 69 cases), 5.6% (next 160 cases)	22% and 15%	1.4% and 0%	4.4 d and 3.8 d (mean)	

Abbreviations: DFS, disease-free survival; LOS, length of stay; OS, overall survival; QOL, quality of life; VATS, video-assisted thoracoscopic surgery.

Data from Refs. ^{6,8,10,14–19}

lymphadenectomy using robotic techniques.^{21,22} The oncologic sequelae of and indications for performing segmentectomy as opposed to lobectomy remain active areas of study for both VATS and robotic techniques.

One disadvantage of robotic lung resection compared with VATS lung resection is cost. On average, a robotic lobectomy can cost an additional \$3000 to \$5000 per case owing to the use of disposable instruments, the additional sunk cost of the robot itself, and the maintenance plans required for using the robot.^{23,24} Even with this additional cost, however, each robotic lobectomy yields an estimated median profit margin of around \$3500 per patient.²⁵

SUMMARY

Robotic lobectomy and segmentectomy have been demonstrated to be safe operations that can be done expeditiously and with low conversion rates. Perioperative morbidity and mortality is similar to VATS lobectomy/segmentectomy, and improved compared with lung resection via thoracotomy. Long-term oncologic outcomes for robotic lobectomy mirror those demonstrated after VATS and open lobectomy. Improved optics, increased dexterity of the instruments, and better ergonomics can yield subjective advantages to the surgeon. With proper training and experience, robotic lobectomy can become part of the fundamental armamentarium of the modern thoracic surgeon.

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