# Robotic Lobectomy

3

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**Abstract**

This chapter will review the development and technical aspects of anatomic pulmonary resection performed utilizing the da Vinci Surgical System. Indications, patient selection, anesthetic concerns and positioning will be reviewed along with specific information with respect to instrumentation. Step-by-step details of each type of lobectomy will be elucidated in depth, as well as unique considerations for both the Si and the newest Xi system. Extended resections, including concomitant chest wall resection, bronchial and vascular sleeve resections and bilobectomy/pneumonectomy will not be addressed here.

**Keywords**

Lobectomy • Robotic • VATS • Lymph node dissection • Anatomic

## 3.1 Development of Robotic Lung Resection

Prior to the 1980s the standard approach for performing major pulmonary resection was rib-spreading thoracotomy. This provided excellent exposure but was associated with potential for exceptional postoperative pain and morbidity in high-risk patients. With the rapid improvements in video technology and development of endoscopic instrumentation like stapling devices, there has been a shift toward a minimally invasive approach to lung resections.

Techniques of minimally invasive video assisted thoracic surgery (VATS) lobectomy were developed more than 20 years ago and have slowly supplanted open approaches for isolated lung lesions in most tertiary centers. The evidence of benefit of this technique over a standard thoracotomy is growing and include improvements in acute postoperative pain, shorter chest tube duration, reduced hospital stay, and lower complications in compromised patients [1–6]. Moreover, with respect to treatment of early stage lung cancer, more recent evidence has shown similar long-term survival in patients having minimally invasive lobectomy versus thoracotomy [7, 8].

However, one major hurdle to more universal adoption has been technical challenges associated with limitation of instrumentation and visualization. Standard endoscopic instruments have only four degrees of freedom resulting in significantly reduced dexterity. Combine this with the operator having to reverse their hand motions, the so-called fulcrum effect, the loss of binocular vision with the standard thoracoscope, and the result is a relatively long learning curve for surgeons unfamiliar with VATS techniques [9, 10].

The development of the da Vinci™ (Intuitive Surgical, Sunnyvale, CA) telerobotic surgical system addressed some of the technical limitations of conventional minimally invasive technology. Since the initial FDA approval of the standard system in 2000 there have been four generations of systems. The latest, the da Vinci Xi system, is currently in use at our institution and has several advantages over conventional thoracoscopy for the operating surgeon:

1. The da Vinci™ visual system provides high definition, stereoscopic binocular vision allowing for depth perception, a big improvement over traditional VATS imaging on a two dimensional display monitor. In addition, the

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image can be magnified up to ten times to give unparalleled detail during dissection and mobilization of hilar structures. The other advantage over conventional thoracoscopy is the stable nature of the camera that is under direct control by the operating surgeon.

2. The da Vinci™ Endowrist instruments restore the degrees of freedom lost with conventional VATS instruments. With seven degrees of freedom the robotic instruments recreate the dexterity associated with direct manual dissection. The robotic arm allows three degrees of movement, insertion, external pitch and external yaw. The endowrist allows four more degrees of movement inside the chest cavity, wrist pitch, wrist yaw, rotation and grasp. Together this greatly enhances the surgeon's ability to manipulate the mediastinal and hilar structures.
3. In addition to greater dexterity, the da Vinci™ system has downscaling capability allowing transduction of the surgeon's movements to finer, precise movements at the instruments tips. This with the tremor filter results in an exceptional level of precision in manipulation of the instruments.

### 3.1.1 Components of the System

The da Vinci™ Surgical System has three main components; the patient cart, surgeon's console and the vision cart (Fig. 3.1). The patient cart contains the four surgical end-effector arms. In the latest Xi model, the endoscope can be controlled by any of the four arms allowing for greater flexibility that increasing the effective working area that can be reached. All four arms including the endoscope are controlled from the surgeon console, which includes the 3D image viewer, the master hand controls, and the multifunction foot pedals that allow application of energy, control of the camera and switching from instrument arms. The endoscope provides a high-definition, binocular view of the surgical field with both 0° and 30° options.

The vision cart contains a touchscreen monitor to provide a view of the operative field to the bedside assistants and OR staff. An electrosurgical unit is integrated into the vision cart providing monopolar or bipolar energy to the various da Vinci™ Xi instruments being utilized. There are a variety of instrument options available for pulmonary resection. Typically, at least three instruments are used for anatomic lung resection: a forceps (Cadiere, Fenestrated Bipolar or Prograsp), an energy dissection device (Maryland bipolar, monopolar spatula, hook cautery) and a retractor (Tip up fenestrated grasper, Thoracic grasper).

### 3.1.2 Patient Selection and Indications

Selection criteria for robotic lung resection are similar to VATS and most thoracotomy approaches. As with any surgical procedure, there is no substitute for sound judgment and while there are no absolute contraindications for robotic lung resection there are several potential relative contraindications particularly early in one's experience:

- Inability to maintain lung isolation
- Adherent hilar nodal disease (either inflammatory or neoplastic)
- Large, central lesions

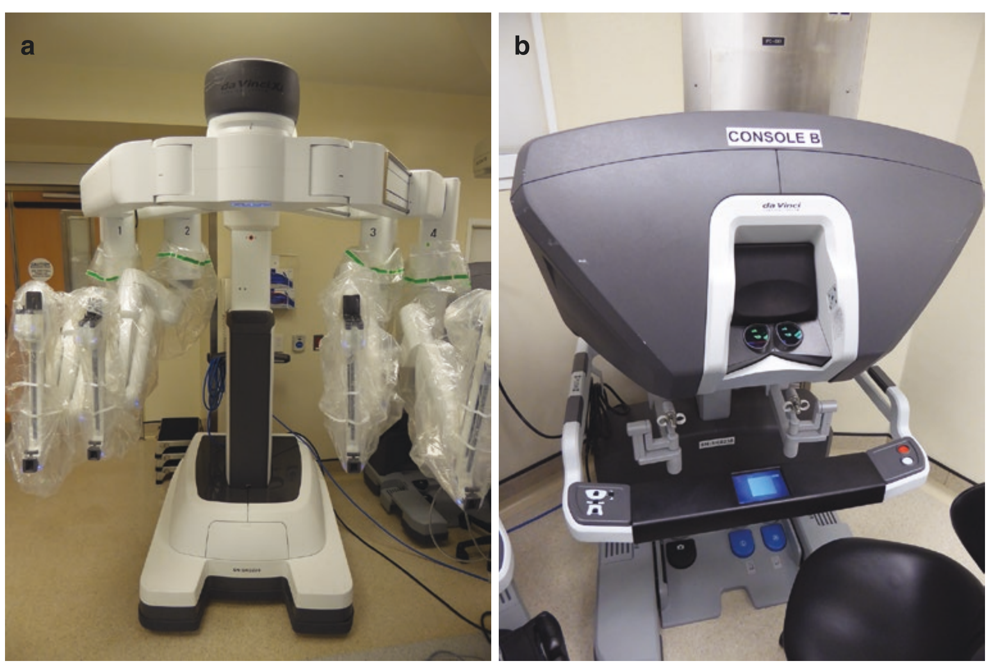


**Fig. 3.1** Da Vinci Xi Surgical System

- Need for sleeve (bronchial or vascular) resection
- Locally advanced tumors invading the chest wall or mediastinum

While dense pleural adhesions often have been cited as a relative contraindication for a VATS approach, this is less so for robotic surgery as the visualization and instrument dexterity offered makes extensive adhesiolysis feasible.

## 3.2 Surgical Technique for Robotic Pulmonary Lobectomy

### 3.2.1 Preparation of the Robotic System

The nursing and technical staff of the operating set up the robotic system (cart, surgeon's console, visual system) concurrently as the patient is being brought into the room and placed under anesthesia. It is an efficient practice to allow the components of the system to remain in dedicated rooms to minimize setup time and potential for damage. When using the Si system the arms are positioned on the ipsilateral side as the planned resection. This is less critical with the Xi system because of the enhanced targeting feature and ability of the arms to rotate up to 270° theoretically allowing the cart to be positioned virtually anywhere with respect to the operating Table.

### 3.2.2 Anesthetic Consideration and Patient Positioning

The most common anesthetic strategy involves general anesthesia with endotracheal intubation and lung isolation, but variations include low tidal volume ventilation with or without $CO_2$ insufflation or intravenous anesthesia with spontaneous ventilation. Standard intraoperative monitoring includes EKG, arterial line for blood pressure monitoring and urinary catheter. We do not routinely place a thoracic epidural for robotic lung resections, instead utilizing multilevel intercostal nerve blocks, peripheral patient-controlled analgesia and liberal used of non-steroidal anti-inflammatory medications.

The patient is positioned in the lateral decubitus position with generous flexion of the operating table to establish a level horizontal surface from the arm to the iliac crest. This is essential, particularly in female patients, to allow for full range of motion of the instruments. This maneuver also aids in opening the intercostal spaces reducing pressure on the intercostal nerve from the trocars.

If one is employing the second (S) or third (Si) generation system, an important step prior to prepping and draping is to move the operating table slightly away from the anesthesia area and to angle the foot of the operating table away from the surgical cart. The smaller the angle of approach of the cart with respect to the longitudinal axis of the patient, the greater the table should be rotated. For example, if one wishes to bring the arms over the patient's head, the table should be angled 90° from the original table position. Care must be taken to insure that there is sufficient length of the circuit tubing available during this positioning, and the anesthesia team must be comfortable that there is adequate access to the patient's airway once docking of the robotic system has taken place.

### 3.2.3 Port Placement

The same incision strategy may be employed no matter which lung resection is planned. We prefer to place endoscope port in the seventh or eighth intercostal space at the posterior axillary line. If $CO_2$ insufflation is to be utilized, it may be initiated at 8–10 mmHg. Following initial exploration the remaining ports are placed in the following locations: One accessory port is placed typically in the ninth intercostal space just posterior to a vertical line from the scapula tip; a second posterior port that is useful for retraction of the lung, particularly during the posterior dissection, is placed superiorly and posterior to the ninth interspace port; the final port is placed in the fifth intercostal space in the mid-axillary line. This may be enlarged at any point in the procedure to 3–4 cm to allow for introduction of additional instruments and ultimately for specimen removal (Fig. 3.2). When using one of the older systems (S, Si), an important principle of port placement is to insure that each are spaced roughly 8 cm (one handbreath) apart in order to avoid external instrument arm collisions.

**Fig. 3.2** Port strategy for 4-arm robotic lobectomy

### 3.2.4 Docking the Robotic Cart

Once the incisions have been made the patient cart is ready to be docked.

#### 3.2.4.1 S or Si Systems

The instrument arms should be placed in a neutral position with the instrument arms on either side of the camera arm. For four-arm procedures two instrument arms are positioned on the side of the camera arm corresponding to the side of the planned resection. The cart is then docked from the posterior aspect of the patient with the center column and camera arm in line with the center of the planned field of dissection. For most pulmonary resections a 45-degree angle relative to the long axis of the patient is ideal. It is imperative to position the cart and space the arms to avoid external instrument collisions and insure adequate range of motion of the instruments.

Once the surgical cart is in its final position the camera arm is secured, and the robotic scope is introduced so that the remainder of the ports can be placed under direct vision. If a utility incision is used, the port should be positioned in the middle of the incision to allow for passage of additional non-robotic instruments. Once the instruments are introduced the range of motion of each arm should be tested to confirm there are no major conflicts (Fig. 3.3).

**Fig. 3.3** Docking for da Vinci Si procedure

#### 3.2.4.2 Xi System

Two recent innovations in the da Vinci™ Xi system have lead to substantial simplification of the docking process. First, the instrument arms are now mounted on a boom that can rotate 270-degrees. Laser cross hairs from the center of the boom allow rapid positioning of the cart over the camera port. Once the scope is inserted into the chest, it projects its own crosshairs that may be used for targeting the desired anatomic field. In the case of pulmonary resection the superior (upper and middle lobes) or inferior (lower lobe) pulmonary hilum is centered on the endoscope view. The targeting button on the scope is then depressed, and the boom will rotate automatically to maximize the range of motion of each arm and minimize internal and external arm conflicts. Second, the connection mechanism between the arm and port has been re-engineered to allow more a more facile connection. Third, there is a patient clearance feature on each arm that allows maximum spacing between the arms externally while maintaining the internal range of motion of the instruments. At this point, the remaining ports are docked and instruments inserted (Fig. 3.4).

Once the instruments are introduced and visible on the endoscope view, the surgeon can move to the console, and an assistant remains at the table to provide additional exposure and perform instrument exchanges as required. The assistant may also be required to pass and fire endoscopic staplers for division of the hilar structures and fissures as required.

### 3.2.5 Instrumentation

#### 3.2.5.1 S or Si System

There are a wide variety of instrument choices available. A forceps is most commonly controlled by one hand for grasping tissue, and the options include the Cadiere, Prograsp or Fenestrated Bipolar forceps. The authors favor the Fenestrated Bipolar instrument because of the option to apply bipolar cautery to small vessels when necessary. In another hand there is typically a dissecting instrument, such as the Permanent Spatula, Maryland Bipolar, or Hook Cautery. The authors prefer the spatula as it is blunt and can be used safely to sweep tissue as well as divide tissue with good hemostasis. The fourth arm has either a retraction instrument or suction.

#### 3.2.5.2 Xi System

Similar instruments are utilized for the Xi System. Of note, there are several instruments not currently available on the Xi system, including all 5-mm instruments, the suction irrigator and the Thoracic Grasper. The Tip up Fenestrated Grasper is an excellent, broad-based instrument for lung retraction. This is employed through the most superior posterior port and allows for excellent retraction of the lung.

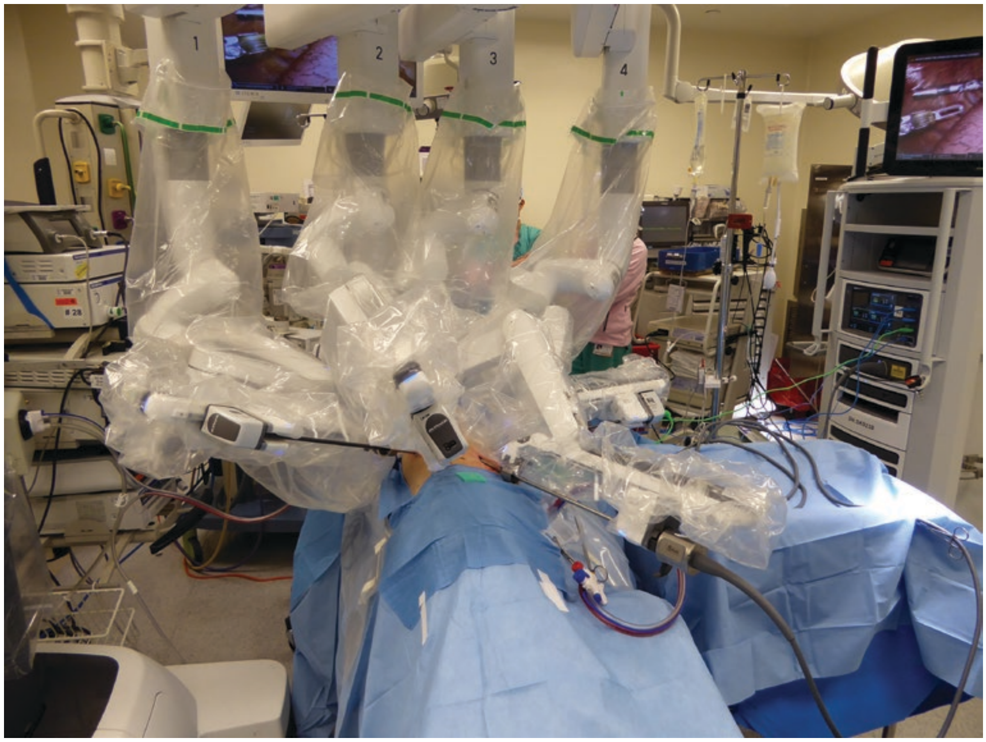

**Fig. 3.4** Docking for da Vinci Xi procedure

### 3.2.6 Posterior Hilar Dissection

In almost every instance of anatomic lung resection it is the authors' preference to begin with posterior hilar dissection. The inferior pulmonary ligament is divided with electrocautery, and the inferior ligament and periesophageal nodes are removed. The superior segment of the lower lobe is then retracted anteriorly, and the posterior pleural is divided at its interface with the lung parenchyma up to the superior hilum. The hilar lymph nodes are individually removed. In the right chest this includes the interlobar "sump" nodes between the right upper lobe and the bronchus intermedius. A subcarinal lymph node dissection is performed (Fig. 3.5). It is critical, particularly on the left side, to have the bedside assistant provide additional exposure of subcarinal space, either through lung retraction or by depressing the inferior vein (left) or pericardium (right).

When performing lower lobectomy, it is advantageous to sweep the posterior parenchymal tissue distally particularly in the areas between the hilar structures and to remove the regional nodes. This will greatly facilitate subsequent isolation and division.

### 3.2.7 Right Upper Lobectomy

The initial posterior hilar dissection is performed as described above. Removal or partial dissection of the sump nodes with identification of the right upper lobe bronchus (Fig. 3.6) greatly enhances division of the bronchus. It is our practice to perform an anterior-to-posterior approach with little or no dissection in the fissure. The superior hilar vessels are placed on tension by retracting the upper lobe laterally, and the pleura is incised above and below the superior vein to expose its entire extent from the takeoff of the middle lobe vein inferiorly to the course of the truncus arteriosus superiorly. Hilar nodes in these two areas should be removed both for oncologic and practice purposes. The middle lobe vein and the ongoing pulmonary artery should be identified and preserved (Fig. 3.7). Once isolated, the upper lobe vein is divided with

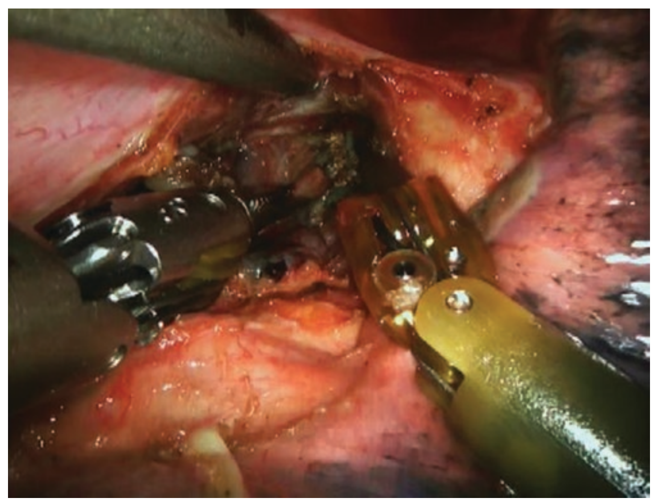

**Fig. 3.5** Subcarinal (level 7) node dissection from the right side

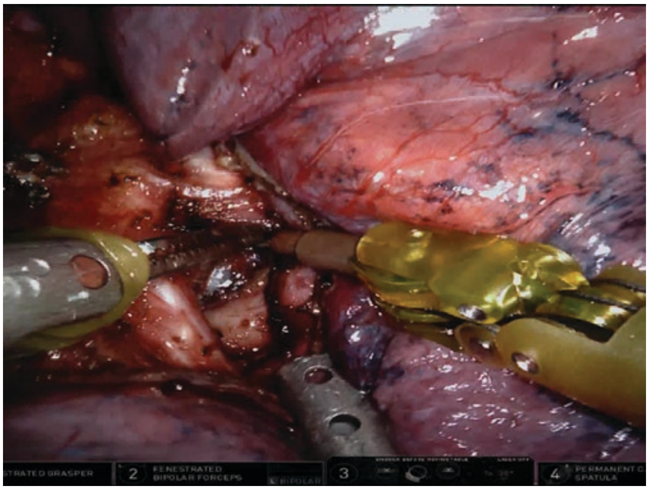

**Fig. 3.6** Exposure of right upper lobe bronchus

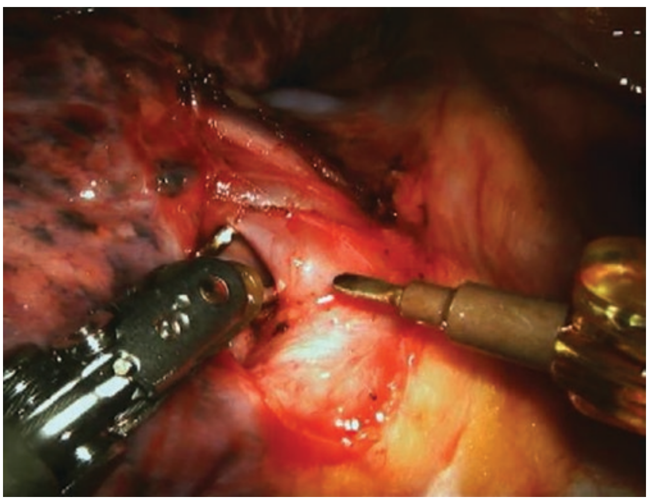

**Fig. 3.7** Isolation of the right superior pulmonary vein

an endovascular stapler introduced through the posterior inferior port. This may done with conventional endoscopic staplers (Si) or the robotic stapler (Xi). Use of the robotic stapler requires upsizing to a 12 mm robotic port. Of note all division of the hilar structures may be done by passage of the staplers from the posterior port. Division of the pleural reflection is continued superiorly around the hilum until the right upper lobe bronchus is reached.

Next, the hilar node adjacent to the truncus arteriosus is mobilized sufficiently to allow for isolation and division of the vessel. Once the truncus is divided, the peribronchial lymph nodes and any remaining sump nodes that have not been previously excised should be removed completely. This maneuver will complete the mobilization of the bronchus and will clearly reveal the existence and location of the posterior ascending artery branch. These two remaining structures may then be divided in any order that is convenient. Occasionally, when the posterior ascending branch arises more proximal on the main pulmonary artery, it is necessary to divide this branch first (Fig. 3.8). The bronchus can be divided with a 3.5–4.8 mm stapler or cut sharply and sewn closed with a 3–0 or 4–0 absorbable suture. The horizontal fissure is completely last with multiple fires of the endovascular stapler introduced from the anterior incision.

It is most convenient to perform the right paratracheal lymph node dissection following removing of the lobectomy specimen as it obviates retraction of the lung for exposure. All tissue from the trachea to the superior vena cava the azygos vein to the thoracic inlet and down to the level of the pericardial reflection is removed (Fig. 3.9). Once all dissection is completed and specimens are removed, multi-level intercostal blocks with local anesthetic are performed, and a single 28Fr chest tube is placed posteriorly and apically. The

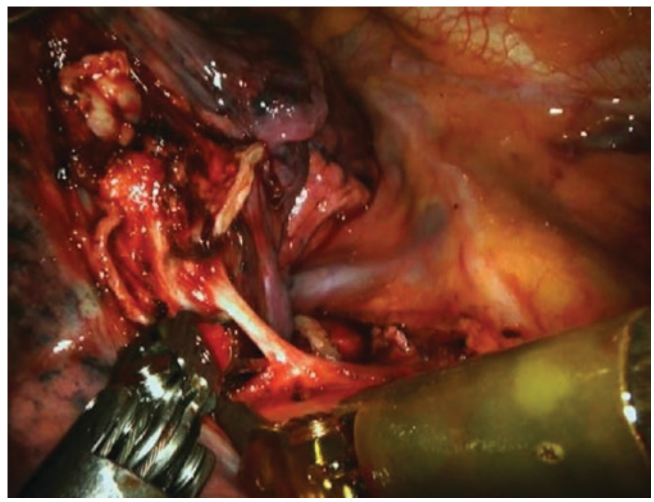

**Fig. 3.8** Exposure of the right upper lobe posterior ascending pulmonary artery

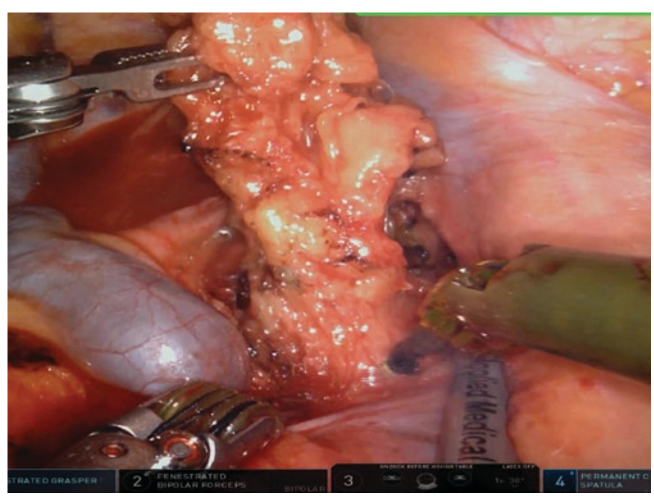

**Fig. 3.9** Right paratracheal lymph node dissection

lung is re-expanded under direct vision, and the wounds are closed in a standard fashion.

### 3.2.8 Lower Lobectomy

The steps for completing a lower lobectomy on either side are nearly identical.

Following the posterior hilar dissection, if the major fissure is entirely or substantially complete, it is advantageous to divide the fissure anteriorly. Usually, there are level 11 interlobar lymph nodes present overlying the basilar artery, and it is advisable to begin fissure dissection in this area. Excising these nodes will expose the artery readily. On the right side these lymph nodes occupy the space between the basilar artery, the lower and middle bronchi and the middle lobe artery. Removing them entirely delineates the anatomic relationships completely (Fig. 3.10). The anterior fissure can then be completed either with cautery or use of an endovascular stapler. On the left side it is imperative to remove the interlobar lymph nodes residing in the secondary carina between the upper and lower lobe bronchi. This again allows for completion of the fissure anteriorly AND it prevents inadvertent division of the entire left mainstem bronchus.

Once the anterior fissure is divided the plane between the basilar artery and lower lobe bronchus is developed through blunt dissection. The authors prefer a gentle sweeping motion alternately using the spatula and the bipolar forceps. With the magnified and binocular vision of the robotic visual system, one can easily separate the plane between the two completely. On the right side it is a little more difficult because of the bronchial anatomy. The posterior fissure may be divided in a manner similar to the anterior portion, either with electrocautery or by stapling. Alternatively, the posterior fissure may be divided last following the hilar structures.

At this point, all the hilar structures should be ready to divide with the endoscopic staplers introduced through the

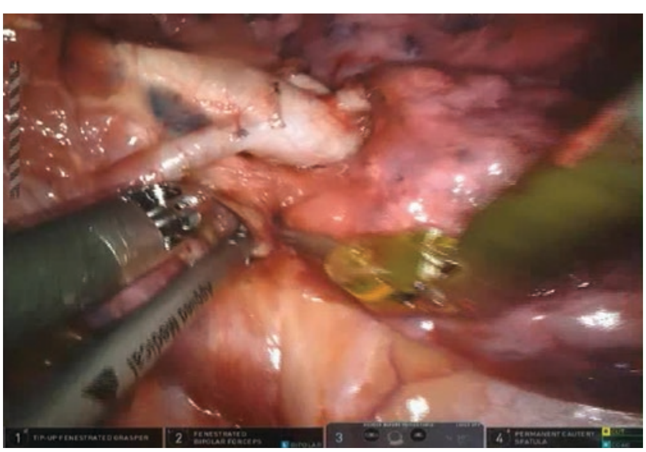

**Fig. 3.10** Complete dissection of the anterior major fissure (right side)

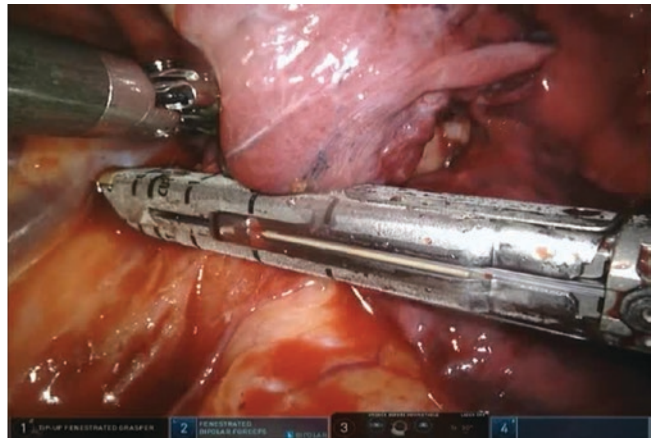

**Fig. 3.11** Division of the left inferior pulmonary vein

anterior incision. The lung is retracted superiorly, and the bedside assistant removes the instrument arm from the anterior incision. Use of articulating and curved tip staplers can facilitate passage and division. The inferior vein is divided first (Fig. 3.11) followed by the bronchus, and lastly the basilar artery. Once the hilar structures are sequentially divided, any remaining portion of the posterior major fissure is completed with the endoscopic staplers to complete the lobectomy. The specimen is placed in a polypropylene sac and brought out through a utility incision. The paratracheal or aortopulmonary node dissection is performed.

### 3.2.9 Middle Lobectomy

The initial steps for a middle lobectomy are identical to that for a lower lobectomy. Following the posterior hilar dissection, the anterior portion of the major fissure is explored and the mediastinal pleural overlying the basilar pulmonary artery is divided to allow identification and excision of the interlobar lymph nodes, exposing the basilar pulmonary artery and the takeoff of the middle lobe bronchus. Once the anterior fissure is divided, the mediastinal pleura overlying the middle lobe vein is divided to isolate the vessel from the remainder of the superior vein. It is then divided with a vascular stapler load introduced through the posterior access incision (Fig. 3.12). The middle lobe bronchus is mobilized by removing the peribronchial nodes and may be divided by stapling either through the posterior or anterior incisions. A curved tip staple load is particularly useful for this. The remaining middle lobe artery branches should be clearly identified, isolated and divided. Most commonly there are two artery branches, and it is important to divide the more anterior branch prior to division of the fissure in order to avoid injury (Fig. 3.13). The horizontal fissure is divided last usually by passing the stapler through the anterior incision.

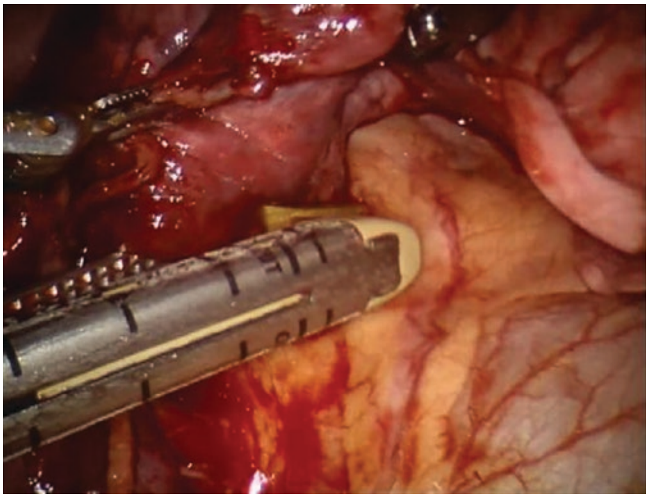

**Fig. 3.12** Division of the middle lobe vein

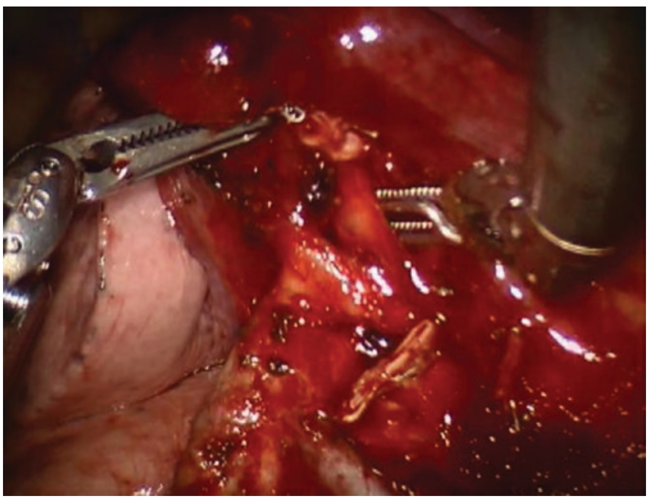

**Fig. 3.13** Exposure of the middle lobe arteries

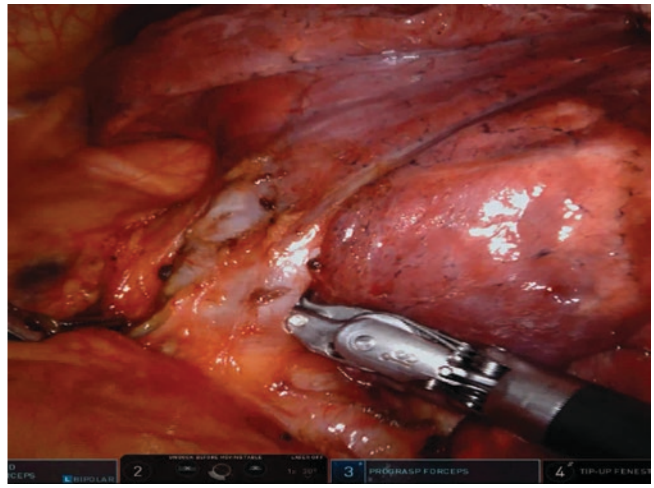


**Fig. 3.14** Mobilization of the left superior pulmonary vein

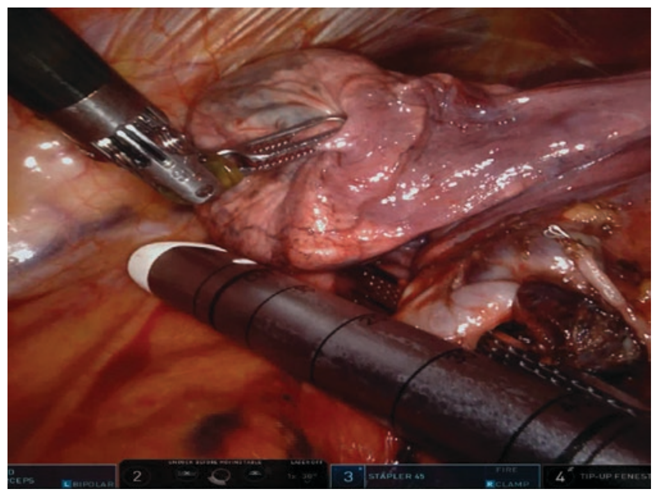


**Fig. 3.15** Division of the left anterior/apical pulmonary artery branches

### 3.2.10 Left Upper Lobectomy

The initial posterior hilar dissection is performed with resection of the posterior hilar and subcarinal lymph nodes. The lung is then retracted laterally in order to place the superior hilar structures on tension. The mediastinal pleura over the superior pulmonary vein is incised from the interlobar area inferiorly to the superior hilum near the aortic arch. The inferior portion of the vein can be mobilized away from the bronchus using blunt dissection, and the superior extent of the vein is separated carefully from the pulmonary artery. The superior vein can then be isolated and divided (Fig. 3.14). The hilar lymph nodes between the upper lobe bronchus and first pulmonary artery branches that should be mobilized away or removed in order to allow the anterior and apical branches to be isolated and divided (Fig. 3.15). As with right upper lobectomy, all of the hilar structures may be resected by stapling through the posterior port. The peribronchial and interlobar lymph nodes between the upper and lower lobe bronchi are removed entirely to allow mobilization and division of the upper lobe bronchus.

Following division of the bronchus, lateral and posterior retraction of the upper lobe will expose the remaining pulmonary branches (Fig. 3.16). Each is mobilized under direct vision and divided sequentially until the lingular and each of the posterior branches have been ligated. The precise sequence in which the vessels are taken can vary depending on their relationship to each other giving the best exposure for stapling. Alternatively, depending on the clinical situation or surgeon preference, the posterior arterial branches

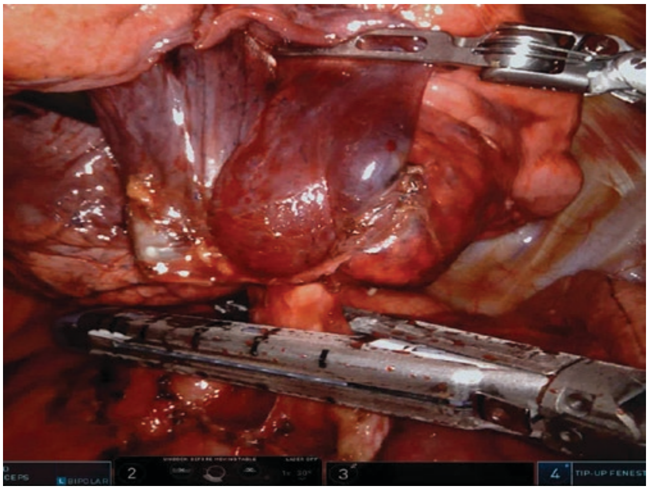


**Fig. 3.16** Division of the left upper lobe bronchus

may be isolated and divided prior to dissection of the anterior vessels and bronchus. Once all of the hilar structures have been divided the major fissure can be completed with multiple fires of the endovascular stapler.

## 3.3 Results and Discussion

Robotic lung resection has been performed by thoracic surgeons for more than a decade with increasingly frequency throughout the world. The first published series appeared in 2002 from Melfi et al. [11]. This heterogenous group of robotic thoracoscopic procedures included five lobectomies and demonstrated the feasibility of using the da Vinci™ system in thoracic surgery with no operative mishaps and appropriate functioning of the robotic arms for the procedure.

Following this landmark report, numerous reports of experience using the robotic system for lung resection followed including our own experience from Memorial Sloan Kettering Cancer Center New York [12]. Our initial series consisted of 34 consecutive patients that underwent attempted robotic lobectomy with four conversions to thoracotomy (12%). All types of lobectomy were performed showing the versatility of the robotic system. No perioperative deaths were observed and a 26% morbidity rate, comparable to techniques of open and VATS lobectomy. Chest tube duration (3 days) and length of hospital stay (4.5 days) were comparable to standard techniques. All patients underwent an R0 resection and had a median of four lymph node stations dissected. Since our series other centers around the world have subsequently reported on their experiences [13–17]. These studies report perioperative mortality rates from 0 to 3%, morbidity rates from 10 to 26%, conversion rates of 0–12% and median length of stay of 2–6 days.

With such reproducible perioperative results, the procedure has gained in popularity in recent years. A recent report reviewing the State Inpatient Databases, in the US, showed robotic lobectomy accounted for 0.2% of total lobectomies in 2008 rising to 3.4% in 2010 [18]. This still remains a small proportion of all patients have lobectomy but represents a rapid growth in the case volume. This same study demonstrated most recent results from many institutions across eight states showing that robotic technique was equivalent or superior to open lobectomy as assessed by mortality, length of stay, routine discharge and complication rate.

A major concern for widespread utilization of robotic lobectomy has focused on cost implications. A cost comparison from our own center has been conducted comparing costs of robotic lobectomy to conventional VATS lobectomy and open thoracotomy [19]. The difference in total average costs was calculated for each group. Within the minimally invasive group, robotic lobectomy was associated with increased cost compared to conventional VATS lobectomy but the average cost of robotic lobectomy was substantially less than thoracotomy, primarily because of a decreased length of stay. With any new technology, the expectation is that as the volume of use goes up, the initial capital costs and disposable costs will reduce as the volume of sales of the robotic system increases nationally and internationally.

Another concern is over the oncologic efficacy of robotic lobectomy. Two recent studies attempt to address this. The first is a multi-institutional retrospective review of patients undergoing robotic lobectomy for early stage lung cancer focusing on long-term outcome [20]. Three hundred twenty-five patients from three separate centers including 123 consecutive patients from our own center were evaluated. The majority of cases were subtypes of adenocarcinoma (73%) and had clinical stage I disease (95.4%). Overall 5 year survival for pathological stages IA, IB and II were 91%, 88% and 49% respectively. These stage-specific survivals were consistent both with the largest recent series of VATS lobectomies and the data used for the seventh edition of the lung cancer staging system, derived largely from cases of conventional open surgery [21–23].

The second study was a recent multi institutional, retrospective study of robotic lobectomy and segmentectomy used the prevalence of pathologic nodal upstaging as a surrogate measure for the completeness of nodal evaluation [24]. The authors concluded the rate of robotic pathologic nodal upstaging for clinically stage I NSCLC appeared to be superior to the VATS approach and similar to the open approach. Overall and disease free survival rates were comparable to open and VATS technique, albeit with a rather short median follow-up of 12.3 months [24]. Together, these studies provide some objective evidence of the oncologic adequacy of robotic lobectomy compared with open and VATS non-robotic techniques. As the previous published series mature with time, more robust long-term oncologic data with become available.

## 3.4 Summary

The technique of robotic lobectomy is well established and feasible. There are several advantages for the operating surgeon, including superior visualization, instrumentation and ergonomic ease. The greatest overall advantage over VATS may be in the surgeon's ability to control the key aspects of the procedure. Legitimate concerns, such as cost and long-term, patient-centered outcomes, should be addressed with ongoing studies.

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