



# Advanced resections in minimally invasive surgery: robotic pneumonectomy

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**Abstract:** Radical surgery including standard anatomical resections (segmentectomy, lobectomy and pneumonectomy) remains the standard treatment for lung cancer. These procedures are historically performed by an open approach, but in the last years minimally invasive approaches [video-thoroscopic thoracic surgery (VATS), and robotic-assisted surgery] have gained popularity and acceptance in the thoracic surgical domain. These minimally invasive approaches have shown an increased benefit for patients because they are associated with minor morbidity, and less postoperative hospital stay compared to a conventional thoracotomy. Robotic thoracic surgery is increasing in the last decade due to its advantages compared to VATS: a best vision, an increased degree of freedom in movements, and absence of the tremor. The robotic technique was largely used for performing lobectomy and segmentectomy in early-stage lung cancer; however, few reports described its use in performing pneumonectomy. In this article we describe indications for robotic pneumonectomy, the robotic set up, the surgical technique, and we discuss the benefit, the disadvantages of this minimally invasive approach.

**Keywords:** Robotic; pneumonectomy; lung cancer

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## Introduction

Over the last three decades there was a worldwide diffusion of minimally invasive techniques in performing anatomical lung resections (lobectomy and segmentectomy) for early-stage lung cancer. Video-assisted thoracoscopic surgery (VATS) and more recently robotic-assisted surgery have become routine approaches in the surgical treatment of non-small cell lung cancer in stage I and II. These minimally invasive approaches have shown an increased benefit for patients because they are associated with minor morbidity, and less postoperative hospital stay compared to a conventional thoracotomy (1-4). Moreover, they have been shown to allow similar oncologic results (5)

and to be superior for elderly people (6) and for patients with reduced pulmonary function (7). Although these evidences demonstrate a real benefit of minimally invasive procedures, recent studies show that the majority of lobectomies for early stage lung cancer are performed by open technique (8,9). Thus, the idea of approaching with a vats or robotic approach a patient who may require a pneumonectomy is likely to be met with skepticism, hesitation, and disapproving looks from many thoracic surgeons.

Despite the rapid expansion of robotic approach in performing lung resection with mature results and large experience to date the majority of oncological centers have reported on lobectomy (10-14) and segmentectomy

(15-17), but few centers have published on robotic pneumonectomy (18-21).

In this article we describe indications for robotic pneumonectomy, the technical set up of the robot, the operating technique, and we discuss benefit, and disadvantages of this minimally invasive approach.

## Indications

Indications for robotic pneumonectomy are the followings: (I) lung cancer or associated lymphadenopathy involving an important portion of the pulmonary artery and when vascular reconstruction is not feasible; (II) high selected patients with synchronous ipsilateral multilobar malignancies; (III) tumors less than 5–6 cm extended into



**Figure 1** CT scan showing a left upper lobe non-small cell lung cancer involving the inferior lobe.

different lobes across the (*Figure 1*).

## Preoperative work-up

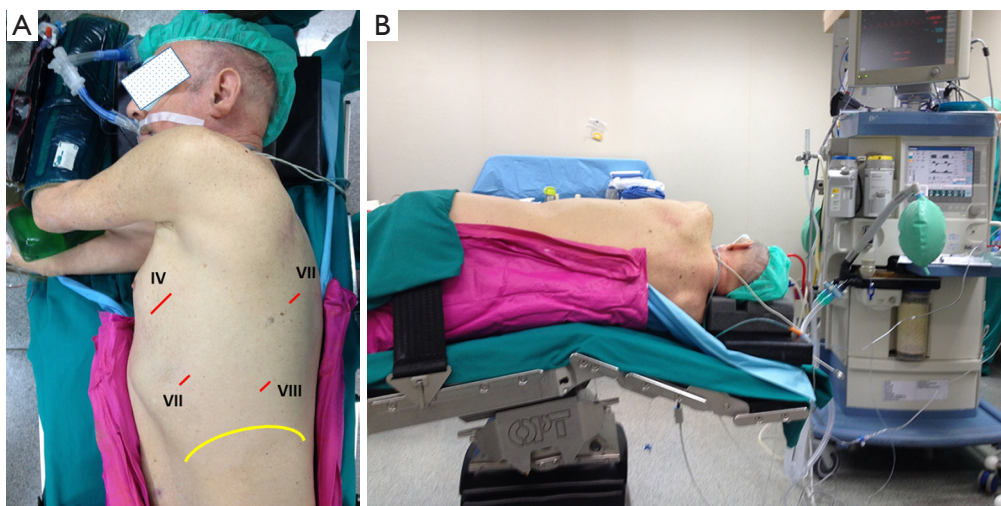
Preoperative evaluation is similar for all our pulmonary resections, and includes computer tomography of the chest, abdomen and brain, positron emission tomography imaging, pulmonary function tests, quantitative perfusion scan, cardiac evaluation including echocardiogram. Bronchoscopy with endobronchial ultrasound evaluation is performed to obtain cito/istological diagnosis of the tumor and to evaluate mediastinal lymph nodes.

## Surgical technique

### *Anesthetic set up, patient positioning, and robotic set up*

A double lumen endotracheal tube is positioned for obtaining a single-lung anesthesia. A central venous access and invasive blood pressure control are installed.

Patient position is lateral decubitus with the arm in front of the patient (*Figure 2A*) and the hip positioned at the same level of the chest (*Figure 2B*) allowing the camera to move without catching on the hip. Anesthesia is located to the face side of the patient to allow the access to the endotracheal tube without problems. If conversion to open surgery is required without urgency, the arm is moved up and a lateral muscle-sparing thoracotomy is performed. The robot cart is located at the patient's head side, with the console in the same room (*Figure 3*).



**Figure 2** Patient's operating position. (A) Patient position with port placement for a four-arm approach. Yellow curve indicates the diaphragm; (B) patient and table position.



**Figure 3** A panoramic view of the operating room with the docked robotic arm.



**Figure 4** A case of left robotic pneumonectomy performed for an interlobar non-small cell lung cancer infiltrating both the left pulmonary lobes (22). The movies illustrate the different steps in performing the robotic pneumonectomy including the patient positioning, the vessels and bronchial isolation and resection, the lymph node dissection, and the specimen removal from the chest cavity.

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A complete four-arm approach is used to complete robotic pneumonectomy. A 4-cm minithoracotomy is usually performed in the fourth intercostal space, anteriorly (*Figure 2A*) without spread of the ribs with the use of a skin retractor. Through this incision the camera is introduced into the chest; pleural cavity is explored for evaluating the presence of adhesions, pleural or parenchymal nodules, the exclusion of the lung, and other possible contraindication to continue the scheduled surgical procedure. The camera port is introduced in the 7<sup>th</sup> intercostal space at the posterior axillary line, and two other 7-mm ports are placed in the 8<sup>th</sup>–9<sup>th</sup> intercostal space, and at the 7<sup>th</sup> intercostal space in the

posterior aspect of the scapula's tip, respectively (*Figure 2A*).

After docking the robot, the robotic instruments are inserted under vision into the pleural cavity.

## Left pneumonectomy

### *Veins isolation and resection*

For the left pneumonectomy (see *Figure 4*), the camera port is positioned few centimeters posteriorly respect to the right side to avoid that the presence of the heart may render difficult the vision of the anatomical structures of the hilum. The first step is the isolation of the inferior vein. After moving the lung upward, the inferior pulmonary ligament is resected by hook cautery. At this step, the subcarinal lymph-node dissection is accomplished by opening the posterior mediastinal pleura. The inferior vein is isolated and, after being surrounded by a vessel loop, it is sectioned with En-doGia Reticulator vascular cartridge inserted by the assistant surgeon through the utility incision after the removal of the robotic arm and controlled (*Figure 5A*). With the use of the new Da Vinci Xi machine, this suture is performed by an EndoWrist robotic stapler directly controlled by the surgeon at the console. The superior vein is prepared in the same way: the vessel is encircled (*Figure 5B*) and transected with endostapler or Endowrist stapler with vascular cartridge introduced through the posterior trocar incision of the 8<sup>th</sup> intercostal space.

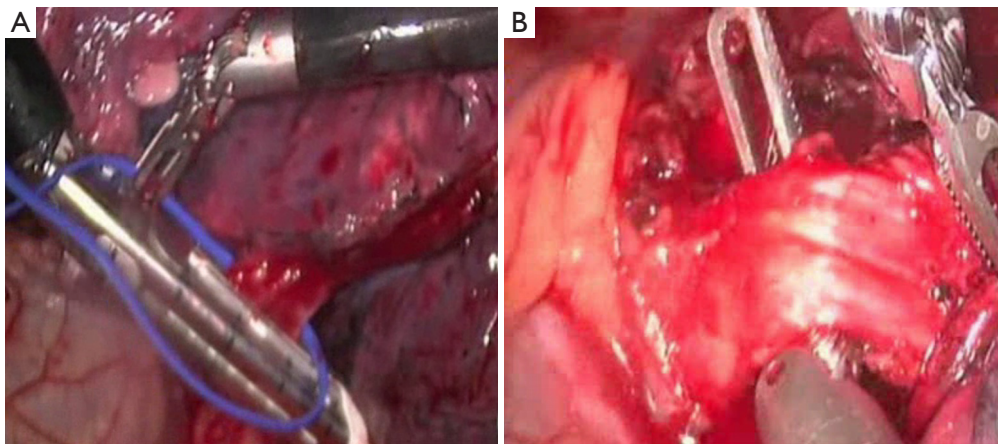
### *Artery isolation and resection*

The pulmonary artery is visualized easily after the resection of the pulmonary veins. To complete di liberation of the main left pulmonary artery, the node dissection of the station #5 is performed (*Figure 6*) by using the hook cautery and the Cadiere forceps so that the plane between the main bronchus and the artery is performed. Once the artery has been encircled by a vessel loop, the stapling articulated device (EndoGia or EndoWrist) is introduced by the posterior trocar and the artery is transected (*Figure 7*). The lung retraction is maintained by Cadiere forceps introduced through the posterior robotic arm.

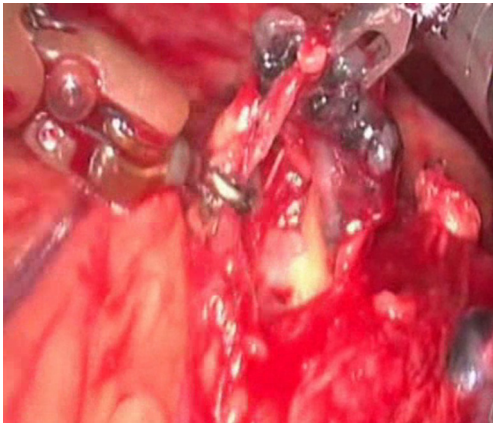
### *Bronchus isolation and resection*

The last step is the bronchus isolation. Lymph nodes of station #7 have been removed before or they may be removed during this step as previously described. Lymph

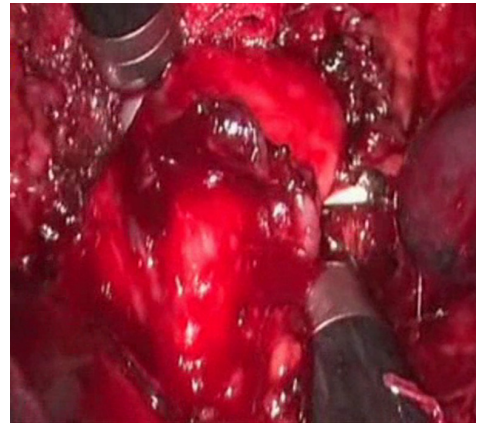




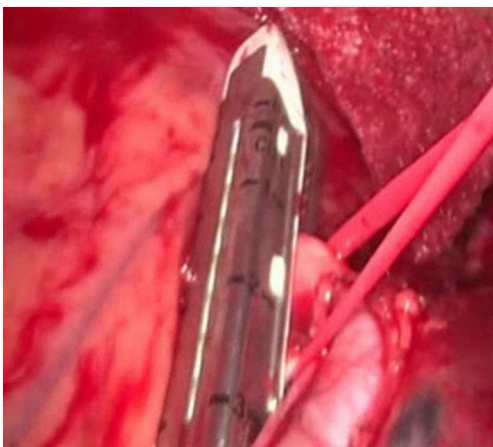
**Figure 5** Venous pulmonary isolation and resection. (A) Isolation and resection of the left inferior pulmonary vein; (B) isolation of the left superior pulmonary vein.



**Figure 6** Dissection of aorto-pulmonary lymph nodes.



**Figure 8** Intraoperative isolation of the left main bronchus.



**Figure 7** Intraoperative view of the left main pulmonary artery resection by endostaplers after its isolation.

nodes of the tracheobronchial angle are removed following the same steps of open surgery. The bronchus is isolated and surrounded by using two Cadiere forceps (*Figure 8*). The stapler is introduced through the posterior port at the 8<sup>th</sup> intercostal space by using a 45 mm green cartridge.

The lung is removed from the chest through the anterior mini-thoracotomy without rib spreading using an EndoCatch (Autosuture, Covidien) (*Figure 9*). One 32 Fr pleural drain is positioned through the camera port.

### Right pneumonectomy

The different steps for performing a right pneumonectomy are similar to the left procedure. The first step is the isolation of the veins by using the hook cautery or Cadiere



**Figure 9** Extraction from the left chest cavity of the EndoCatch containing the robotically resected left lung.

forceps introduced through the utility incision, and two Cadiere forceps one of which is used for retracting the lung for a better exposure. A Maryland bipolar forceps may be used at the place of the cautery hook in case of the phrenic nerve is attached to the hilar structures, in order to dissect the tissue around the superior pulmonary vein. After the dissection of the inferior pulmonary ligament, the inferior vein is isolated and sectioned with endostapler or EndoWrist introduced through the utility incision. The superior vein is then isolated and resected in the same way with the stapler introduced through the posterior port in the 8<sup>th</sup> intercostal space. The artery is freed by sharp and blunt dissection, it is encircled and resected with endostapler or EndoWrist introduced through the 8<sup>th</sup> intercostal space posterior port.

The lung is retracted with the Cadiere forceps and the right main bronchus is isolated. The endostapler (45 mm, green cartridge) or EndoWrist is introduced into the chest through the 8<sup>th</sup> intercostal space and the bronchus stapled and resected.

The dissection of paratracheal lymph nodes (#2R and #4R) and subcarinal station is performed by using the hook and a Cadiere forceps. Sometimes a Harmonic scalpel may be used in patients with large amount of mediastinal fat for reducing bleeding and lymphatic leakage.

### Postoperative care

Patients are usually extubated in the operative room. A single chest tube connected to a water seal device without suction, with the tip in the midthoracic cavity (usually

a 32 Fr), is used for balancing the mediastinum. The tube is removed at the 3<sup>rd</sup> or 4<sup>th</sup> postoperative day if the mediastinum is balanced, and there is no bleeding.

### Comments

After reviewing the English literature, we found that a total of nine robotic pneumonectomies have been attempted and only six were completed by using robotic assistance (11,13,18-20), and three provided technical details of the procedures. We added another case since our previous reports (11,18); thus, we performed a total of 4 robotic pneumonectomies (3 left and one right) so that the total number rise 7 cases completely robotic performed. Giulianotti reported two conversions: one for “oncologic reasons”, and the other for a right sided pulmonary artery. In all the reported case/series, it appears that each of the surgeon had reached a large experience with the range of cases between 38 and 363; however, we were the only to indicate the prior case experience with lobectomy before we attempt the pneumonectomy.

From a technical point of view, the lateral position should be preferred because it allows a better exposure of the pulmonary veins and artery during dissection and resection. We think that the utility thoracotomy is useful because it allows the assistant surgeon to directly suck intraoperative fluids, blood, and steam produced during the use of coagulation; it allows to bring in and take out the chest cavity the resected lymph nodes and the small gauzes used during the anatomical dissection, and, above all, it allows to control directly from outside the chest an eventual vascular injury and bleeding.

In our initial experience in robotic pneumonectomy, we resected pulmonary veins as the initial step to achieve a better exposure of the pulmonary artery, but this produced a congestion of the whole lung increasing difficulties in lung mobilization. In the other 3 cases, we used a different order of vessel resections: we resected as first step the superior pulmonary vein, then the main pulmonary artery, and finally the inferior pulmonary vein. In this way, we had a decreasing of the technical inconveniences and the operative time.

In our experience of 4 cases of robotic pneumonectomy, the mean operative time was 225 minutes (range, 170–320 minutes). All patients were extubated immediately after the surgical operation in the operative room, and no patient was recovered at intensive care unit. In our short series, the mean postoperative stay was 7 days (range, 7–8 days). The

mean number of resected lymph nodes was 25 (age, 19–34). No postoperative complications occurred in the four patients.

With the advent of new robotic instruments (Hem-o-lok for vessel closure) and robotic staplers (EndoWrist) (23), we think that the time of the operation is certainly reduced due to the great and easy maneuverability of the instruments directly controlled by the surgeon at the console.

Management of the main bronchus, particularly in the left side, pose a challenge during robotic pneumonectomy. In fact, it is important to get a proximal bronchial transection ideally behind the aortic arch, which is relatively difficult to achieve. To obtain a short bronchial stump, we applied a considerable traction on the lung to overcome the aortic arch and we used roticulator staplers (45 mm) to try and get as far down as we could.

A problem during robotic pneumonectomy is the possibility of extracting the whole lung from the thorax through a 4-cm utility thoracotomy that seems like it should be a challenge. In our experience, the extraction of the whole lung was possible in all cases by using EndoCatch, without rib spreader, and with a rocking and rotating motion.

The completeness of resection obtained by the robotic approach is equivalent to that of open surgery, including the completeness of lymph node dissection of stations #5, #6, #7, #8, and #9 on the left side, and of #2, #4, #7, #8, and #9 on the right side.

In conclusion, although large experience has been gained with robotic lung resection, robotic pneumonectomy remains an operation that is still undergoing development and should be reserved for centers with high experience. Selection of patients who underwent robotic pneumonectomy is crucial, and surgeons who performed this challenging procedure should have a lot of experience in robotic surgery.

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## Footnote

*Conflicts of Interest:* The authors have no conflicts of interest to declare.

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