



Robotic sleeve lower lobectomy

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Abstract: Sleeve lobectomy was originally designed as an alternative to a pneumonectomy in patients with impaired pulmonary function. Many studies have shown that sleeve lobectomy is comparable to a pneumonectomy in terms of oncologic efficacy, morbidity, mortality, and long-term survival. In addition, presumably by preserving lung function and decreasing the complications that are inherent to a pneumonectomy, sleeve lobectomy has been shown to be superior to a pneumonectomy in terms of complications and quality of life. Sleeve lobectomy is indicated in all patients with N0 and selected N1 disease in whom the tumor extends past the bronchial orifice of the lobe. Sleeve lobectomy has been reported by minimally invasive techniques. However, the bronchial anastomosis is quite cumbersome when performed by conventional video-assisted thoracic surgery (VATS). The robotic surgical platform by virtue of magnified 3-dimensional visualization, ease of preparation of the bronchial stumps and setup of the anastomosis, and wristed instrument maneuverability in a confined space, enables sleeve lobectomy using minimally invasive techniques. Robotic sleeve lobectomy has been reported with excellent results. The technical principles and dissection with robotic sleeve lobectomy are the same as those of open surgery. Patient selection and extensive experience with lung resection using the robotic platform are mandatory to perform these complex and rare procedures. This article outlines the technical aspects of performing a robotic sleeve lower lobectomy.

Keywords: Robotic surgery; sleeve lobectomy; minimally invasive surgery; non-small cell lung cancer; central lung tumor

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Introduction

Sleeve lobectomy was first introduced by Allison and was originally designed as an alternative to a pneumonectomy in patients with impaired pulmonary function (1). Since Allison's report in 1954, many studies have shown that sleeve lobectomy is comparable to a pneumonectomy in terms of oncologic efficacy, morbidity, mortality, and long-term survival (2-5). In addition, presumably by preserving lung function and decreasing the complications that are inherent to a pneumonectomy, sleeve lobectomy has been shown to be superior to a pneumonectomy in terms of complications and quality of life. Sleeve lobectomy is indicated for tumors that extend past the bronchial orifice of the lobe. Although a sleeve lobectomy should be

considered in all patients who would otherwise require a pneumonectomy due to the location of the tumor in the bronchus, it is especially indicated in patients with a limited respiratory reserve, patients with comorbidities, and the elderly. Presently, the indications for sleeve lobectomy are: (I) R0 achievement; (II) N0 and selected N1 disease; (III) less aggressive tumors such as carcinoids, localized squamous cell carcinoma, and selected patients with adenocarcinoma; (IV) poor lung function; (V) avoidance of pneumonectomy; and (VI) advanced age and/or comorbid conditions in presence of less aggressive disease.

Minimally invasive sleeve lobectomy has been performed by video-assisted thoracic surgery (VATS) (6). However, sleeve lobectomy by VATS has been hampered by the limitation of the 2-dimensional visualization of the operative

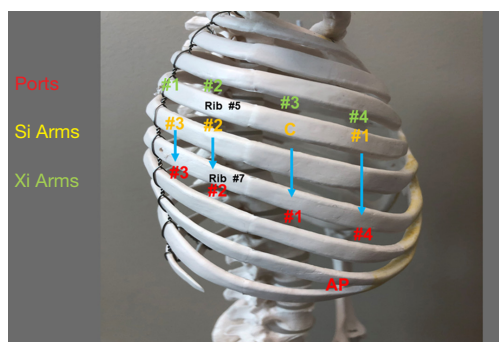


Figure 1 Port placement for sleeve right lower lobectomy. C, camera; AP, Assistant Port.

field and the shortcomings of the conventional un-wristed instruments. The main difficulty in performing sleeve lobectomy by VATS has been the bronchial anastomosis (7).

Robotic lobectomy is now widely accepted as feasible and safe, and a number of studies have shown decreased blood loss and length of stay (8). A meta-analysis comparing robot-assisted thoracic surgery (RATS) to VATS and open approaches found RATS to be superior with respect to transfusions, complications, length of inpatient stay and 30-day mortality (9). The number of robotic lobectomies has increased in recent years (10).

In 2006, Ishikawa *et al.* described the technique of robotic bronchoplasty in a cadaver model (11). The robotic surgical platform by virtue of magnified 3-dimensional visualization, ease of preparation of the bronchial stumps and setup of the anastomosis, and wristed instrument maneuverability in a confined space, enables sleeve lobectomy using minimally invasive techniques (12-14). Durand reported 486 major robotic anatomic lung resections (15). Ten patients (2%) underwent robotic bronchial sleeve resections. The mean operative time was 164±43 minutes and there were no conversions to a thoracotomy.

This article outlines the technical aspects of performing a robotic sleeve lower lobectomy.

Surgical technique

All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee(s) and with the Helsinki Declaration (as revised in 2013). Written informed consent was obtained from the patient for publication of this article and the accompanying images. A copy of the written consent is available for review by the editorial office of this

journal.

Sleeve lower lobectomy is an extension of the robotic lower lobectomy technique. We use the completely portal robotic lobectomy technique using four arms (CPRS-4) (16-19).

Sleeve right lower lobectomy

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

Figure 1 shows port placement with the Da Vinci Xi Platform (Intuitive Surgical, Mountainview, CA, USA).

All ports are placed in the 7th intercostal space. Ports are placed 9 cm apart.

Port #1 (8 mm) is the camera port. A line is drawn from the tip of the scapula to the costal arch. This delineates the highest point in the chest and the mid-scapular line (posterior axillary line). Pleural entry is with a Hassan needle. Saline is infused and care is taken to look for easy egress of the saline from the needle. If there is any question of pleural adhesions, we use a Visiport Instrument (Covidien Inc., Norwalk, CT, USA) for entry into the pleural space under direct vision. If the Visiport is used, a purse string is placed in the muscle layer and tied around the robot camera port in order to prevent CO₂ leakage.

Warm, humidified CO₂ is insufflated through this port at a flow of 6 L/min to a pressure of 6–8 mmHg in order to push the lung and diaphragm away. The other ports are placed under direct vision. Da Vinci arm #3 is placed through Port #1.

Port #2 (8 mm) is placed in the 7th intercostal space in the poster scapular line. This Port is 9 cm posterior to Port #1 and accommodates Da Vinci arm #2.

Prior to the placement of Port #3 (12 mm), a 21-gauge needle is inserted into the 7th intercostal space at costovertebral junction from the patient's back and injects a 10 mL subpleural bubble of 0.25% bupivacaine with epinephrine near the intercostal nerve. Next, Port #3 is placed 10 cm posterior to Port #2 and 4 cm from the spine in the 7th intercostal space. This port accommodates Da Vinci arm #1. This 12 mm port allows for the use of the robotic stapler. In order to use other instruments, a 12 to 8 mm

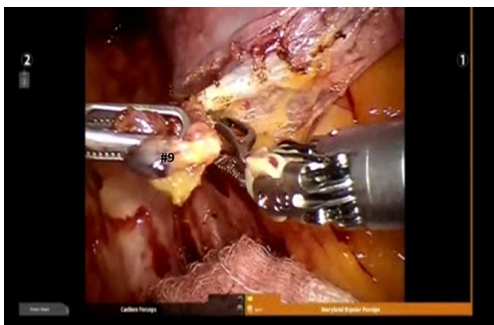


Figure 2 Begin by dividing the inferior pulmonary ligament and remove station #9, and #8 nodes.

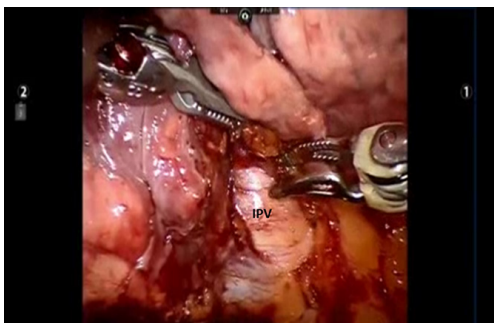


Figure 3 Dissection is carried up to the inferior border of the IPV. IPV, inferior pulmonary vein.

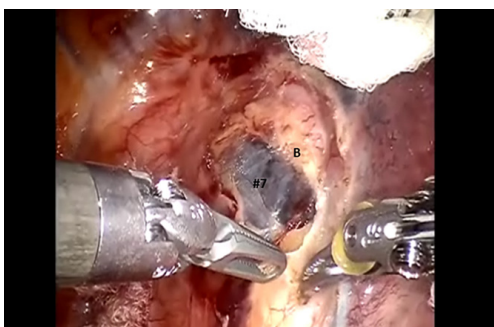


Figure 4 The right mainstem bronchus is identified and dissection is carried posterior to the edge of the cartilage. Station #7 nodes are removed and the subcarinal artery is controlled at the carina. B, bronchus.

Cannula Reducer is used.

Port #4 (12 mm) is placed 9 cm anterior to Port #1 in the 7th intercostal space at the anterior scapular line. This port accommodates Da Vinci arm #1. This 12 mm port allows for the use of the robotic stapler. In order to use other

instruments, a 12 to 8 mm Cannula Reducer is used.

The Assistant Port #5 uses a 10–12 Versiport trocar and is placed in the 9th intercostal space and is triangulated between Port #1 and #4. It should be two or three ribs lower than and as distant to the Da Vinci ports as possible to maximize assistant workspace. Keeping this port off the trajectory lines for those ports will facilitate the patient-side assistant's access for retraction and other maneuvers.

Instruments include 0° and/or 30° down viewing endoscope, 5 mm Thoracic Grasper (left ③), Cadiere Forceps (left ②) and Curved Bipolar Dissector (right ①). For the anastomosis we use the small robotic needle driver (right ①) and the robotic DeBakey forceps (left ②).

The DA Vinci Xi System Endowrist staplers are used. The Endowrist Stapler 30 with White Load is used for dividing the pulmonary artery and vein. The Endowrist Stapler 45 with Green Load is used for dividing the lung tissue.

Begin by dividing the inferior pulmonary ligament and remove station #9, and #8 nodes. Dissection is carried up to the inferior border of the inferior pulmonary vein (IPV) (Figures 2,3). The most posterior arm is used to retract the lower lobe medially and anteriorly in order to remove lymph nodes from station #7. Next open the pleura anterior to the vagus nerve and divide the anterior branch of the nerve which traverses the subcarinal space. Be certain that the nasogastric tube has been removed and the esophagus is decompressed. This opens the subcarinal space and allows for better access to the station #7 nodes (Figure 4). Identify the right mainstem bronchus and stay posterior to the edge of the cartilage. Remove the station #7 nodes and control the subcarinal artery at the carina. At the end of the dissection the right and left mainstem bronchi should be visible, and the posterior aspect of the pericardium should be cleaned and clearly visible. Next, the most posterior arm is used to retract the upper lobe inferiorly during dissection of stations 2R and 4R, clearing the space between the superior vena cava (SVC) anteriorly, the trachea posteriorly, and the azygos vein inferiorly (Figure 5).

Completion of the lymph node dissection opens the mediastinal space and facilitates the dissection of the artery and the bronchus.

Next the lung is retracted posteriorly and held in place with the robot arm. The bifurcation of the right superior and IPVs is dissected and delineated. The location of the right middle lobar vein should be positively identified to avoid inadvertent transection. The IPV is encircled using the Cadiere Forceps and divided using a white vascular

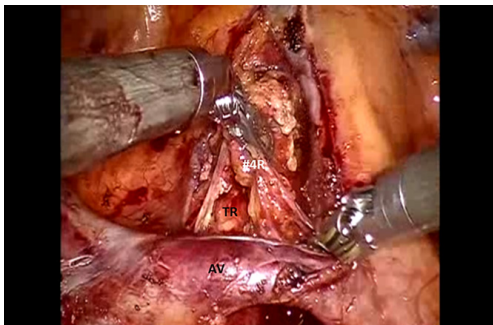


Figure 5 Station 4R nodes are cleared from the space between the superior vena cava anteriorly, the TR posteriorly, and the AV inferiorly. TR, trachea; AV, azygos vein.

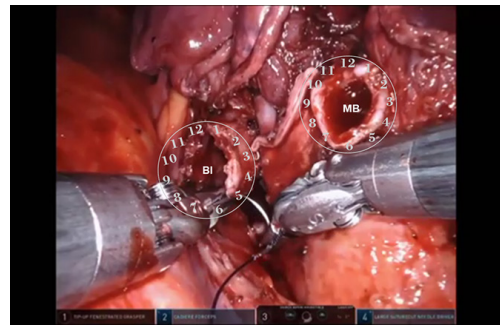


Figure 7 Placing an imaginary clock face on the BI and MB facilitates accurate suture placement. BI, bronchus intermedius; MB, middle lobe bronchus.

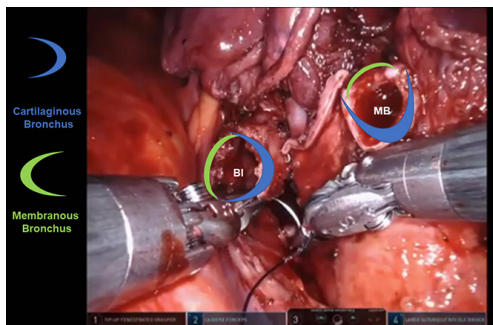


Figure 6 The bronchi are dissected and freed extensively in order to prevent any tension at the anastomosis. The cut ends of the BI and MB are seen. The membranous and cartilaginous portions of the bronchi are delineated. BI, bronchus intermedius; MB, middle lobe bronchus.

cartridge.

The anterior branch of the lower lobe pulmonary artery is most superficial and usually does not have overlying nodal tissue. This branch is identified and traced back to the main trunk of the pulmonary artery. Next the sub adventitial plane overlying the pulmonary artery is developed and nodal tissue (station #11) is removed. Retraction is released and the lung is allowed to remain in its normal position, thereby facilitating visualization of the oblique fissure. The dissection is carried posteriorly in the sub adventitial layer and the superior segmental branch of the lower lobe pulmonary artery is identified. The major fissure is then divided from an anterior to posterior direction using a stapler which is introduced from the anterior port.

The pulmonary artery branch to the lower lobe is

identified. At times the superior segmental pulmonary artery and the inferior lower lobe segmental artery can be taken by encircling the pulmonary artery proximal to the takeoff of the superior segmental artery. Other times these branches need to be taken separately. We prefer to take the inferior segmental artery first, thereby making the encirclement of the superior segmental artery easier. Next the posterior aspect of the oblique fissure is divided using a stapler with a purple cartridge.

Bronchotomy is localized by using bronchoscopic guidance. The monopolar shears are used to cut the bronchus and to prepare the ends of the proximal bronchus intermedius (BI) and middle lobe bronchus (MB). The bronchi are dissected and freed extensively in order to prevent any tension at the anastomosis (*Figure 6*). Negative bronchial margins are confirmed by frozen section prior to the anastomosis. We have used 3-0 Vicryl, 4-0 Vicryl, and 3-0 and 4-0 V-Loc (Covidien Inc.) suture cut to an 8 cm length on an RB1 needle for the anastomosis.

Video of the anastomosis can be accessed on <https://youtu.be/zHjDGvu0lrw>.

Presently we prefer a 3-0 STRATAFIX Spiral PDS Plus (Ethicon Inc., Bridgewater, NJ, USA) on an RB1 needle. The design of the STRATAFIX suture requires a single knot to be placed at the completion of the anastomosis. Anastomosis is begun with STRATAFIX #1 (S1). The S1 needle is passed from the outside in at the 5 o'clock position on BI and inside out at the 7 o'clock position on MB (*Figures 7,8*). The Suture is passed through the "eyelet" and fixed. For the second bite, the S1 needle is passed outside in at the 6 o'clock position on MB and inside out at the 6 o'clock position on BI (*Figure 9*). Suturing with S1 is continued in a clockwise manner until the border

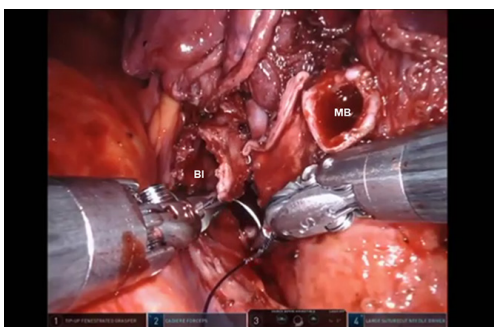


Figure 8 Anastomosis is begun with a 3-0 STRATAFIX suture which is passed from outside in at the 5 o'clock position on BI and from the inside out at the 7 o'clock position on MB. BI, bronchus intermedius; MB, middle lobe bronchus.

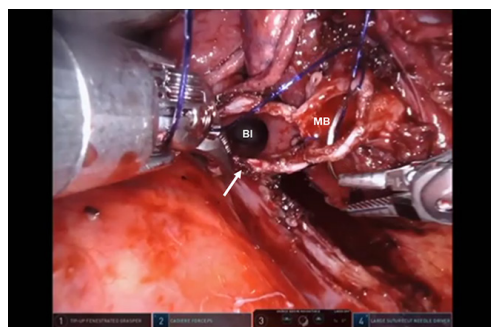


Figure 11 Suturing with S1 is continued in a clockwise manner until the border between the cartilaginous and membranous walls of the bronchi (arrow). BI, bronchus intermedius; MB, middle lobe bronchus.

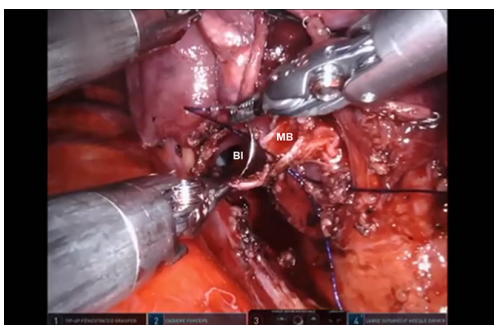


Figure 9 For the second bite, the needle is passed outside in at the 6 o'clock position on MB and inside out at the 6 o'clock position on BI. BI, bronchus intermedius; MB, middle lobe bronchus.

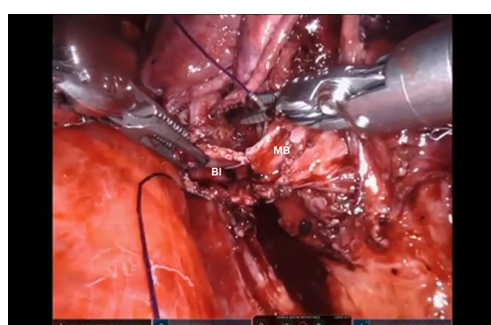


Figure 12 A second 3-0 STRATAFIX (S2) suture is passed from outside in at the 8 o'clock position of the MB and inside out at the 4 o'clock position of the BI. BI, bronchus intermedius; MB, middle lobe bronchus.

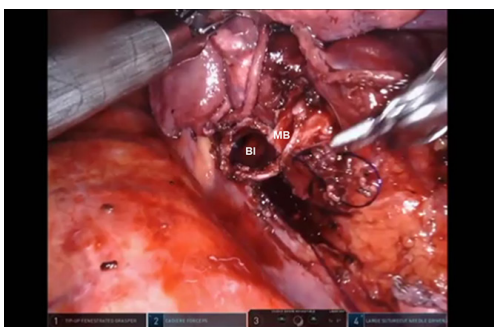


Figure 10 Suturing with S1 is continued in a clockwise manner until the border between the cartilaginous and membranous walls of the bronchi. BI, bronchus intermedius; MB, middle lobe bronchus.

between the cartilaginous and membranous portions of the bronchi (Figures 10,11). Next a second STRATAFIX (S2) suture is passed from outside in at the 8 o'clock position

of the MB and inside out at the 4 o'clock position of the BI (Figure 12). S2 is passed through the "eyelet" and fixed. Next, S2 is used to reapproximate BI to MB in an anti-clockwise direction making sure to prevent any torsion at the anastomosis and to match up the cartilaginous walls of the bronchi (Figure 13). Suturing with S1 stops at the inferior junction of the cartilaginous and membranous walls of the bronchi (Figure 14). Once S2 reaches the superior junction of the cartilaginous and membranous walls of the bronchi, it is used to reapproximate the membranous portion of BI and MB (Figures 15,16) S1 and S2 are tied at the inferior junction of the cartilaginous and membranous walls of the BI and MB bronchi (Figure 17). The placing the knot on the cartilaginous portion of the bronchi prevents inadvertent narrowing of the membranous portion of the bronchi. After the completion of the anastomosis, CO₂ is

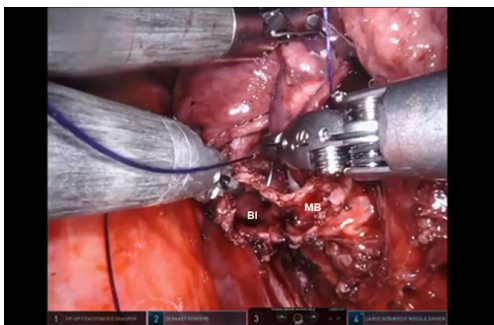


Figure 13 S2 is used to reapproximate BI to MB in an anti-clockwise direction making sure to prevent any torsion at the anastomosis and to match up the cartilaginous walls of the bronchi. BI, bronchus intermedius; MB, middle lobe bronchus.

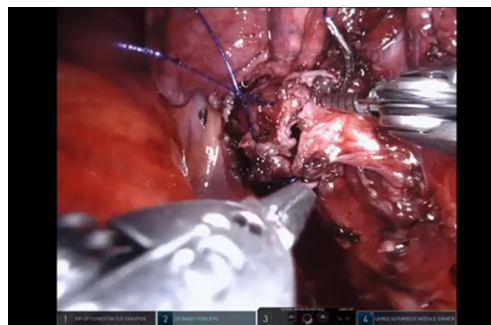


Figure 16 S2 is used to reapproximate the membranous walls of BI and MB. BI, bronchus intermedius; MB, middle lobe bronchus.

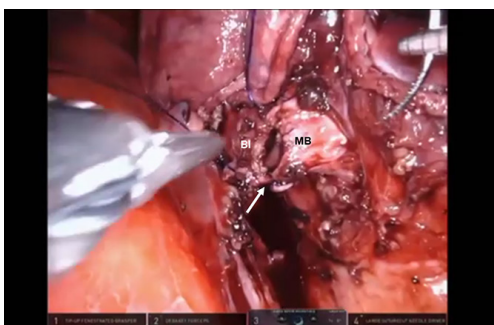


Figure 14 Suturing with S1 stops at the inferior junction of the cartilaginous and membranous walls of the bronchi (arrow). BI, bronchus intermedius; MB, middle lobe bronchus.

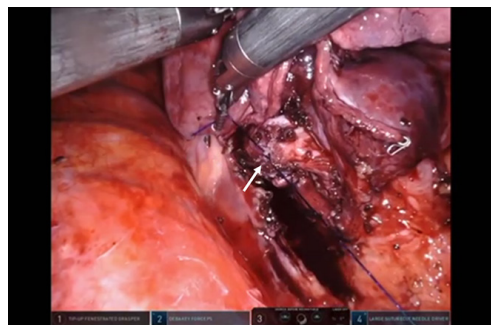


Figure 17 S1 and S2 sutures are tied at the inferior junction of the cartilaginous and membranous walls of the BI and MB. The arrow indicates the tied suture. BI, bronchus intermedius; MB, middle lobe bronchus.

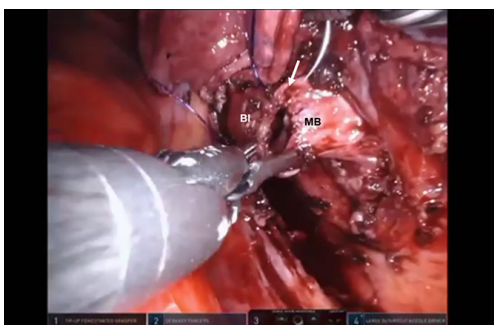


Figure 15 Once S2 reaches the superior junction of the cartilaginous and membranous portion of the bronchi (arrow), it is used to reapproximate the membranous walls of BI and MB. BI, bronchus intermedius; MB, middle lobe bronchus.

turned off, the anastomosis is submerged in warm water and tested for leaks by inflating the lung. In addition, the integrity of the anastomosis is confirmed by bronchoscopy. A 28 French chest tube is placed through the Assistant Port and positioned posteriorly in the pleural space.

Sleeve left lower lobectomy

Port placement: *Figures 18,19* show left sided port placement. Port placement is similar to the right sided approach.

Begin by dividing the inferior pulmonary ligament and remove station #9, and #8 nodes (*Figure 20*) The lung is retracted medially and anteriorly in order to remove lymph nodes from station #7. The nasogastric tube should

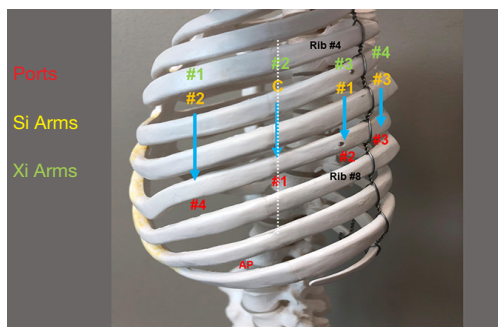


Figure 18 Port placement for sleeve left lower lobectomy. C, camera; AP, Assistant Port.

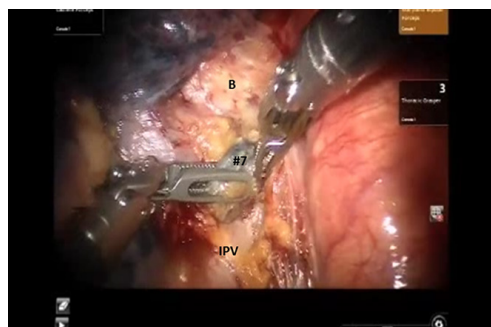


Figure 21 Station #7 nodal bundle is accessed between the IPV and the left mainstem bronchus. IPV, inferior pulmonary vein; B, bronchus.

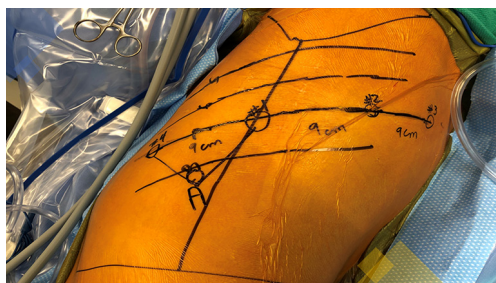


Figure 19 Port placement for sleeve left lower lobectomy. A line is drawn from the tip of the scapula to the costal arch. This delineates the highest point in the chest and the midscapular line (posterior axillary line). Port #1 is the camera port and is placed in the 7th intercostal space in the midscapular line. Port #2 is placed in the 7th intercostal space in the posterior scapular line. This Port is 9 cm posterior to Port #1. Port #3 is placed 9 cm posterior to Port #2 in the 7th intercostal space just medial to the spine. Port #4, is placed 9 cm anterior to Port #1 in the 7th intercostal space at the anterior scapular line. The Assistant Port #5 (A) uses a 10–12 Versiport trocar and is placed in the 9th intercostal space and is triangulated between Port #1 and #4.



Figure 20 Begin by dividing the inferior pulmonary ligament and remove station #9 nodes.

be removed in order to create a greater space for the subcarinal and mediastinal dissection. Next open the pleura anterior to the vagus nerve. Identify the left mainstem bronchus and stay inferior to the edge of the cartilage. The station #7 nodal bundle is accessed between the IPV and the left mainstem bronchus. The nodal bundle is traced to the carina and is then removed (*Figure 21*). Next the upper lobe and lower lobe are retracted in opposite directions and the fissure is identified. Dissection of nodal bundle in station #11 allows for the identification of the pulmonary artery in the fissure. The artery is most superficial at the junction of the lingula, upper lobe and the lower lobe. The sub-adventitial plane is entered, and dissection is carried posteriorly under the pulmonary parenchyma in the posterior aspect of the fissure toward the main pulmonary artery. The Cadiere Forceps is used to pass a vessel loop under the pulmonary parenchyma in the posterior aspect of the fissure. A stapler with a blue cartridge is used to divide the tissue in the posterior aspect of the fissure. The sub-adventitial plane is then developed anteriorly in order to identify the lower lobe branch of the pulmonary artery. The anterior aspect of the oblique fissure is divided. The superior segmental pulmonary artery is also identified. The Cadiere Forceps is passed under the superior segmental pulmonary artery, a vessel loop is passed underneath and used to encircle and elevate the vessel, and the vessel is divided with a stapler with a white vascular cartridge introduced from a medial to lateral direction. Next the lower lobe artery is encircled and divided in a similar fashion with a white cartridge.

The lung is elevated and retracted medially. The Cadiere Forceps is passed from a medial to lateral direction under the IPV, a vessel loop is used to encircle and elevate the

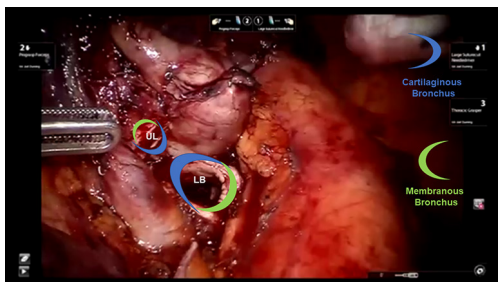


Figure 22 The bronchi are dissected and freed extensively in order to prevent any tension at the anastomosis. The cut ends of the LB and UL are seen. The membranous and cartilaginous portions of the bronchi are delineated. LB, left mainstem bronchus; UL, left upper lobe bronchus.

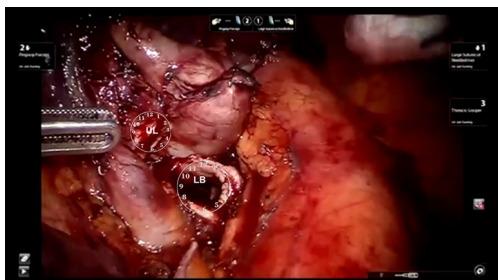


Figure 23 Placing an imaginary clock face on the LB and UL facilitates accurate suture placement. LB, left mainstem bronchus; UL, left upper lobe bronchus.

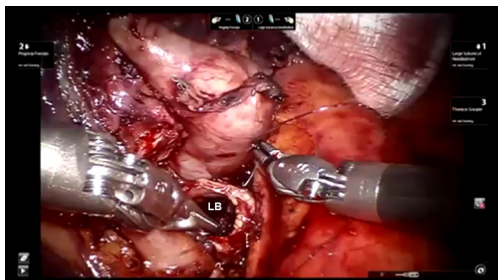


Figure 24 3-0 STRATAFIX suture (S1) is passed outside in at 12 o'clock position on LB. LB, left mainstem bronchus.

vein. The IPV is divided using a stapler with a white vascular load introduced from inferior to superior direction.

Preparation of the left mainstem bronchus (LB) and left upper lobe bronchus (UL) is similar to what has been outlined for sleeve right lower lobectomy (Figures 22,23). The anastomosis is started on the superior aspect of the

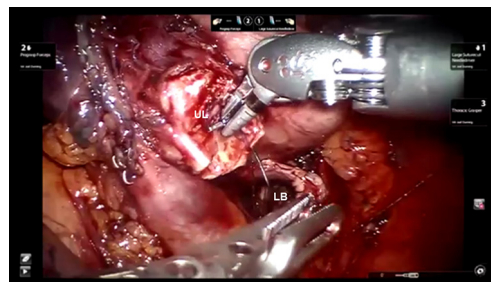


Figure 25 The suture is continued and inside out at 1–2 o'clock position on UL. UL, left upper lobe bronchus; LB, left mainstem bronchus.

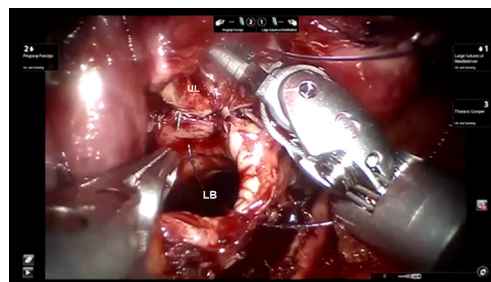


Figure 26 The S1 needle is passed from inside out at the 2 to 3 o'clock position on UL and outside in at the 10 o'clock position on LB. UL, left upper lobe bronchus; LB, left mainstem bronchus.

cartilaginous portion of the LB which is at 12 o'clock position and the superior aspect of the cartilaginous portion of the UL which is 2 o'clock position and carried in an anti-clockwise fashion reapproximating the cartilaginous bronchus of the LB and UL ending at the inferior junction between the cartilaginous and membranous walls. 3-0 STRATAFIX (S1) is passed outside in at 12 o'clock position on LB and inside out at 1–2 o'clock position on UL (Figures 24,25). The suture is then tightened by passing it through the “eyelet”. For the second bite, the S1 needle is passed from inside out at the 3 to 4 o'clock position on UL and outside in at the 11 o'clock position on LB. For the third bite, the S1 needle is passed inside out at 5–6 o'clock position on UL and outside in at the 10 o'clock position on LB. For the fourth bite, the S1 needle is passed inside out at the 6–7 o'clock position on UL and outside in from the 9 o'clock position on LB. The suturing is continued in an anti-clockwise manner until the inferior border between the cartilaginous and membranous wall of the bronchi (Figures 26-29). A second 3-0 STRATAFIX suture (S2) is started at the superior border of the membranous bronchus

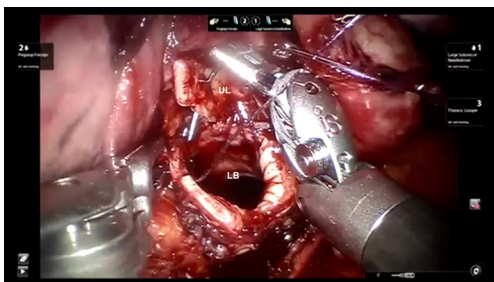


Figure 27 The S1 needle is passed inside out at 4–5 o'clock position on UL and outside in at the 9 o'clock position on LB. UL, left upper lobe bronchus; LB, left mainstem bronchus.

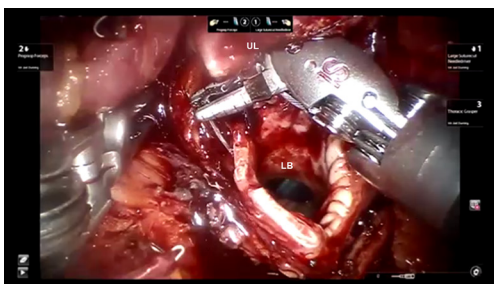


Figure 28 The S1 needle is passed inside out at the 6 o'clock position on UL and outside in from the 8 o'clock position on LB. UL, left upper lobe bronchus; LB, left mainstem bronchus.

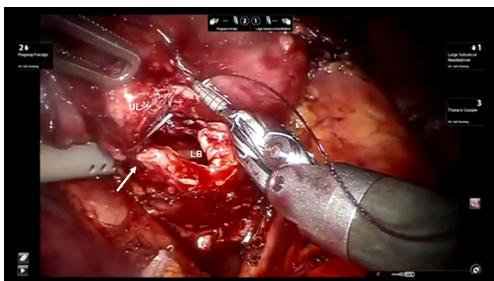


Figure 29 The suturing is continued in an anti-clockwise manner until the inferior border between the cartilaginous and membranous walls of the bronchi (arrow). UL, left upper lobe bronchus; LB, left mainstem bronchus.

and used to close the membranous bronchus (*Figure 30*). S1 and S2 are tied in the lower border of the membranous bronchus placing the knot onto the cartilaginous portion of the bronchi. The integrity of the anastomosis is checked as has been outlined previously (*Figure 31*).

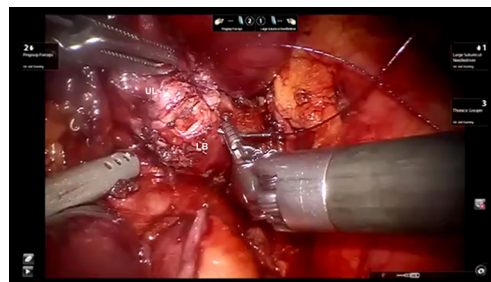


Figure 30 A second 3-0 STRATAFIX suture (S2) is started at the superior border of the membranous bronchus and used to close the membranous bronchus. UL, left upper lobe bronchus; LB, left mainstem bronchus.

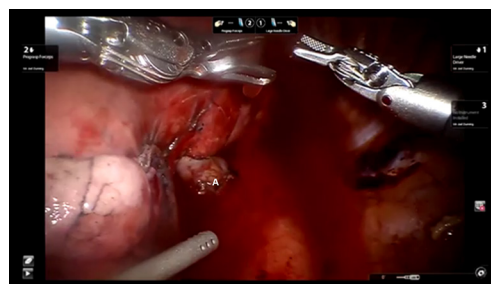


Figure 31 After the completion of the anastomosis, CO₂ is turned off, the anastomosis is submerged in warm water and tested for leaks by inflating the lung. A, anastomosis.

Comment

Sleeve lobectomy is an oncologically valid alternative to pneumonectomy and leads to better postoperative pulmonary function without any decrease in long-term survival.

Sleeve lobectomy has been shown to confer a benefit in early overall and disease-free survival in matched cohorts, when compared to pneumonectomy (20,21).

By virtue of superior visualization and more precise instrument maneuverability the robotic platform facilitates sleeve lobectomy using minimally invasive techniques. When compared with VATS and open surgery, robotic sleeve lobectomy has been shown to be a safe procedure with similar oncologic survival for centrally located non-small cell lung tumors (7).

The key to excellent and consistent results with robotic sleeve lobectomy are: (I) patient selection; (II) extensive experience with robotic lobectomy and segmentectomy

procedures; and (III) a methodical approach to the bronchial anastomosis as has been described in this paper.

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