# THE ROBOTIC THORACIC SURGERY

Honorary Editors: Weihong Meng, Mingxiao Hou
Editor: Shumin Wang, MD, PhD


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# THE ROBOTIC THORACIC SURGERY (FIRST EDITION)

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# Evolving thoracic surgery: from open surgery to single port thoracoscopic surgery and future robotic

**Diego Gonzalez-Rivas**

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Thoracic Surgery is a continuous evolving specialty. In the past, thoracic surgeons had to make large incisions in order to operate any pathology inside the chest. This often meant big, painful and ugly scars and long recovery times after surgery. But his history of thoracic surgery changed since the beginning of video-assisted thoracoscopic surgery (VATS).

Hans Christian Jacobaeus provided the first description of a thoracoscopy in 1910 (1). During decades the role of thoracocopy was only related to diagnostic and minor therapeutic procedures. Since the past two decades, thoracoscopic procedures have increasingly gained acceptance specially with the introduction of VATS major pulmonary resections (2).

Although there is no standardised technique for the thoracoscopic approach used in this type of procedure, most groups use a utility incision of about 4-6 cm, and add between 1-3 ancillary incisions, i.e., there is variability in the number of incisions used, depending on the centre in question. The most common approach comprises a utility incision plus two supporting incisions, i.e., three ports, and a very important consideration is the obviation of rib-spreading (3).

The use of multiple ports seems to entail more facilities for performing VATS lung resection and provides different angles for hilar dissection and lymphadenectomy. However, the performance of a lobectomy can be accomplished by only one incision with similar results (4). With increased experience in VATS lobectomy, we have gradually improved less invasive techniques and thanks to the advances in the field of thoracoscopic surgery the indications and contraindications for lung cancer treatment have been changed overtime.

We evolved from the conventional VATS to a single incision approach after gained experience via three ports. The first step was to avoid the posterior incision to perform cases by the double port technique (5), and the second step was avoid the inferior incision and insert the camera and the instruments through the utility incision (*Figure 1*).

We started to perform major pulmonary resections by uniportal approach in 2010 in our department (6). No other reports were described in the literature before. Actually we apply the single-port technique for most major resections including advanced and complex cases (7). To date we have performed 430 single-port VATS pulmonary resections (140 were lobectomies) through a single-incision (*Figure 2*) with excellent postoperative results.

The advantage of using the camera in coordination with the instruments is that the vision is directed to the target tissue, bringing the instruments to address the target lesion from a straight perspective, thus we can obtain similar angle of view as for open surgery (*Figure 3*). Coventional three-port triangulation creates a new optical plane with genesis of dihedral or torsional angle that is not favorable with standard two-dimension monitors. Instruments inserted parallel to the videothoracoscope also mimic inside the chest maneuvers performed during open surgery. There is a physical and mathematical demonstration about better view and instrumentation obtained in the uniportal VATS over conventional approach. Other potential advantage could be less postoperative pain: only one intercostal space is involved and avoiding the use of a trocar could minimize the risk of intercostal nerve injury. Further studies will be required to demonstrate other geometric aspects like ergonomy and that there is less pain with single incision techniques, compared to conventional VATS for lobectomy.

On the other hand technology improves and there is

 

**Figure 1** Surgical instrumentation (camera placed in the posterior part of the incision)

**Figure 2** Postoperative result with chest tube placed through the incision

**Figure 3** Surgeons position (anterior location)

no question that robotic surgery has an important role in the future of thoracic minimally invasive surgery. Over the past 10 years, robotics have revolutionized surgery, and new innovations are continuing to push the boundaries of surgery (8). We are currently in a phase of rapid growth and dissemination of the applications for robotic surgical technology within thoracic surgery (9).

The first generation of robotic technology appeared twenty years ago (10). The robot lets surgeons carry out keyhole surgery remotely, allowing them to control robot arms from a console that also provides a three-dimensional image of the proceedings. The idea to develop robotic surgery platforms evolved from the need to improve the precision of surgical techniques. There is no doubt that robotics will be always more precise than even the most skilled surgeon with the steadiest hand. This development is growing and probably will allow surgeons to perform extremely complex surgical procedures using a minimally invasive approach through a small single hole in a near future.

Anyway nowadays, in my opinion, there are several disadvantages with robotic pulmonary resection: still is a hybrid procedure (robot makes the dissection and VATS is used for staplers) high cost, the need of 3-4 incisions, time-consuming procedure, difficulties to detect nodule lesions and to solve a major bleeding event. However, several advantages of the robot over VATS are clear: instrumentation with more degree of motion and perfect 3D view, specially to achieve a radical lymph node dissection and teaching residents (robotic lobectomy can be performed with no previous VATS experience) (11).

Therefore the adoption of new emergent robotic technology and the minimization of surgical aggression is a recommendable way to follow (12,13). We truly believe on the use of the single port technique for major pulmonary resections because we understand that the future goes in that direction, i.e., robotics and single-port. The instruments that would be necessary develop in the next future for single port robotic surgery should be vessel and bronchus sealer devices, snake-like arms inside the chest for instrumentation, wireless cameras and feedback robotic tactile Systems. We have to be open to the new therapies and the next robotic era because the future of lung cancer treatment probably will be related to genetic, selective molecular chemotherapy and microrobotic technology.

## Acknowledgements

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# Robotic thoracic surgery: from the perspectives of European chest surgeons

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**Abstract:** Although thoracic surgery is one of the fastest growing programs, the results of robotic thoracic surgery reports are presented very rarely. In this manuscript, the development of robotic thoracic surgery programs in Europe and the initial results are discussed. Several European countries lead the development of robotic surgery in the world, especially for lung cancer surgery and for thymus—thymoma surgery. Yet, we may not recognize any major advantage in the outcome when compared to video-assisted thoracic surgery (VATS). But, certainly, the superior capabilities of the intraoperative instrumentation of robotic surgery will be beneficial. More experience in robotic surgery may provide superior results in oncological, physiological and life quality measurements.

**Keywords:** Lobectomy; robotic surgery; video-assisted thoracic surgery (VATS); lung cancer

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Video-assisted thoracoscopic surgery (VATS) has been a strong alternative to thoracotomy for lobectomy in patients with early stage lung cancer. The success of improved endoscopic video systems and endoscopic staplers has increased the thoracic surgeons' capabilities to perform complicated thoracic procedures since 2000. In the current era, the world wide experience with VATS resections for lung cancer is sufficiently large to compare the outcome with open thoracotomy, which was unforeseen in 1993 by an experienced author of the North America (1). Miller predicted that VATS would be a tool to be used in 25-30% of all activities of an active, general thoracic surgeon's practice. More than this, he did not believe lung cancer surgery could have ever been a common indication for VATS.

In 2008, a comprehensive and methdological review and survey demonstrated that VATS lobectomy was not a commonly used procedure among European surgeons, with a rate of not more than 5% using the VATS technique among the surgeons who filled out the survey (2). Although in current practice, there are several European thoracic surgery clinics performing VATS lobectomy at a rate higher than 50% in all lung cancer patients (personal communications). However, there is still a lack of adoption of the technique. This may be attributed to several factors, including a lack of oncological control by means of lymph node dissection and experience, and limitations in instrumentation and depth sensation. In addition to the above mentioned concerns, a fear of hemorrhage and an inability to control the bleeding has made thoracic surgeons hesitate to adopt the minimally invasive lobectomy. All of these have occurred within the past two decades.

To overcome these limitations in minimally invasive resections, robotic surgery has been designed. With the development of the surgical robot (Intuitive, Da Vinci, Inc, Sunnyvale, CA, USA), the performance of urologic, gynecologic and cardiac operations has been proven to be safe and feasible. Robotic thoracic surgery reports were presented within the past decade very rarely (3-6). Several European countries—Italy, France, Austria, Germany, Switzerland and Belgium—lead the development of robotic surgery in the world, especially Italy for lung cancer surgery and Germany for thymus—thymoma surgery. This manuscript describes the development of a robotic thoracic surgery program in the context of Europe.

 

## European surgeons and their contributions to robotic surgery platform

Several European thoracic surgery centers did important contributions to Robotic thoracic surgery. University of Pisa was the first to perform a robotic lobectomy in Europe with da Vinci Robotic Systems in February 2001 and published this initial experience in 2002 (3). They summarized their robotic lobectomy experience in 2008 on 107 good-risk patients. They reported that all their patients returned to preoperative levels of physical activity within 10 days (7). From November 2006 through September 2008, 54 patients with suspected or proven clinical stage 1 or 2 lung cancer were recruited to undergo robotic lobectomy. Veronesi was the sole surgeon to perform these lobectomies in several European centers. She concluded that the robotic lobectomy with lymph node dissection is practicable, safe and associated with shorter postoperative hospitalization than open surgery. She found that the robotically dissected mediastinal lymph nodes were similar in number to those of open surgery and robotic lobectomy could be applied to early lung cancer treatment (8). In 2013, a large robotic thymectomy series was published by the University of Padua. Authors described the robotic thymectomy technique as a safe and effective procedure. They observed a neurological benefit in great number of patients and a better clinical outcome was obtained in patients with early stages of clinical conditions (9). Four European centers collected their data on robotic thymoma resections. They analyzed 79 patients with early stage thymoma who were operated on between 2002 and 2011. They indicated that the robotic enhanced thoracoscopic thymectomy for early stage thymoma was a technically sound and safe procedure with a low complication rate and short hospital stay (10). The oncologic outcomes seemed good (10).

## VATS and robotics and VATS versus robotics

A lobectomy with systematic mediastinal lymph node dissection remains the "gold standard" for the treatment of early-stage NSCLC (11). Although this concept was already accepted during the era of open thoracotomies, lobectomies with VATS continues to be questioned. With the advancement of minimally invasive surgery, many surgeons have developed capabilities to perform lobectomy with VATS. After a decade of collecting data on VATS lobectomies, comparisons of open versus VATS have become available. When a VATS lobectomy is compared with that of thoracotomy, VATS is shown to have a decreased hospital stay, an improved postoperative pulmonary function, decreased pain, and a lower morbidity (12-14). However, concerns remain over the oncological principles of lung cancer surgery and VATS' ability to respect them. The published research favors the abovementioned benefits of the new technology VATS over the open approach (15). Finally, the survival data establishes that VATS is at least equivalent to thoracotomy for the early-stage of NSCLC. Despite the development of new instrumentation for the VATS approach, the standardization of the VATS technique, and the superior outcomes of VATS, a review of the STS database shows a limited adoption (16). Yet, due to the challenges of learning and practicing the techniques, we do not have enough evidence to say that VATS is the "standard-of-care" for the treatment of early stage lung cancer.

Although both VATS and robotics are minimally invasive techniques using a comparable number of ports, there tends to be a comparison or split of the data. While robotic surgeons site VATS' results and benefits, VATS surgeons often deny the similarities, instead demanding the original data provided by the robotic surgeons. As there are not many reports on robotic lung cancer surgeries, it is too early to know and compare the long term survival rates. Recently published reports suggest that there may be certain advantages of the robotic approach over VATS. It is suggested that the robotic surgery offers better instruments and a better view of the operative field: 3-dimensional rather than 2-dimensional; 10× magnification rather than 2× or 3×; and less fogging, therefore less camera manipulation required. Most surgeons who passionately try to learn both the VATS and robotic techniques agree that the robot provides clear advantages for mediastinal and esophageal operations (17). The advantages for robotic lung surgery may include better dissection of enlarged or metastatic N1 lymph nodes off the pulmonary artery, more precise and thorough N2 lymph node dissection, and less operative blood loss. The robot may be less painful than VATS and leads to fewer conversions. However, there are no reports that clearly support these "advantages" and improved outcomes for robotic resections.

There are several large series of lung cancer resection. The robotic group had a reduced morbidity, a lower mortality, an improved mental health, and a shorter hospital stay when comparing the 106 patients who had a lobectomy with robotic surgery with the 318 propensity-matched patients who underwent lobectomy via nerve and rib-sparing thoracotomy (17). According to the author of this paper, robotic surgery is clearly superior to the open approach. Therefore, the concern is not that robotic surgery is superior to the open approach, but if there are any superiorities to the VATS technique.

Swanson and co-workers analyzed the STS data to compare the VATS to robotics. The results indicate that robotic lobectomy and wedge resection seem to have higher hospital costs and longer operating times, without any differences in the adverse events (18). This study shows some noteworthy limitations (18). These include the lack of preoperative data—patient body mass index and smoking habits—and postoperative data—pain scores, quality of life, morbidity, and time to return to work. Furthermore, intraoperative data regarding the precision of surgery—the surgical margins, the adequacy of lymph node dissection, the amount of bleeding, and adverse events during surgery—were not evaluated.

## Results of robotic lung cancer surgery

Previous reports demonstrate the safety of robotic pulmonary resections (19,20). Veronesi and associates from Milan report the safety of a 4-arm robotically assisted (not completely portal) lobectomy (with a 3- to 4-cm access incision, such as the one used by VATS surgeons) in 54 patients (8). Ninan and coworkers report the effectiveness of a completely portal 3-arm robotic lobectomy in 74 patients (19). Another study by the same group reports that robotic video-assisted pulmonary resection was accomplished in 197 of 200 patients: a total of 154 patients underwent lobectomy; 4 patients required bilobectomy, and 35 patients underwent segmentectomy. One patient received a left pneumonectomy. Three patients required conversion to a thoracotomy. The median operative time was 90 minutes. The median length of hospital stay was 3 days. The 60-day mortality and morbidity rates were 2% and 26%, respectively. Robotic VATS (RVATS, as the group names the technique) lung resection is technically feasible and safe. Their results indicate that the procedure is associated with a reduced length of stay, and a low morbidity and mortality (20). Our operative results and complications show similarities with this report.

One of the most influential manuscripts presented the long term outcomes of 325 robotic lobectomy patients who were operated on at three thoracic surgery centers (two from Italy and one from the US) from 2002 to 2010 (21). They concluded that the robotic lobectomy was a safe procedure for early stage lung cancer patients. The long term stage specific survial was acceptable and consistent with prior results for VATS and thoracotomy (21).

## Learning, education and future perspectives

There are two recently published papers questioning the transition from VATS to robotics.

The second paper evaluates an established VATS single surgeon's learning curve in a robotic lobectomy program (22). This retrospective review was conducted on patients undergoing minimally invasive lobectomy (robotics or VATS) for lung cancer. It concludes that, based on the clinical outcomes, there does not seem to be a significant advantage for an established VATS lobectomy surgeon to transition to robotics. The learning curve for robotic upper lobectomies seems to be significantly more difficult than that for lower lobectomies (22). Although our program demonstrates similarities in terms of starting a robotic thoracic program after an established VATS program, we don't share the conclusions given in this paper. We believe the advancement of the technology brings superior health care. Today we may not recognize these differences as they happened during the initial development of VATS. Today, we may not yet provide the data necessary to demonstrate the superiority of the robotic technology over VATS. But the next generation of surgeons, with their enthusiasm and computer-based capabilities, will decide. Forecasting the future trends, one may clearly see that standardization in surgical education may only be provided through computer-based systems, rather than the classical Halstedian learning systems (see one—do one—teach one). The apprenticeship style of learning may fade away within two decades. Instead, the next generation may rely on simulators, learning through simulation rather than on patients; they may even be recognized and certified as surgeons by the computer-enhanced accreditation systems. Even today, simulators and robots have the capability to differentiate an expert from a novice (23). In this study, the authors describe an open-ended longitudinal study and automated motion recognition system capable of objectively differentiating between the clinical and technical, operational skills in robotic surgery.

The robot measures and collects data on the skill paramaters of the trainees operating it. As the novices gain practice during the training protocols, their results, measured by the robot, converge to be the same as those of expert robotic surgeons (23).

The robotic technology may bring new surgical educational standards worldwide. Through the standardization of these

 

**Figure 1** Docking from posterio-superior of the patient for a right lobectomy patient.

techniques, patients may be operated on in a standard way around the world. The computer enhanced programs may allow monitoring of the quality of surgery. Telesurgical apprenticeship or assistance may be provided to those who need mentorship or assistance during a particular surgery. Yet we may not have the data to prove the clear benefits of robotic surgery unless more surgeons adopt the techniques.

From the discussion, it is clear that European chest surgeons credited robotic thoracic surgery and created the most of the literature and the data behind it. We believe that robotic thoracic surgery will be developed by the enthusiastic chest surgeons all around the world. The European Society of Chest Surgeons will start to organize robotic surgery courses and will help dissemination of the knowledge in the upcoming years.

## Robotic surgery experience in our center

We started our thoracic robotic program after an established experience of VATS surgery program. Our VATS program included >300 anatomical lung resections and >350 thymectomies and >60 thymomectomies. The idea of the start of a thoracic robotic program relied on the difficulties of some anatomical VATS lung resections. Here, in this manuscript, we presented our experience in the first 29 months of experience. We still continue to perform VATS anatomical resections for lung cancer and other pathologies, which may enable comparative studies in the upcoming years. Our case series demonstrates a nice distribution among pathologies and type of operations. This may provide the evidence of similarities with VATS abilities. We may also claim that the rate of segmentectomy is relatively higher when compared to lobectomy, which may be a sign that the robot could be used for even more precise dissection of small vessels and bronchi.

**Table 1** Characteristics of the patients

| Patient characteristics (n: 87) | | |
|---|---|---|
| Male/female | 62/25 | |
| Median age, years | 56 | [7-84] |
| Median tumor diameter | 2.4 cm | 0.5-8.5 |
| Lobectomy | 35 patients | (40.2%) |
| Pneumonectomy | 2 patients | (2.2%) |
| Segmentectomy | 26 patients | (29.8%) |
| Wedge resection (metastasectomy—diagnostic resection for solitary pulmonary nodule) | 11 patients | (13%) |
| Mediastinal mass (including bronchogenic and enteric cysts) | 12 patients | (13.7%) |
| Giant bullectomy | 1 patient | (1.1%) |

Between October 2011 and March 2014, 87 consecutive patients (25 females and 62 males) underwent a robotic assisted thoracic surgery. We preferred docking from superior and posterior to the patient in all lung resections (*Figure 1*). The patient characteristics are listed in *Table 1*. Thirty-five patients underwent an anatomical lobectomy. Only two patients underwent lobectomy for benign lesions: one patient with bronchiectasis and one patient with pulmonary aspergilloma. All other patients were operated on for lung cancer. Four patients had a neoadjuvant treatment due to single node N2 disease prior to the scheduled robotic operations. Two patients underwent left pneumonectomy, one patient for invasive N1 lymph node, and the other one for a hilar located, sleeve impossible lesion.

Twenty-six patients were operated on using formal segmentectomies: 13 from the right lung and 13 from the left lung. Eleven patients had a segmentectomy from the upper lobes and 15 patients from the lower lobes. The mean duration of chest tube drainage and postoperative hospital stay were 3±3.1 [1-10] days and 4±1.8 [2-7] days, respectively. Out of 74 lung resection operations, four patients required conversions to a muscle-sparing mini-thoracotomy due to bleeding (two patients) and difficulties (two patients). In our series, upper-lobe NSCLC lesions predominated, with the right upper lobe being the most common tumor site.

No patient required an epidural catheter for postoperative pain control. The median length of stay in the intensive

 

**Table 2** Complications after anatomical lung resections in 63 patients (wedge resections are excluded)

| Perioperative events in anatomical lung resections, n: 63 | |
|---|---|
| 30-day mortality, n (%) | 1 (1.5) |
| Supraventricular arrhythmia, n (%) | 3 (4.7) |
| Prolonged air leaks (>5 days), n (%) | 8 (12.6) |
| Heart failure, n (%) | 2 (3.1) |
| Conversion for difficulty, n (%) | 2 (3.1) |
| Conversion for bleeding, n (%) | 2 (3.1) |

care unit (ICU) was 1 (range, 0-1) day. The complication rate for the study cohort was 20 out 87 patients (*Table 2*). Most complications occurred in patients who underwent a lobectomy (9/35). The most common complications were air leaks for more than five days (five patients) and atrial fibrilation (three patients). One patient died within 30 days of the operation; he was discharged after a right upper lobectomy for squamous cell lung cancer. He was readmitted one week later with an infiltration of the contralateral lung and leucocytosis of 88.000/mL. He was diagnosed with a concurrent lymphoblastic lymphoma through the bone marrow aspiration biopsy, and died of chemotherapy side effects.

## Acknowledgements

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# Anesthesia of robotic thoracic surgery

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## Introduction

Robot-assisted thoracic surgery is one of the more mature techniques among minimally invasive surgeries. With the improvement of the cooperation between operative and surgical proficiency, the operation and perioperative times required for each stage of robot-assisted thoracic surgery have been gradually shortened. The advantages of robot-assisted thoracic surgery are also increasingly prominent.

The bulkiness and particularity of the robot operating technology render anesthetic management both difficult and complex. In addition, the anesthesia requirements of thoracic surgery are different from those of robot-assisted surgeries of other specialties. In particular, $CO_2$, artificial pneumothorax, prolonged one-lung ventilation (OLV) and other factors exert significant influence on respiration and circulation, making anesthesia in thoracic surgery a more demanding procedure. The anesthesiologist must fully understand not only the surgical technique and the related equipment but also their impacts on the patient and the corresponding pathophysiological changes to ensure both the success of the surgery and patient safety.

## Pre-anesthetic visit and assessment

Robot-assisted thoracic surgery usually involves multiple small incisions and applies artificial tension pneumothorax and prolonged OLV; thus, patient selection is strict. This precaution is directly related to the occurrence of perioperative complications and the overall therapeutic effect.

In addition to the preoperative routine examination performed for thoracic laparoscopic surgery, assessment of the intubation conditions needs to be emphasized. If it is likely going to be difficult for the patient to be intubated (e.g., the patient has severe trismus, severe facial deformities or severe scoliosis), the patient should be classified as having an anesthesia contraindication. Although pulmonary function measurements are not necessarily related to postoperative ventilatory failure, nor are they necessarily predictive for the occurrence of postoperative respiratory failure, pulmonary function testing, blood gas analysis and chest X-ray can all help determine whether a patient can tolerate the prolonged OLV. Under the resting state air inhalation conditions, if conditions such as hypercapnia ($PaCO_2$ >50 mmHg), hypoxemia ($PaO_2$ <65 mmHg), chronic obstructive pulmonary disease (COPD), bronchospasm, asthma, or severe emphysema are detected, then the patient cannot tolerate OLV and the hypercapnia, hypoxemia and pleural positive impact caused by continuous $CO_2$ infusion. Therefore, these patients are not suitable for this type of surgery. Patients with moderate COPD should go through hormone and physical therapy with bronchodilators or adrenocorticotropic steroids and wait until their lung functions are improved before being considered for robot-assisted thoracic surgery. Those patients who have long smoking histories must quit smoking 1 to 2 weeks prior to the surgery. Obese patients usually have reduced tolerance to OLV and are encouraged to try to lose weight before the surgery. Very young patients are also not suitable for robot-assisted thoracic surgery due to their small body size and short height, which make them unfit for OLV.

Secondly, the evaluation of the patient's cardiopulmonary function should be conducted according to the clinical guidelines for non-cardiac surgery within the chest. Those patients who are suffering from unstable angina or a recent myocardial infarction are particularly sensitive to acute myocardial ischemia and trauma during the surgery and are more vulnerable to heart failure. Therefore, precautions must be exercised when selecting these patients for robot-assisted thoracic surgery. All of a cardiac patient's cardiovascular medications must be continued until the day of surgery, especially β-blockers, which should be continuously applied to reduce the stress on the myocardium and to maintain a relatively slow heart rate. However, for elderly patients who are unusually sensitive to β-blockers, greater caution should be exercised; in particular, in case of the application of intraoperative and postoperative thoracic epidural blocks, sympathetic nerves will be further blocked, and some patients might not be able to tolerate the procedure. In case of electrolyte abnormalities, especially arrhythmias caused by potassium and magnesium abnormalities, the electrolytes need to be controlled within the normal range before the surgery.

In addition, the patient's coagulation parameters should be within the normal range, and patients' medications on aspirin and other antiplatelet drugs need to be discontinued at least 7 days before the surgery. Oral anticoagulants (dicoumarol) also need to be discontinued for a sufficient time prior to the surgery.

## Indications and contraindications of anesthesia

### *Indications*

(I) Clear surgical indications, such as lobectomy and lymph node dissection, esophageal surgery, and less than 5 cm mediastinal neoplasm resection, are all indications for robot-assisted thoracic surgery;

(II) The patient's condition: the body height should be greater than 130 cm, and the body weight should be more than 30 kg;

(III) Respiratory system conditions: examinations of lung function, blood gas analysis, chest X-ray and airway should be normal and viable for double-lumen endotracheal intubation and should be tolerant to OLV;

(IV) Cardiovascular system conditions: no acute coronary syndrome, heart failure, serious arrhythmias or severe valvular disease should be present;

(V) Laboratory tests: no liver or kidney dysfunctions and coagulation disorders should be present;

(VI) Others: the patient should meet the requirements for conventional thoracotomy or thoracoscopic surgery.

### *Contraindications*

(I) Patients who have severe airway difficulties and severe thoracic or spinal deformities in the preoperative assessment should not be considered;

(II) Patients who are suffering from severe COPD, severe pulmonary hypertension, severe emphysema, bronchial asthma, and severe pleurisy or ipsilateral pleural adhesions should not be eligible;

(III) Patients who have a history of cardiac surgery or chest surgery should not be considered;

(IV) Other special cases that are unfit for thoracic surgery and anesthesia should not be considered.

## Anesthesia method

### *Intraoperative monitoring*

Robot-assisted thoracic surgery anesthesia does not require special procedures besides the clinical anesthesia monitoring requirements proposed by the American Society of Anesthesiologists (ASA). Some complex non-invasive or invasive monitoring techniques can be selected according to the actual condition of the patient. In developing a perioperative care strategy, anesthesiologists must take full account of factors such as the surgeon's surgical experience and the possible operation time, along with the risks introduced by changes in these factors.

Routine monitoring indicators should include 5-lead electrocardiogram (ECG), pulse oximetry, end-tidal carbon dioxide ($P_{ET}CO_2$), continuous invasive arterial pressure, central venous pressure, bispectral index, degree of neuromuscular blockade, temperature monitoring, and others.

Surgical incisions in the left side of the chest might affect ECG monitoring to some extent. In particular, such incisions render the V4~V6 leads, which are more sensitive in the diagnosis of myocardial ischemia in the frontal lateral wall, unusable. Artificial pneumothorax can change the axis and amplitude of the ECG and can further impact the judgment of myocardial ischemia and arrhythmia. Therefore, it is necessary to simultaneously monitor changes in leads II and changes in the lateral chest lead ECG and the ST segment.

$P_{ET}CO_2$ mainly reflects on the ventilation conditions, rather than directly on the body's acid-base status and oxygenation, especially in the case of robot-assisted thoracic surgery, which is under comprehensive influences by many factors. $P_{ET}CO_2$ measurements can vary significantly at different times; however, most of the time, there is a good correlation between $P_{ET}CO_2$ and $PaCO_2$, and observation of the dynamic change of $P_{ET}CO_2$ is useful in the judgment of $PaCO_2$. Therefore, $P_{ET}CO_2$ can be routinely used for robot-assisted thoracic surgery but cannot completely replace blood gas analysis. In particular, in cases of OLV and prolonged OLV-induced composite carbon dioxide pneumothorax, the blood gas analysis should be conducted regularly to make timely adjustments.

Transesophageal echocardiography (TEE) is used for robot-assisted thoracic surgery monitoring only in very special circumstances. If the patient has severe cardiovascular dysfunction, TEE in robot-assisted thoracic surgery can provide references for the anesthesiologist in regard to double-lumen endotracheal tube positioning, the dynamic monitoring of left ventricular myocardial ischemia and cardiac function, guiding the capacity treatment, and other procedures.

### *Selection of anesthesia*

#### General anesthesia

Relative to laparoscopic surgery, robot-assisted surgery requires more complete muscle relaxation. After the operation arm is mounted with the instrument and enters the patient's body, the patient's position cannot be changed. Patient body movement during the surgery may lead to serious consequences; thus, it is especially important to have perfect neuromuscular monitoring and muscle relaxant application. During the induction and maintenance of anesthesia, intravenous or inhaled anesthetics that have relatively small hemodynamic impacts are preferred. Halide inhalation anesthetics have strong anesthetic effects and low minimum alveolar gas effective concentrations, which can be coupled with high oxygen concentrations. In addition, halide inhalation anesthetics lead to rather low blood/air partition coefficients and can also speed the induction of anesthesia and awakening, which are easier to control and therefore especially suitable for thoracic anesthesia.

#### Combined regional anesthesia with general anesthesia

It has been reported that combined regional anesthesia with general anesthesia can be applied to robot-assisted thoracic surgery anesthesia. The advantages of this method are that it can reduce the amount of anesthetics needed for general anesthesia during the intraoperative maintenance period and can have a smaller hemodynamic impact, with a smooth transition to postoperative analgesia. In general, fast and lightly induced anesthesia is combined with a thoracic paravertebral block. First, a paraspinal block is performed; when successful, general anesthesia is induced using fentanyl (3-5 μg/kg), propofol (0.5-1 mg/kg), and rocuronium (1 mg/kg). In the intraoperative duration, low-dose propofol (50 μg/kg/min) is continuously and intravenously applied, together with a single dose of an intravenous injection of rocuronium to maintain anesthesia. However, this method is time-consuming, and the paravertebral block also has a certain failure rate.

### *Pre-anesthesia medication*

Currently, pre-surgical medication is generally not applied. When the patient is wheeled into the surgery room, midazolam 2 mg and/or penehyclidine 0.5-1 mg are intravenously injected into the patient to help reduce airway secretions and to prevent laryngeal spasm during the intubation. Intravenous injection of dexmedetomidine (1 μg/kg, 10-15 min) before the induction can generate a good sedative effect and a stable hemodynamic effect, which is a viable option.

## Induction of anesthesia

The induction of anesthesia is usually performed by intravenous induction. The optional intravenous anesthetics include propofol (1.5-2.5 mg/kg) or etomidate 0.3 mg/kg), while the narcotic analgesics include the most commonly used sufentanil (0.5-1 μg/kg). The muscle relaxants have a very wide range of choices, among which rocuronium (0.6-0.9 mg/kg) is most commonly used. Other drugs can be used appropriately based on the patient's condition. After successful muscle relaxation, double-lumen endotracheal intubation is performed, and mechanical ventilation is executed after the bronchoscopy positioning.

## Maintenance of anesthesia

Anesthesia can be maintained by continuous intravenous infusion of propofol (4-6 mg/kg/h) and remifentanil (0.3-0.5 μg/kg/min), and alternatively by targeted, controlled infusion of propofol with a final plasma concentration of 1-1.5 μg/mL and remifentanil with a final plasma concentration of 5-10 ng/mL. The patient's response to surgical stress and sedation can be determined based on hemodynamic changes and the bispectral index (BIS), while the anesthetic depth can be controlled by adjusting the concentration of sevoflurane inhalation. Muscle relaxants can be injected intermittently and intravenously according to the requirements of muscle relaxation. Thirty minutes before the expected completion of surgery, inhalation of anesthetics is discontinued, and the intravenous anesthetic propofol and narcotic analgesic remifentanil infusion rates are gradually increased as guided by the hemodynamic parameters to maintain the proper depth of anesthesia. Meanwhile, a single intravenous injection of sufentanil (5-15 μg) or a non-steroidal anti-inflammatory analgesic can be performed. At the end of the surgery, intravenous infusions of anesthetics and narcotic analgesics are stopped. Because this anesthesia method adopts intravenous infusion or injection of the drugs at the induction and awakening stages while adopting a combined intravenous and inhalational application of the drugs in the maintenance stage, it is also called "the sandwich technique". This anesthesia technique can ensure early extubation and rapid patient recovery.

Robot-assisted thoracic surgery anesthesia should appropriately limit the uses of opioids, benzodiazepines and muscle relaxants. Generally, the inhaled concentration of sevoflurane is 3-5%. The application of midazolam to maintain anesthesia intraoperatively is not recommended to facilitate early postoperative extubation. Remifentanil can provide hemodynamic stability and has a better inhibitory effect on the stress response than the traditionally used opioids. In addition, remifentanil has no delay of postoperative respiratory depression and no need of prolonged postoperative ventilator support and, thus, is more reasonable for use in maintaining anesthesia in robot-assisted thoracic surgery than fentanyl or sufentanil.

## Anesthetic management

Robot-assisted thoracic surgery is a new challenge to surgeons and anesthesiologists. The surgeon has to complete various surgical procedures in a small space, which requires high stability of the respiratory cycle and demands regular communication and cooperation between the anesthesiologist and the surgeon. The anesthesiologist needs to be vigilant and to pay special attention to the impacts of prolonged operation on the circulation, oxygen deficiency derived from the OLV, hyperintrathoracic pressure caused by $CO_2$ pneumothorax and the surgical procedure and should actively respond should these abnormalities occur. The focus of anesthesia management is to maintain the respiratory function and hemodynamic stability.

### *Issues related to anesthesia management*

The bulky robot requires a large space in the surgery room, which inevitably distances the anesthesiologist and the patient. With the robot, monitors, displays surrounding the patient, the anesthesiologist often does not have easy access to the patient during the surgery. To facilitate the surgical exposure and the surgeon's work, the patient is placed at a 90° angle to the anesthesiologist, in which the patient's head and arms are all blocked by the robot. When the robot assumes its position and is secured, it may be the case that the anesthesiologist is not able to complete the necessary close operations, thus increasing the risk in the surgery. Therefore, all narcotic operations, including the establishment of the central venous channels, invasive arterial pressure catheterization and the confirmation of lung isolation, etc., have to be completed before the patient's final position is secured.

To ensure smooth intraoperative management, long infusion pipelines are used, and the positions of three-way valves and injections are reasonably set so that they can be adjusted under direct vision. Similarly, the cords to the monitors and the ventilator circuit should also be long enough for the anesthesiologist to work remotely and should be fastened in the cluster and in a visible manner to avoid any disconnections caused by the movement of the surgical bed. Because the patient's head position is blocked by the main body of the robot, anesthesia headstock cannot be used; in addition, the use of prolonged threaded pipe also increases the risk of disconnection of the endotracheal catheters. Therefore, the endotracheal catheters and the ventilator circuit must be well connected to each other and securely fastened. A dedicated pipeline holder for anesthesia tubes can be used as long as they do not affect the robot arm.

During the surgery, the robot's position cannot change in relation to the patient's movement. Because any movement of the patient's chest will lead to accidental organ damage or vascular cutting, with serious consequences, adequate muscle relaxation and absolute braking on the patient must be ensured. Appropriate muscle relaxants need to be administered to patients, even those with myasthenia gravis. Although neuromuscular monitoring has some significance, there are still some problems to be solved regarding its implementation process. There are various factors in robot-assisted thoracoscopic surgical procedures that can cause pressure on the patient's body, which can lead to severe nerve damage on the pressured area (such as the commonly occurring brachial plexus injury). In addition, special attention should be paid to protection of the facial skin and eyes; foam pad protectors can be used when necessary to prevent bruises to the face and eye damage. For patients suffering from spine diseases, especially when combined radicular symptoms or corresponding impaired nerve function, special care must be taken to minimize the risk of orthostatic nerve/muscle complications during lateral position surgery.

### *Management of OLV*

In robot-assisted thoracic surgery, anesthetic techniques of lung isolation and OLV are essential, of which the most commonly used methods include double-lumen endotracheal intubation or single-lumen tube with bronchial occlusive cuff (e.g., a Univent catheter). For patients with difficult-to-plant intubation, bronchial occlusive catheters are preferred over double-lumen tubes. If double-lumen tubes are used, the appropriate intubation model (currently the most widely used ones are left lateral surgical double-lumen endotracheal catheters) should be selected while taking into account the patient's gender, height, weight and other comprehensive factors. Under the condition of no airway injury, larger-sized catheters are preferred. During the intubation process, the use of bronchoscopy is helpful to determine the catheter position and to assess airway anatomical abnormalities or airway foreign bodies. Lung isolation must be confirmed before performing OLV.

During OLV, the respiratory rate and tidal volume are first adjusted. While maintaining hemodynamic stability and not affecting the surgery, adequate minute ventilation should be ensured as much as possible and the tidal volume setting should not be too high so that the airway pressure can be maintained at 20-30 mmHg. If intraoperative lung inflation is necessary, special care has to be taken to avoid the iatrogenic spread of tumor tissue into the lung parenchyma by the intrathoracic surgical instruments.

One of the problems of prolonged OLV is that the ipsilateral lung is under a non-ventilated condition, which readily leads to $CO_2$ accumulation; secondly, the lateral atelectasis can lead to increased pulmonary artery pressure, pulmonary vascular resistance and right ventricular filling pressure, with reduced intrathoracic blood flow and reduced cardiac output, eventually leading to hypoxemia and hypercapnia, especially among obese patients and/or long-term smokers. In addition, OLV can cause atelectasis, pulmonary edema and ventilation/perfusion disorders. The adverse effects caused by OLV can even be extended to the postoperative stage, directly impacting on the patient's recovery and prognosis. A continuous positive airway pressure (CPAP) (5-10 cm $H_2O$) exerted on the ipsilateral lung helps to improve oxygenation and reduce diversion. The intraoperative application of double-lumen tubes is meant to make the ipsilateral lung collapse; additionally, low tidal volume ventilation or positive end-expiratory pressure (PEEP) is sometimes needed on the contralateral lung, which might increase the central venous pressure, pulmonary artery pressure, and intrathoracic pressure and might therefore enhance the $CO_2$ level or even cause hypoxic vasoconstriction.

Measures to address OLV-related problems include close monitoring of $SpO_2$, $P_{ET}CO_2$ and real-time monitoring of arterial blood gases. Once hypoxemia or $CO_2$ accumulation occurs, the respiratory parameters should be actively adjusted, and the respiratory rate is usually adjusted to a level 20% higher than that for double-lung ventilation. If $SpO_2$ continuously decreases, the surgeon should be notified to suspend the surgery; double-lung ventilation then needs to be applied to correct hypoxia and to resume the OLV and the surgery.

### *Management of $CO_2$ pneumothorax*

Robot-assisted thoracic surgery requires not only OLV but also continuous blowing of $CO_2$ into the ipsilateral chest, producing an artificial pneumothorax to exclude air, to increase protection from electrical burns and to reduce the incidence of air embolism while facilitating lung collapse, revealing the surgical field. The pressure of the artificial pneumothorax is usually 5-12 mmHg, which may cause increased $CO_2$ levels in the blood; coupled with the *in vivo* accumulation of $CO_2$ resulting from OLV, $CO_2$ pneumothorax may have a significant impact on a severely ill patient. If the pressure of the blowing $CO_2$ cannot be strictly controlled and monitored, the artificial pneumothorax may sometimes lead to tension pneumothorax, giving rise to significantly decreased venous return and hypotension. The risks of $CO_2$ pneumothorax also include venous air embolism, reduced blood amount in right side of the heart and acute cardiovascular collapse (i.e., hypotension, hypoxemia, arrhythmia, etc.), even causing a positional change of the double-lumen balloon.

During the surgery, the air blowing pressure, airway pressure, exhaled tidal volume and central venous pressure should be monitored in real time. Central venous pressure monitoring helps to assess the impact of artificial $CO_2$ pneumothorax, while direct monitoring of the pleural cavity pressure can avoid excessive pressure-induced tension pneumothorax. To minimize the impact of $CO_2$ pneumothorax, it is recommended that $CO_2$ be slowly applied one minute after the opening of the chest, and its blowing speed should be adjusted according to hemodynamic changes. Appropriate reducing $CO_2$ blowing pressure also alleviates the impact of pneumothorax.

### *Intraoperative circulation management*

Through pulmonary artery catheterization, chest bioelectrical impedance, TEE and other technologies, it has been demonstrated that $CO_2$ pneumothorax can reduce cardiac output by 10% to 30%. Measurements of venous oxygen saturation and lactate concentrations have demonstrated that patients are generally well tolerant of hemodynamic changes during $CO_2$ pneumothorax. The reduced cardiac output is associated with various factors, such as increased vena cava pressure induced by the increased intrathoracic pressure, increased venous resistance, retention in the venous blood, and others. The reduction in reflux is proportional to the decrease of the cardiac output. OLV induces lung V/Q imbalance, increases pulmonary artery pressure and reduces cardiac output; $CO_2$ pneumothorax elevates mediastinal pressure, inhibits systolic and diastolic functions and accelerates the accumulation of $CO_2$ in the body, leading to acidosis, which is manifested by decreased blood pressure and high heart rate. The blood pressure can be raised by rapid fluid replacement and vasopressor application via appropriate uses of phenylephrine or dopamine. Some believe that appropriately controlling the infusion amount can reduce exudate in the surgical field and can make it easier to operate; in the absence of massive bleeding, infusion of excessive liquid is indeed unnecessary.

### *Management of fluid balance and body temperature*

Fluid balance is essential. Adequate intravascular volume is the prerequisite to hemodynamic stability and adequate organ perfusion. Robot-assisted thoracic surgery usually adopts limited fluid treatment strategies to ensure the patient's central venous pressure is slightly lower than its preoperative level.

In prolonged robot-assisted thoracic surgery, the body temperature must be closely monitored to avoid the adverse effects caused by intraoperative hypothermia. The nasopharyngeal temperature should also be routinely monitored. Generally, the patient's body temperature should be appropriately maintained above 36 ℃. To prevent hypothermia, a proper operating room temperature should be maintained, and the exposure time of the patient should be minimized when positioning the patient's body; insulation can be used if necessary.

### *Management of intraoperative internal environment*

$CO_2$ pneumothorax during robot-assisted thoracic surgery can cause increased $CO_2$ levels in the blood while OLV can also cause the *in vivo* accumulation of $CO_2$. The reduced cardiac output and elevated mediastinal pressure induced by OLV and $CO_2$ pneumothorax can accelerate *in vivo* $CO_2$ accumulation. The necessity of intervention to adjust the body's acid-base balance depends on the decompensation between arterial blood gas pH and base excess; if the patient has poor cardiopulmonary function and loses self-regulation of the acid-base balance during prolonged surgery and shows respiratory acidosis complicated by metabolic acidosis decompensation, correction is necessary, and special attention should be paid to the occurrence of metabolic acidosis decompensation coupled with hyperkalemia.

### *Emergency responses*

Starting from preoperative preparation, the anesthesiologist and the entire surgical team must always be prepared for the emergency of converting the procedure to an open surgery, which is different from traditional thoracoscopic surgery. Whether it is lung, esophageal or mediastinal robot-assisted thoracic surgery, sudden, excessive and difficult-to-control thoracic bleeding is the most serious complication in robot-assisted thoracic surgery, and the consequences could be disastrous. An emergency plan to be implemented in response to major blood loss and cardiovascular accidents must be developed. In robot-assisted thoracic surgery, unlocking and removing the robot is the first step to be taken under a state of emergency. Each member of the team should be familiar with this operation, ensuring that the robot can be unlocked and removed within 1 minute in case of a crisis. At the same time, the entire team should have acquired the basic skills of CPR training and knowledge of advanced life support. Of particular note, before the artificial pneumothorax is removed and double-lung ventilation is restored, successful external defibrillation can be very difficult; therefore, external defibrillation should not be performed before unlocking and removing the robot.

## Postoperative analgesia

Compared with pain in conventional thoracic surgery, pain after the robot-assisted thoracic surgery is present to a lesser extent; nonetheless, some degree of pain stress is still present and can be detrimental to the patient's postoperative rehabilitation. Typically, significant postoperative pain continues for approximately 48 h. Analgesic options include continuously applied wound infiltration anesthesia through a porous catheter, intercostal nerve block, paravertebral block, pleural cavity analgesia, epidural block, intrathecal morphine injection, and patient-controlled intravenous analgesia (PCIA), among others. All of these options provide high-quality analgesic efficacy. Paravertebral block combined general anesthesia is an important method of intraoperative and postoperative analgesia and also serves as one of the multimodal analgesia regiments. Continuous percutaneous paravertebral block can provide safe and effective postoperative analgesia. Intrathecal anesthesia is also used for postoperative analgesia with satisfactory analgesia. PCIA is currently the most commonly used clinical postoperative analgesia and has satisfactory analgesic effects.

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# Cost concerns for robotic thoracic surgery

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In an era of increasing scrutiny of expenditure on healthcare, the cost of technological developments such as robotic surgery is an important consideration. Prior studies have shown that robotic thoracic procedures can be performed safely with perioperative results that are comparable to thoracotomy and VATS approaches (1-3). Whether this technology adds benefit at a cost that is reasonable is an unanswered question. Given the high capital and maintenance costs of these systems, it is necessary to analyze their cost to the healthcare system. Assessing the cost and value of robotic surgery is, however, a complex undertaking.

In attempting to elucidate the cost implications of robotic technology, one strategy would be to perform a cost comparison between robotic, VATS and thoracotomy procedures. This approach has been demonstrated in a recent retrospective study comparing VATS and thoracotomy for lobectomy (4). In this study, thoracotomy was on average $700 more per procedure in terms of hospital cost, despite the fact that operating room (OR) time was lower than with VATS. The likely difference was due to shorter hospital stay and complications in the VATS cohort. A similar study was performed for robotic, VATS and thoracotomy for lobectomy (5). Even without taking into consideration the indirect and amortized costs, robotic surgery adds additional direct OR costs compared with conventional VATS or thoracotomy.

There are two main sources of disposable costs at the time of the procedure. The first is the cost of the drapes, valued at approximately $200 USD. The second is the cost of the instruments. This varies depending on how many and what type of instruments are employed. On average each instrument used for a procedure costs $200 USD, with the expense of instruments ranging from at least $400 to $1,000 USD. The total additional disposable cost of employing robotics is therefore between $600 and $1,200. In the case of robotics compared with thoracotomy, however, this added OR cost did not result in greater overall cost of the entire hospital stay. We have previously shown that the average cost of robotic lobectomy was more expensive than VATS, yet substantially less expensive than thoracotomy.

Unlike the VATS study, this observation was made taking into account two additional costs of robotics that are more difficult to calculate in a consistent manner. The first is the direct OR cost, i.e. the cost associated with increased time associated with system setup and increased operative time. While there is no doubt that early in the development of robotic procedures this component adds substantial increased cost, it is also likely that with continued refinement in technique and experience of both surgeon and OR team, this will be minimized. Moreover, the difference between different surgeons and centers is difficult to ascertain. The second is the amortized cost of the robotic system. This is calculated by the following formula: (total capital cost of the system + total service costs over the life of the system)/total number of cases performed with the system. At best the amortized cost is an estimate based on a large number of assumptions: duration of use of a particular system, total service costs, total capital costs and total number of cases performed with a given system. It is inaccurate to assign a fixed additional amortized cost to each robotic procedure.

For example, in our previous analysis the amortized cost of each case was calculated by adding the following: the initial purchase cost, the service costs (assuming a 10-year life span of the system) and dividing by an estimate of the total number of cases performed. In order to determine the latter, the actual number of cases performed with the system was added to the projected additional number of cases for the remainder of the 10-year life span of the system assuming utilization at a fixed level from the most recent year. However, soon after the study the institution acquired 3 new systems, returning the original system and receiving credit. Should this be subtracted from the capital cost of the original or from the subsequent systems? If from the subsequent systems, should it be applied to the cost of a single system or to all of the new systems? Does this now mean that the actual cases performed with the original system are now more or less costly?

Perhaps the best method to evaluate the cost implications of any technology for thoracic surgical procedures is a formal cost effectiveness analysis. This has not been done for VATS technology. For a cost analysis between robotics, VATS and thoracotomy one would have to assume that the three approaches are equivalent in clinical efficacy. This may be problematic given that there is no level I evidence showing that any minimally invasive approaches are equivalent to conventional thoracotomy. Outcome data for robotic lobectomy are only beginning to emerge and are largely drawn from single arm retrospective experiences (6). While VATS lobectomy series are greater in number, the majority are retrospective, with few cohort studies comparing VATs to thoracotomy. The few cohort studies that do exist focus largely on perioperative outcome (7-9), showing an advantage for VATS, but there has been recent evidence that suggests that for the surgical treatment and staging of early stage lung cancer, a VATS approach may be associated with a lower rate of accurate hilar lymph node assessment compared with thoracotomy (10).

Moreover, there are two areas of potential cost benefit not likely to be included in cost analyses of robotic technology. The first is the impact of robotics on the volume of cases in general and for a particular institution. What is the cost benefit if a patient decides to pursue surgical therapy at a particular hospital based on the availability of a minimally invasive robotic approach? Second, what is the cost benefit of robotics if it allows wider implementation of a potentially more cost effective alternative, i.e. minimally invasive lung resection instead of thoracotomy? A recent analysis of the voluntary Society of Thoracic Surgery (STS) database demonstrated that, while the percentage of all lobectomies performed by VATS has been increasing, the overall percentage of cases performed by VATS during the 3-year study period ending in 2006 was only 20%. Furthermore, another recent analysis of a non-voluntary national insurance database indicated that <6% of lobectomies were performed via VATS. The fact remains that the majority of major lung resections performed in the United States are still via thoracotomy. If robotic technology can result in a more widespread adoption of a minimally invasive approach in a safe and appropriate manner that has not been achieved with VATS, the added cost may be justified by all the potential benefits over traditional open surgery. This point also addresses the issue of the cost benefit of robotic technology to those patients who are able to undergo minimally invasive surgery instead of thoracotomy. It is important to take into account the cost benefit to the patient of faster recovery, quicker return to preoperative activity level such as return to work, as well as less expenditure for management of postoperative complications and outpatient services like visiting nurse and rehabilitation.

The capital cost of robotic surgical systems, particularly as there is currently only a single supplier, is significant. This cost must be evaluated critically because of the implications on healthcare expenditures in general. However, the financial impact of robotics is no less significant than other seemingly less costly technological innovations that are implemented without the same attention to cost or efficacy that surgical robotics receives. It is incumbent upon all healthcare practitioners to critically evaluate the costs and benefits of any new technology in order to determine the appropriate utilization of our limited healthcare resources.

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Pulmonary Resection

# A systematic review and meta-analysis on pulmonary resections by robotic video-assisted thoracic surgery

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**Background:** Pulmonary resection by robotic video-assisted thoracic surgery (RVATS) has been performed for selected patients in specialized centers over the past decade. Despite encouraging results from case-series reports, there remains a lack of robust clinical evidence for this relatively novel surgical technique. The present systematic review aimed to assess the short- and long-term safety and efficacy of RVATS.

**Methods:** Nine relevant and updated studies were identified from 12 institutions using five electronic databases. Endpoints included perioperative morbidity and mortality, conversion rate, operative time, length of hospitalization, intraoperative blood loss, duration of chest drainage, recurrence rate and long-term survival. In addition, cost analyses and quality of life assessments were also systematically evaluated. Comparative outcomes were meta-analyzed when data were available.

**Results:** All institutions used the same master-slave robotic system (da Vinci, Intuitive Surgical, Sunnyvale, California) and most patients underwent lobectomies for early-stage non-small cell lung cancers. Perioperative mortality rates for patients who underwent pulmonary resection by RVATS ranged from 0-3.8%, whilst overall morbidity rates ranged from 10-39%. Two propensity-score analyses compared patients with malignant disease who underwent pulmonary resection by RVATS or thoracotomy, and a meta-analysis was performed to identify a trend towards fewer complications after RVATS. In addition, one cost analysis and one quality of life study reported improved outcomes for RVATS when compared to open thoracotomy.

**Conclusions:** Results of the present systematic review suggest that RVATS is feasible and can be performed safely for selected patients in specialized centers. Perioperative outcomes including postoperative complications were similar to historical accounts of conventional VATS. A steep learning curve for RVATS was identified in a number of institutional reports, which was most evident in the first 20 cases. Future studies should aim to present data with longer follow-up, clearly defined surgical outcomes, and through an intention-to-treat analysis.

**Key Words:** Robotics; video-assisted thoracic surgery; systematic review; meta-analysis; minimally invasive surgery

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## Introduction

The 'minimally invasive' revolution that began in the 1980s has made a significant impact in many specialties of surgery. The first pulmonary resections by video-assisted thoracic surgery (VATS) were described in the early 1990s (1,2). Since then, there has been growing evidence to suggest that similar or improved long-term oncologic efficacy and survival can be achieved with superior perioperative outcomes by VATS compared to conventional thoracotomy for selected patients with early-stage non-small cell lung cancers (NSCLC) (3,4).

With technological innovation in the form of robotic surgery, robotic video-assisted thoracic surgery (RVATS) emerged as an alternative technique for pulmonary resections in the early 2000s (5,6). Proponents of RVATS emphasize its superior imaging and improved maneuverability compared to conventional VATS, as well as technical advantages such as movement scaling and tremor filtration (7). However, critics of this novel procedure cite its lack of robust clinical evidence as well as its high cost relative to conventional VATS (8). The present systematic review aims to assess the safety and efficacy of pulmonary resections by RVATS, with particular focus on perioperative outcomes, long-term survival and recurrence for malignant lesions. In addition, cost and quality of life (QoL) studies were also systematically evaluated.

## Methods

### Literature search strategy

Electronic searches were performed using Ovid Medline, EMBASE, Cochrane Central Register of Controlled Trials, Cochrane Database of Systematic Reviews, and Database of Abstracts of Review of Effectiveness from their date of inception to March 2012. To achieve the maximum sensitivity of the search strategy and identify all studies, we combined "robotics" or "robotic surgery" or "computer-assisted surgery" as Medical Subject Headings (MeSH) terms or keywords with "lung" or "VATS" or "video-assisted thoracic surgery" or "lobectomy" as MeSH terms or keywords. The reference lists of all retrieved articles were reviewed for further identification of potentially relevant studies. All relevant articles identified were assessed with application of predefined selection criteria.

### Selection criteria

Eligible studies for the present systematic review included those in which patients with histologically proven NSCLC underwent pulmonary resection by RVATS. For studies that included patients who had NSCLC as a subset of patients who had other pathological entities, results for patients who had NSCLC were extracted if possible. When centers have published duplicate trials with accumulating numbers of patients or increased lengths of follow-up, only the most updated reports were included for qualitative appraisal. It is acknowledged that criteria for patient selection for RVATS varied amongst institutions and sometimes within an institution in different time periods. All publications were limited to human subjects and in English language. Abstracts, case reports, conference presentations, editorials and expert opinions were excluded. Studies that included ten or less patients who underwent pulmonary resections by RVATS were also excluded.

### Data extraction and critical appraisal

Findings from initial scoping searches were used to decide outcomes for the present review. The primary outcomes included perioperative mortality and morbidity. Secondary outcomes included quality of life assessment, cost analysis, conversion rate, operating time, intraoperative blood loss, duration of chest drainage, duration of hospitalization, recurrence rate and long-term survival. All data were extracted from article texts, tables, and figures. Two investigators (C.C. and S.A.) independently reviewed each retrieved article. Discrepancies between the two reviewers were resolved by discussion and consensus. The final results were reviewed by the senior investigators (T.D.Y. and C.M.).

### Statistical analysis

Meta-analysis was performed by combining the results of reported incidences of any assessed outcomes in comparative studies. The relative risk (RR) was used as a summary statistic. $X^2$ tests were used to study heterogeneity between trials. $I^2$ statistic was used to estimate the percentage of total variation across studies, due to heterogeneity rather than chance. All statistical analysis was conducted with Review Manager Version 5.1.2 (Cochrane Collaboration, Software Update, Oxford, United Kingdom).

## Results

### Quantity of trials

A total of 393 records were identified through the five electronic database searches. After removal of duplicates and limiting the search to humans and English language, 317 articles remained to be screened. Exclusion of irrelevant studies resulted in 36 articles, which were retrieved for more detailed evaluation. Manual search of references identified three additional potentially relevant studies. After applying the selection criteria, 18 articles remained for assessment (9-26). A summary of these studies from 12

 

**Table 1** Summary of relevant studies identified in the present systematic review on robotic video-assisted thoracic surgery for pulmonary resections

| Institutions | Author | Reference Number | Publication year | Study period | Study type | n | Follow-up (months) |
|---|---|---|---|---|---|---|---|
| MSKCC, NY, USA | Park* | (9) | 2012 | 2002–2010 | ROS | 123 | 27 |
| Milan, Italy | | | | 2006–2010 | | 82 | |
| Pisa, Italy | | | | 2004–2010 | | 120 | |
| Milan, Italy | Veronesi | (10) | 2011 | 2006–2010 | ROS | 91 | 24 |
| Milan, Italy | Veronesi | (11) | 2010 | 2006–2008 | ROS | 54 | NR |
| Pisa, Italy | Melfi | (12) | 2008 | NR | ROS | 107 | NR |
| Pisa, Italy | Melfi | (13) | 2002 | 2001-2001 | ROS | 11 | NR |
| MSKCC, NY, USA | Park | (14) | 2008 | 2007–2007 | ROS | 12 | NR |
| MSKCC, NY, USA | Park | (15) | 2006 | 2002–2004 | ROS | 34 | NR |
| Birmingham, USA | Cerfolio* | (16) | 2011 | 2010–2011 | ROS | 168 | NR |
| Birmingham, USA | Cerfolio | (17) | 2011 | 2009–2010 | ROS | 62 | NR |
| Miami, USA | Dylewski* | (18) | 2011 | 2006–2010 | ROS | 200 | NR |
| Miami, USA | Ninan | (19) | 2010 | 2008–2009 | ROS | 76 | 10.2 |
| Goyang, Korea | Jang* | (20) | 2011 | 2009–2009 | ROS | 40 | NR |
| Innsbruck, Austria | Augustin* | (21) | 2011 | NR | ROS | 26 | 27 |
| Rochester, USA | Fortes* | (22) | 2011 | 2008–2010 | ROS | 23 | 7 |
| Chicago, USA | Giulianotti* | (23) | 2010 | 2001–2009 | ROS | 29 | 60 |
| Grosseto, Italy | | | | | | 9 | |
| Washington DC, USA | Gharagozloo* | (24) | 2009 | 2004–2008 | ROS | 100 | 32 |
| Washington DC, USA | Gharagozloo | (25) | 2008 | 2004–2007 | ROS | 61 | 28 |
| City of Hope, USA | Anderson* | (26) | 2007 | 2004–2006 | ROS | 21 | 9.8 |

ROS, Retrospective observational study. NR, not reported. *Updated study included for detailed analysis.

institutions are presented in *Table 1*. After selecting studies with the most updated data, nine reports were examined in detail, including 941 patients from 12 institutions.

## Surgical technique and patient selection

All nine studies selected for detailed analysis used the same master-slave robotic system (da Vinci, Intuitive Surgical, Sunnyvale, California). The majority of resections were lobectomies, but a smaller proportion of bilobectomies, pneumonectomies, sleeve lobectomies, segmentectomies and wedge resections were also performed. The number of ports used in each institution, as well as the size of the access port/incision used for specimen retrieval, varied between studies. Similarly, the number of lymph node stations dissected and the total number of lymph nodes removed differed between institutions. The majority of patients selected for pulmonary resection had a preoperative histological diagnosis of primary NSCLC with early clinical staging. Other indications for surgery included metastatic disease and carcinoid tumors. A summary of patient baseline characteristics and surgical details are presented in *Table 2*.

## Assessment of perioperative outcomes

The perioperative mortality rates ranged from 0 to 3.8%. Overall morbidity rates ranged from 10% to 39% and major morbidity rates ranged from 0 to 5% in three studies (9,20,26). The most commonly reported postoperative complications included tachyarrhythmias (3-19%) (9,16,18,21,22,24,26), prolonged air leak (4-13%) (16,18,20-24), pneumonia (1-5%) (18,24) and acute

 

**Table 2** Summary of surgical details and baseline characteristics of patients who underwent robotic video-assisted thoracic surgery

| Author | Age | Gender (Male) | Primary NSCLC | Staging^ | Resection type | | | | | Lymph nodes | | Access | Port |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | LR | BR | PR | SR | WR | Stations | Number | | |
| Park | 66 [30-87] | 63% | 325/325 | cI | 324 | 1 | 0 | 0 | 0 | 5 [2-8] | NR | < 8 cm | 3 or 4 |
| Cerfolio | 67 [21-87] | 45% | 168/168 | NR | 106 | 0 | 0 | 16 | 26 | 8 | 17 | >15 mm | 4 or 5 |
| Dylewski | 68 [20-92] | 45% | 125/200 | cIA | 160* | 4 | 1 | 35 | 0 | 5 [4-8] | NR | 2-4 cm | 4 |
| Jang | 64±10 | 58% | 40/40 | cI | 40 | 0 | 0 | 0 | 0 | 7 [2-10] | 22 [7-45] | 2-5 cm | 3 |
| Augustin | 65 [47-82] | 54% | 24/26 | cI | 26 | 0 | 0 | 0 | 0 | NR | NR | 5-7 cm | 3 |
| Fortes | 70 [51-86] | 48% | 16/23 | cI-II | 18 | 1 | 0 | 1 | 3 | 4 | 12 [2-50] | 2-3 cm | 3 or 4 |
| Giulianotti | 66 [16-78] | 50% | 24/38 | cI-II | 32 | 3 | 3 | 0 | 0 | NR | 8 [1-18] | 4-5 cm | 3 or 4 |
| Gharagozloo | 65±8 | 42% | 100/100 | cI-II | 100 | 0 | 0 | 0 | 0 | 4R; 5L | 12 ± 3 | 2-3 cm | 3 or 4 |
| Anderson | 67 [36-86] | 52% | 19/21 | cI | 14 | 2 | 0 | 5 | 1 | NR | 16 [2-58] | 3-4 cm | 4 or 5 |

*Includes 154 lobectomies, 3 sleeve lobectomies and 3 en bloc resection with lobectomies; ^Majority of patients; NR, Not reported. Resections types: LR, Lobectomy; BR, Bilobectomy; PR, Pneumonectomy; SR, Segmentectomy; WR, Wedge resection; R, Right-sided disease; L, Left-sided disease.

**Table 3** Summary of perioperative outcomes for patients who underwent robotic video-assisted thoracic surgery

| Author | Mortality | Morbidity | | | Conversion rate | Operating time (min) | Blood loss (mL) | Chest drain (days) | Length of stay (days) |
|---|---|---|---|---|---|---|---|---|---|
| | | Total | Major | Minor | | | | | |
| Park | 0.3% | 25% | 4% | 22% | 8.3% | 206 [110-383] | NR | 3 [1-23] | 5 [2-28] |
| Cerfolio^ | 0% | 26% | NR | NR | 11.9% | 132±60 | 30±26 | 1.5 [1-6] | 2 [1-7] |
| Dylewski | 1.5% | 26% | NR | NR | 1.5% | 175 [82-370] | 70 [25–500] | 1.5 [1-35] | 3 [1-44] |
| Jang | 0% | 10% | 0% | 10% | 0% | 240±62 | 219±123 | NR | 6 [4-22] |
| Augustin | 3.8% | 15% | NR | NR | 19.2% | 228 [162-375] | NR | 7 [3-15] | 11 [7-53] |
| Fortes | 0% | 39% | NR | NR | 4.3% | 238 [156-323] | 133 [0-2000] | 2 [1-12] | 3 [1-13] |
| Giulianotti | 2.6% | 11% | NR | NR | 15.8% | 209±66 | NR | NR | 10 [3-24] |
| Gharagozloo | 3% | 21% | NR | NR | 1% | 216±27 | NR | NR | 4 [3-42] |
| Anderson | 0% | 29% | 5% | 33% | 0% | 216 [60-384] | 100 [2-600] | 2 [1-5] | 4 [2-10] |

NR, Not reported; ^62 patients excluded from analysis by author due to conversion (n=13), irresectable disease (n=7) or sublobar resections (n=42).

respiratory distress (1-4%) (16,22-24). The conversion rates from RVATS to open thoracotomy ranged from 0 to 19.2%. Average operating time varied between 132 to 238 minutes, whilst blood loss ranged from 30 to 219 mL. The median length of hospitalization was from 2 to 11 days and the duration of chest drainage was 1.5 to 7 days. A summary of perioperative outcomes are presented in *Table 3*. Jang *et al*. conducted a three-arm retrospective study comparing 40 patients who underwent RVATS to 40 patients who underwent conventional VATS at the beginning of their institutional experience and 40 patients who underwent conventional VATS after two years of experience, performed by the same surgeon. Their results indicated superior perioperative outcomes for RVATS compared to the first 40 patients who underwent conventional VATS, with fewer complications, shorter hospital stays and lower conversion rates. However, RVATS resulted in similar perioperative outcomes when compared to 40 patients who underwent conventional VATS after 2 years of surgical experience (20). Two retrospective propensity-score analyses comparing

 

| Study or Subgroup | RVATS Events | RVATS Total | Open Thoracotomy Events | Open Thoracotomy Total | Weight | Risk Ratio M-H, Random, 95% CI |
|---|---|---|---|---|---|---|
| Cerfolio 2011 | 28 | 106 | 120 | 318 | 80.0% | 0.70 [0.49, 0.99] |
| Veronesi 2010 | 11 | 54 | 10 | 54 | 20.0% | 1.10 [0.51, 2.37] |
| **Total (95% CI)** | | **160** | | **372** | **100.0%** | **0.77 [0.54, 1.09]** |
| Total events | 39 | | 130 | | | |

Heterogeneity: Tau² = 0.01; Chi² = 1.10, df = 1 (P = 0.29); I² = 9%

Test for overall effect: Z = 1.47 (P = 0.14)

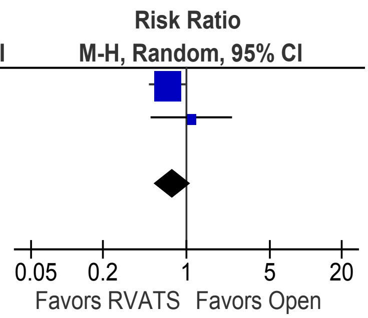


**Figure 1** Forest plot of the relative risk (RR) of postoperative morbidity after robotic video-assisted thoracic surgery (RVATS) versus open thoracotomy for patients with early-stage non-small cell lung cancer. The estimate of the RR of each trial corresponds to the middle of the squares, and the horizontal line shows the 95% confidence interval (CI). On each line, the numbers of events as a fraction of the total number randomized are shown for both treatment groups. For each subgroup, the sum of the statistics, along with the summary RR, is represented by the middle of the solid diamonds. A test of heterogeneity between the trials within a subgroup is given below the summary statistics

**Table 4** Summary of long-term survival and recurrence outcomes for patients who underwent robotic video-assisted thoracic surgery for non-small cell lung cancer

| Author | 5-year survival | Overall recurrence | Local recurrence | Systemic recurrence | Both local and systemic |
|---|---|---|---|---|---|
| Park | 80% | 9.8% | 2.8% | 5.2% | 1.8% |
| Cerfolio | NR | NR | NR | NR | NR |
| Dylewski | NR | NR | NR | NR | NR |
| Jang | NR | NR | NR | NR | NR |
| Augustin | 63.6% | 7.7% | 3.8% | 0% | 3.8% |
| Fortes | NR | 0% | 0% | 0% | 0% |
| Giulianotti | 71.4% | 4.8% | 0% | 4.8% | NR |
| Gharagozloo | NR | 6% | 0% | 6% | 0% |
| Anderson | NR | NR | 0% | NR | NR |

NR, Not reported.

RVATS with open thoracotomy for patients with early-stage NSCLC were reported (11,16). A meta-analysis of these two comparative studies assessing perioperative morbidity outcomes identified a trend favoring RVATS compared to conventional thoracotomy (24% *vs*. 35%, P=0.14), as shown in *Figure 1*. The length of hospitalization was significantly shorter after RVATS compared to propensity-matched patients who underwent open thoracotomy in both studies. However, RVATS consistently required a significantly longer operative time.

### Assessment of overall survival and recurrence

Survival was calculated from the date of surgery. Of the three studies that presented data on long-term survival for patients with malignant disease, the overall 5-year survival rates ranged from 64% to 80% (9,21,23). An additional study reported an overall survival of 99% after a median follow-up of 32 months (24). Overall recurrence ranged from 0% to 9.8%, including 0% to 4.8% local recurrence, 0% to 6% systemic recurrence, and 0% to 3.8% for both local and systemic recurrence at the time of the latest follow-up. These outcomes are summarized in *Table 4*.

### Assessment of costs

Park and Flores conducted the only cost analysis to date, comparing conventional VATS (n=87) to RVATS (n=12) to open thoracotomy (n=269) in a retrospective study (14). All direct and indirect expenditures were included to calculate the average hospitalization costs, and the surgeon's fee was added to calculate the overall cost. This study reported that RVATS was on average $3,981 more expensive than conventional VATS, but $3,988 cheaper than open thoracotomy. After taking into account the amortized cost of employing the robot for each case, an additional $1,715 was required for each patient who underwent RVATS. The increased cost of RVATS compared to conventional VATS occurred almost exclusively on the first day of hospitalization, the reasons for which remained uncertain. Suggested explanations included additional robotic-related equipment and increased likelihood of performing additional procedures, such as bronchoscopy and adhesiolysis. The main factor in reducing the costs of VATS and RVATS compared to thoracotomy was the reduced length of hospitalization.

### Assessment of quality of life

Cerfolio *et al*. reported a quality of life assessment in their propensity-score analysis involving 106 patients with NSCLC who successfully underwent RVATS lobectomy and 318 patients who underwent rib- and nerve-sparing thoracotomy (16). The participants were given the 12-item Short Form Health Survey (SF-12) with supplemental questions about analgesic control at 3 weeks and 4 months postoperatively. Results of this study reported a significantly higher mental QoL score for the RVATS cohort at 3 weeks postoperatively (53.5 *vs*. 40.3, P<0.001) and a similar trend favoring RVATS for physical QoL score at the same time interval (40.1 *vs*. 34.1, P=0.07). However, both the mental and physical QoL scores were similar between the two groups at 4 months postoperatively. Pain scores out of 10 was also significantly lower in the RVATS group at 3 weeks (2.5 *vs*. 4.4, P=0.04). The authors of this study conceded that patients were informed that RVATS was a ‘new and less invasive’ technique, which may have contributed to bias in their reporting.

## Discussion

Since the first case-series report on pulmonary resection by RVATS was published in 2002, a number of studies have demonstrated the feasibility of this novel technique with encouraging results (13). Advantages of RVATS compared to conventional VATS include the additional four degrees of freedom (internal pitch, internal yaw, rotation and grip), the elimination of the fulcrum effect, superior 3-D vision from binocular camera, reduced human tremor and improved ergonomic position for the surgeon (12). With these technological improvements, RVATS has the potential to allow more complex procedures such as sleeve lobectomies and chest wall resections to be performed, where conventional VATS might fail (17,27). Indeed, many advocates of RVATS consider it as the leading edge of the swinging pendulum in the paradigm shift towards minimally invasive thoracic surgery (9). On the other hand, critics of RVATS cite the lack of tactile feedback, personnel and cost commitments, as well as prolonged operating time as significant disadvantages of this surgical technique.

The present systematic review identified nine updated retrospective observational studies, mostly from institutions in the United States and Italy involving patients with early-stage NSCLC who underwent lobectomy procedures. These studies reported comparable perioperative outcomes to the results of a recent systematic review on conventional VATS (4). The most common postoperative complications from RVATS, such as tachyarrhythmia, prolonged air leak, pneumonia, and acute respiratory distress, were similar to complications identified for conventional VATS (3). A meta-analysis involving two propensity-score analyses revealed a trend towards fewer complications after RVATS compared to open thoracotomy for selected patients with early-stage NSCLCs. Unfortunately, robust long-term oncologic outcomes such as 5-year survival and disease recurrence rates for patients with malignancies are relatively scarce, with only one small case-series reporting follow-up of more than three years (23). Finally, there is limited but important evidence suggesting superior outcomes in cost and quality of life for selected patients who underwent RVATS compared with propensity-matched patients who underwent open thoracotomy (11,16).

The effect of a steep learning curve for RVATS has been well documented. Perioperative outcomes such as operating time and conversion rates have been shown to significantly improve after the initial learning period. A study by Veronesi estimated the number of operations considered necessary to attain adequate skill in RVATS to be approximately twenty, which is supported by two other institutional experiences (10,13,24). Melfi pointed out that early experiences in RVATS were disadvantaged by a lack of standardized surgical techniques, limited training opportunities, as well as underdevelopment of robotic instrumentation (12). The importance of specialized training for scrub nurses and anesthetists were also highlighted in other studies (12,17). Results from the present systematic review identified the studies with the highest conversion rates (21,23) and operating times (21) were from institutions with fewer than thirty reported cases. This suggests that perioperative outcomes are likely to improve in specialized centers after the initial steep learning curve period. Similarly, these findings may advocate that RVATS should only be performed in tertiary high-volume referral centers with an adequately trained and specialized team of RVATS staff.

A number of limitations exist in the present systematic review. Firstly, it should be acknowledged that publication bias is inherently associated with novel surgical techniques, and unpublished outcomes may differ to the results reported from the selected tertiary centers. Secondly, patient inclusion in each institution was highly selective and variable, and results should be interpreted with caution in view of a lack of randomized-controlled trials comparing RVATS to conventional VATS or open thoracotomy. In addition, many studies presented surgical outcomes without standardized definitions or an intention-to-treat analysis. Examples include the variable definition of 'conversion rates', morbidity outcomes, and the exclusion of patients with extensive disease or those who required conversion from statistical analysis. For example, Giulianotti *et al*. reported one of the highest conversion rates from RVATS to open thoracotomy (6/38, 15.8%) (23). However, three of these conversions were decided after exploratory thoracoscopy and before the robot was docked. In contrast, the multi-institutional report by Park *et al*. reported a conversion rate of 8.3%, with a definition of 'conversion' as the use of open thoracotomy after docking the robot to the patient and initiation of robotic dissection (9). Finally, Cerfolio and colleagues excluded all patients who had conversions (13/168) and those who had metastatic pleural disease (n=7) in their propensity-score analysis comparing RVATS to open thoracotomy (16). Inconsistent reporting of morbidity outcomes was also evident, with only three studies presenting data according to standardized morbidity definitions (9,16,20).

Overall, the current literature suggests that minimally invasive pulmonary resections by RVATS is feasible and can be performed safely for selected patients in specialized centers. However, important questions remain to be answered. Long-term oncologic efficacy compared to open thoracotomy for patients with NSCLC remains to be seen, and the perioperative superiority of RVATS compared to conventional VATS, which is now performed in many centers at a significantly lower cost, is thus far unconvincing. Until such evidence is presented in the form of well-designed randomized controlled trials or a large multi-institutional registry, the role for RVATS will continue to be questioned. Nonetheless, proponents of RVATS highlight the indirect benefits of robotic technology in encouraging the thoracic community to accept and adopt minimally invasive surgery in general (17). Future studies should aim to present long-term follow-up data and use clearly defined surgical outcomes in the form of an intention-to-treat analysis.

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# Robotic lobectomy for non-small cell lung cancer (NSCLC): Multi-center registry study of long-term oncologic results

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## Introduction

Minimally invasive video-assisted thoracic surgery (VATS) lobectomy has proven to be feasible and oncologically acceptable for non-small cell lung cancer (NSCLC) and a number of other conditions. Multiple studies have demonstrated clear benefits of VATs over a traditional thoracotomy approach, such as decreased length of stay, decreased short-term postoperative pain and fewer complications (1-4). Despite this, however, a VATS approach to anatomic resection is still not the current standard and is only slowly being implemented more widely. The explanation is likely multifactorial including: (I) technical issues, such as two-dimensional imaging and limited maneuverability of instrumentation; (II) lack of adequate training; and (III) concerns about the consequences of major vascular injury with a closed chest approach.

In order to address the perceived technical limitations of conventional minimally invasive platforms a master-slave robotic surgical system was developed (da Vinci Surgical System, Intuitive Surgical, Sunnyvale, California). The major advantages were in the three-dimensional visual system that re-establishes binocular vision and instrumentation capable of seven degrees of freedom enabling wristed movement for dissection. The initial intent for this robotic system was for use in closed chest coronary surgery, but this has not eventuated. Instead, the major applications have been for pelvic procedures, such as prostatectomy and hysterectomy. Use of robotics for general thoracic surgical procedures dates back to initial case reports in the early 2000's, but it was not until 2004 and 2006 that actual series of robotic lobectomies were reported by Melfi and colleagues and Park and coauthors, respectively (5,6). These centers reported the initial technique and experience demonstrating feasibility and concordance of outcomes with the largest series of VATS lobectomies. However, long-term data are lacking in a larger cohort of patients.

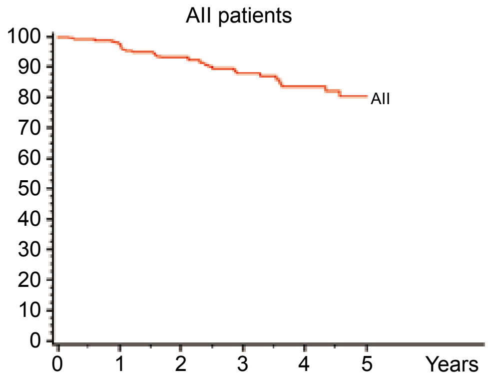
## Rationale and methods

Early in the development of thoracic robotic surgery it was clear that there were only a handful of centers throughout the world utilizing robotics for major pulmonary resection. In order to evaluate a large cohort of patients that underwent robotic lobectomy to analyze both the perioperative and long-term survival results a multicenter retrospective registry was created using prospectively collected data from the thoracic surgery divisions of three institutions active in robotic pulmonary resection: Memorial Sloan-Kettering Cancer Center, New York, New York, USA, The European Institute of Oncology, Milan, Italy and Ospedale Cisanello, Pisa, Italy. Eligible patients were those with biopsy-proven or suspected primary NSCLC isolated to the chest who subsequently underwent attempted robotic lobectomy for primary NSCLC. Patients with carcinoid tumor, small cell lung cancer, benign or metastatic lesions were excluded. Information regarding preoperative characteristics, operative details, hospital course, pathologic findings and postoperative follow-up were recorded prospectively and sent to one institution (Milan) for analysis.

## Techniques of robotic lobectomy

One of the strengths of the study was that the patient selection and surgical approach was virtually uniform despite the retrospective design. The majority of patients had clinical early stage disease with no prior treatment, and patients gave informed consent to undergo robotic

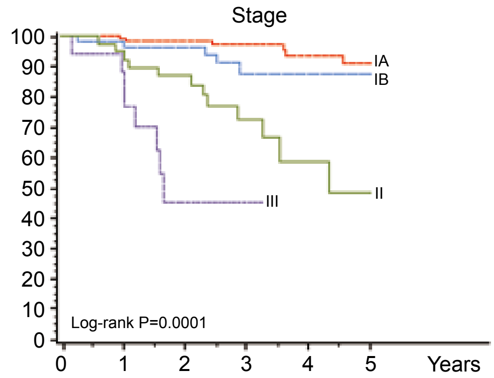



| N° at risk | | | | | |
|---|---|---|---|---|---|
| 325 | 248 | 174 | 101 | 62 | 38 |

**Overall Survival (95% CI)**

| 1-year | 2-year | 3-year | 5-year |
|---|---|---|---|
| 98 (96-99) | 93 (90-96) | 88 (83-93) | 80 (73-88) |

**Figure 1** Overall survival for the group.




| N° at risk | | | | | | |
|---|---|---|---|---|---|---|
| IA | 176 | 143 | 105 | 64 | 41 | 27 |
| IB | 72 | 52 | 37 | 22 | 15 | 6 |
| II | 54 | 36 | 28 | 14 | 6 | 5 |
| III | 20 | 15 | 2 | 1 | – | – |

**Overall Survival (95% CI)**

| | 1-year | 2-year | 3-year | 5-year |
|---|---|---|---|---|
| IA | 99 (98-100) | 99 (97-100) | 97 (94-100) | 91 (83-99) |
| IB | 97 (93-100) | 97 (93-100) | 88 (77-98) | 88 (77-98) |
| II | 96 (90-100) | 87 (76-98) | 72 (56-88) | 49 (24-74) |
| III | 89 (75-100) | 43 (16-69) | 43 (16-69) | – |

**Figure 2** Overall survival for stage-specific survival.

surgery. Each surgeon performed robotic lobectomy employing a technique that conformed to the CALGB 39802 consensus criteria for VATS lobectomy (7): use of non-rib-spreading incisions with a 3-4 cm utility incision, videoscopic guidance and traditional hilar dissection. Two of the surgeons employed a total of 4 incisions while the third used 3 incisions, and all phases of dissection were performed with robotic instrumentation. Patients underwent systematic hilar and mediastinal lymph node dissection. Operative times were measured from first incision to closure, and conversion was defined as use of a rib-spreading thoracotomy at any point after docking of the robot to the patient and initiation of robotic dissection.

## Results

From November 2002 through May 2010 325 patients underwent robotic lobectomy for primary NSCLC at three centers. Sixty-three percent of the patients were male and 85% were former or current smokers. Fifty-one percent of the procedures were upper lobectomies (92 RUL, 75 LUL), and 40% were lower lobectomies (71 RLL, 57 LLL). The majority of cases were subtypes of adenocarcinoma (73%), and most patients were clinical stage I (247 IA, 63 IB) and had no preoperative therapy.

Median operative time was 206 minutes, ranging from 110 to 383 minutes. There were no intraoperative deaths and the conversion rate to thoracotomy was 8% (27/325). Three patients (0.9%) had conversion for minor bleeding that did not require intraoperative or postoperative transfusion. Overall morbidity rate was 25.2% (82/325), and 12 patients had major complications (3.7%), including bronchopleural fistula (2), pulmonary embolism (3), acute renal insufficiency (3), hemorrhage (2) and myocardial infarction (2). Supraventricular tachycardia was the most common postoperative complication, occurring in 37 patients (11.4%). Median chest tube duration was 3 days (range, 1-23 days) and length of stay was 5 days (range, 2-28 days). There was one in-hospital death in a patient that developed acute renal insufficiency followed by a pulmonary embolism and death on postoperative day 12, with a mortality rate of 0.3%.

Seventy-six percent (248/325) of patients were pathologic stage I (176 IA, 72 IB), and 68 (21%) patients were upstaged. The median tumor size was 2.2 cm (range, 0.7-10.2 cm) and the median number of lymph node stations dissected was 5 (range, 2-8). Sixty-one patients (19%) had metastatic nodal disease and 67 patients received adjuvant cytotoxic chemotherapy. At a median follow-up of 27 months 280 patients (86%) were without evidence of disease and 32 patients (10%) had recurred with 25 dead of their disease. The majority (72%) were distant (17 distant only, 6 locoregional + distant) and 28% (9/32) were locoregional only. Overall 5-year survival for the group was 80% (*Figure 1*) and stage-specific survival is shown in *Figure 2*.

## Impact and significance

This study is important for several reasons. First, it is the largest experience of totally robotic lobectomies reported to date. Previous initial feasibility studies had small numbers of patients, and like those this report shows perioperative results consistent with large VATS lobectomy experiences with short chest tube duration and length of stay, as well as low major morbidity (3.7%) and in-hospital mortality (0.3%) rates. Second, it is a multicenter, international experience with one center in the United States and two in Italy employing similar patient selection criteria, surgical technique and prospective evaluation of perioperative and long-term outcome. This demonstrates not only feasibility of the technique, but reproducibility as well. Third, this report is the first to look at the long-term oncologic outcome of robotic lobectomy for early NSCLC. The overall and stage-specific survivals are consistent with both the largest series of VATS lobectomies and the most recent data used for the revisions to the lung cancer staging system.

There are, however, limitations of this study and questions regarding the role of robotic technology in thoracic surgery. As this is a retrospective review, there are inevitable biases in patient selection and unknown differences between centers despite the fact that the patient characteristics and surgical techniques appear similar. Another limitation is the lack of other short- and long-term outcome measures, such as postoperative pain, respiratory function, rates of post-thoracoscopy pain and quality of life. Lastly, a comparative arm of VATS and/or thoracotomy patients is lacking. If utilization of robotic technology for thoracic surgical procedures increases, it will be important for future studies to attempt to discern differences between robotic and non-robotic approaches (VATS and thoracotomy) with respect to important outcomes, such as postoperative pain, quality of life and cost.

Robotic lobectomy is a feasible, safe and oncologically sound surgical treatment for early-stage lung cancer. The technique is reproducible across multiple centers and yields results consistent with the best seen with conventional VATS. It should not be considered experimental, but an accepted minimally invasive thoracic surgical technique. Future evaluation of differences between robotic versus VATS versus thoracotomy approaches to thoracic diseases is warranted.

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# Perspectives on robotic pulmonary resection: It's current and future status

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## Current status of robotic pulmonary resection

Currently robotic pulmonary resection, as described in the previous chapter by Dr. Parks, is performed in select centers in the United States, Europe, and other parts of the world. It still represents less than 1% of how pulmonary resections are performed, with the main reason relating to the limited platform availability of the robot to thoracic surgeons. A few hospitals have robots, and are mostly used by urologists and gynecologic surgeons. However, thoracic surgeons are using it more frequently. In fact, recent data from Intuitive Surgical suggests that the greatest growth in robotic use over the past year is by thoracic surgeons.

There are several ways to perform robotic pulmonary resections including completely portal robotic lobectomy; meaning only trocars are placed through the incisions. An international writing committee has submitted a suggested nomenclature for robotic pulmonary resection. In this yet to be published article, completely portal is abbreviated as CPR and robotic assisted is abbreviated as RA. This nomenclature differentiates the different ways to perform robotic pulmonary resection. The important point is that the robot has now been used on almost a thousand patients to safely perform pulmonary resections and provides a minimally invasive surgical method.

A few of the advantages of the robot over VATS are obvious and they include: improved visualization, improved instrumentation that provide the surgeon more degrees of movement, better lymph node visualization and dissection, the ability to teach using a dual console, and the simulator. However, a few disadvantages include: limited platform availability as well as the capital and maintenance costs and expensive software incurred with the robot. An additional drawback is the fact that instruments have to be replaced after 10-20 uses based on whether they are 5 or 8 mm respectively. Finally, a complete portal approach does not allow the surgeon to palpate the lung whereas a robotic-assisted approach (such as VATS) allows the surgeon to feel the outer one-third of the lung.

Obviously, the enthusiasm for the robot has stemmed from its success in mediastinal resections and esophageal resections. Although this textbook is limited to pulmonary resections, we would be remiss and incomplete if we did not mention the success the robot has had in the mediastinum and esophagus for both malignant and benign esophageal lesions. This is a main reason why the thoracic surgeon has extended the use of the robot for pulmonary resection.

## Future status of robotic pulmonary resection

The future of robotic surgery is exciting. There are several technical problems with robotic pulmonary resection. The primary limitation is the fact that the bedside assistant is placing the stapler on the pulmonary arteries and pulmonary veins. A robotic stapler that can be controlled by the surgeon is almost ready for release (planned release date is mid-June 2012).

Perhaps the most important instrument that will be released in the next year is a robotic vessel sealer, which is similar to the robotic harmonic scalpel but is a wristed instrument. This vessel sealer will allow the surgeon to go through the fissure, to seal and cut small pulmonary arteries and veins that are 7 mm or smaller and to seal the base of lymph nodes. Some surgeons are currently using the robotic

Harmonic scalpel for lymph node dissections during VATS or robotic surgery. However, the edges of this instrument are extremely hot and can damage surrounding tissue.

Another exciting instrument that has just made its way to the market in March 2012 is the robotic suction irrigator. It is a major advance that allows the surgeon to control both the suction and irrigation in the operative field. It can also be used for blunt dissection.

A promising area that the robot provides exclusively is the use of fluorescence of tissue. A special robotic camera can be placed into the operative field and allows the surgeon to view the tissue in a different color. Currently, indigotine (Indigo carmine) is the fluorescence agent of choice. It is given intravenously to the patient and by a specialized robotic camera the surgeon views vascularized tissue as green in the monitor and non-vascularized tissue as brown. Its current clinical usefulness is during partial nephrectomy by the urologist. However, we envision a more sophisticated use of the fluorescence of tissue. The ability to tag specific antigens such as Thymic ones, may allow the thoracic surgeon to be able to see the difference between thymus gland and the surrounding fat using the da Vinci monitor and the specialized camera. Fluorescence may also be able to help identify small pulmonary nodules that are embedded in the deep pulmonary parenchyma.

Other new techniques are being developed to help find small pulmonary nodules. These include placing magnetic coils or clips into or near small pulmonary nodules or by placing seeds or clips that emit a very low level of radiation. Specialized instruments are then hooked to the robotic arms that guide the surgeon to the nodule in question even though it cannot be seen or palpated.

There are many obstacles to adoption of the robot. The most important one is the lack of standardized credentialing. Some surgeons often try to perform pulmonary resections before the surgeons and/or their surgical teams have mastered easier robotic operations such as mediastinal tumor resection or lymph node biopsy. It is our belief there should be a standardized pathway or progression toward credentialing (1). This stepwise progression starts with inanimate object training, followed by on-line credentialing, followed by cadaver work, followed by the performance of level one surgical operation such as removal of small mediastinal tumors and lymph node biopsies. After 2 or 3 of these have been performed, level two operations should be performed next. These include wedge resection of the lung for interstitial lung disease and the enucleation of benign esophageal tumors. Once the team and the surgeon are comfortable with level I and II operations, the more complicated pulmonary lobectomy and pulmonary segmentectomy can be attempted. It is important to note that the credentialing may be required not only for the surgeon but rather the entire surgical team. Surgeon credentialing should apply to various surgical operations and not to all chest operations, i.e. a surgeon may be capable of safely performing a robotic wedge resection, but the surgeon may not be capable of safely performing a robotic lobectomy. All these issues need to be further addressed and resolved at a national level.

There have been several robotic surgeons who have misrepresented robotic surgery and had marginal results. Credentialing currently is not promulgated by a national board and is essentially in the hands of individual hospitals. This has led to misinterpretation, confusion, and some controversy. Clearly, a consensus statement from the STS, AATS, and ESTS is needed on credentialing for robotic surgery. Other impediments to adoption include the cost of buying a robot, the fee for maintenance of robot and its equipment and the limited platform availability to the thoracic surgeon.

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# Open, thoracoscopic and robotic segmentectomy for lung cancer

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**Abstract:** While lobectomy is the standard procedure for early stage lung cancer, the role of sublobar resection is currently under investigation for selected patients with small tumors. In this review, studies reporting outcomes on open, thoracoscopic and robotic segmentectomy were analyzed. In patients with stage I lung cancer, with tumors <2 cm in diameter and within segmental anatomic boundaries, segmentectomy appears to have equivalent rates of morbidity, recurrence and survival when compared to lobectomy. Segmentectomy also resulted in greater preservation of lung function and exercise capacity than lobectomy. It appears reasonable to consider segmentectomy for patients with stage I lung cancer (particularly in air-containing tumors with ground glass opacities) where tumors are <2 cm in diameter and acceptable segmental margins are obtainable, especially in patients with advanced age, poor performance status, or poor cardiopulmonary reserve. The results of two ongoing randomized controlled trials (CALGB 140503 and JCOG0802/WJOG4607L) and additional well-designed studies on open, thoracoscopic, and robotic segmentectomy will be important for clarifying the role of segmentectomy for lung cancer.

**Keywords:** Lung cancer surgery; minimally invasive surgery; thoracoscopy/video-assisted thoracoscopic surgery (VATS); segmentectomy

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## Introduction

The first segmentectomy, a lingulectomy, was performed by Churchill and Belsey in 1939 for the treatment of bronchiectasis (1). Over the subsequent decades, segmentectomy was increasingly applied to small primary lung cancers (2,3). However in 1995, the Lung Cancer Study Group (LCSG) performed a randomized controlled trial of lobectomy versus limited resection for T1 N0 non-small cell lung cancer (NSCLC) and found that limited pulmonary resection for tumors <3 cm in size resulted in increased locoregional recurrence compared to lobectomy (4). Subsequently in North America, the use of segmentectomy for NSCLC was generally limited to patients with marginal cardiopulmonary function (5).

The LCSG trial is the only randomized controlled trial of lobectomy versus limited resection for lung cancer to date, and is indeed a landmark study. However, it enrolled patients from 1982-1988 (4) and the landscape of thoracic oncology has changed considerably. Since then, there have been new developments leading to renewed interest in segmentectomy for small primary lung cancer tumors (5). Firstly, there is now strong evidence that low-dose computed tomography (LDCT) screening in high-risk patients reduces lung cancer deaths. Importantly, the screening protocols have identified greater numbers of smaller lung tumors (<2 cm), which are more frequently operable and curable (6,7). Of note, the LCSG trial did not specifically assess the effect of lobectomy versus segmentectomy on smaller tumors, as 30% of patients in that study had tumors that were larger than 2 cm (4). Secondly, since 1995, newer staging modalities have emerged which will likely improve patient selection for anatomic lung resection (4). Thirdly, surgeons have advanced the fields of video-assisted thoracoscopic surgery (VATS) and robotic surgery, with increasing experience at applying those approaches to segmentectomy. These new developments have led to a growing number of studies investigating the use of open, minimally invasive and robotic segmentectomy for carefully selected patients with smaller tumors less than 2 cm in size, especially in patients with marginal cardiopulmonary function (5).

A previous review of these studies demonstrated that when compared to thoracoscopic lobectomy, thoracoscopic segmentectomy had equivalent rates of morbidity, recurrence and survival in selected patients (5). When compared to open segmentectomy, thoracoscopic segmentectomy was found to have equivalent oncologic results, with shorter length of stay, reduced rates of morbidity, and lower cost. There have since been additional studies on segmentectomy, including further reports on uniportal and robotic approaches. This review is an update on the current role of segmentectomy and will focus on the most relevant recent studies on open, minimally invasive and robotic segmentectomy for lung cancer.

## Open segmentectomy *vs.* open lobectomy

Since the LCSG study, although there have been no new randomized trials, there have emerged several retrospective studies comparing open segmentectomy to open lobectomy (8). In contrast to the LCSG trial, which enrolled patients from 1982-1988 and included 30% of patients with tumors >2 cm, these studies reflected a more current medical and surgical practice, and focused on examining the role of segmentectomy for tumors >2 cm in diameter. These studies reported similar outcomes and have found no significant differences in morbidity, mortality, locoregional recurrence or survival between segmentectomy and the lobectomy (8).

Most of these studies had groups well-matched for pulmonary function, but an important limitation of these studies is that many did not include information on preoperative co-morbidities. Three recent retrospective studies on segmentectomy *vs.* lobectomy did however include preoperative comorbidities and pulmonary function tests in their analysis. In 2011, Schuchert and colleagues compared the results of 107 patients undergoing resection for stage IA NSCLC (≤1 cm) via lobectomy (n=32), segmentectomy (n=40) or wedge resection (n=35) (9). Preoperative forced expiratory volume in 1 second (FEV1) was significantly lower in the sublobar resection (segmentectomy, wedge) groups compared with the lobectomy group; but age, sex distribution, tumor size, histology and preoperative comorbidities were similar between groups. Mean follow-up was 42.5 months and there was no statistically significant difference in overall disease recurrence or estimated 5-year disease-free survival (lobectomy, 87%; segmentectomy, 89%; wedge, 89%; P>0.402). While the authors note that a VATS approach was used more often than an open approach (57% *vs.* 43%) they did not specifically study the effects of open *vs.* VATS approach on outcomes.

Carr and colleagues conducted a retrospective study comparing the outcomes of 429 patients undergoing resection of stage I NSCLC via lobectomy or anatomic segmentectomy (10). The segmentectomy group (n=178) was older and had more co-morbidities—more likely to have coronary artery disease (18.5% *vs.* 12.8%, P=0.036) or chronic obstructive pulmonary disease (26.4% *vs.* 14.4%, P=0.0001)—than the lobectomy group (n=251). The segmentectomy group also had worse pulmonary function than the lobectomy group (FEV1 81.1±17.6 *vs.* 71.8±25.6, P=0.02). The authors found no difference in 30-day mortality (1.1% *vs.* 1.2%), recurrence rates (14.0% *vs.* 14.7%, P=1.00), or 5-year cancer-specific survival (T1a: 90% *vs.* 91%, P=0.984; T1b: 82% *vs.* 78%, P=0.892) when comparing segmentectomy and lobectomy for pathologic stage IA non-small cell lung cancer, when stratified by T stage. Of note, this study included patients who underwent both open and VATS approaches, and an open approach was used less often with segmentectomy than with lobectomy (41% *vs.* 60.6%, P=0.0001). The authors did not specifically evaluate outcomes by type of approach.

With regard to the role of open segmentectomy in the elderly, Kilic and colleagues conducted a retrospective review of 78 patients >75 years of age who underwent segmentectomy *vs.* lobectomy for stage 1 NSCLC. The segmentectomy group included more patients with chronic obstructive pulmonary disease (COPD) and diabetes. The tumors were significantly larger in the lobectomy group (3.5 *vs.* 2.5 cm, P<0.0001). The authors found no significant difference in 5-year disease-free survival between segmentectomy and lobectomy (11). Outcomes associated with an open *vs.* VATS approach were not specifically evaluated.

In addition to the single-institution retrospective studies described above, there has been one population-based study of open segmentectomy and lobectomy for stage I NSCLC. In 2011, Whitson and colleagues analyzed 14,473 patients undergoing anatomic segmentectomy or lobectomy for stage I NSCLC derived from the Surveillance Epidemiology and End Results (SEER) database. The authors were unable to stratify by open or VATS approach, but presumably most of the operations were performed open. Lobectomy was demonstrated to be associated with improved overall ($P<0.0001$) and cancer-specific ($P=0.0053$) 5-year survival compared with segmentectomy. After adjusting for tumor size, this improvement in survival remained. However, it is difficult to draw specific conclusions from this study because, in addition to its retrospective nature, the study did not have data on patient preoperative co-morbidities and pulmonary function—important variables which may have significantly affected both procedure selection and postoperative outcomes.

## Advantages of open segmentectomy *vs.* open lobectomy

Since the 1995 LCSG randomized trial, there have been numerous retrospective studies that have shown that there are no differences in recurrence and survival between open segmentectomy and open lobectomy, even in patients with greater co-morbidities and worse pulmonary function (10), patients older than 75 years of age (11), and patients with larger tumors between 2 and 3 cm in size (10). Furthermore, in one study, open segmentectomy was found to preserve postoperative pulmonary function at 90%±12% of preoperative levels (12). There is one recent population-based analysis which found that patients undergoing anatomic segmentectomy had a decreased survival rate when compared to those undergoing lobectomy for stage I NSCLC. However, this study did not include information about patient comorbidities or cardiopulmonary function; patients in segmentectomy could have had reduced cardiopulmonary function, greater co-morbidities or other factors that affected survival.

## Advantages of segmentectomy *vs.* wedge resection

With regard to the outcomes of patients undergoing an open segmentectomy versus wedge resection for stage I NSCLC, multiple reports show a decreased risk of recurrence and equivalent or improved survival in patients undergoing open segmentectomy compared to those undergoing wedge resections (8). When compared with the wedge resection, segmentectomy has also been shown to be associated with a larger parenchymal margin (13,14), a higher yield of lymph nodes and rate of nodal upstaging (14), and reduced risk of locoregional recurrence (15). Based on these studies, segmentectomy would be the preferred procedure for patients considering sublobar resection.

### Predictors for prognosis and recurrence

With regard to predictors for prognosis and recurrence for patients with NSCLC who underwent segmentectomy, Koike and colleagues found age >70 years, gender (male), >75% consolidation/tumor ratio on high-resolution CT, and lymphatic permeation to be independent poor prognostic factors, and lymphatic permeation to be an independent predictor for recurrence (16). Yamashita and colleagues found KI-67 proliferation index to be a predictor of early cancer death (17). Traibi and colleagues have also shown male gender, FEV1 ≤60% and open (as opposed to VATS) surgery to be risk factors for postoperative complications (18).

In 2013, Koike and colleagues reported risk factors for locoregional recurrence and survival in patients undergoing sublobar resection (patients who underwent segmentectomy or wedge resection in the analysis) (15). They found four independent predictors of locoregional recurrence: wedge resection, microscopic positive surgical margin, visceral pleural invasion, and lymphatic permeation. Independent predictors of poor disease-specific survival were smoking status, wedge resection, microscopic positive surgical margin, visceral pleural invasion, and lymphatic permeation.

## Thoracoscopic segmentectomy *vs.* open segmentectomy

Since the 1995 LCSG randomized trial, there have been significant advancements in thoracoscopic surgical techniques, including a better understanding of the potential advantages of the thoracoscopic lobectomy and segmentectomy for anatomic pulmonary resection (5). The studies included in the present review will use the definition of thoracoscopic segmentectomy as the completion of sublobar anatomic pulmonary resection, with individual vessel ligation and without the use of a utility thoracotomy, retractors or rib-spreading (5). Studies using a "hybrid" segmentectomy with mini-thoracotomy fall into the category of open surgery and are not included in this section.

The first retrospective study comparing outcomes of thoracoscopic and open segmentectomy was performed by Shiraishi and colleagues in 2004 (19). The authors selected patients with clinical stage IA peripheral tumors (<2 cm) and reviewed the outcomes of 34 patients who underwent VATS segmentectomy versus 25 who underwent open segmentectomy. They found no significant differences in postoperative complications and perioperative deaths. Long-term survival was not evaluated in this study.

In 2007, Atkins and colleagues conducted a retrospective study comparing the results of 48 patients who underwent VATS versus 29 who underwent an open approach (20). The authors found no significant differences in preoperative co-morbidities, pulmonary function, operative time, estimated blood loss, nodal stations sampled and chest tube duration between the two groups. In addition, no significant differences were seen in locoregional recurrences between the open (8.3%) and the VATS (7.7%) approaches (P=1.0). However, there was a significantly decreased length of hospital stay for the VATS group when compared to the thoracotomy group (4.3±3 *vs.* 6.8±6 days; P=0.03). At approximately 30 months postoperatively, it was found that the VATS group had improved long-term survival when compared with the thoracotomy group (P=0.0007), although the groups were not matched oncologically.

Schuchert and colleagues performed a retrospective review of patients who underwent VATS segmentectomy (n=104) versus those who underwent thoracotomy (n=121) (21). There were no significant differences between the two groups in age, gender, histology, and pulmonary function as measured by FEV1 and DLCO. The VATS group had slightly smaller tumor sizes than the thoracotomy group (2.1±1.1 *vs.* 2.4±1.2 cm, P=0.05) and there were fewer lymph nodes harvested during VATS segmentectomy when compared with open segmentectomy (6.4. *vs.* 9.1, P=0.003). The VATS group also had a decreased length of hospital stay compared to the thoracotomy group (5 *vs.* 7 days, P<0.001). There were significantly fewer perioperative pulmonary complications in the VATS group as well (15.4% *vs.* 29.8%; P=0.012) but both groups, VATS and open, had similar rates of postoperative complications. Most importantly, regarding margins, it was demonstrated that a margin: tumor size ratio >1 was associated with a decrease in recurrence (14.7%) when compared to a ratio <1 (28.9%, P=0.037). In addition, the authors performed a propensity analysis that showed no significant difference in recurrence-free or overall survival. Interestingly, there were also no significant differences in locoregional or overall survival between groups with tumors >2 cm and tumors <2 cm.

In another analysis, Leshnower and colleagues conducted a retrospective review of 17 patients who underwent VATS segmentectomy versus 26 who underwent a thoracotomy approach for patients with primary lung cancer and metastatic disease (22). The two groups were similar with regards to age, tumor size, gender, body-mass index, co-morbidities and pulmonary function. An average of 3 lymph node stations were sampled in both groups and there were no significant differences in numbers of lymph nodes sampled (VATS 4.0±3 *vs.* open 6.1±5, P=0.40). There was also no significant difference between the groups in operative time. There were 2 (4.8%) deaths within 30 days after surgery in the thoracotomy group but none in the VATS group. Furthermore, the VATS group had decreased chest tube duration (VATS 2.8±1.3 *vs.* open 5.2±3 days, P=0.001) and reduced hospital length of stay (VATS 3.5±1.4 *vs.* open 8.3±6 days, P=0.01). In addition, the authors found that average hospital costs were approximately $1,700 less for the VATS group, although this finding was not statistically significant.

## Advantages of thoracoscopic segmentectomy *vs.* open segmentectomy

In summary, the above studies comparing VATS segmentectomy with open segmentectomy show that VATS segmentectomy for stage I NSCLC is feasible and safe (19-22). VATS segmentectomy appears to be associated with an equivalent survival rate when compared to the open approach: all studies report 0% 30-day mortality for the VATS group, compared to 1.7-7.7% 30-day mortality for open segmentectomy, and there is no apparent difference in long-term survival. The VATS approach was also found to be associated with shorter length of stay, lower costs, reduced rates of overall complications, including fewer cardiopulmonary complications and reduced length of chest tube duration (5). At this time, it appears that there are no significant differences in operative times between the VATS *vs.* open approach: one study has shown a longer operative time (19), and the other three have shown similar operative times (20-22).

## Thoracoscopic segmentectomy *vs.* lobectomy *vs.* wedge resection

Evaluation of thoracoscopic segmentectomy *vs.* thoracoscopic lobectomy or wedge resection for NSCLC is also under current investigation. Harada and colleagues conducted an analysis of pulmonary function for patients undergoing VATS segmentectomy (n=38) or VATS lobectomy (n=45) for stage I NSCLC (23). The authors found that 50% fewer segments were resected in the segmentectomy group and that the number of resected segments was associated with reduced forced vital capacity (FVC) and FEV1 at 2-

 

and 6-month postoperatively (P<0.0001). Consequently, at six months after surgery, the segmentectomy group had regained exercise capacity while the lobectomy group continued to have a 10% loss in exercise capacity.

In 2004, Iwasaki and colleagues performed a retrospective review of patients who underwent VATS lobectomy (n=100) or VATS segmentectomy (n=40) for stage I and II NSCLC (24). The authors found no significant differences in 5-year survival between the segmentectomy and lobectomy groups (77.8% *vs.* 76.7%, P=0.47). Shapiro and colleagues also conducted a retrospective study of VATS segmentectomy (n=31) *vs.* VATS lobectomy (n=113) but solely for stage I NSCLC (25). The segmentectomy group was found to have a longer smoking history and reduced pre-operative pulmonary function when compared to the lobectomy group (FEV1 83% *vs.* 92%, P=0.04). Despite differences in baseline patient fitness between the segmentectomy and lobectomy groups, there were no significant differences in complication rates, perioperative mortality, hospital length of stay, local recurrence (3.5% *vs.* 3.6%) and total recurrence rate (17% *vs.* 20%). In terms of lymph nodes dissected, segmentectomy was equivalent to lobectomy, with both groups having approximately five nodal stations sampled and ten lymph nodes resected. Mean follow-up for the segmentectomy and lobectomy groups were 21 and 22 months respectively, and both groups had similar overall and disease-free survival rates (P>0.5).

In 2010, Sugi and colleagues conducted a retrospective study of 159 patients who underwent VATS wedge resection (n=21), VATS segmentectomy (n=43) or VATS lobectomy (n=95) for stage I NSCLC (26). The lobectomy group had a higher percentage of patients with pathological stage greater than pT1N0 when compared to the segmentectomy group (18% *vs.* 8%, P=0.07). Follow-up was five years and the groups had similar 5-year recurrence-free and overall surviva, although there were differences in tumor size between the groups—the VATS wedge group had tumors <1.5 cm, the segmentectomy group had tumors <2 cm and the lobectomy group had tumors >2 and <3 cm. Yamashita and colleagues compared the results of VATS segmentectomy (n=38) or VATS lobectomy (n=71) with systemic lymphadenectomy (27). Both groups had similar recurrence-free and overall survival, although there were differences in tumor size between the segmentectomy and lobectomy groups (1.5 *vs.* 2.5 cm, P<0.0001).

Nakamura and colleagues performed a retrospective review of patients undergoing VATS lobectomy (n=289), VATS segmentectomy (n=38) or VATS wedge resection (n=84) for stage I NSCLC (28). The authors found differences in the mean tumor size between the lobectomy (2.57 cm), segmentectomy (1.98 cm) and wedge resection groups (1.85 cm). In this study, 5-year survival was lower for the wedge resection group (71.2%), compared to the lobectomy (90%) and segmentectomy (100%) groups. However, compared to the other groups, the wedge resection group comprised sicker patients with more co-morbidities.

Yamashita and colleagues evaluated the results of patients undergoing VATS segmentectomy (n=90) or VATS lobectomy (n=124) for stage IA NSCLC (29). There was a higher percentage of T1a tumors in the segmentectomy group when compared with the lobectomy group (84% *vs.* 58%, P<0.001). The segmentectomy group had a smaller median tumor size (15 *vs.* 20 mm). However, both groups were similar with regards to operative time, intraoperative blood loss, chest tube duration, and hospital stay. There were fewer numbers of dissected lymph nodes in the segmentectomy group when compared to the lobectomy group (12.1 *vs.* 21, P<0.0001) but both groups were also similar with regards to morbidity, 30-day mortality, recurrence, disease-free and overall survival.

Zhong and colleagues conducted a retrospective review of patients undergoing VATS segmentectomy (n=81) or VATS lobectomy (n=120) for stage IA NSCLC (30). There were no significant differences between the groups in pre-operative co-morbidities, pulmonary function, tumor size or histology. Both groups had similar operative times, similar rates of postoperative complications and no perioperative deaths. There were no differences between VATS segmentectomy and lobectomy with regards to lymph nodes resected (11.2±6.5 *vs.* 14.5±8.1, P=0.18). Length of hospital stay was also similar between both groups. There were no significant differences in local recurrence rates and 5-year overall or disease-free survivals. Multivariate Cox regression analyses also showed that tumor size was the only independent prognostic factor for disease-free survival. Another study compared the results of 73 VATS trisegmentectomies for stage IA (n=45) and IB (n=11) lung cancer with 266 VATS left upper lobe lobectomies for stage IA (n=105) and IB (n=73) lung cancer (31). There were no significant differences in overall complication rates or survival between patients undergoing VATS trisegmentectomy and those undergoing lobectomy for either stage IA lung cancer or stage IB lung cancer.

A retrospective review of patients undergoing VATS segmentectomy (n=26) or VATS lobectomy (n=28) for stage

 

IA NSCLC was also conducted by Zhang and colleagues (32). Again, there were no significant differences in operative time, estimated blood loss, number of lymph nodes resected and postoperative complications. Both groups had similar local recurrence rates and 3-year survival. Of note, the authors did find a significantly decreased length of hospital stay in the VATS segmentectomy group by approximately three days (P=0.03). Postoperative FEV1 was also decreased to a lesser degree in the VATS segmentectomy group. Tumor size, however, was not reported in this study.

Zhao and colleagues compared the results of patients undergoing VATS segmentectomy (n=36) or VATS lobectomy (n=138) for stage I NSCLC (33). There were no significant differences in blood loss, operative time, chest tube duration and length of hospital stay between the two groups. There was also no significant difference in local recurrence and in recurrence-free survival between the two groups, although the study was limited by a relatively short follow-up of less than one year and by not including tumor size data.

## Advantage of thoracoscopic segmentectomy over thoracoscopic lobectomy and wedge resection?

These studies demonstrate that although thoracoscopic segmentectomy is a more complex procedure than the thoracoscopic lobectomy (5), the rates of morbidity, recurrence and survival are similar among patients with tumors >2 cm in diameter. Specifically, there were no significant differences in overall complication rates (25,26,29,30,32,33), local recurrence rates (25,26,29,30,32,33), 5-year recurrence-free survival (26,27,29,30) and 5-year survival rates (24,26,27,29,30). The studies also show no difference in operative time between the two groups (29,30,32,33). In addition, the segmentectomy groups had similar (25,29,30,33), or reduced lengths of hospital stay (32) when compared to the lobectomy groups. It appears that thoracoscopic segmentectomy is able to preserve more lung function (23,32) and exercise capacity (23) than thoracoscopic lobectomy, although long-term follow-up data is needed.

There are, however, important limitations to the abovementioned studies. Firstly, some studies did not report the tumor size data (31-33). Of the studies that did, most found that the lobectomy groups had significantly larger tumors than the segmentectomy groups (23-29). This difference in tumor size limits interpretation of results because tumor size is known to be a prognostic factor of survival for NSCLC (30,34). However, in one recent study where both thoracoscopic segmentectomy and lobectomy groups were well-matched in tumor size, histology, preoperative co-morbidities and pulmonary function (30), both groups had similar local recurrence rates, disease-free and overall survival. This is consistent with previous data from the open segmentectomy literature. For example, in 2006, Okada and colleagues conducted a multi-center study of 567 patients with tumor size <2 cm who underwent open segmentectomy or lobectomy (35). Mean tumor size for the segmentectomy and lobectomy groups were 1.57 cm and 1.62 cm (P=0.056), respectively. The segmentectomy was associated with equivalent 5-year survival when compared to the lobectomy (83.4% *vs.* 85.9%, respectively).

Another limitation of the above-referenced studies is that many of them, with the exception of four studies (27,29,30,33), did not report the percentage of patients with bronchoalveolar carcinoma or adenocarcinoma *in situ*. This is an important variable to account for (5), as demonstrated by a study performed by Nakayama and colleagues that examined the results of 63 patients with adenocarcinoma who underwent open sublobar resection of clinical stage IA NSCLC (36). The authors classified the patients' tumors as either "air-containing type" (n=46) or "solid-density type" (n=17) according to the tumor shadow disappearance rate on high-resolution CT. After resection, 38 of the 46 air-containing tumors were identified as bronchoalveolar carcinomas whereas all solid-density type tumors were non-bronchoalveolar carcinomas. Air-containing tumors were associated with better overall 5-year survival than solid-density tumors (95% *vs.* 69%, P<0.0001).

The VATS wedge resection procedure yields a smaller parenchymal margin, reduced number of resected lymph nodes and reduced sampling of nodal stations when compared to segmentectomy (14). There have also been two studies comparing the survival outcomes of this procedure with that of the VATS segmentectomy and lobectomy. However, in the wedge resection group, the tumors were smaller (26,28) or the patient population had greater co-morbidities, which limits interpretation of results (28); further studies with groups that are better matched will be needed prior to making any conclusions regarding the role of VATS wedge resection role in NSCLC.

Further study is also needed regarding selection criteria for the thoracoscopic segmentectomy. Based on the reviewed evidence, it appears reasonable to consider segmentectomy for patients with small, peripheral tumors (in particular air-containing tumors with ground glass opacities suggesting bronchoalveolar histology) that are less than 2 cm in diameter when an acceptable segmental margin is obtainable (margin ≥ tumor diameter), especially in patients with advanced age, poor performance status, or poor cardiopulmonary reserve. Future retrospective studies would benefit from controlling for tumor size, operative co-morbidities, type of cancer, tumor location (including distance from the margin to the edge of the tumor and resection margin) and propensity score matching. There are two ongoing randomized trials (discussed below) that will clarify the role of the thoracoscopic segmentectomy in lung cancer.

## Feasibility of mediastinal lymph node dissection (MLND)

Mediastinal lymph node assessment is a critical component of segmentectomy for NSCLC. Mattioli and colleagues reported that open segmentectomy procures an adequate number of N1 and N2 nodes for pathologic examination (37). When comparing the thoracoscopic segmentectomy to the thoracoscopic lobectomy, two studies preliminarily demonstrate no significant differences in lymph nodes harvested or nodal stations sampled (25,30) while one reported fewer lymph nodes harvested with the segmentectomy (29). When comparing open *vs.* thoracoscopic segmentectomy, one study found no difference in lymph nodes harvested (22), while another reported fewer lymph nodes harvested with the VATS approach (21).

In addition, two studies compared the completeness of lymph node evaluation during anatomic resection of primary lung cancer by open and VATS approaches (38,39). Most of the analyses performed in these studies grouped segmentectomies together with lobectomies, thereby limiting the ability to draw any conclusions specifically regarding segmentectomy. However, in one of the studies which reported analyses of nodal upstaging from the Society of Thoracic Surgery national database, the authors did report one subset analysis that showed off the 170 VATS segmentectomies analyzed, upstaging from cN0 to pN1 was seen in 4% of patients compared with 5.3% among 280 open segmentectomies (38). The authors noted that the differences in upstaging between VATS and open approaches may have been the result of approach bias, and that equivalent nodal staging may be possible with increasing experience with VATS (38).

Preliminarily, based on the available evidence, it appears that it is possible to achieve adequate lymph node dissection with segmentectomy, but that surgeon experience does play an important role, particularly in the case of the thoracoscopic segmentectomy. More detailed investigation on lymph node evaluation in VATS versus open segmentectomy and VATS segmentectomy *vs.* VATS lobectomy is therefore needed.

## Other types of thoracoscopic segmentectomy

### Totally thoracoscopic segmentectomy

There have been a few small case series reported on the “totally thoracoscopic” or “complete VATS” technique for segmentectomy (39-46). In this technique, there is no access incision, and the specimen is retrieved through one of the port sites that is enlarged at the end of the procedure; only video-display and endoscopic instrumentation are used (47). There is no evidence that there are advantages associated with this approach, although it does allow the surgeon to use carbon dioxide insufflation. The largest series reported is from Gossot and colleagues, who performed totally thoracoscopic anatomic segmentectomy on 117 patients (48). The authors reported five conversions to thoracotomy with mean operative time of 181±52 minutes, mean intraoperative blood loss of 77±81 mL, and postoperative complication rate of 11.7%. The mediastinal lymph node harvested and nodal stations sampled were 21±7 and 3.5±1. The average length of hospital stay was 5.5±2.2 days. Preliminarily, it appears that totally thoracoscopic segmentectomy is feasible and safe, although further studies with longer follow-up that compare this technique with traditional open and VATS approaches are needed.

### Uniportal segmentectomy

VATS segmentectomies are typically performed via two to three incisions, but Gonzalez-rivas and colleagues presented the first case report demonstrating that the procedure is feasible with one incision and through one port (49). Subsequently, they reported their initial results for 17 uniportal VATS anatomic segmentectomies. Mean operative time was 94.5±35 minutes, 4.1±1 nodal stations were sampled and 9.6±1.8 lymph nodes were resected. There were no conversions. Median tumor size was 2.3±1 cm, chest tube duration was 1.5 days (range, 1-4 days) and the median length of stay was 2 days (range, 1-6 days) (50). Wang and colleagues also demonstrated their experience, performing thoracoscopic lobectomy (n=14) and segmentectomy (n=5) with radical MLND through a single small (3- to 5-cm) incision (51). Mean operative time was 156±46 minutes, median number of lymph nodes harvested was 22.9±9.8, and blood loss was 38.4±25.9 mL. There were no conversions and 30-day mortality was 0%. The authors did not assess for differences by type of operation and there was no long-term follow-up. Preliminarily, it appears that single-incision segmentectomy is feasible and safe, although further studies comparing single-port to traditional open and VATS approaches are needed.

## Robotic segmentectomy

A recent review of a national database demonstrated that robotic pulmonary resections have increased from 0.2% in 2008 to 3.4% in 2010 (52). The vast majority of robotic procedures are lobectomies, but there has been a small increase in robotic segmentectomies performed as well.

A retrospective study of 35 patients who underwent robotic thoracoscopic segmentectomy was performed, including 12 patients who had stage IA NSCLC (53). In this series, median age was 66.5 years, tumor size was 1.4 cm, operative time was 146 minutes and number of lymph node stations sampled was 5 (54). Four patients had perioperative complications, and 60-day mortality was 0%, while length of hospital stay was two days. Pardolesi and colleagues reported the initial results of 17 patients who underwent robotic segmentectomy at three institutions (55). The authors used a 3- or 4-incision strategy with a 3-cm utility incision in the anterior fourth or fifth intercostal space. Mean age was 68.2 years and mean duration of surgery was 189 minutes. There were no major intraoperative complications and no conversions were needed. Postoperative morbidity rate was 17.6%, median postoperative stay was five days and postoperative mortality was 0%.

Based on these reports, robotic segmentectomy appears to be a safe and feasible operation although additional studies comparing the outcomes of the robotic segmentectomy with the open and VATS approaches, as well as with the lobectomy, will be needed.

## Limitations

There were several key limitations to the studies discussed above. Firstly, because the studies were retrospective in nature, there was the potential for surgeons' bias to affect the type of operation a patient received, which could have affected outcomes. In addition, often, the studies did not compare groups that were well-matched—which could have affected results. For example, in studies where patients in the VATS segmentectomy group were sicker than those in the comparison group (9-11,21,25), the benefits of VATS segmentectomy could have been underestimated. In studies where the VATS group had slightly smaller tumors than those in the comparison group (21,24,26-29), there may have been an overestimation of the benefits of VATS segmentectomy.

To reduce the impact of treatment-selection bias and confounding in estimating the effects of segmentectomy *vs.* lobectomy, randomized controlled trials should continually be performed (described below). Future retrospective studies should also aim to match variables that have confounding effects, use stratification or multivariate regression analysis where appropriate, and incorporate propensity score matching when possible (56,57).

## Future research

In the studies reviewed above, there was no data reported on the tolerance of patients for resection of secondary cancers. This would be an important area for future research because up to 11.5% of patients who undergo pulmonary resection for stage I NSCLC develop additional primary lung cancers (25,58). By causing less trauma than open segmentectomy, and preserving more lung function than lobectomy, VATS segmentectomy theoretically would offer patients higher tolerance for resection of secondary cancers when compared to the open segmentectomy or open or VATS lobectomy (5).

In addition, future studies should aim to include data on the number and type of nodal stations sampled or lymph nodes dissected. Only four of the studies in this review (22,25,29,30) reported specific information on lymph node sampling with segmentectomy. The effect of surgeon experience on outcomes in segmentectomy also deserves attention, as there is currently no published data on the topic.

There are two ongoing large-scale randomized controlled trials that will improve our understanding of the outcomes of limited resection for NSCLC: CALGB 140503 and JCOG0802/WJOG4607L (59,60). CALGB 140503, sponsored by the Alliance for Clinical Trials in Oncology, will evaluate the outcomes of patients who are randomly assigned to undergo limited resection (segmentectomy or wedge resection) or lobectomy, with the VATS or thoracotomy approach determined by the surgeon (60). JCOG0802/WJOG4607L, sponsored by the Japan Clinical Oncology Group and the West Japan Oncology Group, will evaluate outcomes of patients who are randomly assigned to undergo segmentectomy (wedge resections are excluded) or lobectomy (59). Both studies will clarify the role of segmentectomy for NSCLC but will have some limitations as well. CALGB 140503 may be limited in its final analysis because the limited resection group includes not only patients undergoing segmentectomy, but also patients undergoing wedge resection. And in both CALGB 140503 and JCOG0802/WJOG4607L, the operative approach—VATS *vs*. open—will not be a primary outcome variable.

## Conclusions

Based on the reviewed evidence, it appears reasonable to consider segmentectomy for patients with stage I NSCLC tumors (particularly in air-containing tumors with ground glass opacities) that are <2 cm in diameter when an acceptable segmental margin is obtainable (at least 2 cm), especially in patients with advanced age, poor performance status, or poor cardiopulmonary reserve. The outcomes of CALGB 140503 and JCOG0802/WJOG4607L and additional well-designed studies on open, thoracoscopic, and robotic segmentectomy will be important for further clarifying the role of segmentectomy for NSCLC.

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# Are video-assisted thoracoscopic surgery (VATS) and robotic video-assisted thoracic surgery (RVATS) for pulmonary resection ready for prime time?

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Although video-assisted thoracoscopic surgery (VATS) was described twenty years ago, it only accounts for 2-5% of all pulmonary lobectomies performed in the United States and the United Kingdom (1). In addition, nearly 80% of VATS cases performed take place in specialty academic centers (2). The reasons for the lack of widespread acceptance are (I) the perceived complexity of the technique, (II) inadequate instrumentation and resources, and (III) concern regarding the potential compromise of safe surgical and oncologic principles, despite the reported benefits of perioperative pain, cosmesis, pulmonary complications, and length of stay (1). We recently reported the outcomes of a hybrid VATS technique in 1,170 cases in the community setting, the largest reported VATS series in the literature, which addressed those three concerns and demonstrated outcomes comparable to the conventional VATS technique (1,2). As we described, this hybrid technique, utilizing a 10 mm port site in the 8th inter-space and a 8-10 cm incision mini-thoracotomy in the 4th inter-space, provides the benefits of minimally invasive surgery while allowing the flexibility required for a solo-practitioner to perform safe and appropriate oncologic thoracic surgery in a community setting (1,2). Now the question is how good are the reported outcomes for VATS and robotic video-assisted thoracic surgery (RVATS) in specialized centers? Here, we will introduce two meta-analyses recently published that systemically review the outcomes (3,4).

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The main criticism of the evidence in favor of VATS compared to open thoracotomy has been that the studies were biased because they were non-randomized observational retrospective studies and thus more favorable patients may have been selected for the new technique (3). To address this concern, the data of 7,739 unmatched non-small cell lung cancer (NSCLC) patients from 3 retrospective studies were analyzed, 5,636 open thoracotomy versus 2,094 VATS, as well as differences in propensity score matched patients in open thoracotomy versus VATS, 1,681 cases in each group (3). Mortality, prolonged airleak, and sepsis were significantly lower in the VATS unmatched comparison, but not significantly lower in the matched VATS comparison (3). Overall perioperative morbidity and length of hospital stay were consistently lower in VATS in both the matched and unmatched comparisons (3). While previous smaller studies have demonstrated the benefits of VATS compared to open thoracotomy, this review further contextualized those results for clinical practice (3).

 

Over the last decade there have been small reports of RVATS utilizing the $1 million US dollar master-slave robotic system (da Vinci, Intuitive Surgical, Sunnyvale, California), but there has been controversy regarding the actual benefits of this expensive technology (4). A systematic review of 941 patients (mostly NSCLC, some carcinoid and metastatic disease) from 12 institutions in 9 reports compared RVATS to VATS and open thoracotomy. They demonstrated equivalent oncologic outcomes to open thoracotomy, and the overall mortality ranged from 0-3.8%, overall morbidity from 0-39%, average operative time from 132-238 minutes, rates of conversion to open thoracotomy from 0-19%, average chest tube days from 1.5-7 days, and median length of hospital stay from 2-11 days. In contrast, our hybrid VATS series demonstrated an overall perioperative mortality of 4.3%, overall morbidity of 21.1%, mean operative time of 52 minutes, no conversions to open thoracotomy, mean chest tube days of 4.5 days, and mean length of hospital stay of 7 days (1). RVATS was on average $3,981 US dollars more expensive than VATS, but $3,988 US dollars cheaper than open thoracotomy (4). However, an extra $1,715 US dollars of amortized cost had to be accounted for utilizing the robot for each RVATS patient. Furthermore, although they demonstrated an improved quality of life score in the RVATS patients compared to open thoracotomy 3 weeks after operation, there was no difference at 4 months. Although they demonstrated the feasibility of this technology which has a well reported steep learning curve, the benefits of RVATS over VATS, especially considering the increased cost, have yet to be demonstrated.

Although the benefits for RVATS remain controversial, especially in the current economic environment where comparative-effectiveness and maximizing health care dollars are essential (4), there is further evidence that VATS is a feasible technology which provides benefits to patients. Although there is no large prospective randomized trial to definitively answer the question regarding the benefits of VATS compared to open thoracotomy, our reported hybrid VATS technique and large series demonstrated its benefits when performed outside of specialty academic centers and addressed the major concerns preventing widespread implementation (1,2). Although the meta-analysis demonstrated a possible element of bias in the retrospective comparisons of VATS to open thoracotomy reported in the literature vis-à-vis mortality, prolonged air leak, and sepsis, they still found a significant improvement in morbidity and length of stay even after propensity score matching (4). The results of these latest studies (3,4) taken together with our series (1,2) will hopefully lead to a greater adoption of VATS in pulmonary resection and provide the benefits of minimally invasive surgery to more patients in the future regardless of whether they are treated at specialty centers or in the community.

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Pulmonary Resection

# Robotic lobectomy—the future of minimally invasive lobectomy?

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It has been almost 20 years since the first reports of minimally invasive lobectomies appeared. Despite the tremendous amounts of research performed on VATS lobectomy showing its benefit over open thoracotomy, a mere 32% of all lobectomies are performed via this technique in the Society for Thoracic Surgeons database and only 6% in the Nationwide Inpatient Sample (1). So, why is it that in a recent review of clinical stage I lung cancers over 70% were still completed using open thoracotomy?(2). Advocates of an open approach still cite the ability to sample and perform a "more thorough" lymphadenectomy, the instability of the VATS platform and the lack of precision with the fissure-less-dissection VATS technique as reasons to maintain the status quo.

However, the introduction of robotic assisted lobectomy promises to address the concerns from open thoracotomy advocates (1,3-5) by allowing surgeons to have a stable platform to likely perform a lymphadenectomy similar to open thoracotomy with equal precision given the superior image, magnification and stability. Clearly many thoracic surgeons are interested as evidenced by the growth and plans by Intuitive Surgical makers of the da Vinci robotic surgery system. But, is all the hype true or is this all driven by the marketers trying to sell more robotic surgery systems? In a recent systematic review entitled, "A systematic review of meta-analysis on pulmonary resection by robotic video-assisted thoracic surgery" Cao and colleagues looked at a total of 941 patients in 12 institutions who had undergone robotic pulmonary resection (6). The results of this meta-analysis discuss and highlight the current issues surrounding pulmonary resection.

It is reasonable to conclude that at the current time, robotic pulmonary resection is relatively safe in expert centers; one notes however that of the 18 papers reviewed in this paper, 13 are from the same 6 authors. Perioperative mortality ranges from 0-3.8% which is similar to reported VATS lobectomy rates and consistent with open lobectomy for similar stage cancers. Conversions rates from robotic to open thoracotomy remain higher than anticipated with some reports showing a nearly 1 in 5 conversion rate. However, one must remember that these reported outcomes likely represent the first robotic cases for all authors. Until more experience and outcomes are reported from other academic and non-academic centers around the world the feasibility and safety outcomes apply only to experienced centers.

There is little comparative data where the outcomes of robotic lobectomy are directly compared to standard VATS or open lobectomy. Logic dictates that robotic lobectomy will be superior to open thoracotomy in terms of operative and clinical outcomes such as length of stay and blood loss, very much like VATS is to open surgery with these same parameters. In the meta-analysis, the one comparative paper by Jang *et al*. (7) showed what most experienced VATS surgeons would expect: that ultimately the operative outcomes are going to be similar in terms of length of stay, operative length, and blood loss when compared to at least 2 years of experience with VATS lobectomy. More recent publications are also confirming these findings but longer term studies are needed to prove the true benefits of robotic surgery (1).

Adoption and integration of robotic lobectomy into practice however, is going to depend upon more than similar operative outcomes in the era of cost constraint. Robotic lobectomy will have to show a survival and/or an oncologic benefit. Although some survival data is reported and similar to open or VATS cases, the next several years are likely to see additional research using surrogate measures of oncologic effectiveness in robotic surgery since 5 year survival data is still maturing. When the rate of nodal upstaging is used as one of the measures, there appears to be some value in robotic lobectomy since upstage of clinical stage I cancers may be higher (21%) with robotic surgery (8) when compared to VATS (11.6%) or open (14.3%) (2).

At the current time, the benefit of robotic lobectomy is in increasing the number of minimally invasive lobectomies. However, that means open surgeons need to learn a new set of techniques, be successful at the technique and integrate the technique. Although the learning curve is estimated at about 20 cases, it's likely that this learning curve will be shorter for most surgeons with a more standardized approach, consistent proctoring and the educational platforms available to robotics, which are unique. There is little benefit in converting experienced VATS surgeons based on the current data of similar operative outcomes and they may wish to wait until additional data supporting robotic over VATS lobectomy is produced. The robotic platform may also encourage experienced VATS surgeons to expand the indications for a minimally invasive lobectomy (3).

Lastly and probably most contentious is the question on many surgeons tongues - what about the cost? This ultimately may be the key breaking point for robotic surgery since the institution has to have the funds to purchase and then operate the system. As expected, the United States leads all countries in terms of purchased and installed robotic surgery systems whereas Canada, Europe and Asia whose health systems are more centralized have fewer. Nary a robot is seen in the developing world.

Even with purchased and operational systems, cost and cost-effectiveness are front and center in most administrators' minds. The only cost analysis cited was performed using only 12 robotic cases and certainly does not reflect the current environment (9). The challenge in any study around cost will be the definitions of "cost" since there is no consistent methodology. Truthfully, this is probably best evaluated as part of a randomized trial comparing robotic lobectomy to VATS and open so that clinical outcomes and cost data are collected and analyzed prospectively.

Like Cao and colleagues concluded in their review, the current status of robotic surgery remains in the area of safety and feasibility. While experienced centers are reporting outcomes similar to historic controls, these results are from 6 authors. The generalizability to less experienced centers will require other centers to report their results. More data is required to determine the benefits of robotic lobectomy in terms of oncologic effectiveness and cost effectiveness. Fortunately, the future of robotic lobectomy appears to be bright and promising especially if the robotic research that has begun in several of these centers focusing on the key issues of oncologic effectiveness and cost effectiveness favors robotics.

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# Robotic lung segmentectomy for malignant and benign lesions

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**Objective:** Surgical use of robots has evolved over the last 10 years. However, the academic experience with robotic lung segmentectomy remains limited. We aimed to analyze our lung segmentectomy experience with robot-assisted thoracoscopic surgery.

**Methods:** Prospectively recorded clinical data of 21 patients who underwent robotic lung anatomic segmentectomy with robot-assisted thoracoscopic surgery were retrospectively reviewed. All cases were done using the da Vinci System. A three incision portal technique with a 3 cm utility incision in the posterior $10^{th}$ to $11^{th}$ intercostal space was performed. Individual dissection, ligation and division of the hilar structures were performed. Systematic mediastinal lymph node dissection or sampling was performed in 15 patients either with primary or secondary metastatic cancers.

**Results:** Fifteen patients (75%) were operated on for malignant lung diseases. Conversion to open surgery was not necessary. Postoperative complications occurred in four patients. Mean console robotic operating time was 84±26 (range, 40-150) minutes. Mean duration of chest tube drainage and mean postoperative hospital stay were 3±2.1 (range, 1-10) and 4±1.4 (range, 2-7) days respectively. The mean number of mediastinal stations and number of dissected lymph nodes were 4.2 and 14.3 (range, 2-21) from mediastinal and 8.1 (range, 2-19) nodes from hilar and interlobar stations respectively.

**Conclusions:** Robot-assisted thoracoscopic segmentectomy for malignant and benign lesions appears to be practical, safe, and associated with few complications and short postoperative hospitalization. Lymph node removal also appears oncologically acceptable for early lung cancer patients. Benefits in terms of postoperative pain, respiratory function, and quality of life needs a comparative, prospective series particularly with video-assisted thoracoscopic surgery.

**Keywords:** Lung resection; robotic surgery; segmentectomy; lung cancer

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## Introduction

Anatomic segmentectomy of the lung is the removal of a segment of the lobe. For many decades pulmonary segmentectomy has been used for the treatment of bronchiectasis and tuberculosis via thoracotomy. Recently, with the developments in video instrumentation and refinements in surgical techniques, segmentectomy has been a popular approach with video-assisted thoracic surgery (VATS). It has been preferred for tumors smaller than 2 cm and negative lymph nodes (1,2) and for larger tumors in patients with poor pulmonary function who could not tolerate lobectomy, especially those who do not have visceral pleural invasion (2,3). Although VATS has been used for segmentectomy for the past 5 years, robotic anatomic lung segmentectomy has been reported to be feasible only in two articles in the pubmed search (4,5).

As an academic thoracic surgery center performing minimally invasive anatomical lung resections with VATS for 8 years, we have recently developed a robotic surgery program with the da Vinci Robotic System (Intuitive Surgical, Inc, Mountain View, California, USA) which started on October 2011. In this study we aimed to analyze the segmentectomy operations performed for various etiologies.

 


**Figure 1** (A) The CT shows an 84-year-old male with squamous cell carcinoma who previously had colon carcinoma; (B) the CT shows a 37-year-old male admitted with hemoptysis, after bronchoscopy revealed no pathology. He underwent a left lower lobe common basal segmentectomy with the diagnosis of echinococcus alveolaris; (C) the CT shows a 67-year-old male with a history of undiagnosed cerebral mass of 1 cm. He underwent mediastinoscopy and resection of superior segment of right upper lobe. Pathology revealed adenocarcinoma.

## Patients and methods

From the prospectively recorded database, anatomical segmentectomy patients' data was retrieved. The data was analyzed for age, gender, etiology, pulmonary function tests, complications, mortality, duration of chest tube and duration of postoperative hospital stay. The number of mediastinal lymph node stations dissected and the number of dissected lymph nodes in patients with either primary or secondary lung cancer were also analyzed. For metastasectomies only single lesions close to the segmentary bronchus and primary lung cancer smaller than 2 cm were candidates for robotic segmentectomy operations (*Figure 1*). Patients who had primary lung tumors larger than 2 cm but smaller than 4.5 cm (2 patients) with compromised pulmonary functions were also underwent robotic common basal segmentectomy operations. According to our protocol; all patients who had an indeterminate nodule, or proven lung cancer or a possible metastatic lung cancer, had a PET-CT. Mediastinoscopy was reserved only for the patient who had a possible brain metastases.

Robotic operations for indeterminate nodules were performed after localization of the nodule either with operative view (retraction of visceral pleura), after palpation with finger prior to the docking without access thoracotomy, or from 3 dimensional (3D) images of chest tomography.

All operations were performed by a single console surgeon (AT). All patients had anatomical segment resections as described below. Chest tubes were removed during the hospital stay if the length of stay was shorter than 5 days. If the drainage lasted longer and patients did not have any other problems (one patient), then the patients were discharged with chest tubes attached to the Heimlich valve.

### *Surgical technique*

The patient was positioned on lateral decubitus position. The table was tilted either anteriorly or posteriorly depending on the type of segmentectomy operation to be performed. For superior segments of both lower lobes and posterior segment of the right upper lobe anterior tilt was preferred. For the resection of other segments a posterior tilt was preferred. Three ports were opened while trying to keep 10 cm between each port and 10 to 15 cm from the target which was hilum of the lobe containing the segment to be resected. The camera was placed in the middle port. The robot was docked from the posterior of the patient with 30 to 45 degrees between the vertebral column of the patient and transverse axis of the cart (*Figure 2*).

With the robotic camera in up position, ports and instruments were placed and pleural symphyses were divided. Service port was performed at $10^{th}$-$11^{th}$ intercostal space at the posterior part of the thoracic wall. The rest of the operation was done with the camera in down position. Maryland or curved bipolar forceps for right arm and prograsper for left arm were used as needed. Segmentectomies were performed by dissecting the fissure and removing the nodes around the segmentary artery and bronchus. Arteries and veins were clipped with Hem-o-Lok (Teleflex Medical, Research Triangle Park, NC) or stapled with a vascular stapler. Bronchus was always stapled (*Figures 3-5*). Imaginary intersegmental plane was stapled after ventilating

 

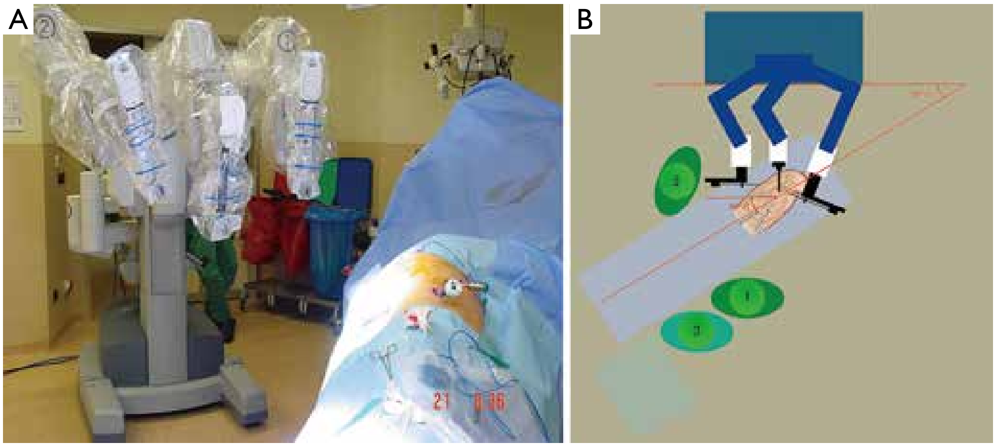


**Figure 2** Docking of da Vinci. Arm numbers should be seen by the surgeon 1 at the table (arrows). The transverse axis of the da Vinci approaches from posterior of the patient with 30 to 45 degrees to vertebral column of the patient. 1, surgeon responsible from docking (may shift to console); 2, assistant surgeon is responsible for service, retraction, clipping and stapling; 3, nurse position.


**Figure 3** Resection for a lingual sparing left upper lobectomy needs division of the superior segmentary vein, and proximal arteries to the left upper lobe and apicoposterior segment of the upper lobe bronchus.

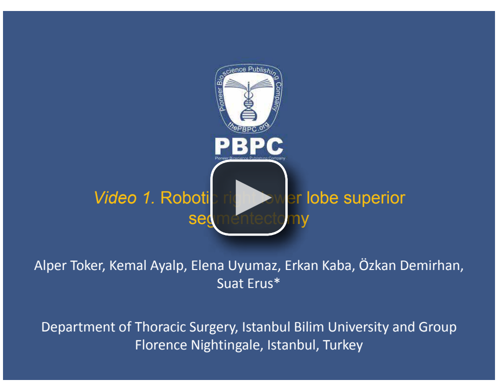


**Figure 4** Robotic right lower lobe superior segmentectomy (6).

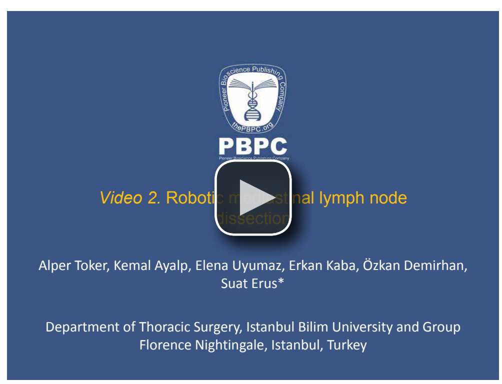


**Figure 5** Robotic mediastinal lymph node dissection (7).

**Table 1** Data of patients who underwent pulmonary segmentectomy operation

| Items | RATS (n=21) [range] |
|---|---|
| Age | 59±16 [28-84] |
| Gender | |
| Male | 12 (57.1%) |
| Female | 9 (42.8%) |
| Side | |
| Right | 10 (47.6%) |
| Left | 11 (52.3%) |
| Location | |
| Upper lobe | 8 |
| Apicoposterior right | 4 |
| Lingula sparing lobectomy | 2 |
| Lower lobe | 13 |
| Superior segmentectomy | 5 |
| Common basal segmentectomy | 8 |
| Mean duration of Console time (minutes) | 84±26 [40-150] |
| Mean $FEV_1$ (mL) | 2,278±662 [1,274-4,870] |
| Mean duration of drainage (days) | 3±2.1 [1-10] |
| Mean duration of postoperative stay (days) | 4±1.4 [2-7] |
| Morbidity rate | 4 (19%) |
| Mortality rate | 0 |
| Pathology | |
| Malignant | 15 (71.4%) |
| Benign | 6 (28.5%) |
| Mean number of lymph nodes dissected from mediastinum (stations 2-9) (nodes) | 14.3 [2-21] |
| Mean number of lymph nodes dissected from N1 stations (10-11-12) (nodes) | 8.1 [2-19] |
| Mean number of mediastinal stations dissected | 4.2 [2-6] |
| Pain scale | |
| Visual analog scale on postoperative day 2 and day 15 | 3.4-1.4 |
| Histology of primary lung cancer | |
| Adenocarcinoma with lepidic pattern | 5 |
| Adenocarcinoma | 3 |
| Squamous cell carcinoma | 2 |
| Large cell neuroendocrine tumor | 1 |
| TNM staging of primary lung cancer patients | |
| T1aN0M0 | 6 |
| T1bN0M0 | 2 |
| T1aN1M0 | 1 |
| T1bN1M0 | 1 |
| T2aN0M1 | 1 |

and deflating the remnant lung. In none of the patients, glues or sealants were used. Chest was closed by placing a single 28 F chest tube from the camera port.

### *Pain management*

Routine pain management was with intercostal blocks to two intercostal spaces upper and two intercostal spaces lower around the ports (not more than 20 mL Marcaine) (Astra Zeneca, Istanbul) and 1 gram perfalgan (Bristol-Myers Squibb, New York City) intravenous infusion every 6 hours, and voltaren SR 75 mg (Novartis, Basel) are given through intramuscular route twice a day until chest tube is removed. After the removal of the chest tube or discharge of the patient oral medication with paracetamol and non-steroid anti-inflammatory drugs were given. Visual Analog Scale (VAS) was recorded by the anesthesiologists at 48 hours after the operation and by surgical team on postoperative day 15 as a part of data collection for possible evaluation of our pain management approach.

## Results

The mean age was 59 (range, 28-84) years. Twenty-one segmentectomies, 10 from the right lung and 11 from the left lung were performed. Eight patients had a segmentectomy from the upper lobes and 13 patients from the lower lobes. Common basal segmentectomy (eight patients) and superior segmentectomy of the lower lobes (five patients) were the most commonly employed segmentectomies. Mean duration of console time was 84±26 (range, 40-150) minutes. Mean force expiratory volume ($FEV_1$) in the first second was 2,278±662 (range, 1,274-4,870) mL. The mean duration of chest tube drainage and postoperative hospital stay were 3±2.1 (range, 1-10) and 4±1.4 (range, 2-7) days respectively. Conversion to open surgery was not necessary. Postoperative complications occurred in four patients (19%). The prolonged air leak (>5 days) was the cause of morbidity in all patients. None of the patients experienced a major cardiopulmonary complication. The mean number of mediastinal stations and number of dissected lymph nodes were 4.2 and 14.3 (range, 2-21) lymph nodes from mediastinal stations and 8.1 (range, 2-19) lymph nodes from hilar and interlobar stations, respectively. VAS was 3.4 and 1.4 on postoperative day 2 and day 15 (*Table 1*). The mean diameters of the malignant lesions were 1.9 (range, 1-4.3) cm. There were eight (72.7%) adenocarcinoma histology including five patients with lepidic pattern as the most common primary lung cancer. Eight patients (72.7%) out of 11 primary lung cancer were recorded to be in stage 1A. Six patients were operated on for benign diseases (bronchiectasis one patient, granuloma four patients and echinococcus alveolaris one patient). Four patients had segmentectomy operation for single pulmonary metastases (three patients for colon carcinoma and one patient for uterus leiomyoma).

## Discussion

VATS segmentectomy has been proved to be a safe procedure with fewer complications and a reduced hospital stay when compared with an open segmentectomy (8). The peri-operative outcome, including operative time, blood loss, duration of chest tube drainage and length of hospital stay, have been shown to be similar in another comparative study (9). This study also demonstrated that thoracoscopic segmentectomy is feasible with regard to peri-operative and oncological outcomes for Stage IA non-small cell lung cancer (NSCLC), especially T1a and carefully selected T1b descriptor (9). Thoracoscopic segmentectomy has been compared to thoracoscopic lobectomy when analyzing oncologic results in small (≤2 cm) peripheral stage IA NSCLC (10). Local recurrence rates with thoracoscopic segmentectomy (5.1%) have been reported to be similar to the thoracoscopic lobectomy (4.9%). No significant difference has been observed in 5-year overall or disease-free survival (10). Recent literature also demonstrated support for less invasive video thoracoscopic surgical techniques in pulmonary segmentectomy operations like uniportal and total thoracoscopic segmentectomies (11,12).

It is clear that, as lung screening programs increase around the world, the need for minimally invasive segmentectomies is also increasing. Certainly, robotic lung segmentectomies might be another minimally invasive lung segment resection technical option.

Growing knowledge of robotic lobectomies for lung cancer would provide additional experience for performing segmentectomy operations for lung cancer. Yet, there are only two articles published to assess the feasibility of robotic segmentectomy operation (4,5). In one of them Dylewski *et al.* (5) reported 35 segmentectomy patients and in the other Pardolesi *et al.* (4) reported 17 segmentectomy patients. Mean duration of surgery was reported to be 189 minutes with no major intraoperative complications and conversion to open procedure was reported as unnecessary (4). In this study postoperative morbidity rate was 17.6% with a median postoperative stay of 5 (range, 2-14) days, and postoperative mortality was 0% (4). The final pathology was reported to be NSCLC in eight patient, typical carcinoids in two, and lung metastases in seven. Because the other study (5) described a robotic series of almost 200 patients with mainly lobectomies, we do not have a detailed data regarding to segmentectomy operations.

Our indications and perioperative and postoperative outcomes are quite similar to those of Pardolesi and colleagues (4). In our experience, 15 out of 21 patients (75%) were operated on for malignant lung diseases. Conversion to open surgery was not necessary. Postoperative complications occurred in four patients (19%). Mean console robotic operating time was 84±26 (range, 40-150) minutes which was quite similar to that of Dylewski's experience (5). The duration of our console time was shorter than the reported experiences even with VATS. Mean duration of chest tube drainage and postoperative hospital stay were 3±2.1 (range, 1-10) and 4±1.4 (range, 2-7) days respectively, which was also quite similar to the above mentioned study (4). The mean number of mediastinal stations and number of dissected lymph nodes were 4.2 and 14.3 (range, 2-21) lymph nodes. From hilar and interlobar stations, a mean of 8.1 (range, 2-19) lymph nodes were dissected in patients primary or secondary lung cancer. We need to stress that, five of our patients were not good candidates for lung resection due to compromised pulmonary, renal and cardiac problems. But we did not experience any adverse event in those patients. Our surgical technique demonstrated similarities with those of Pardolesi's (4). However, our access port, similar in size to their experience (4), was located at posterior thoracic cavity at $10^{th}$-$11^{th}$ intercostal space. This port may not only have allowed the greater movement of the equipment within the cavity but also may have avoided the disturbance of the mammary gland in female patients. In our experience, we used only one Maryland forceps or curved bipolar forceps and one Prograsper forceps for each patient. Expenditures for these including the drapes cost a total of 600 USD, excluding the maintenance and initial costs of the robot.

The major difficulty in robotic segmentectomy operation is the resection without palpation. This could be overcome by palpating and tattooing the lesion prior to the implementation of the robotic arms. If this was not possible, 3D images could be used to identify the lesion, the vessels and the bronchus. Segmentectomy operation with robotic surgery requires a good knowledge of the anatomy of pulmonary vessels and bronchi in each patient (13).

 

The foreknowledge of the anatomy of each patient would contribute to the safety and accuracy of the operation (13). It has been reported that presurgical planning based on patient's actual 3D pulmonary model was useful for patients with stage IA NSCLC ≤2 cm in diameter and for selecting an appropriate VATS lung resection for an individual (14). Apparently, this may be a required preoperative technique in robotic segmentectomy as well. Although we only had three patients with this preoperative investigation, we discussed with experienced radiologists before each operation to delineate the borders of resection from axial, coronal and sagittal tomographies. Especially for metastasectomies, we believe that CT image evaluation on monitor with a qualified radiologist is essential to ensure that the lesion is solitary.

Robotic segmentectomy may provide better dissection capabilities around smaller vessels and the lymph nodes around lobar and segmentary bronchi. However, developing these techniques may require preparation and patience to overcome the difficulties of a correct docking, developing dissection techniques.

Yet, the provided data and results about performing robotic segmentectomies may not fully satisfy the thoracic surgical community. However, we have demonstrated that the robotic anatomic lung segmentectomy is a feasible and safe procedure with an acceptable operating time, adequate lymph node dissection, less pain and few complications.

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*Authors' contributions:* A.T. designed the overall study with contributions from K.A. K.A. designed and carried out experiments, collected data. E.U. designed and carried out experiments and collected and analyzed data with E.K. and Ö.D. S.E. carried out experiments, and analyzed data with A.T.
*Disclosure:* The authors declare no conflict of interest.

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# A complete video—atlas of five robotic—assisted lobectomies

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Editor's Key Points

1. These narrated videos are extremely valuable materials demonstrating the detailed surgical techniques of each of the five robotic-assisted lobectomies
2. Dr Park described an approach based on a video-assisted thoracoscopic surgery (VATS) lobectomy incision strategy, which could be reproducible for VATS surgeons
3. For those used to the conventional open technique, the very intuitive and user-friendly robotic interface may be easier to master than the different set of hand-eye skills demanded by VATS, hence, the robotic system may provide the non-VATS surgeons an excellent route into the world of minimally invasive thoracic surgery
4. Promising results have been reported by a small number of specialist centers with particular experience using the robotic systems

--T.D.Y.

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Advances in technology have allowed minimally invasive approaches for pulmonary lobectomy to be utilized increasingly over traditional thoracotomy for the purported benefits of decreased surgical trauma resulting in shorter hospital stay, quicker recovery, less pain and decreased morbidity. While video-assisted thoracic surgery (VATS) lobectomy was initially developed in the early 1990s, it has taken two decades for VATS lobectomy to become a more widely available and reproducible technique. This is in part because of the training required to teach and learn a different approach to handle hilar dissection in a closed chest. It may also be because of the limitations of VATS technology and instrumentation.

Telerobotic surgical technology with a binocular visual system and wristed instrumentation was developed in order to overcome the limitations in the established minimally invasive technology. While initially developed and first reported for closed chest coronary revascularization, robotics has enabled rapid and nearly uniform adoption of a minimally invasive approach for pelvic procedures, such as prostatectomy and hysterectomy, where vision and maneuverability are limited. The capital costs of these systems and the question of whether clear-cut benefits exist, aside from those to the operating surgeon, are important and unresolved issues.

In the arena of general thoracic surgical procedures, the development of robotic approaches has been slowly increasing, as more emphasis is placed on minimally invasive surgery. However, much like the early experiences with VATS lobectomy there only a few centers of excellence in robotic thoracic surgery exist worldwide. Teaching materials, training courses and opportunities for mentoring are sparse.

These narrated videos represent an effort to demonstrate one approach in utilizing robotic technology to perform minimally invasive lobectomy. *Video 1* reviews the docking process. *Videos 2* to 6 demonstrate the technical aspects of right upper lobectomy (*video 2*), right middle lobectomy (*video 3*), right lower lobectomy (*video 3*), left upper lobectomy (*video 5*) and left lower lobectomy (*video 6*), respectively. The approach is based on a VATS lobectomy incision strategy consistent with the CALGB 39802 registry study. In this regard, it is a reproducible technique for those individuals who already have some advanced VATS experience. In many ways the two-dimensional video clips cannot adequately represent the three-dimensional nature of the robotic dissection, but the viewer should focus on how the robotic system is implemented to achieve a precise bimanual hilar dissection.

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*Disclosure:* Bernard Park is a speaker and proctor for Intuitive Surgical.

 

# Robotic-assisted pulmonary resection—Right upper lobectomy

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## Introduction

General thoracic surgery is the fastest growing sector of robotic surgery. The reason is advantage the robot offers in mediastinal work such as thymectomy, resection of esophageal leiomyoma, removal of bronchogenic or esophageal duplication cysts, and even diaphragmatic plication. Once general thoracic surgeons try the robot and see the improved visualization they are often willing to continue to learn to do more with it. We have now applied it to pulmonary resections.

There are multiple published articles that have shown the efficacy and safety of robotic pulmonary resection including lobectomy, segmentectomy, and even several reports of pneumonectomy (1-4). However, there are difficulties in learning robotic surgery. It is a "team sport" where the bedside assistant is the one currently placing the stapler on the arteries and the veins, which makes everyone anxious. Another difficulty relates to the high capital cost of a robotic surgery program, including purchasing a robot, the additional expenses of buying a second console and replacing robotic surgical equipment and finally getting time on the robotic platform for the patients.

Despite the debate, cardiac and thoracic surgeons are currently learning many robotic surgery techniques. We recently helped design and develop a CPRL-4 technique and have published the world's largest experience with it - in over 100 lobectomies. We now have completed over 180 robotic lobectomies with only one 30 or 90 day mortality. In addition, with other authors, we have written an international nomenclature paper on this issue (JTCVS 2012, publication pending) and have proctored many surgeons and trained two robotic surgery fellows. We have also published the largest series on robotic Ivor Lewis esophageal resection with a two-layered hand-sewn anastomosis. In addition, we have the world's largest series on the robotic resection of posterior mediastinal tumors.

Based on our experience, we know all too well the difficulties in establishing robotic programs in North America. Some of these difficulties include: anesthesia push- back because of the safety concerns, and increased time, the limited degree of robot platform availability, and the fact that teams are best if they perform several robotic operations a week to get experience. In this *Art of Operative Technique Teachers' Section*, we will display the specific step-by-step approach for a robotic right upper lobectomy.

## Operative techniques - robotic right upper lobectomy

Port placement (*Figure 1*)

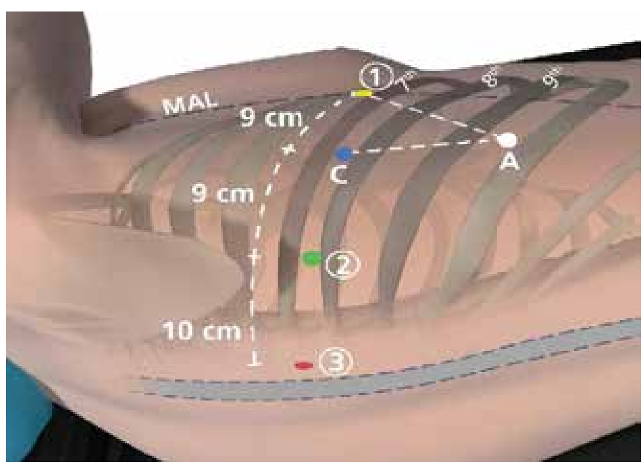


**Figure 1** da Vinci Right Lobectomy port placement.

 

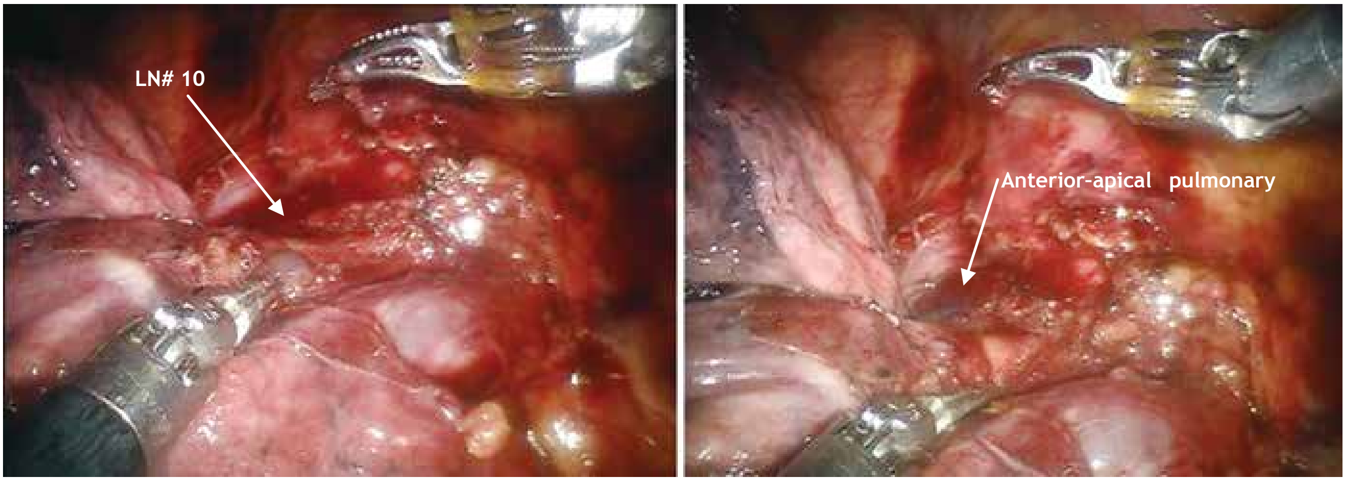


**Figure 2** Identification of LN # 10 at anterior–apical pulmonary artery branch.

1. Start with the creation of a 5 mm port to facilitate port placement in the midaxillary line (MAL) placed over the 7th rib into the 6th intercostal space (ICS). Later this will become *da Vinci* Instrument Arm ① port.
2. Use a 5 mm videoscope through this port to ensure entry into the pleural space and to visualize placement of *da Vinci* and assistant ports. Start $CO_2$ insufflation (warmed and humidified) to displace the diaphragm inferiorly.
3. Mark the spinous processes of the vertebral bodies on the patient (grey zone in *Figure 2*). Did not understand the grey zone! Perform a paravertebral block posteriorly with a local anesthetic (21 gauge needle) from ribs three to eleven under the pleural surface (0.25% Marcaine with epinephrine).
4. *da Vinci* Instrument Arm ③ Port, 5 mm (Red): Place port in the ICS that is two rib spaces inferior to the major fissure and slightly anterior to the spinous process of the vertebral body. Distance to *da Vinci* Instrument Arm ② port should be at least 10 cm.
5. *da Vinci* Instrument Arm ② Port, 8 mm (Green): Placed in the 7th ICS. Distance to *da Vinci* Instrument Arm ③ port is 10 cm and to the camera port should be at least 8-9 cm. If stapler access from this location is deemed necessary, dilate this port to a 13 mm *da Vinci* cannula during the surgery.
6. Assistant Port, 15 mm (White): Use a small 21-gauge needle to identify the most anterior and inferior aspect of the chest that is just above the diaphragmatic fibers. Port location should be chosen so that a triangle is established with Camera Port and Arm ① Port with the Assistant Port at the tip equidistant to each port. 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, etc.

## Right upper lobectomy

- Instrumentation: 0° and/or 30° down endoscope, 5 mm Thoracic Grasper (left ③), Cardiere Forceps (left ②) and Permanent Cautery Spatula or Curved Bipolar Dissector (right ①)
- First inspect the pleural space and explore to ensure that there are no metastatic lesions on the diaphragm or the parietal or visceral pleura.
- Dissection is started at the N2 mediastinal lymph nodes. If the lung deflates well the nodes #9, #8 and then #7 can be completely removed (*Figure 3*). If the lung does not deflate sufficiently it is best to start at the #7 station and then move cephalad toward the trachea and remove #10R and separate the azygous vein off of the trachea. Removal of the lymph nodes first opens up the anatomy and affords visual inspection of the N2 nodes.
- The dissection is carried down between the hilar structures and the phrenic nerve.
- Sweep phrenic nerve gently down to remove the #10R lymph node avoiding the small phrenic vein that goes to the large #10R lymph node that is routinely found in this area.

 

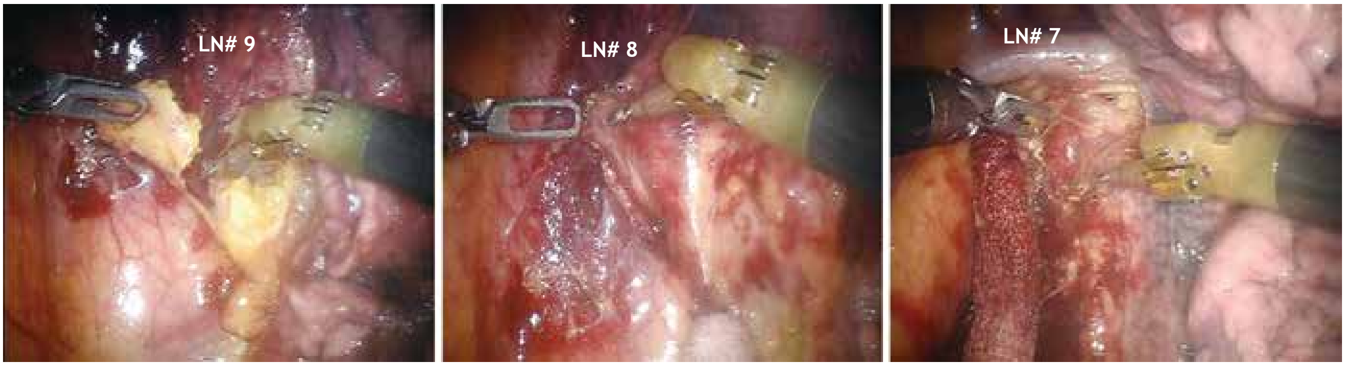


**Figure 3** N2 mediastinal lymph node resection.

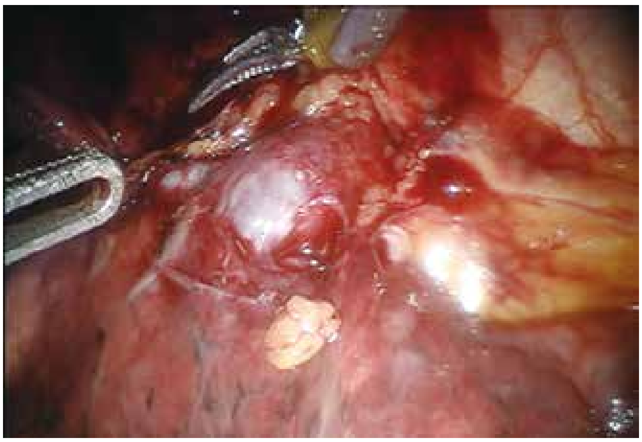

**Figure 4** Identification of superior pulmonary artery.

- ❖ Develop the bifurcation between middle and upper lobe veins by bluntly dissecting it off of the underlying pulmonary artery. It can be easily encircled with the Cardiere Forceps or Curved Bipolar Dissector and a vessel loop; and subsequently stapled with a vascular stapler (*Figure 4*).
- ❖ The #10R lymph node between the anterior-apical pulmonary artery branch and the superior pulmonary vein should be removed or swept up towards the lung. This exposes the anterior apical pulmonary artery branch (*Figure 2*).
- ❖ Continue en bloc dissection of the hilar tissue to cleanly expose the main pulmonary artery.
- ❖ Encircle the superior pulmonary vein with an 8 cm vessel loop and retract it off the pulmonary artery behind it. Using the vessel loop as a guide, the linear stapling device is passed across the right superior pulmonary vein and fired (*Figure 5 A-D*).
- ❖ Next the anterior apical trunk pulmonary artery branch is encircled with a vessel loop and transected with a linear stapler in the same fashion as the vein (*Figure 6*). Exposure might be improved by using the left hand *EndoWrist* instrument to deflect the trachea downward and enable the tip of the stapler device to go above the trachea.
- ❖ The operation is now changed to a posterior approach in contrast to continue this anteriorly as done commonly via VATS lobectomy.
- ❖ The RUL bronchus' anatomy is exposed from posterior one. This is not possible or difficult to do with VATS in an anterior to posterior approach. However, the robot allows us to operate from either ways as seen here. The upper aspect of the RUL bronchus is easily seen coming off the trachea. The dissection is continued inferiorly to expose the inferior edge of the RUL bronchus and free it from the bronchus intermedius. Once the anatomy is identified, a Cardiere Forceps can be placed under the RUL bronchus to confirm complete dissection (*Figure 7*).
- ❖ Lymph node dissection (10R and 11R, hilar and interlobar) is continued along the right main bronchus and the bifurcation between the bronchus intermedius and the upper lobe bronchus identified (*Figure 8*).
- ❖ Encircle the right upper lobe bronchus with a vessel loop and transect with a linear stapler (gold or purple load). Care must be taken to apply only minimal retraction on the specimen to avoid tearing of PA branches (*Figure 9*).
- ❖ Next the posterior segment of the pulmonary artery is exposed. The surrounding N1 nodes can be removed and the posterior artery can be encircled with a vessel loop and taken with a vascular stapler. A vessel-sealing device or Titanium clips applied by the *EndoWrist* Small

 

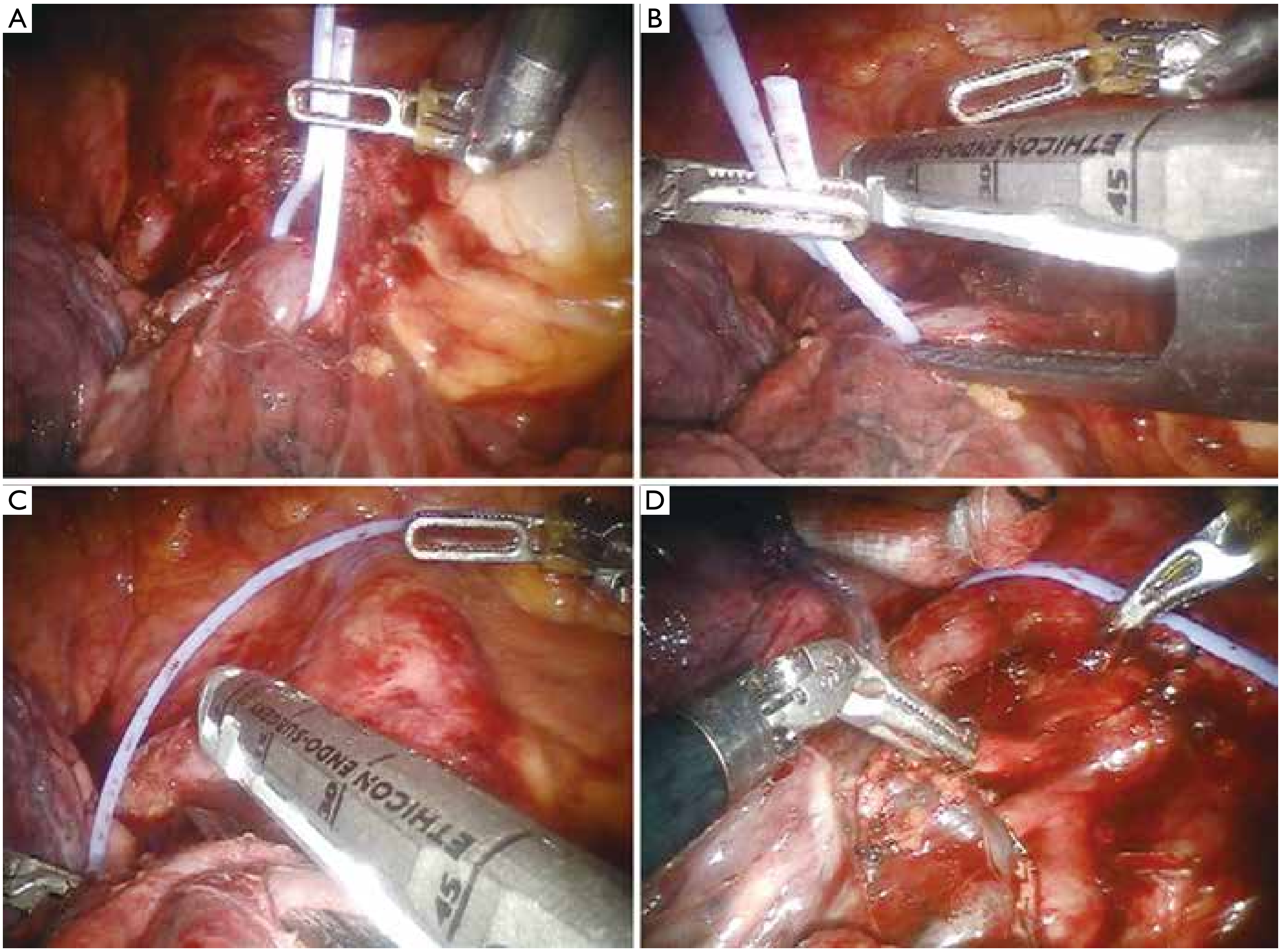


**Figure 5** Transection of right superior pulmonary vein: A. vessel loop placed; B. Vessel loop guiding stapler; C. stapler placed; D. vein transected.

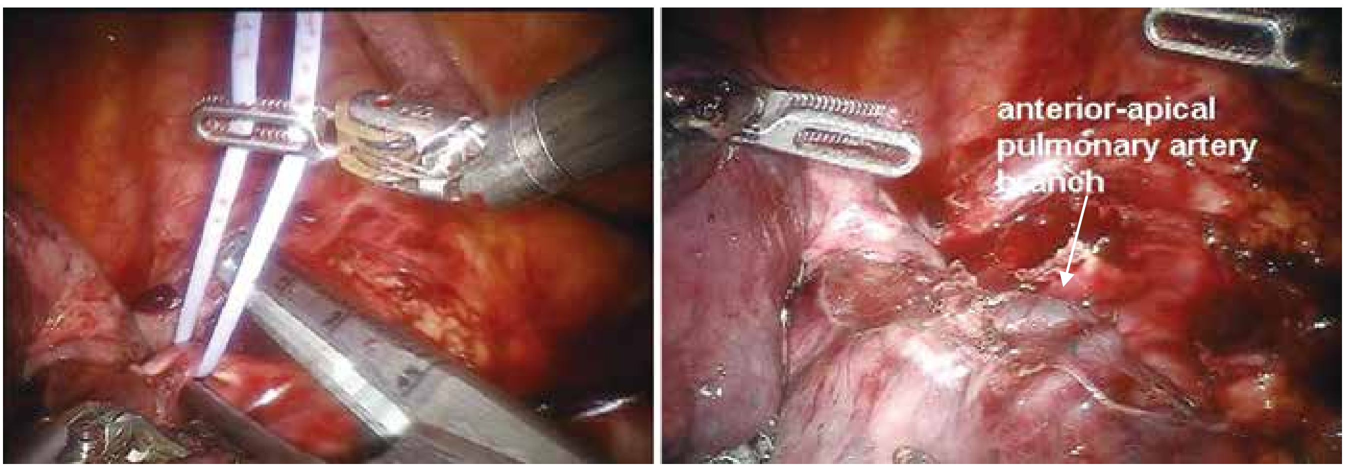


**Figure 6** Transection of anterior apical pulmonary artery branch.

 

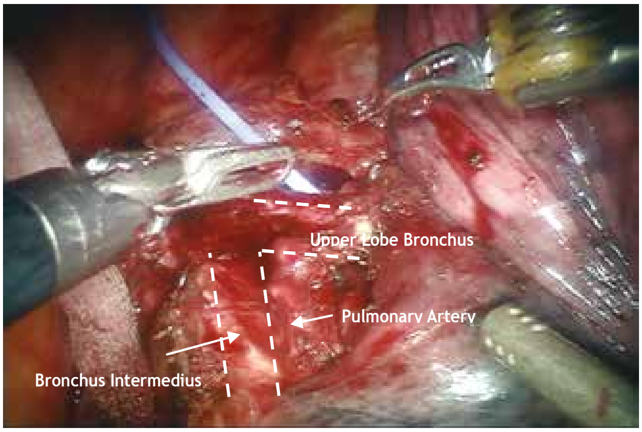


**Figure 7** Identification of RUL bronchus, bronchus intermedius and Pulmonary Artery.

**Figure 8** Removal of hilar and interlobar lymph node stations (10R & 11R).

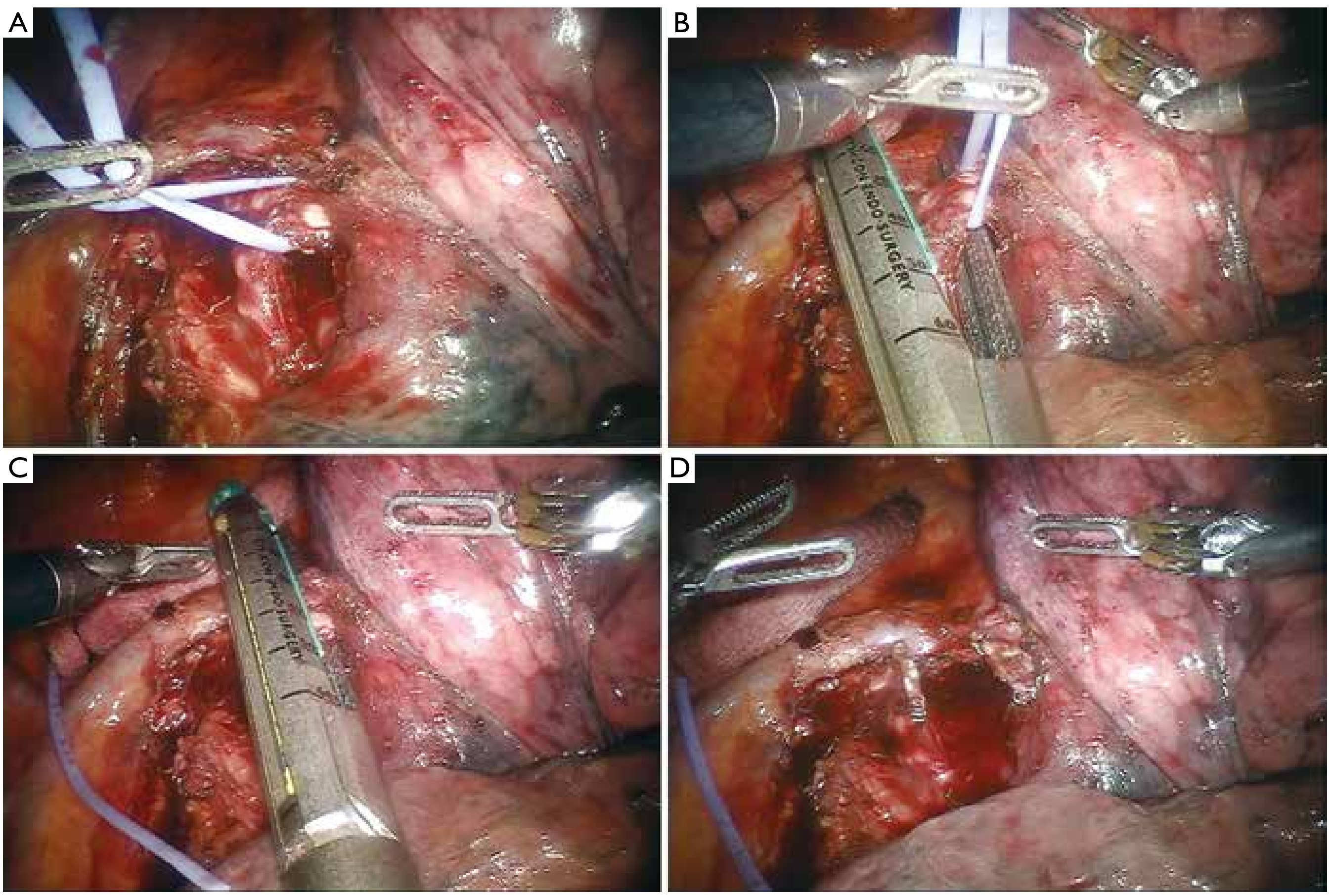


**Figure 9** Transection of right upper lobe bronchus: A. vessel loop placed; B. Vessel loop guiding stapler; C. stapler placed; D. bronchus transected.

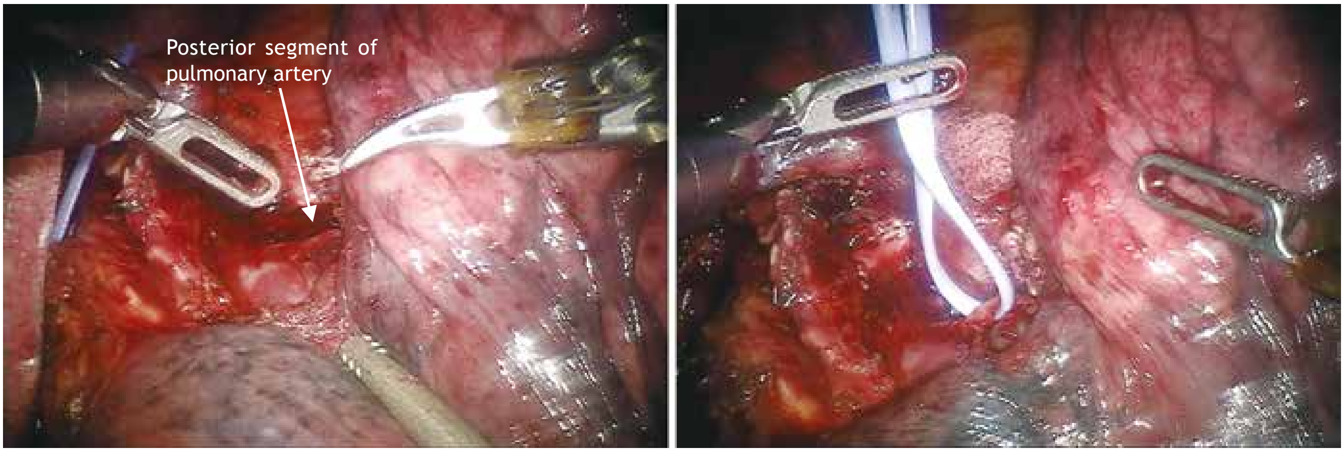


**Figure 10** Identification of posterior segment of pulmonary artery.

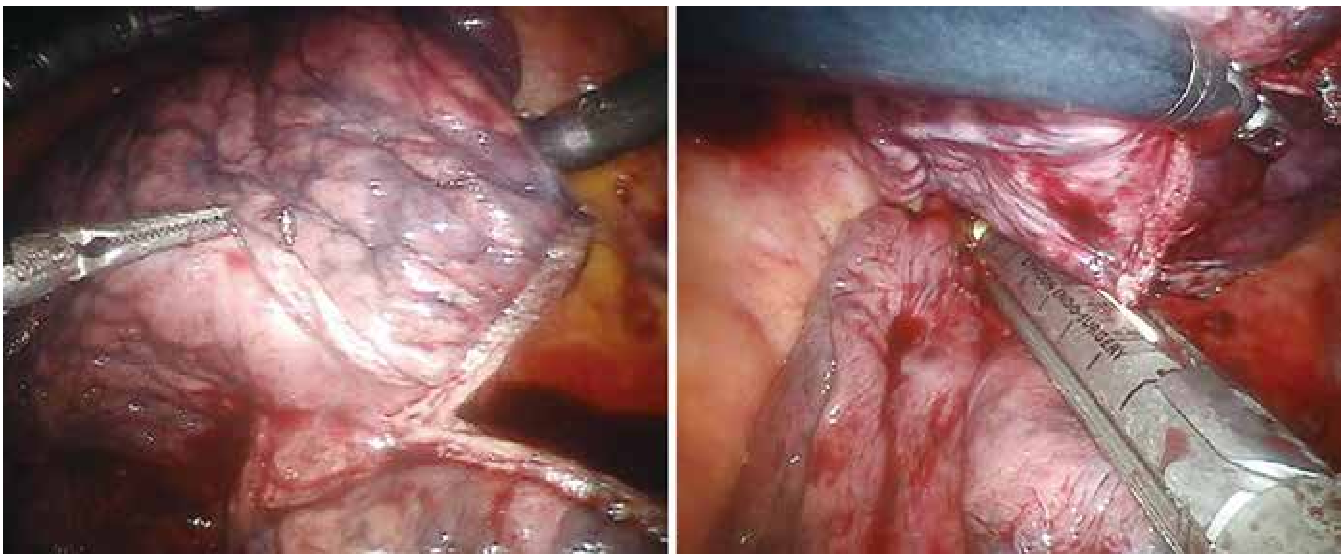

**Figure 11** Transection of minor fissure.

Clip Applier could be used if the vessel is less than 6 mm in size (*Figure 10*).

- ❖ Prior to finishing the operation by stapling the fissure last, the anterior aspect of the pulmonary artery is carefully inspected to ensure that there are no PA branches remaining. If so these are usually quite small and can be easily torn and hence must be carefully ligated.
- ❖ The fissure between the right upper lobe and the right middle lobe is now taken with a gold or purple stapler (*Figure 11*). Usually this is done anterior to posterior, however if the space between the PA and the Right Middle Lobe vein is already developed it can be done in the reverse direction as shown in *Figure 11*.
- ❖ As the fissure is completed the main pulmonary artery should be seen and the stapler should be placed just above it and again ensuring that all small PA branches to the RUL have been taken. The right middle lobe PA branch can be easily seen and should be preserved. The RUL must be lifted up to ensure the specimen bronchus is included in the resected specimen.
- ❖ To delineate the minor fissure, the upper lobe is retracted superiorly and the middle - lower lobe pushed inferiorly (*Figure 12*).
- ❖ Minor fissure is divided with a gold or purple load linear stapler (*Figure 13*).
- ❖ The lobe, now free of any attachments is placed

 


**Figure 12** Minor fissure exposed for transection.

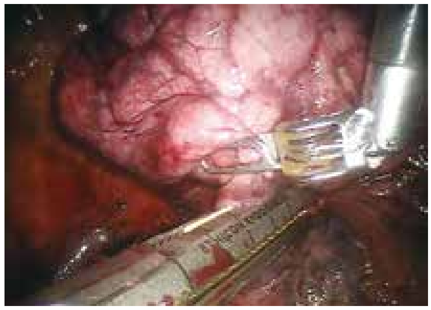
**Figure 13** Transection of minor fissure.

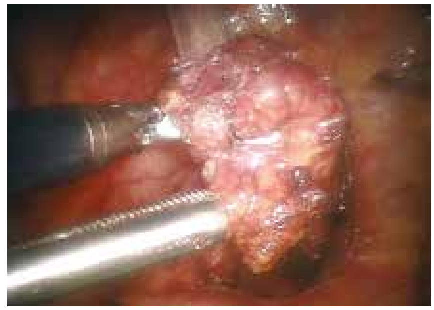
**Figure 14** Removal of superior mediastinal lymph node stations.


**Figure 15** “Anchor” bag inserted through assistant port.

remotely anteriorly and the remaining LN dissection of station 2R and 4R should be performed (*Figure 14*).

## Specimen removal

- ❖ Instrumentation: 0° endoscope, 5 mm Thoracic Grasper (left ③), Cardiere Forceps (left ②) and 5 mm Thoracic Grasper (right ①) With completion of the lymph node dissection and the lobe completely resected, an “Anchor” bag is inserted into the chest from the assistant port in the 9$^{th}$ ICS (*Figure 15*).
- ❖ The lobe is then held up freely in the dome of the chest by the Thoracic Grasper. This is to utilize gravity to facilitate bagging of the lobe (*Figure 16*).
- ❖ The open Anchor bag is placed below the freely hanging lobe (*Figure 17*).
- ❖ The lobe is then dropped and pushed into the bag. Visualize that the complete specimen is contained in the bag while the assistant slowly closes the “Anchor” bag (*Figure 18 A-C*).
- ❖ The straps of the bag are brought out though the 15 mm access port.
- ❖ A small 20 Fr chest tube is placed apically and posteriorly via the most anterior port and guided into position by the *EndoWrist* instrument in arm ②. Once completed, $CO_2$ is turned off and the right thorax vented.
- ❖ *EndoWrist* instruments are removed, the *da Vinci* arms are undocked and Patient cart pushed back.
- ❖ Extend the assistant port in the 9$^{th}$ ICS to an appropriate size needed to remove the tumor en bloc.
- ❖ Pull tissue straight out of thoracic cavity. Once specimen is removed use traditional VATS if needed:
    - o Check for bleeding
    - o Check cannula sites under endoscopic view for hemorrhage.
- ❖ Fill chest with warm saline solution, expand lung to 20 cm $H_2O$ and check for air leaks if not done already previously.
- ❖ If one is found a 5-0 polypropylene with an RB-1 needle can be used to provide an airtight closure of the bronchial stump.
- ❖ Chest tube is employed as per surgeon’s standard routine.

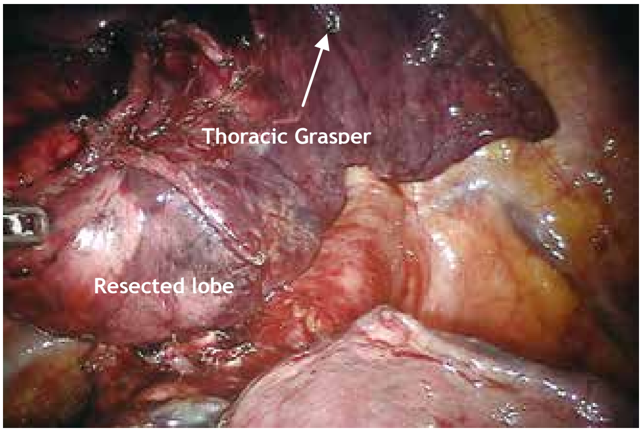


**Figure 16** Thoracic Grasper lifting resected lobe for "bagging".

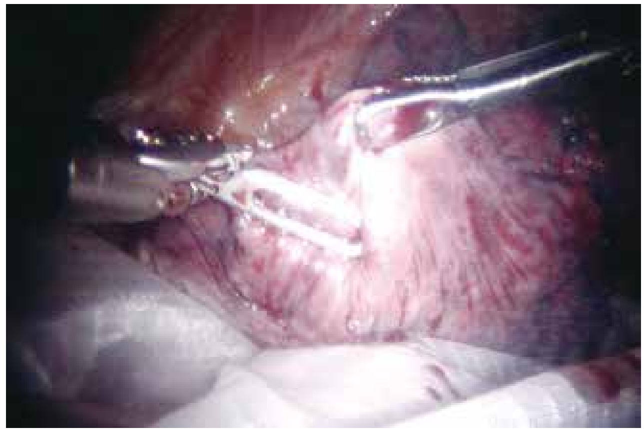

**Figure 17** Open "Anchor" bag below free lobe.

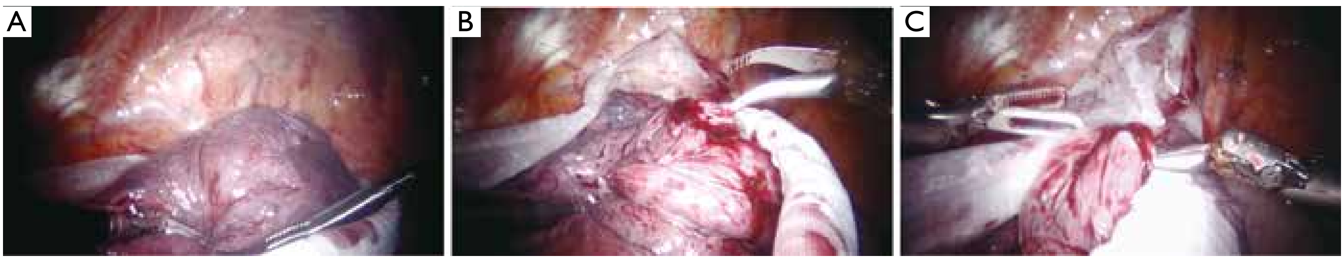


**Figure 18** A. lobe pushed into bag opening; B. closing of the bag; C. Visual confirmation that specimen is in bag.

- Close incisions with absorbable suture:
  - o All cannula sites 8 mm or greater with size 0 suture at the fascia level
- Skin closed with subcuticular absorbable suture without knots.

## Comments

As shown above via the specific operative techniques, pictures, and graphics there is outstanding visibility of the anatomic structures during robotic surgery. Many people worry about encircling the vessels because of the lack of proprioception; however, the reality is that the enhanced visibility allows one to start with a blunt instrument such as a Caudier in a safe plane. The key is starting in a safe plane. For example, when encircling the superior pulmonary vein it is best to dissect the middle lobe vein from the upper lobe vein. Then identify and dissect the plane of the upper lobe vein off of the underlying pulmonary artery. The entrance point for the blunt Caudier and the exit point for the blunt Caudier should be clearly identified. Then the clamp is gently placed just under the vein and you can clearly see it come under the view and above the artery. The key to doing this safely is by first dissecting out both the entry and exit part; secondly, by using the blunt instrument (such as a Caudier; and thirdly, by having a vessel loop and rolled up Ray-Tec available to dissect the tissue off of the clamp as it comes under the vein and a Ray-Tec so compress is immediately available in case of injury and bleeding. Then a vessel loop is placed under the vessel. The vessel is retracted upwards in order to dilate the space with an open Caudier that is gently spread under the vessel. We prefer to use the vessel loop to help guide the stapler around.

The bottom line is the future of robotic surgery is extremely bright. Multiple new instruments are coming to market soon to make the operations safer and more efficient. There are even new robotic surgical techniques being developed, including the use of FIREFLY, immunofluorescence, and fluorescence of specific antigens and perhaps organs (such as the thymus). Careful studies are necessary to provide a responsible cost-benefit analysis of this interesting and exciting era of robotic thoracic surgery.

## Acknowledgements

*Disclosure:* Robert J. Cerfolio has lectured and proctors for

 

Intuitive (Sunnyvale, CA). Ayesha S. Bryant declares no confict of interest.

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# Technical points of the operative procedure for robotic-assisted lung resection and lymph node dissection

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## The left-lung upper lobe resection and lymph node dissection

### *Anesthesia, intubation, and posture*

The operation is performed under general anesthesia with double-lumen endotracheal intubation. The patient is placed in the lateral position on the unaffected side. Single-lung ventilation is performed on the unaffected side. The patient holds a pillow with both upper limbs flexed and is placed in the jackknife position.

### *Design of the hole positions*

We use the "8-8-5-7" hole position design method, as follows: an incision is made in the 8$^{th}$ or 9$^{th}$ intercostal space on the posterior axillary line on the affected side. A trocar with a diameter of 12 mm is implanted inside the incision, which is used as the thoracoscope-entry hole. In addition, two more incisions are made: one in the 8$^{th}$ intercostal space on the infrascapular line and the other in the 5$^{th}$ intercostal space on the anterior axillary line. A trocar with a diameter of 8 mm is implanted through each incision, which is used as the instrument-entry hole, through which the arm of the instrument is connected. A 3~4-cm-long incision is made in the 7$^{th}$ intercostal space on the midaxillary line, and a disposable incision protector is implanted through the incision, which is used as the auxiliary operation hole.

### *Technical points of the operative procedure*

The selection of the operative procedure (single direction lobectomy or anatomical) is based on the state of development of the oblique fissure, as follows:

(I) If no oblique fissure has developed, then the single direction lobectomy operative procedure is selected. First, the left upper pulmonary veins are treated (i.e., after the left upper pulmonary veins are freed, the lens is adjusted to the auxiliary operation hole, and a dissecting sealer is inserted through the thoracoscope-entry hole and used to staple and cut off the blood vessels). Next, the left upper lobar apical segmental artery and anterior segmental artery are freed; a dissecting sealer is inserted through the auxiliary operation hole and used to staple and cut off the blood vessels. The left upper lobar bronchus (including the lingular segmental bronchus) is treated. The lens is again adjusted to the auxiliary operation hole. A dissecting sealer is inserted through the thoracoscope-entering hole and used to clip the upper lobar bronchus. Afterward, the anesthetist is instructed to inflate the lung. After confirming that the lower lobe of the left lung has been well inflated, the upper lobar bronchus is clipped and cut off. Subsequently, the remaining upper lobar arteries are treated. After the group 11 lymph nodes inside the oblique fissure are dissected, the lung tissue in the undeveloped oblique fissure is treated. The lower pulmonary ligament is loosened so that it reaches the level of the lower pulmonary veins. Groups 2L, 5, 6, 7, 8, 9, and 10 mediastinal lymph nodes are routinely dissected. One closed thoracic drainage tube is implanted through the thoracoscope-entry hole, and another closed thoracic drainage tube is implanted through the operation hole on the anterior axillary line;

(II) If a pulmonic fissure has well developed, then the anatomical operative procedure is selected. First, the left upper pulmonary veins are treated (i.e., after the left upper pulmonary veins are freed, the lens is adjusted to the auxiliary operation hole, and a dissecting sealer is inserted through the thoracoscope-entering hole and used to staple and cut off the blood vessels). Next, the remaining upper lobar arteries, excluding the apical segmental artery and the anterior segmental artery are treated. Last, the left upper lobar apical segmental artery and anterior segmental artery are freed, and a dissecting sealer is inserted through the thoracoscope-entry hole and used to staple and cut off the blood vessels. The left upper lobar bronchus (including the lingular segmental bronchus) is freed. After the upper lobar bronchus is clipped using a dissecting sealer, the anesthetist is instructed to inflate the lung. After confirming that the lower lobe of the left lung has been well inflated, the upper lobar bronchus is clipped and cut off (whether to first treat the upper lobar apical segmental artery and anterior segmental artery or the upper lobar bronchus depends on their anatomical relationship and should also be based on safety and convenience). The lower pulmonary ligament is loosened so that it reaches the level of the lower pulmonary veins. Groups 2L, 5, 6, 7, 8, 9, and 10 mediastinal lymph nodes are routinely dissected. One closed thoracic drainage tube is implanted through the thoracoscope-entry hole, and another closed thoracic drainage tube is implanted through the operation hole on the anterior axillary line.

## The resection of lingular segment of the left-lung upper lobe

### *Anesthesia, intubation, and posture*

The operation is performed under general anesthesia with double-lumen endotracheal intubation. The patient is placed in the lateral position on the unaffected side. Single-lung ventilation is performed on the unaffected side. The patient holds a pillow with both upper limbs flexed and is placed in the jackknife position.

### *Design of the hole positions*

We use the "8-8-5-7" hole position design method, as follows: an incision is made in the 8th intercostal space on the posterior axillary line on the affected side. A trocar with a diameter of 12 mm is implanted through the incision, which is used as the thoracoscope-entry hole. In addition, two more incisions are made: one in the 8th intercostal space on the infrascapular line and the other in the 5th intercostal space on the anterior axillary line. A trocar with a diameter of 8 mm is implanted through each incision, which is used as the instrument-entry hole, through which the arm of the instrument is connected. A 3~4-cm-long incision is made in the 7th intercostal space on the midaxillary line, and a disposable incision protector is implanted through the incision, which is used as the auxiliary operation hole.

### *Technical points of the operative procedure*

First, the left upper-lobe lingular segmental veins are treated (i.e., after the left upper-lobe lingular segmental veins are freed, the lens is adjusted to the auxiliary operation hole, and a dissecting sealer is inserted through the thoracoscope-entry hole and used to staple and cut off the blood vessels). Next, the lingular segmental artery is treated. Last, the lingular segmental bronchus is freed. After the left upper-lobe lingular segmental bronchus is clipped using a dissecting sealer, the anesthetist is instructed to inflate the lung. After confirming that the proper upper and lower lobes of the left lung have both been well inflated, the lingular segmental bronchus is clipped, and the lower pulmonary ligament is loosened so that it reaches the level of the lower pulmonary veins. One closed thoracic drainage tube is implanted through the thoracoscope-entry hole.

## The left-lung lower lobe resection and lymph node dissection

### *Anesthesia, intubation, and posture*

The operation is performed under general anesthesia with double-lumen endotracheal intubation. The patient is placed in the lateral position on the unaffected side. Single-lung ventilation is performed on the unaffected side. The patient holds a pillow with both upper limbs flexed and is placed in the jackknife position.

### *Design of the hole positions*

We use the "8-8-5-7" hole position design method, as follows: an incision is made in the 8th intercostal space on the posterior axillary line on the affected side. A trocar with a diameter of 12 mm is implanted inside the incision, which is used as the thoracoscope-entry hole. In addition, two more incisions are made: one in the 8th intercostal space on the infrascapular line and the other in the 5th intercostal space on the anterior axillary line. A trocar with a diameter of 8 mm is implanted through each incision, which is used as the instrument-entry hole, through which the arm of the instrument is connected. A 3~4-cm-long incision is made in the 7th intercostal space on the midaxillary line, and a disposable incision protector is implanted inside the incision, which is used as the auxiliary operation hole.

### *Technical points of the operative procedure*

The selection of the operative procedure (single direction lobectomy or anatomical) is based on the state of development of the oblique fissure, as follows:

(I) If no oblique fissure has developed, then the single direction lobectomy operative procedure is selected. First, the left lower pulmonary veins are treated. Next, the left lower-lobe bronchus is treated. Prior to stapling and cutting off the left lower-lobe bronchus, the anesthetist must be instructed to inflate the lung. After confirming that the upper lobe of the left lung has been well inflated, the lower lobar bronchus is clipped and cut off. Then, the lower lobar proper artery and dorsal segmental artery are treated. After the group 11 lymph nodes inside the oblique fissure are dissected, the lung tissue in the undeveloped oblique fissure is treated. Mediastinal lymph nodes are routinely dissected;

(II) If a pulmonic fissure has well developed, then the anatomical operative procedure is selected. First, the left lower pulmonary veins are treated. Next, the lower lobar proper artery and dorsal segmental artery are treated. After the group 11 lymph nodes inside the oblique fissure are dissected, the left lower-lobe bronchus is treated. Prior to stapling and cutting off the left lower-lobe bronchus, the anesthetist must be instructed to inflate the lung. After confirming that the upper lobe of the left lung has been well inflated, the lower lobar bronchus is clipped and cut off. Groups 2L, 5, 6, 7, 8, 9, and 10 mediastinal lymph nodes are routinely dissected.

## The right-lung upper lobe resection and lymph node dissection

### *Anesthesia, intubation, and posture*

The operation is performed under general anesthesia with double-lumen endotracheal intubation. The patient is placed in the lateral position on the unaffected side. Single-lung ventilation is performed on the unaffected side. The patient holds a pillow with both upper limbs flexed and is placed in the jackknife position.

### *Design of the hole positions*

We use the "8-8-5-7" hole position design method, as follows: an incision is made in the 8th intercostal space on the posterior axillary line on the affected side. A trocar with a diameter of 12 mm is implanted through the incision, which is used as the thoracoscope-entry hole. In addition, two more incisions are made: one in the 8th intercostal space on the infrascapular line and the other in the 5th intercostal space on the anterior axillary line. A trocar with a diameter of 8 mm is implanted through each incision, which is used as the instrument-entry hole, through which the arm of the instrument is connected. A 3~4-cm-long incision is made in the 7th intercostal space on the midaxillary line, and a disposable incision protector is implanted through the incision, which is used as the auxiliary operation hole.

### *Technical points of the operative procedure*

The selection of the operative procedure (single direction lobectomy or anatomical) is based on the state of development of the oblique fissure, as follows:

(I) If no oblique fissure has developed, then the single direction lobectomy operative procedure is selected. First, the right upper pulmonary veins are treated (i.e., after the right upper pulmonary veins are freed, the lens is adjusted to the auxiliary operation hole, and a dissecting sealer is inserted through the thoracoscope-entry hole and used to staple and cut off the blood vessels). Next, the right upper-lobe apical segmental artery and anterior segmental artery are treated simultaneously. Afterward, the right upper-lobe bronchus is freed. Prior to stapling and cutting off the upper lobar bronchus, the anesthetist must be instructed to inflate the lung. After confirming that the middle and lower lobes of the right lung have both been well inflated, the upper lobar bronchus is clipped and cut off. After the group 11 lymph nodes inside the oblique fissure are dissected, the pulmonary tissue in the undeveloped oblique fissure is treated along the levels of potential horizontal and oblique fissures. Groups 2R, 3, 4R, 7, 8, 9, and 10 mediastinal lymph nodes are routinely dissected. One closed thoracic drainage tube is implanted through the thoracoscope-entry hole, and another closed thoracic drainage tube is implanted through the operation hole on the anterior axillary line;

(II) If a pulmonic fissure has well developed, then the anatomical operative procedure is selected. First, the right upper pulmonary veins are treated (i.e., after the right upper pulmonary veins are freed, the lens is adjusted to the auxiliary operation hole, and a dissecting sealer is inserted through the thoracoscope-entry hole and used to staple and cut off the blood vessels). Next, the right upper-lobe apical segmental artery and anterior segmental artery are treated simultaneously. Afterward, the group 11 lymph nodes inside the oblique fissure are dissected. The right upper lobar bronchus is freed. Prior to stapling and cutting off the upper lobar bronchus, the anesthetist must be instructed to inflate the lung. After confirming that the middle and lower lobes of the right lung have both been well inflated, the upper lobar bronchus is clipped and cut off. Groups 2R, 3, 4R, 7, 8, 9, and 10 mediastinal lymph nodes are routinely dissected. The lower pulmonary ligament is loosened so that it reaches the level of the lower pulmonary veins. One closed thoracic drainage tube is implanted through the thoracoscope-entry hole, and another closed thoracic drainage tube is implanted through the operation hole on the anterior axillary line.

## The right-lung middle lobe resection and lymph node dissection

### *Anesthesia, intubation, and posture*

The operation is performed under general anesthesia with double-lumen endotracheal intubation. The patient is placed in the lateral position on the unaffected side. Single-lung ventilation is performed on the unaffected side. The patient holds a pillow with both upper limbs flexed and is placed in the jackknife position.

### *Design of the hole positions*

We use the "8-8-5-7" hole position design method, as follows: an incision is made in the 8th intercostal space on the posterior axillary line on the affected side. A trocar with a diameter of 12 mm is implanted through the incision, which is used as the thoracoscope-entry hole. In addition, two more incisions are made: one in the 8th intercostal space on the infrascapular line and the other in the 5th intercostal space on the anterior axillary line. A trocar with a diameter of 8 mm is implanted through each incision, which is used as the instrument-entry hole, through which the arm of the instrument is connected. A 3~4-cm-long incision is made in the 7th intercostal space on the midaxillary line, and a disposable incision protector is implanted through the incision, which is used as the auxiliary operation hole.

### *Technical points of the operative procedure*

The selection of the operative procedure (single direction lobectomy or anatomical) is based on the state of development of the oblique fissure, as follows:

(I) If neither oblique fissures nor horizontal fissures have developed, then the single direction lobectomy operative procedure is selected. First, the right middle pulmonary veins are treated (based on the intraoperative conditions, the lens can be adjusted to the auxiliary operation hole; a dissecting sealer is inserted through the thoracoscope-entering hole and can be used to staple and cut off the blood vessels). Next, the right middle-lobe bronchus is treated. Prior to stapling and cutting off the middle lobar bronchus, the anesthetist must be instructed to inflate the lung. After confirming that the upper and lower lobes of the right lung have both been well inflated, the middle lobar bronchus is clipped and cut off (based on the intraoperative conditions, the lens can be adjusted to the auxiliary operation hole; a dissecting sealer is inserted through the thoracoscope-entering hole and used to staple and cut off the blood vessels). The middle lobar artery is then treated (based on the intraoperative conditions, the lens can be adjusted to the auxiliary operation hole; a dissecting sealer is inserted through the thoracoscope-entry hole and can be used to staple and cut off the blood vessels). After the group 11 lymph nodes inside the oblique fissure are dissected, the pulmonary tissue in the undeveloped oblique fissure and horizontal fissure is treated. Groups 2R, 3, 4R, 7, 8, 9, and 10 mediastinal lymph nodes are routinely dissected. The lower pulmonary ligament is loosened so that it reaches the level of the lower pulmonary veins. One closed thoracic drainage tube is implanted through the thoracoscope-entry hole, and another closed thoracic drainage tube is implanted through the operation hole on the anterior axillary line;

(II) If a pulmonary fissure and a horizontal fissure have well developed, then the anatomical operative procedure is selected. First, the right middle lobar veins are treated (based on the intraoperative conditions, the lens can be adjusted to the auxiliary operation hole; a dissecting sealer is inserted through the thoracoscope-entry hole and can be used to staple and cut off the blood vessels). Next, the middle lobar artery is treated (based on the intraoperative conditions, the lens can be adjusted to the auxiliary operation hole; a dissecting sealer is inserted through the thoracoscope-entry hole and can be used to staple and cut off the blood vessels). Last, the right middle-lobe bronchus is treated. Prior to stapling and cutting off the right middle-lobe bronchus, the anesthetist must be instructed to inflate the lung. After confirming that the upper and lower lobes of the right lung have both been well inflated, the middle lobar bronchus is clipped and cut off. Groups 2R, 3, 4R, 7, 8, 9, 10, and 11 mediastinal lymph nodes are routinely dissected. The lower pulmonary ligament is loosened so that it reaches the level of the lower pulmonary veins. One closed thoracic drainage tube is implanted through the thoracoscope-entry hole, and another closed thoracic drainage tube is implanted through the operation hole on the anterior axillary line.

## The right-lung lower lobe resection and lymph node dissection

### *Anesthesia, intubation, and posture*

The operation is performed under general anesthesia with double-lumen endotracheal intubation. The patient is placed in the lateral position on the unaffected side. Single-lung ventilation is performed on the unaffected side. The patient holds a pillow with both upper limbs flexed and is placed in the jackknife position.

### *Design of the hole positions*

We use the "8-8-5-7" hole position design method, as follows: an incision is made in the 8th intercostal space on the posterior axillary line on the affected side. A trocar with a diameter of 12 mm is implanted through the incision, which is used as the thoracoscope-entry hole. In addition, two more incisions are also made: one in the 8th intercostal space on the infrascapular line and the other in the 5th intercostal space on the anterior axillary line. A trocar with a diameter of 8 mm is implanted through each incision, which is used as the instrument-entry hole, through which the arm of the instrument is connected. A 3~4-cm-long incision is made in the 7th intercostal space on the midaxillary line, and a disposable incision protector is implanted through the incision, which is used as the auxiliary operation hole.

### *Technical points of the operative procedure*

The selection of the operative procedure (single direction lobectomy or anatomical) is based on the state of development of the oblique fissure, as follows:

(I) If no oblique fissure has developed, then the single direction lobectomy operative procedure is selected. First, the right lower pulmonary veins are treated. Next, the right lower-lobe bronchus is treated. Prior to stapling and cutting off the right lower-lobe bronchus, the anesthetist must be instructed to inflate the lung. After confirming that the upper and middle lobes of the right lung have been well inflated, the lower lobar bronchus is clipped and cut off. Then, the lower lobar proper artery and dorsal segmental artery are treated. After the group 11 lymph nodes inside the oblique fissure are dissected, the lung tissue in the undeveloped oblique fissure is treated. Groups 2R, 3, 4R, 7, 8, 9, and 10 mediastinal lymph nodes are routinely dissected;

(II) If a pulmonic fissure has well developed, then the anatomical operative procedure is selected. First, the right lower pulmonary veins are treated. Next, the lower lobar proper artery and dorsal segmental artery are treated. After the group 11 lymph nodes inside the oblique fissure are dissected, the right lower-lobe bronchus is treated. Prior to stapling and cutting off the lower lobar bronchus, the anesthetist must be instructed to inflate the lung. After confirming that the upper and middle lobes of the right lung have been well inflated, the lower lobar bronchus is clipped and cut off. Groups 2R, 3, 4R, 7, 8, 9, and 10 mediastinal lymph nodes are routinely dissected. One closed thoracic drainage tube is implanted through the thoracoscope-entry hole.

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Pulmonary Resection

# Robotic-assisted right middle lobectomy

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## Clinical data

### *History*

The patient, a 56-year-old man, was admitted due to "a mass in the right lung found during health checkup 2 months ago". The patient visited our outpatient department for further treatment due to a mass in the right lung found during health checkup 2 months ago. He had no symptom such as fever, chest tightness, shortness of breath, chest pain, or hoarseness. His physical performance was normal, and the body weight did not obviously change.

### *Physical examination*

Physical examinations upon admission showed no obviously positive signs. The cervical and supraclavicular lymph nodes were not abnormally enlarged.

### *Auxiliary examinations*

Chest CT: a soft tissue density (1.5 cm × 1.5 cm) with irregular margin was found in the right middle lobe (*Figure 1*).

Epigastric ultrasound, bone ECT, and head MRI did not find the evidence of remote metastasis. No obvious abnormality was found in ECG, echocardiography, pulmonary function test, blood gas analysis, and other biochemical tests.

### *Preoperative diagnosis*

A space-occupying lesion in the right middle lung lobe.

## Pre-operative preparation

Based on the imaging results, "a space-occupying lesion in the right middle lung lobe" was considered; however, the possibility of malignancy could not be ruled out. Since it is a small, peripheral lesion, localization was done pre-operatively using percutaneous CT-guided injection of methylene blue dye, followed by wedge resection. The subsequent surgical protocol was determined based on the results of intraoperative frozen section biopsy. The surgery was performed using da Vinci robotic system.

## Surgical procedures

### *Anesthesia and body position*

After the induction of general anesthesia, the patient was placed in a right lateral decubitus position under double-lumen endotracheal intubation. With his hands put in front of head, he was fixed in a jackknife position and provided with single-lung (left) ventilation (*Figure 2*).

### *Procedures*

Incision: a 1.5 cm camera port was created in the $8^{th}$ intercostal space (ICS) right posterior axillary line, two 1.0 cm working ports were separately made in the $5^{th}$ ICS right anterior axillary line and the $8^{th}$ ICS scapular line, and a 4 cm auxiliary port was made in the $7^{th}$ ICS midaxillary line (*Figure 3*).

The robot manipulators were connected over the patient's head. A 12 mm trocar was placed at the camera port in the $8^{th}$ ICS right posterior axillary line to be attached with the camera arm. The 2# arm (with the left hand attached with bipolar coagulation forceps) and 1# arm (with the right hand attached with pericardial forceps) were placed via the incisions at the $5^{th}$ ICS right anterior axillary line and the $8^{th}$ ICS scapular line. Incision protector was

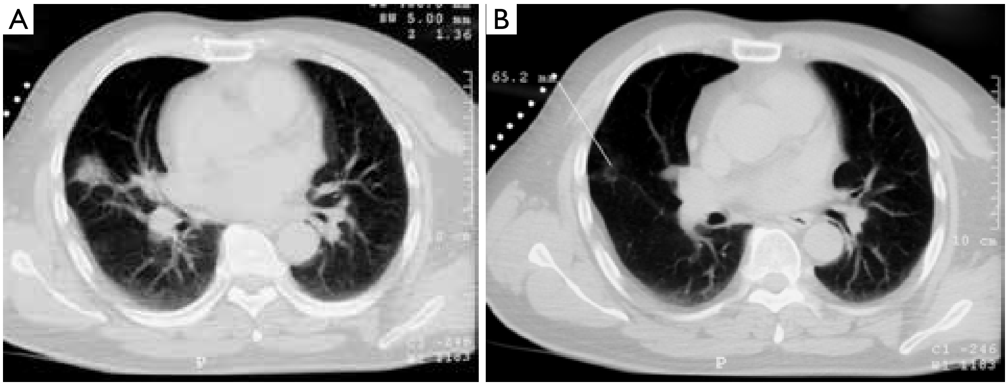


**Figure 1** Chest CT shows: (A) a soft tissue density (1.5 cm × 1.5 cm) with irregular margin in the right middle lobe; (B) angle and depth of puncture.

**Figure 2** The patient's position: in the left lateral decubitus position and in a jackknife position.

**Figure 3** Distribution of incisions: "8857".

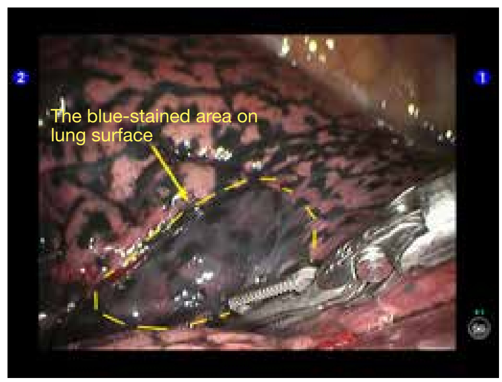


**Figure 4** Puncture site is visible on the surface of the middle lobe and the subpleural area is stained blue.

applied in the auxiliary port. During the thoracic cavity exploration, the puncture site was visible on the surface of the middle lobe and the subpleural area was stained blue (*Figure 4*). Deep nodules at the puncture site were touched.

Pulmonary wedge resection: a linear cutter was inserted via the auxiliary port, and the lesion was wedged out using three blue reloads (*Figure 5*).

The lesion was harvested using an endoscopic retriever; after the lesion was cut open, a homogeneous and dense mass sized 1.5 cm was found inside the pulmonary parenchyma. Frozen pathology showed that it was a lung cancer to be further classified. Lobectomy and lymph node

 

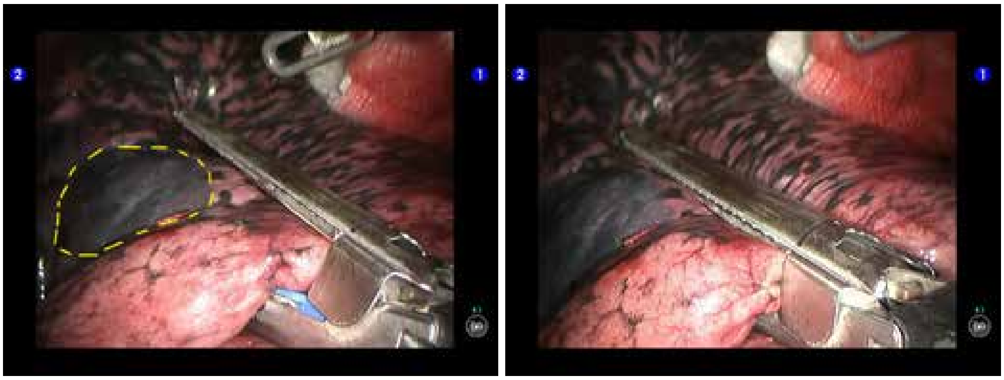

**Figure 5** The lesion was wedged out using three blue reloads.

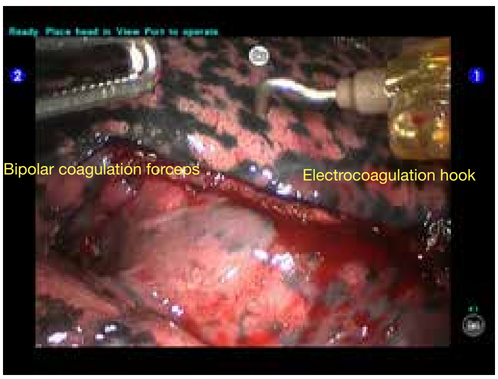


**Figure 6** The left hand was still attached with the bipolar coagulation forceps, whereas the right hand was attached with electrocoagulation hook instead.

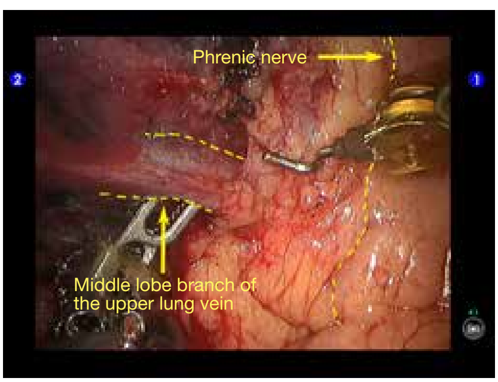


**Figure 7** The mediastinal pleura was cut open behind the phrenic nerve to dissociate the middle lobe.

dissection were then performed.

Lobectomy: the left hand was still attached with the bipolar coagulation forceps, whereas the right hand was

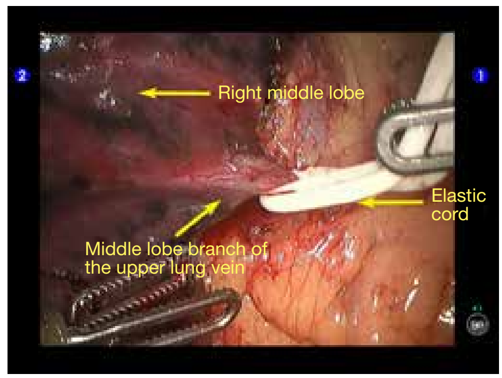


**Figure 8** Pull away with an elastic cord.

attached with electrocoagulation hook instead (*Figure 6*). Further exploration showed that the anterior part of the oblique fissure partially developed while the horizontal fissure basically did not develop. The mediastinal pleura was cut open behind the phrenic nerve to dissociate the middle lobe vein (*Figure 7*), which was tracted with elastic cord and then dissected using a beak-shaped golden reload (*Figures 8,9*). The anterior part of the oblique fissure was then dissected to remove the interlobar lymph nodes near the lung artery (*Figure 10*). The artery in the right middle lobe was dissociated (*Figure 11*) and then transected with the beak-shaped golden reload (*Figure 12*). The anterior part of the oblique fissure and the horizontal fissue were separately dissected with one blue reload (*Figure 13*). A Tri-staple purple reload was applied to clamp the root of the middle lobe bronchus, together with the residual parts of the oblique fissure (*Figure 14*). An anesthesiologist was asked to suction sputum and ventilate the operated lung, and the ventilation was found to be good in the lower lobe. The middle lobe was dissected using the reload and then

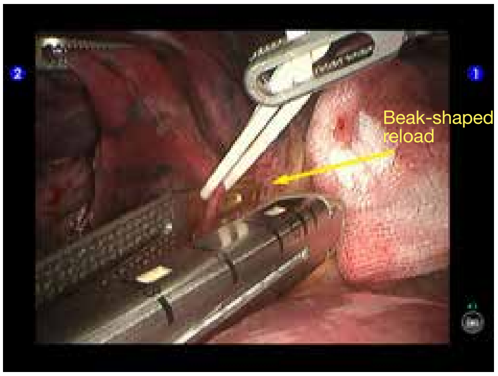


**Figure 9** Dissect using a beak-shaped golden reload.

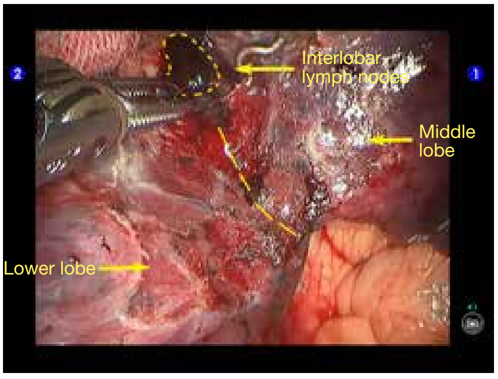


**Figure 10** Remove the interlobar lymph nodes near the lung artery.

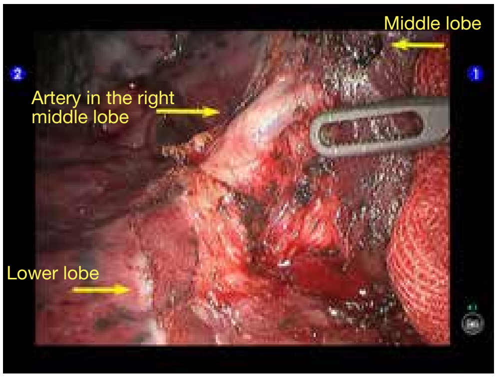


**Figure 11** The artery in the right middle lobe was dissociated.

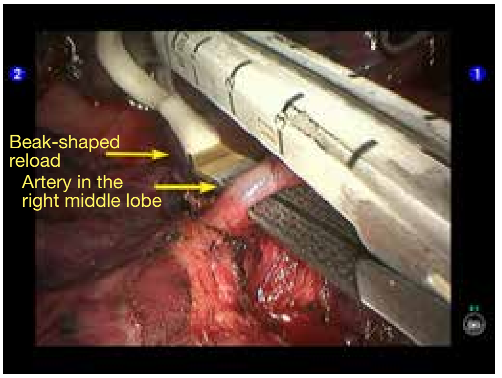


**Figure 12** Artery in the middle lobe was transected using a beak-shaped golden reload.

**Figure 13** The anterior part of the oblique fissure and the horizontal fissue were separately dissected with a blue reload.

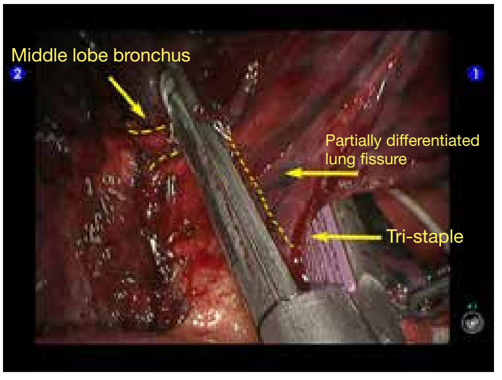


**Figure 14** A Tri-staple purple reload was applied to clamp the root of the middle lobe bronchus, together with the residual parts of the oblique fissure.

 

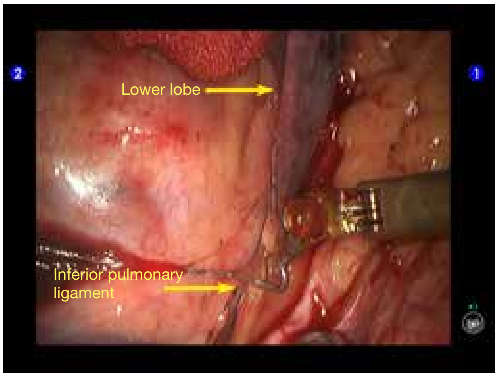


**Figure 15** Dissect the inferior pulmonary ligament.

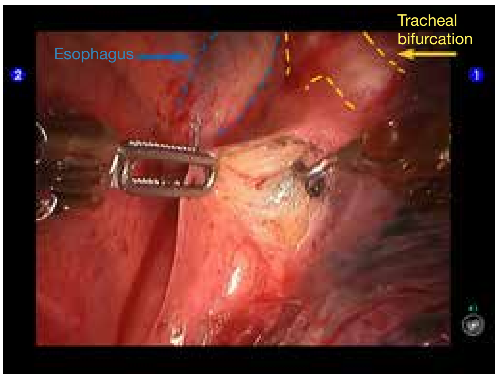


**Figure 16** Open the posterior mediastinal pleura.

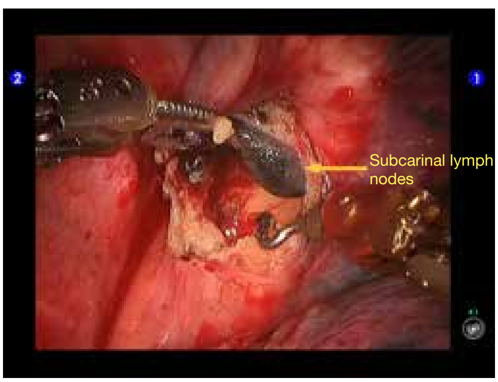


**Figure 17** Remove several subcarinal lymph nodes.

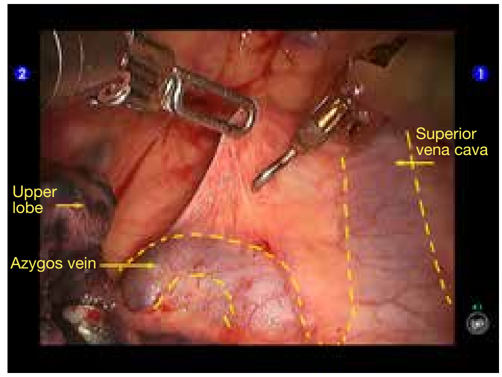


**Figure 18** Open the upper mediastinal pleura.

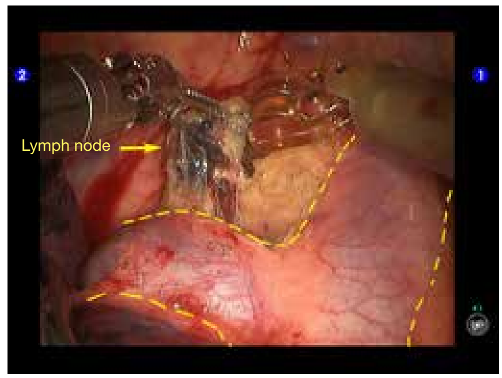


**Figure 19** Remove lymph nodes around the trachea.

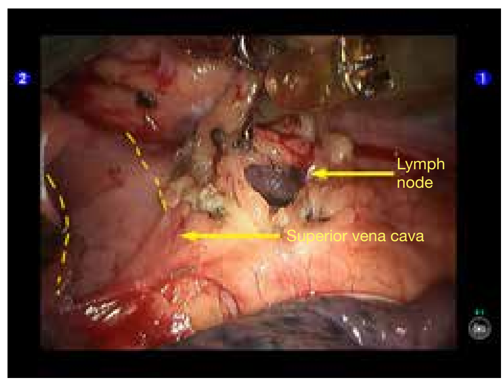


**Figure 20** Remove lymph nodes before the superior vena cava.

removed with the endoscopic retriever.

Lymph node removal: after the lower pulmonary ligament was dissected, no obvious lymph node enlargement was observed (*Figure 15*). Open the posterior mediastinal pleura (*Figure 16*) to remove several subcarinal lymph nodes (*Figure 17*). Open the upper mediastinal pleura (*Figure 18*) to remove several lymph nodes around the trachea (*Figure 19*) and before the superior vena cava (*Figure 20*).

Wash the thoracic cavity. If no air leakage was observed during lung recruitment, suction all the rinsing water. When no obvious bleeding was observed at all the trauma surfaces, the Tistat absorbable hemostatic gauze was applied at each trauma surface, followed by the withdrawal of robot arms. Latex drainage tube was inserted via the 5th ICS incision and placed at the residual cavity of the middle lobe. After having been well fixed, the bottle was sealed with water, and the silicone drainage tube was indwelled at the camera port. Close the chest after lung recruitment.

## Postoperative treatment

Postoperative treatment is similar to that after the conventional open lobectomy. The latex drainage tube was withdrawn 5 days after the surgery, and the silicone drainage tube was removed 11 days after the surgery. The patient was discharged on the 12th post-operative day.

## Pathological diagnosis

Moderately and well-differentiated adenocarcinoma at the right middle lung lobe, without lymph node metastasis. Post-operative pTNM stage: $T_{1a}N_0M_0$, Ia stage.

## Acknowledgements

*Disclosure:* The authors declare no conflict of interest.

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Pulmonary Resection

# Robotic-assisted segmentectomy of lingual segment of the left upper pulmonary lobe

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## Clinical data

Patient: a 50-year-old woman.

### *History*

The patient was admitted due to "repeated hemoptysis for more than half a year". The patient began to cough up blood about 6 months ago. The blood was bright red in color, and the patient spitted about 6 times during each attack. She spitted up fresh blood again one month ago and received anti-inflammatory and hemostasis treatment in a local hospital. Then, she visited our hospital for further management. She did not suffer from fever. Her physical performance was normal, and the body weight did not obviously change.

### *Physical examination*

The body temperature was 36.3 ℃. Auscultation revealed slightly harsh breath sounds in the left upper lung field; however, no dry or wet rales or pleural friction rubs were heard. No other positive sign was detected.

### *Auxiliary examination*

Chest CT: the lingular bronchus of left upper lobe showed cystic and cylindrical dilatation, along with thickened walls. Small dotted and patchy intensities were visible around it. Left bronchial dilation accompanied with peribronchitis was considered (*Figure 1*).

No obvious abnormality was found in ECG, echocardiography, pulmonary function test, blood gas analysis, and other biochemical tests.

Pre-operative diagnosis: bronchiectasis of the left upper lobe.

## Pre-operative preparation

Bronchiectasis of the left upper lobe was considered based on the symptoms, signs, and imaging findings. The symptoms were remarkably alleviated after medical treatment; however, a clear lesion persisted and was confined to the lingular bronchus. Resection of lingual segment of the left upper pulmonary lobe was then decided. The surgery was performed using da Vinci robotic system.

## Procedures

### *Anesthesia and body position*

After the induction of general anesthesia, the patient was placed in a right lateral decubitus position under double-lumen endotracheal intubation. With her hands put in front of head, she was fixed in a Jackknife position with single-lung (right) ventilation (*Figure 2*).

### *Procedures*

Incisions: a 1.5-cm camera port was created in the 8th intercostal space (ICS) at left posterior axillary line, two 1.0-cm working ports were separately made in the 5th ICS at left anterior axillary line and the 8th ICS at scapular line, and a 4-cm auxiliary port was made in the 7th ICS at midaxillary line (*Figure 3*).

The robot Patient Cart were connected over the patient's head. A 12-mm trocar was placed at the camera port in the

 

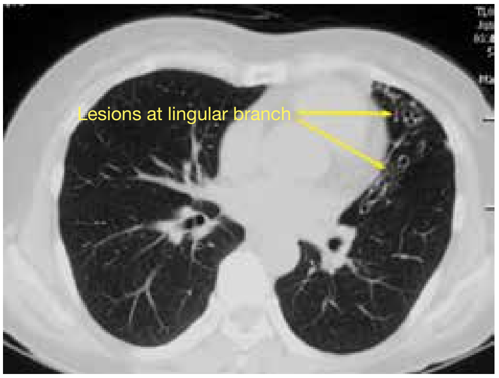


**Figure 1** Dilation of the lingular bronchus of left upper lobe.

**Figure 2** The patient's position: in the right lateral decubitus position and in a Jackknife position.

**Figure 3** Distribution of incisions: "8857".

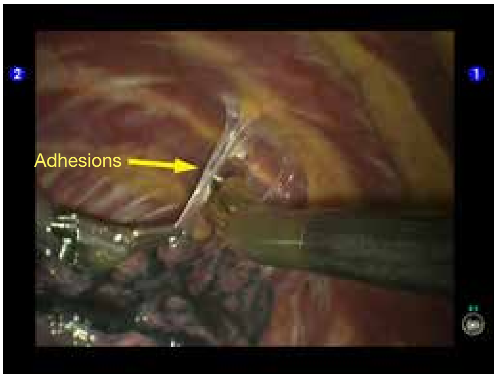


**Figure 4** Dissect the pleural adhesions.

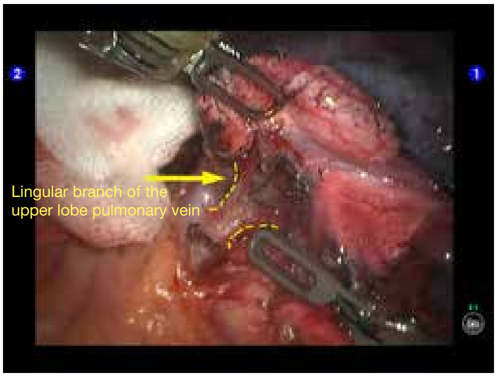


**Figure 5** Dissociate the lingular branch of the upper lobe pulmonary vein.

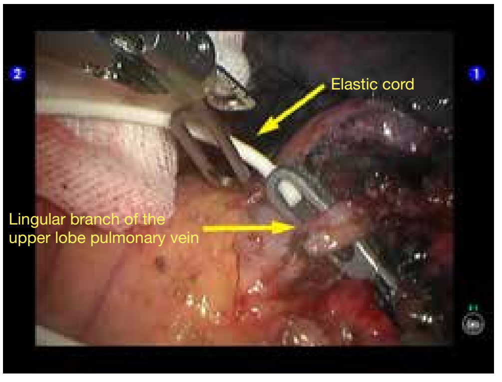


**Figure 6** Insert the elastic cord.

8th ICS at right posterior axillary line to be attached with the camera arm. The robot metal trocars were respectively attached to the 2# arm (left hand) and 1# arm (right hand) at the incisions in the 5th ICS anterior axillary line and the 8th ICS scapular line. Incision protector was applied in the auxiliary port.

The robot Patient Cart is positioned directly above the operating table and then connected. Its left hand is attached

 

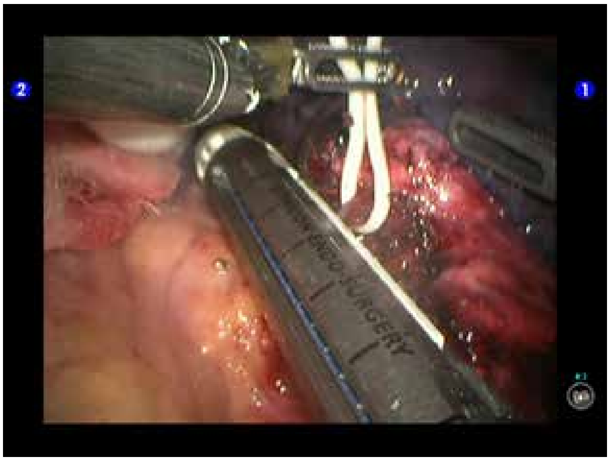

**Figure 7** Transect the lingular branch of the upper lobe pulmonary vein using a white reload.

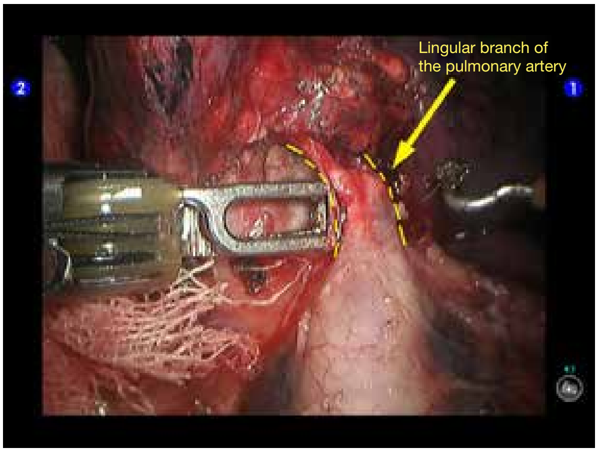


**Figure 9** Expose the lingular branch of the upper lobe pulmonary artery.

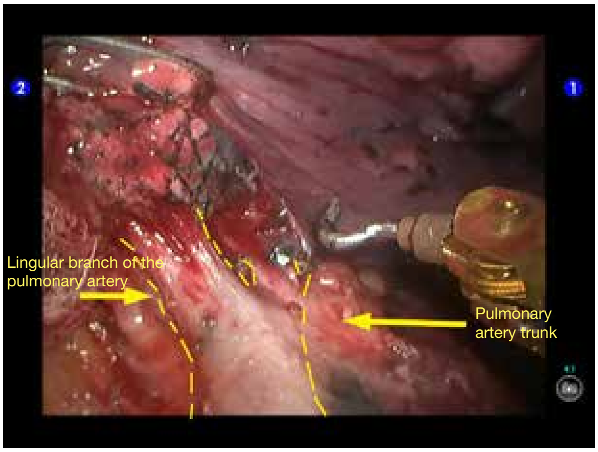


**Figure 8** Dissociate the lingular branch of the upper lobe pulmonary artery.

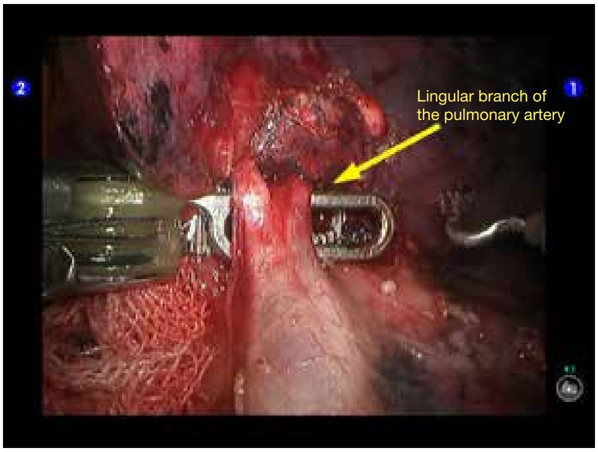


**Figure 10** Expose the lingular branch of the upper lobe pulmonary artery.

to bipolar cautery forceps, and its right hand is attached to a unipolar cautery hook. Inspection of the thoracic cavity showed that there were many cord-like structures adhered in the upper lobe. These cord-like structures were then dissected with the unipolar cautery hook (*Figure 4*). Inspection also showed that the lesion was localized inside the lingual segment of the upper lobe, and the lung fissures developed well.

Segmentectomy: the anterior mediastinal pleura was cut open to dissociate the lingular branch of the upper lobe pulmonary vein (*Figures 5,6*). Endoscopic dissecting sealer was inserted through the auxiliary port, and the vein was transected using a white reload (*Figure 7*). Cut open the oblique fissure to dissociate the lingular branch of the upper lobe pulmonary artery (*Figures 8-12*) and then transect it using a white reload (*Figure 13*). Dissociate the lingular segmental bronchus (*Figures 14-16*) and then clamp it with a blue reload. An anesthesiologist was asked to suction sputum and ventilate the operated lung. After the proper segments of the upper lobe were found to be well ventilated, the lingular segmental bronchus was dissected (*Figure 17*). The inter-segmental gap was separated using two golden reloads and one blue reload, and thus the lingual segment was removed (*Figures 18-20*). A specimen bag was inserted via the auxiliary port to harvest the specimen (*Figure 21*).

Wash the thoracic cavity. The residual lungs were well dilated, without air leakage. The trauma surfaces and the post-operative lung surfaces were sprayed and covered with

 

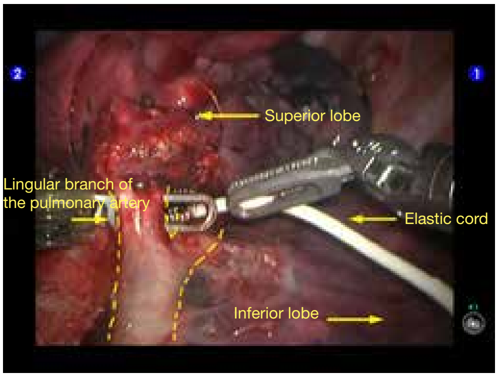


**Figure 11** Insert the elastic cord.

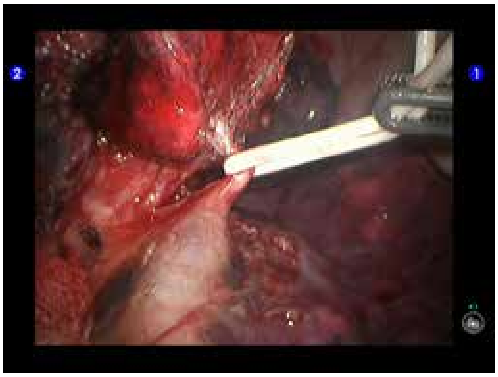

**Figure 12** Pull up the lingular branch of the upper lobe pulmonary artery with the elastic cord.

**Figure 13** Transect the lingular branch of the upper lobe pulmonary artery with a white reload.

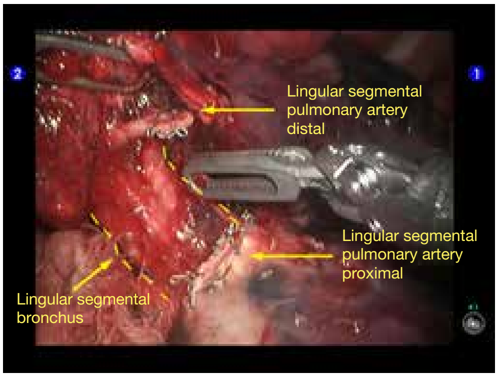


**Figure 14** Dissociate the lingular segmental bronchus.

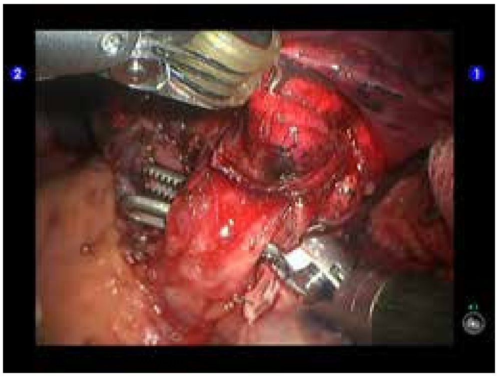

**Figure 15** Expose the lingular segmental bronchus.

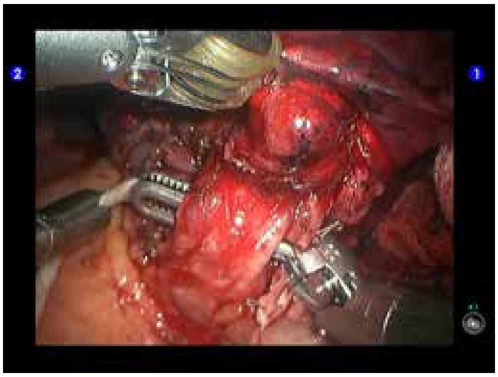

**Figure 16** Insert the traction belt.

the sol of Tistat absorbable hemostatic gauze. After the robot system was withdrawn, the thoracic drainage tube was indwelled at the camera port before closing the chest. Close the chest after lung recruitment.

## Postoperative treatment

Postoperative treatment is similar to that after the conventional open lobectomy. The thoracic drainage tube

 


**Figure 17** Clamp and dissect the lingular segmental bronchus using a blue reload.

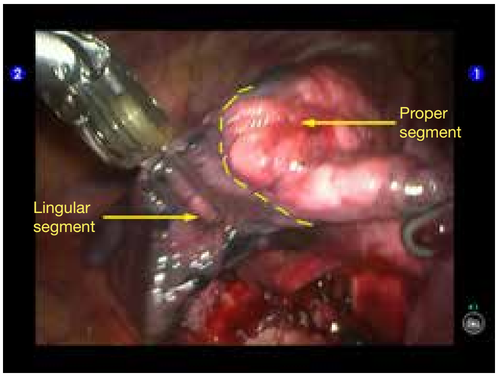


**Figure 18** Determine the inter-segmental gap between the lingular segment and the proper segments.

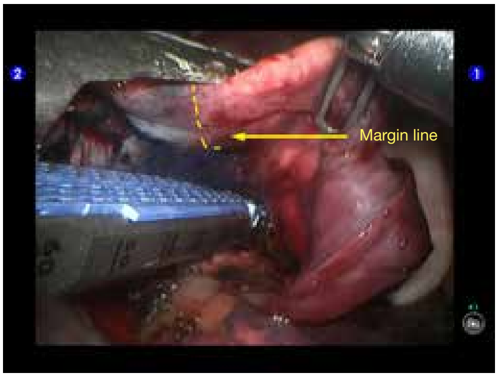


**Figure 19** The inter-segmental gap was separated using two golden reloads and one blue reload.

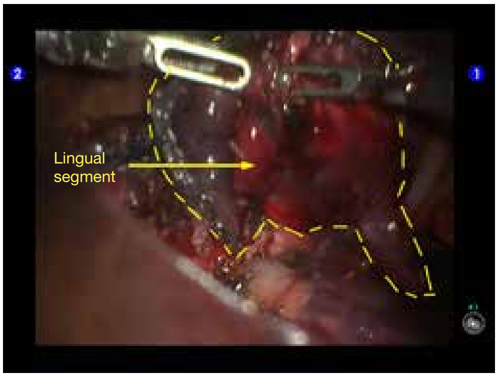


**Figure 20** The dissected lingual segment.

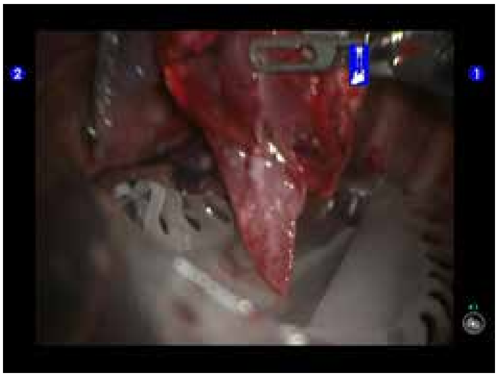

**Figure 21** The dissected lingual segment was harvested using a specimen bag.

was withdrawn 7 days after the surgery.

## Pathological diagnosis

The pathological diagnosis was bronchiectasis of the left upper lobe.

## Acknowledgements

*Disclosure:* The authors declare no conflict of interest.

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# Robotic-assisted right upper lobectomy

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## Clinical data

### *Medical history*

The patient, a 59-year-old man, was found to be with lesion in the right upper lobe of the lung. He received coronary artery bypass graft in the department of cardiac surgery of our hospital due to angina pectoris 3.5 months ago. The pre-operative CT showed a nodular shadow in the right upper lobe of the lung. PET-CT findings were highly suggestive of lung cancer. A second chest CT after the surgery showed that the lesion in the right upper lobe of the lung did not change remarkably. The patient then visited our hospital again and was admitted due to "space-occupying lesion in the right upper lobe of the lung". He had a history of hypertension for over 20 years. Ten years ago, he received a surgery for the gallbladder stones.

### *Physical examination*

No bilateral supraclavicular lymph node enlargement was detected. Chest examination showed no positive sign.

### *Auxiliary examination*

(I) Chest CT showed a lobulated and spiculated nodular shadow in the anterior segment of the right upper lobe, with vesicles visible inside it. No remarkable change was observed when compared with the previous CT findings (*Figure 1*).
(II) Metastasis was not detected on head CT, bone ECT, and abdominal ultrasonography.

## Pre-operative preparation

Same as the conventional open thoracic surgery.

## Procedures

### *Anesthesia and body position*

After the induction of general anesthesia, the patient was under double-lumen endotracheal intubation and underwent left-sided one-lung ventilation.

The patient was placed in the left lateral decubitus position and in a Jackknife position (*Figure 2*).

### *Procedures*

(I) Incisions: a 1.5 cm camera port was created in the 8th intercostal space at right posterior axillary line, and two 1.0 cm working ports were separately made in the 5th intercostal space at anterior axillary line and the 8th intercostal space at scapular line. A 4 cm auxiliary port was made in the 7th intercostal space at midaxillary line (*Figure 3*);
(II) Connection of robot manipulators: the robot patient cart is positioned directly above the operating table and then connected. Its left hand was attached to bipolar cautery forceps, and its right hand was attached to a unipolar cautery hook. Incision protector was applied in the auxiliary port;
(III) Intra-operative inspection showed that the lesion was located at the anterior segment of the right upper lobe, along with pleural indentation. Thus, wedge resection of the lesion was decided, during which a single-use endoscopic linear cutter/stapler (two golden reloads and one blue reload) was used (*Figures 4-6*);
(IV) An extraction bag was inserted to harvest the resected lesion via the incision. A quick-frozen section diagnosis of a lung cancer was made during the surgery, and then lobectomy was further performed (*Figure 7*);

 

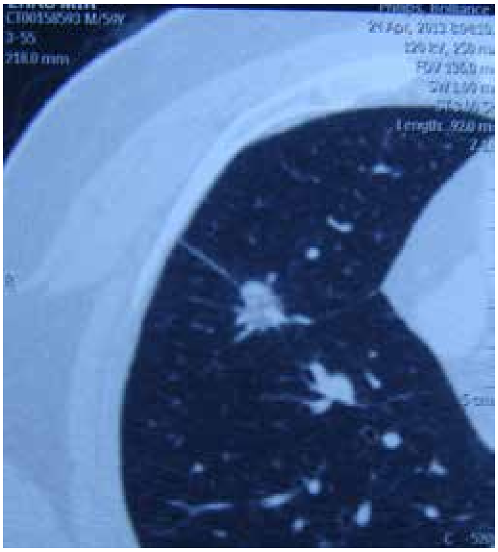

**Figure 1** Chest CT.

**Figure 2** Surgical position.

**Figure 3** Surgical incisions.

**Figure 4** Wedge resection of the lesion.

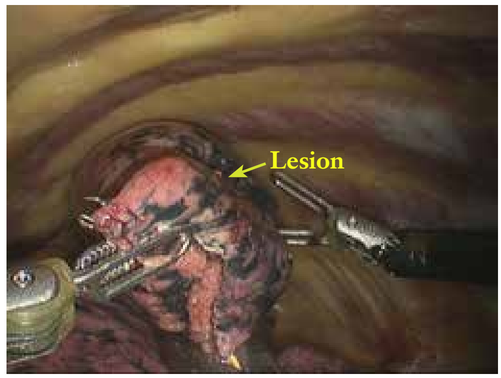


**Figure 5** Wedge resection 2.

(V) Dissociate the upper pulmonary vein behind the phrenic nerve (*Figure 8*);

(VI) Pull the upper pulmonary vein using an elastic cuff (*Figure 9*);

(VII) Cut off the upper pulmonary vein, and then the vein of the right upper lobe of the lung was clamped and divided using the single-use endoscopic linear cutter/stapler (white reload) (*Figure 10*);

(VIII) Dissect the lymph nodes in the pulmonary hilum (*Figure 11*);

(IX) Dissociate the apical and anterior branches of arteries in the superior lobe of right lung (*Figure 12*);

(X) Pull the apical and anterior branches of arteries using elastic cuffs (*Figure 13*);

(XI) Clamp and divide the posterior segmental artery in the right upper lobe using a white reload (*Figure 14*) and the hypoplastic horizontal fissure using a golden reload (*Figure 15*);

 

**Figure 6** Wedge resection 3.

**Figure 7** An extraction bag was inserted to harvest the completely resected lobe via the incision.

**Figure 8** Dissociate the superior pulmonary vein.

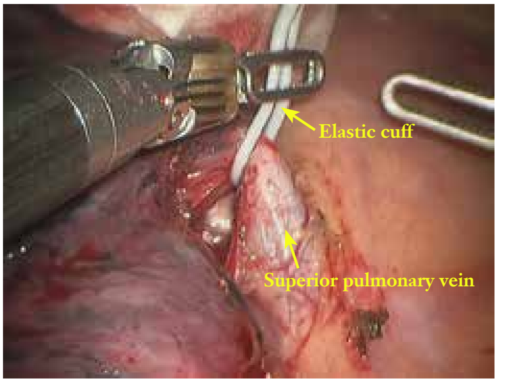


**Figure 9** Pull the superior pulmonary vein using an elastic cuff.

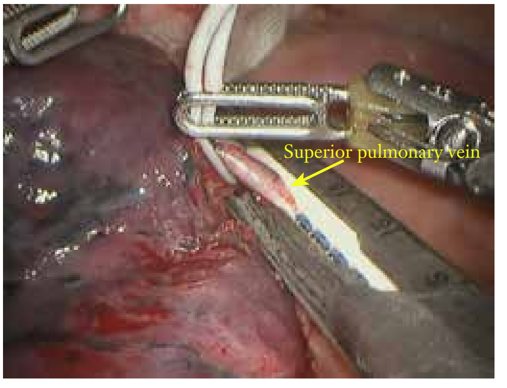


**Figure 10** Single-use endoscopic linear cutter/stapler (white).

**Figure 11** Remove the hilar lymph nodes.

(XII) Clamp and divide the right upper lobe bronchus using a golden reload (*Figure 16*);
(XIII) An extraction bag was inserted to harvest the completely resected lesion via the incision (*Figure 17*);
(XIV) Dissect the lymph nodes in the inferior pulmonary ligament. The inferior pulmonary ligament was dissociated using the unipolar cautery hook till the inferior pulmonary vein level (*Figure 18*);
(XV) Remove several subcarinal lymph nodes (*Figure 19*);
(XVI) Saline is then injected to expand the lungs to identify

**Figure 12** Dissociate the apical-anterior branch of the right upper pulmonary artery.

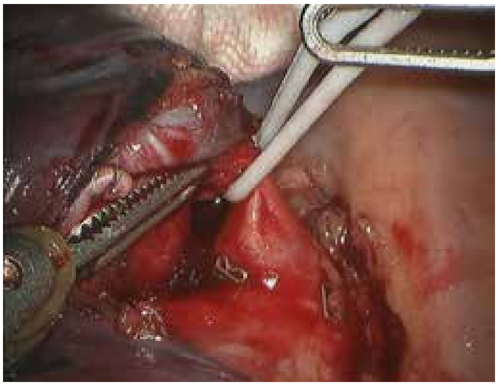

**Figure 13** Pull the apical-anterior branch of the right upper pulmonary artery using elastic cuff.

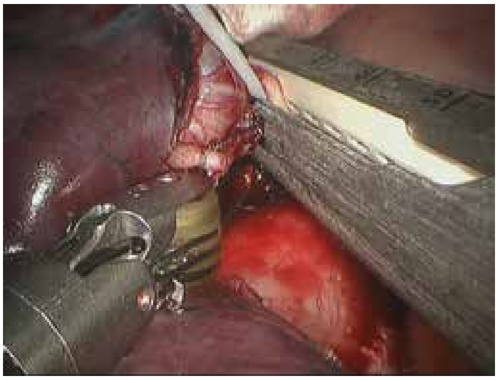

**Figure 14** Clamp and divide the posterior segmental artery in the right upper lobe using a white reload.

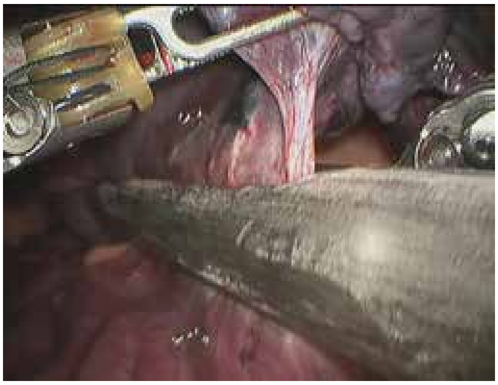

**Figure 15** Clamp and divide the horizontal fissure using a golden reload.

**Figure 16** Clamp and divide the right upper lobe bronchus using a golden reload.

**Figure 17** An extraction bag was inserted to harvest the completely resected right upper lobe through the incision.

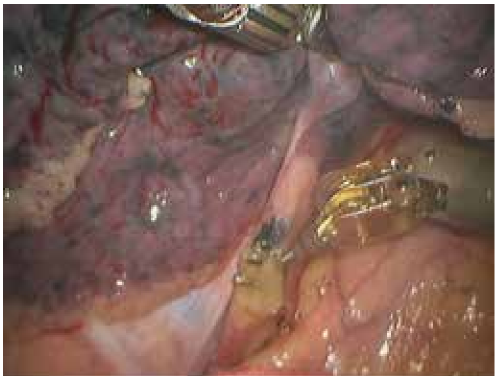

**Figure 18** Remove the lymph nodes in the inferior pulmonary ligament.

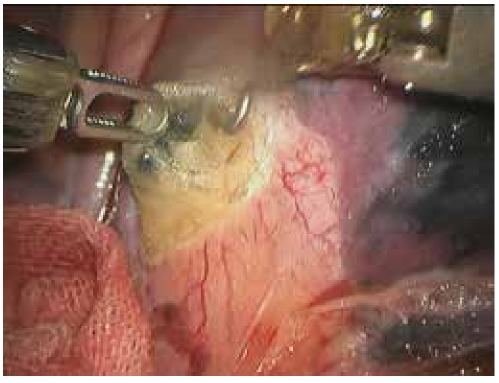

**Figure 19** Remove the subcarinal lymph nodes.

potential leakage of the bronchial stumps (*Figure 20*);

(XVII) Wash the thoracic cavity with warm saline. The robotic arms were withdrawn after the bleeding was stopped. A closed chest drainage tube was placed in the 5th intercostal space at the anterior axillary line, reaching

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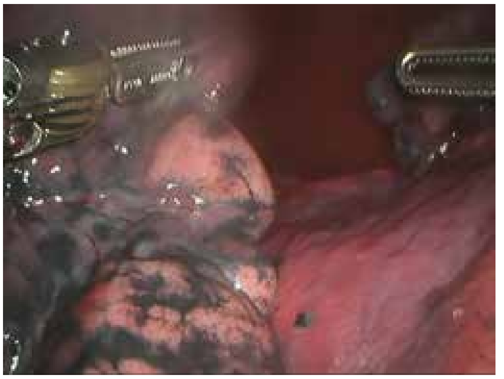

**Figure 20** Bronchial stump leak test showed negative result.

the top of pleura. Close the chest after a closed chest drainage tube was placed at the camera port.

### *Postoperative treatment*

Postoperative treatment was similar to that after the conventional open lobectomy.

## Pathological diagnosis

A moderately-well differentiated adenocarcinoma sized 2.0 cm × 1.5 cm × 1.0 cm in the right upper pulmonary lobe, with visceral pleural invasion. No metastasis was seen at the bronchial stump or the sampled lymph nodes. The post-operational pathological stage: $pT_{2a}N_0M_0$.

## Acknowledgements

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# Robotic-assisted right inferior lobectomy

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## Clinical data

### *Medical history*

The patient, a 60-year-old man, was admitted due to "cough and expectoration lasted for 1 month and became worse in the past 2 weeks". One month ago, the patient developed a cough productive for white sputum but without signs/ symptoms such as blood in phlegm, difficulty in breathing, chest tightness, shortness of breath, fatigue, or night sweats. After oral administration with roxithromycin and cold drugs by himself, the symptoms were resolved, and no other special treatment was applied. In the past 2 weeks, the cough persisted and became worse. He then visited a local hospital, in which the chest CT showed a lobulated soft-tissue mass sized 3.5 cm in the inferior lobe of right lung. He had a history of hypertension for 9 years, which was satisfactorily controlled by the self-administration of hypotensive drugs. In 2004 and 2007, he received two sessions of heart stent implantation due to myocardial infarction, during which a total of 3 stents were implanted. However, he has stopped using anticoagulant drugs.

### *Physical examination*

No bilateral supraclavicular lymph node enlargement was detected. Chest examination showed no positive sign.

### *Auxiliary examination*

(I) Chest PA and LAT and CT. A lobulated high-density shadow sized 3.5 cm was seen in the posterior segment of the right inferior lobe. The bilateral pulmonary hilar and mediastinal lymph nodes were not remarkably swollen (*Figures 1-3*).

(II) Metastasis was not detected on head CT, bone ECT, and abdominal ultrasonography.

## Pre-operative preparation

Same as the conventional open thoracic surgery.

## Procedures

### *Anesthesia and body position*

After the induction of general anesthesia, the patient was under double-lumen endotracheal intubation and underwent left-sided one-lung ventilation.

The patient was placed in the left lateral decubitus position and in a Jackknife position (*Figure 4*).

### *Surgical procedures*

(I) Incisions. A 1.5-cm camera port was created in the 8$^{th}$ intercostal space at right posterior axillary line, and two 1.0-cm working ports were separately made in the 5$^{th}$ intercostal space at anterior axillary line and the 8$^{th}$ intercostal space at scapular line. A 4-cm auxiliary port was made in the 7$^{th}$ intercostal space at midaxillary line (*Figure 5*).

(II) Connection of robot Patient cart. The robot Patient cart is positioned directly above the operating table and then connected. Its left hand was attached to bipolar cautery forceps, and its right hand was attached to a unipolar cautery hook. Incision protector was applied in the auxiliary port.

(III) The adhesion between the inferior lobe and diaphragm was divided using the cautery hook, and

 


**Figure 1** Chest X-ray (A-P view): markings.

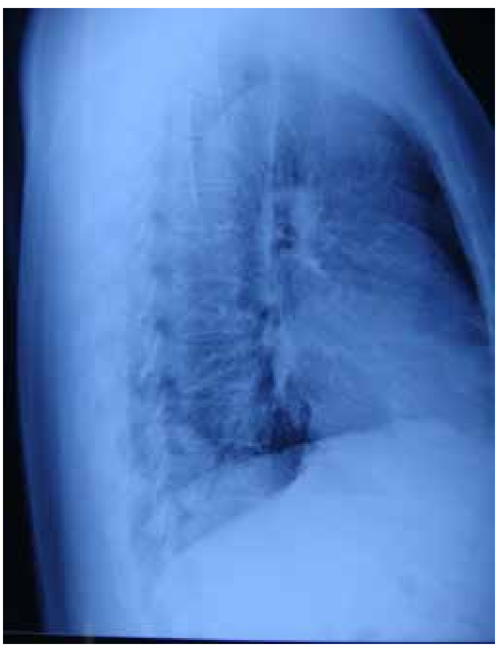

**Figure 2** Chest X-ray (lateral view).

the inferior pulmonary ligament was dissociated using the unipolar cautery hook till the inferior pulmonary vein level (*Figures 6,7*).

(IV) Dissociate the inferior pulmonary vein (*Figure 8*).

(V) Pull the inferior pulmonary vein using elastic cuffs (*Figure 9*).

**Figure 3** Chest CT.

**Figure 4** Surgical position.

**Figure 5** Surgical incisions.

(VI) Cut off the inferior pulmonary vein, and then the vein of the left inferior lobe of the lung was clamped and divided using the single-use endoscopic linear cutter/stapler (white reload) (*Figures 10,11*).

(VII) Dissect the interlobar fissure using the cautery hook (*Figure 12*).

 

**Figure 6** Sharply dissect the adhesions between the lower lobe and the diaphragm.

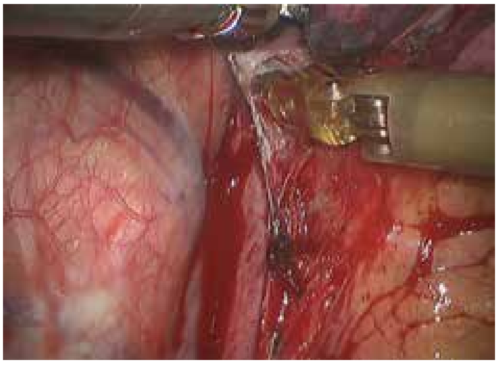

**Figure 7** Divide the inferior pulmonary ligament till the inferior lung vein level.

**Figure 8** Dissociate the inferior pulmonary vein.

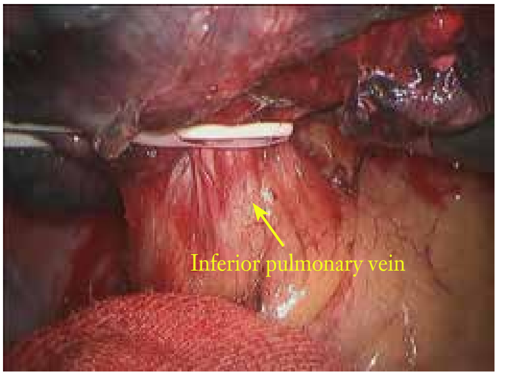


**Figure 9** Pull the inferior pulmonary vein using an elastic cuff: markings.

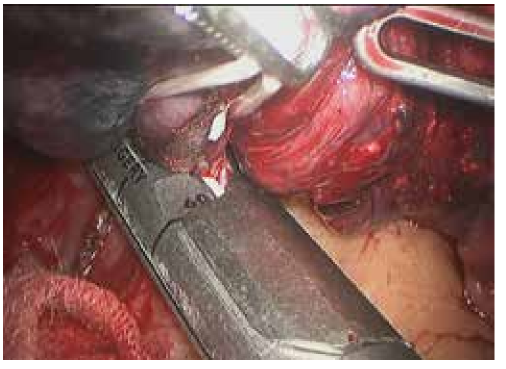

**Figure 10** Transect the inferior pulmonary vein using the endoscopic cutter/stapler (white reload).

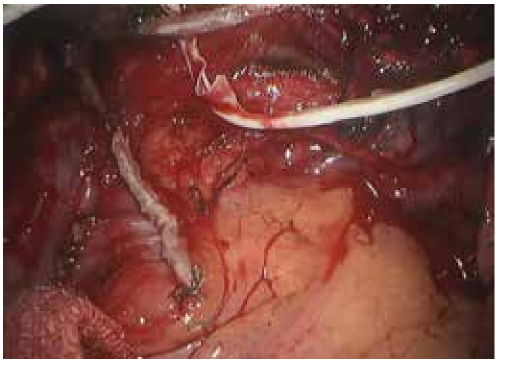

**Figure 11** The inferior pulmonary vein was transected.

(VIII) Remove the interlobar lymph nodes (*Figure 13*).

(IX) Dissociate the arteries in the basal segments of lower lobe (*Figure 14*).

(X) Pull the arteries in the basal segments using elastic cuffs (*Figure 15*).

(XI) The arteries in the basal segments were clamped and divided using the single-use endoscopic linear cutter/stapler (white reload) (*Figure 16*).

(XII) Dissociate the arteries in the dorsal segments of inferior lobe, and then the elastic cuffs were applied (*Figure 17*).

(XIII) The arteries in the doral segments were clamped and divided using the single-use endoscopic linear cutter/stapler (white reload) (*Figure 18*).

(XIV) The lower lobe bronchus was clamped and divided using the single-use endoscopic linear cutter/

 

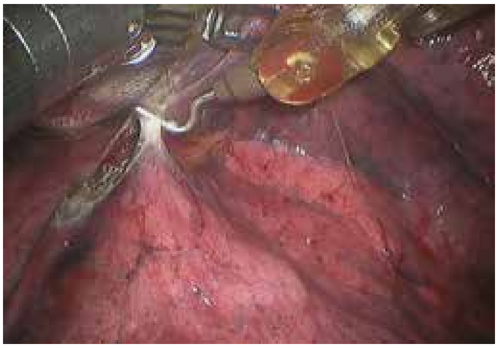

**Figure 12** Dissect the intersegmental fissure using the cautery hook.

**Figure 13** Remove the interlobar lymph nodes.

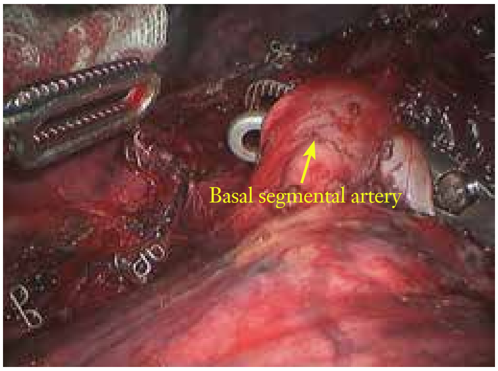


**Figure 14** Dissociate the artery in the basal segment of lower lobe: markings.

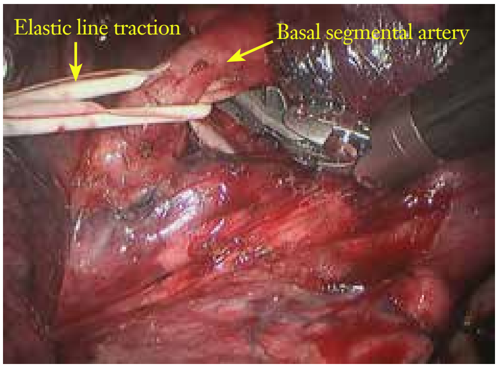


**Figure 15** Pull the artery in the basal segment of lower lobe with elastic cuff: markings.

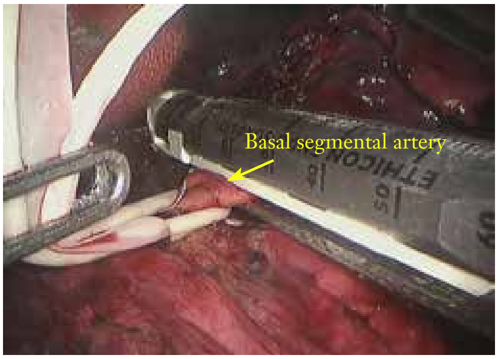


**Figure 16** Transect the artery in the basal segment of lower lobe using the endoscopic cutter/stapler (white reload): markings. (basal segmental artery)

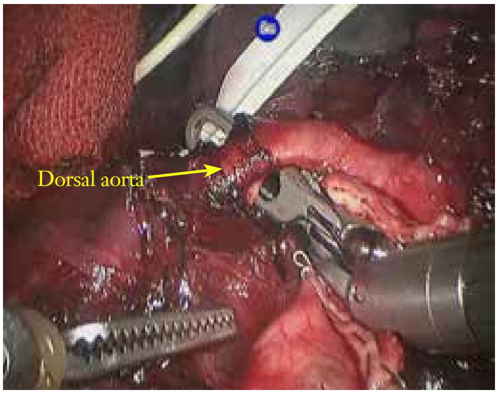


**Figure 17** Dissociate the artery in the dorsal segment of inferior lobe, and then the elastic cuffs were applied: markings.

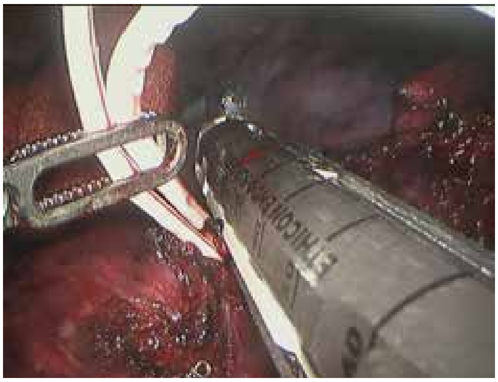

**Figure 18** Transect the artery in the dorsal segment of lower lobe using the endoscopic cutter/stapler (white reload).

**Figure 19** Transect the inferior pulmonary bronchus using the endoscopic cutter/stapler.

**Figure 20** An extraction bag was inserted to harvest the completely resected lobe via the incision.

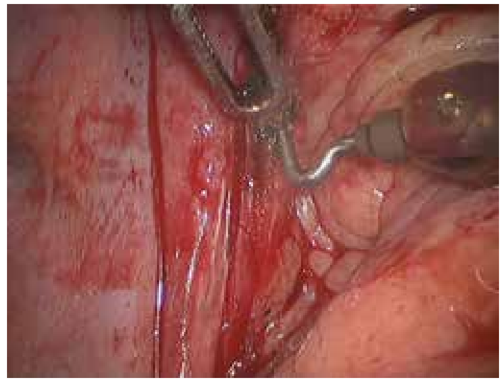

**Figure 21** Remove the lymph nodes in the inferior pulmonary ligament.

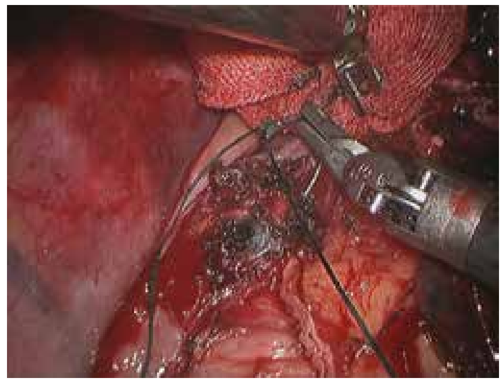

**Figure 22** Dissociate the subcarinal lymph nodes and close the supporting line.

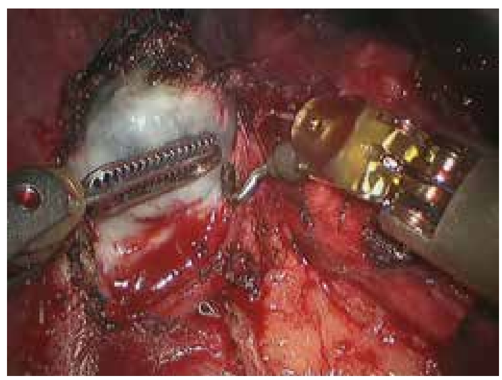

**Figure 23** Completely remove the subcarinal lymph nodes.

stapler (golden reload) (*Figure 19*).

(XV) An extraction bag was inserted to harvest the completely resected right inferior lobe via the incision (*Figure 20*).

(XVI) Remove the lymph nodes in the inferior pulmonary ligament (*Figure 21*).

(XVII) Dissociate the subcarinal lymph nodes and close the supporting line (*Figure 22*).

(XVIII) Completely remove the subcarinal lymph nodes (*Figure 23*).

**Figure 24** Remove the lymph nodes near the trachea.

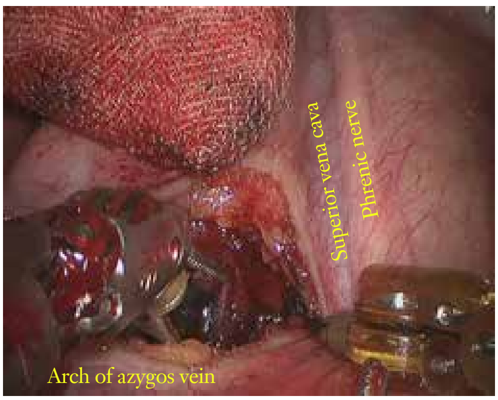


**Figure 25** Remove the lymph nodes in the trachea and bronchus: markings.

**Figure 26** Remove the lymph nodes in front of the trachea.

**Figure 27** Bronchial stump leak test showed negative result.

(XIX) Remove the lymph nodes near the trachea (*Figure 24*).
(XX) Remove the lymph nodes near the tracheal bronchus (*Figure 25*).
(XXI) Remove the lymph nodes in front of trachea (*Figure 26*).
(XXII) Saline is then injected to expand the lungs to identify potential leakage of the bronchial stumps (*Figure 27*).
(XXIII) Wash the thoracic cavity with warm saline. The robotic arms were withdrawn after the bleeding was stopped. Close the chest after a closed chest drainage tube was placed at the camera port.

## Postoperative treatment

Postoperative treatment was similar to that after the conventional open lobectomy.

## Pathological diagnosis

The lesion was a poorly differentiated adenocarcinoma (4.2 cm in diameter) in the inferior lobe of right lung. No metastasis was seen at the bronchial stump. While cancer metastasis was found in station 11 lymph nodes (4/5), it was not detected in other stations. Postoperative pathologic staging: $pT_{2a}N_1M_0$.

## Acknowledgements

*Disclosure:* The authors declare no conflict of interest.

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# Robotic-assisted right middle lobectomy for poorly differentiated squamous cell carcinoma

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## Clinical data

### *Medical history*

The patient, a 73-year-old men, was admitted due to "sputum with blood for one month" and "mass in the right middle lung lobe". One month ago, he developed cough and expectoration with blood-stained sputum. Two weeks ago, chest CT showed a soft-tissue mass with irregular border in the lateral segments of the right middle lung lobe. Bronchoscopy detected a mass at the bronchial orifice in the lateral segments of the right middle lung lobe. No malignant cell was detected at biopsy pathology. The patient's complaints did not include low fever, night sweats, nausea, vomiting, abdominal distension, diarrhoea, heart palpitations, or discomfort of precordial area. His mental status, physical performance, appetite, and sleep were normal, and the body weight did not obviously change. Urination and defecation were normal.

### *Physical examination*

Physical examinations upon admission showed no obviously positive signs. The cervical and supraclavicular lymph nodes were not abnormally enlarged.

### *Auxiliary examination*

Chest CT: a soft-tissue mass sized 4 cm × 3 cm with irregular border and unclear margin was found in the right middle lung lobe (near the pulmonary hilum). The mediastinal lymph nodes were slightly swollen (*Figure 1*).

Epigastric ultrasound, bone ECT, and head MRI did not find the evidence of remote metastasis. Other surgical contraindications including thyroid nodules and breast nodules were ruled out after multidisciplinary consultations.

No obvious abnormality was found in ECG, echocardiography, pulmonary function test, blood gas analysis, and other biochemical tests.

## Pre-operative preparation

Based on the imaging results, "a space-occupying lesion in the right middle lung lobe" was considered, and there was a high possibility of malignancy. Since the mass was close to the pulmonary hilum, making the wedge resection impossible. Thus, resection of the middle lobe was planned. The subsequent surgical protocol was determined based on the results of intraoperative frozen section biopsy. (If the lesion was found to be malignant in the frozen biopsy, lymph node dissection would be performed). The surgery was planned to be completed using da Vinci robotic system.

## Procedures

### *Anesthesia and body position*

After the induction of general anesthesia, the patient was placed in a lateral decubitus position under double-lumen endotracheal intubation. With his hands put in front of head, he was fixed in a Jackknife position with single-lung (left) ventilation (*Figure 2*).

### *Surgical procedures*

Distribution of incisions ("8857"): a 1.5-cm camera port was created in the 8th intercostal space (ICS) at right posterior

 

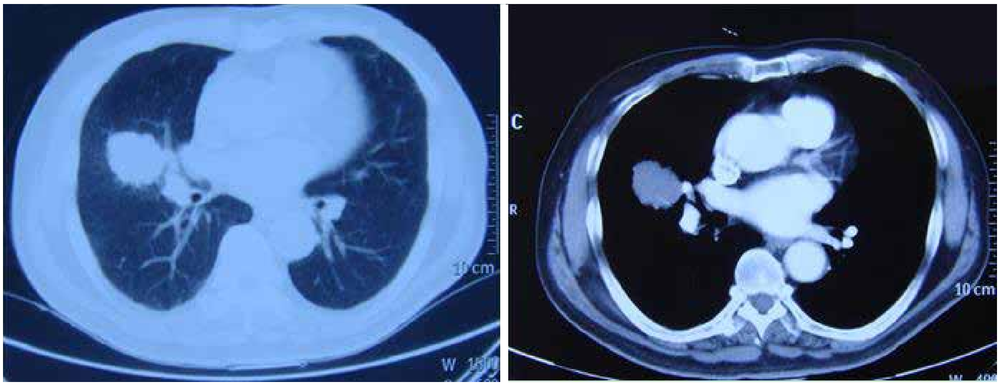

**Figure 1** Chest CT showed that the mass was in the middle lobe of right lung (near the pulmonary hilum), with unclear margin.

**Figure 2** The patient's position: in the left lateral decubitus position and in a Jackknife position.

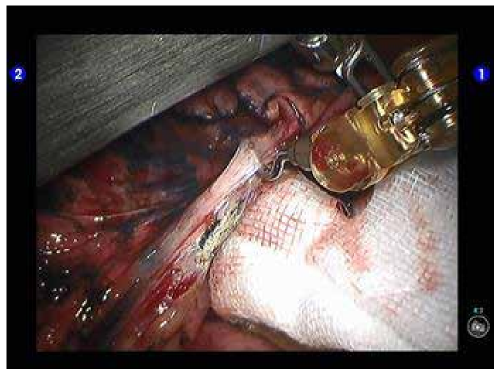

**Figure 4** Dissect the horizontal fissure.

**Figure 3** Distribution of incisions: "8857".

axillary line, and two 1.0-cm working ports were separately made in the 5th ICS at right anterior axillary line and the 8th ICS at scapular line. A 4-cm auxiliary port was made in the 7th ICS at midaxillary line (*Figure 3*).

During the thoracic cavity inspection, the camera was inserted via the camera port and found no obvious adhesion or effusion in the thoracic cavity, and the pulmonary fissures were well developed.

The robot Patient Cart were connected over the patient's head. A 12-mm trocar was placed at the camera port in the 8th ICS at posterior axillary line to be attached with the camera arm. The robot metal trocars were respectively attached to the 1# arm (left hand) and 2# arm (right hand) at the incisions in the 5th ICS anterior axillary line and the 8th ICS scapular line. Incision protector was applied in the auxiliary port.

Lobectomy: the left arm was attached to bipolar cautery forceps, and the right arm to a unipolar cautery hook. The oblique fissure was dissected, the mediastinal pleura was cut open behind the phrenic nerve, and then the middle lobe branches of the upper pulmonary vein was dissociated (*Figures 4,5*). Since an abnormal vascular branch was found at the inner side of the vein, elastic cord was used to suspend and pull the middle lobe vein, and then

 

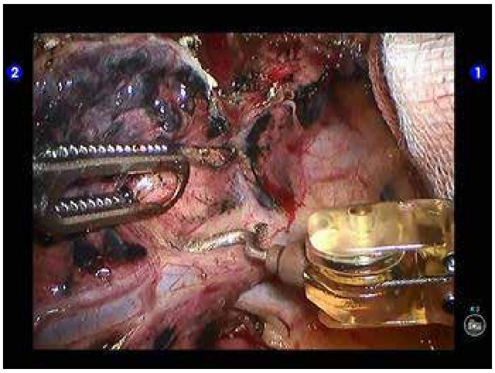

**Figure 5** The vein in the middle lobe was dissociated.

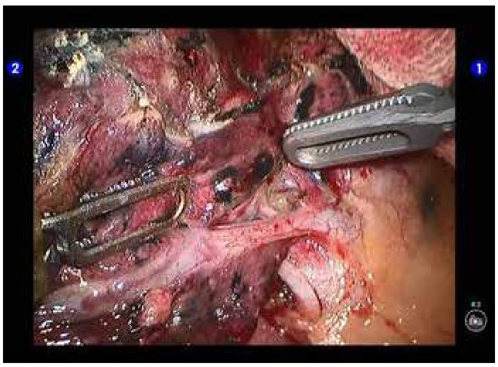

**Figure 6** Abnormal vascular branch was found in the inner side of the middle lobe vein.

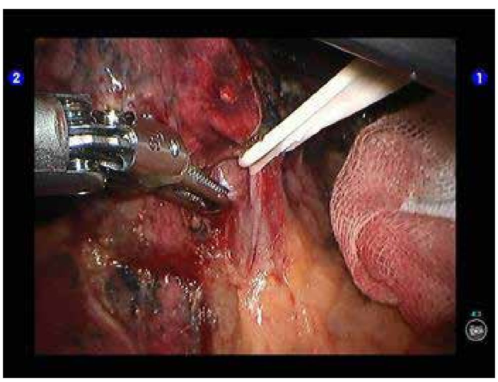

**Figure 7** Pull away the middle lobe vein and then transect the abnormal vessel using the cautery devices.

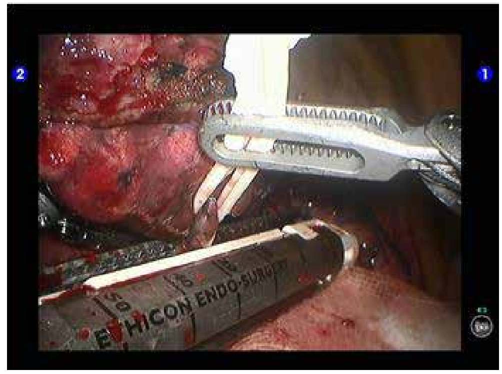

**Figure 8** Transect the middle lobe vein using a white reload.

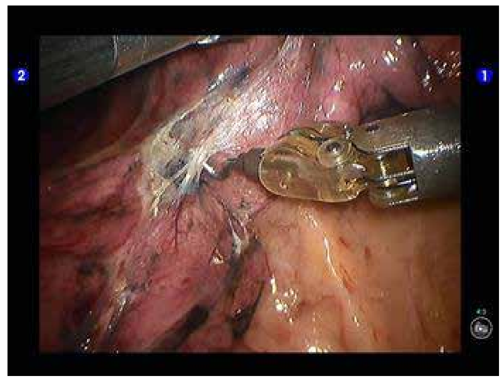

**Figure 9** Dissect the lower part of the oblique fissure.

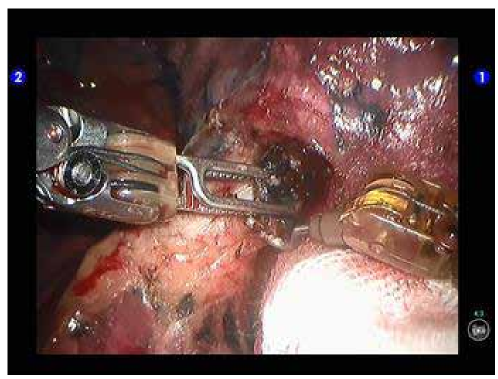

**Figure 10** Remove the interlobar lymph nodes near the lung artery.

the abnormal branch was sealed and handled with bipolar cautery forceps (*Figures 6,7*). The camera arm was inserted via the auxiliary port. Endoscopic flexible cutter/stapler was inserted from the camera port, and the middle lobe vein was transected using a white reload (*Figure 8*). Move the camera back to the camera port. Cut open the inferior part of the oblique fissure (*Figure 9*), remove the interlobar lymph nodes (*Figure 10*), and thoroughly dissociate the middle lobe bronchus. However, the stapler could not go through the small gap between the middle lobe bronchus and vessels

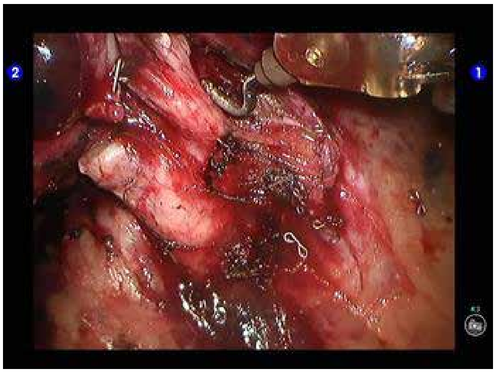

**Figure 11** Dissociate the middle lobe bronchus.

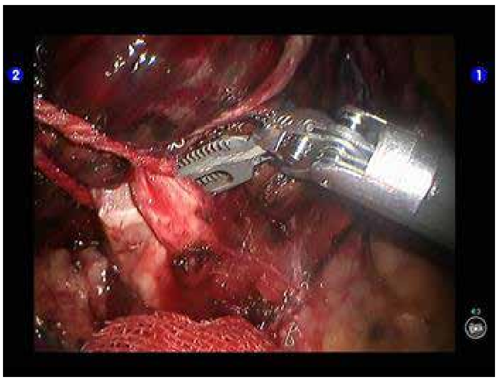

**Figure 12** The gap was found to be too small to allow the passing of stapler after the bronchus was pulled away.

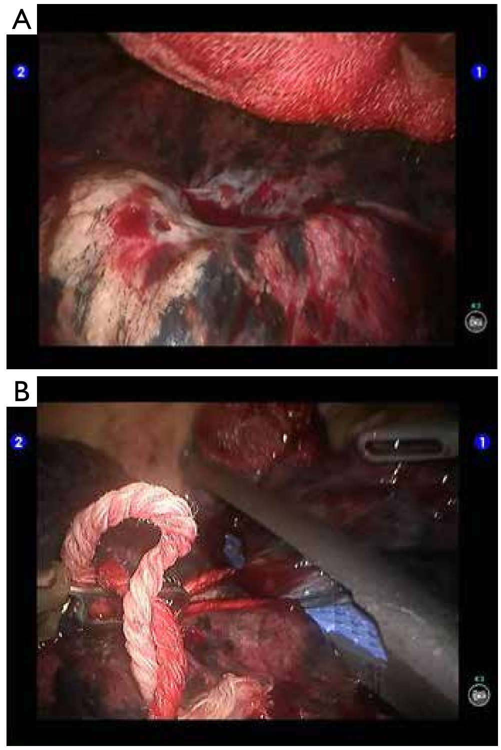

**Figure 13** (A) The middle lobe tumor invaded the upper lobe; (B) remove the involved part of the upper lobe using a blue reload.

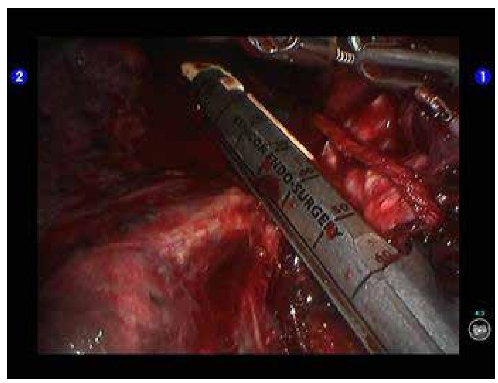

**Figure 14** Clamp the middle lobe bronchus and middle lobe artery together.

(*Figures 11*,*12*). Since the tumor invaded the upper lobe, the involved site was divided at the upper margin using a blue reload (*Figure 13A*,*B*). Inspection showed that there was no residual lymph node around it. The middle lobe bronchus, middle lobe artery, and the residual horizontal fissure were clamped with a golden reload (*Figure 14*). An anesthesiologist was asked to suction sputum and ventilate the operated lung. After CXR revealed good expansion of the lower lobe, release the stapler to divide the middle lobe (*Figure 15*). An endoscopic retriever was inserted via the auxiliary port to harvest the dissected specimen. Frozen pathology showed that it was a lung cancer to be further classified.

Lymph node dissection: remove the hilar lymph nodes (*Figure 16*). After the inferior pulmonary ligament was divided till the inferior lung vein level, no swollen lymph node was seen at the pulmonary ligament or near the esophagus. Open the posterior mediastinal pleura to remove the subcarinal lymph nodes (*Figure 17*). Inspect and remove lymph nodes before the superior vena cava (*Figure 18*). Open the upper mediastinal pleura to remove the lymph nodes near the trachea (*Figure 19*). There were several swollen lymph nodes near the lower trachea and deep behind the azygos vein arch. Dissociate the azygos vein arch from two directions (upward and downward) using elastic cords and then thoroughly remove the lymph nodes (*Figure 20A*,*B*).

Wash the thoracic cavity. Air leakage was observed

 

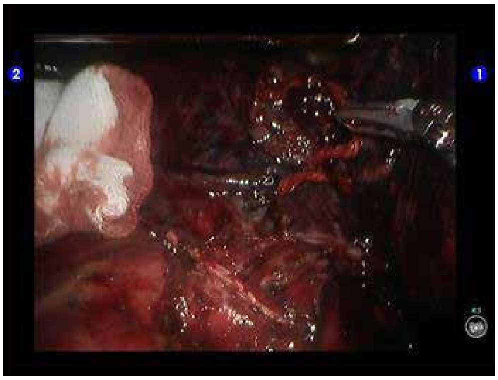


**Figure 15** Transect the bronchus and vessels, and then divide the middle lobe.

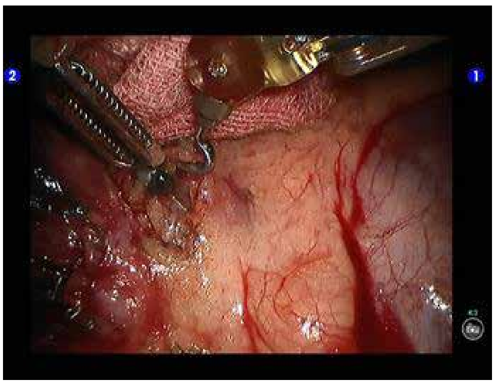


**Figure 16** Remove the hilar lymph nodes.

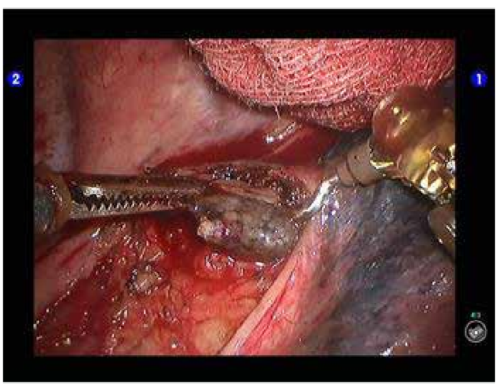


**Figure 17** Open the posterior mediastinal pleura to remove the subcarinal lymph nodes.

at the cut surface of lung after lung recruitment. It was satisfactorily managed using the bipolar cautery forceps. When no obvious bleeding was observed at all the trauma surfaces, the TISTAT absorbable hemostatic gauze was applied at each trauma surface and cut surface. The thoracic


**Figure 18** Remove lymph nodes before the superior vena cava.

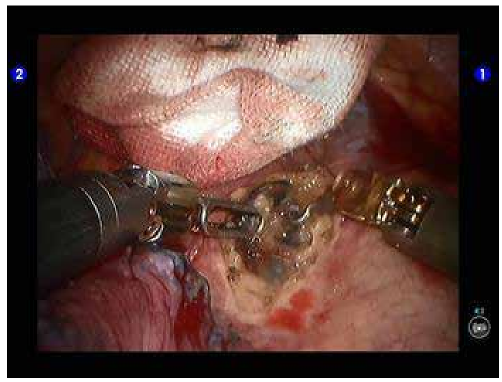


**Figure 19** Remove the superior mediastinal lymph nodes.

drainage tube was indwelled at the working port at the 5th ICS and at the camera port, respectively. Close the chest after lung recruitment.

## Postoperative treatment

Postoperative treatment is similar to that after the conventional open lobectomy. The thoracic drainage tube was withdrawn 14 days after the surgery. The post-operative pathological stage was $pT_{2a}N_0M_0$. Currently the patient was under follow-up.

## Pathological diagnosis

Poorly differentiated squamous cell carcinoma at the right middle lung lobe, accompanied with adenoid differentiation. No cancer cell was detected at the bronchial stump or the hilar/mediastinal lymph nodes.

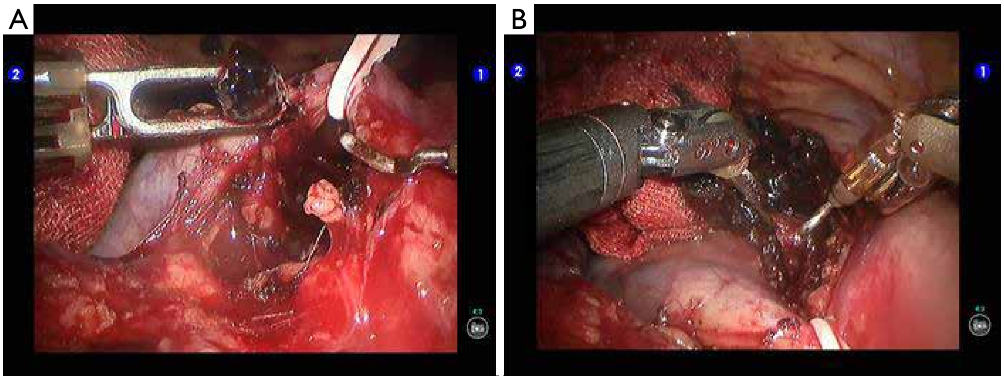

**Figure 20** (A) Dissociate and pull the azygos vein arch and dissociate the lymph nodes near the lower trachea; (B) pull the azygos vein arch to remove the superior mediastinal lymph nodes.

## Comment

Anatomic resection of the middle lobe of right lung is often particularly difficult due to the aplasia of horizontal fissure/oblique fissure or the adhesion of inflammatory lymph nodes around vessels and bronchus. In our current case, adhesion of lymph nodes around vessels, invasion of tumor into the upper lobe, and aplasia of lobar fissure were observed; thus, the bronchus, middle lobe artery, and horizontal fissure were also transected and removed after the middle lobe vein transection and lymph node removal. A key point in this procedure is the resection scope. Efforts should be made to ensure thorough resection and meanwhile protect the inferior lobe bronchus and lung artery from being damaged. Also, removal of lymph nodes must also be thorough. In our current case, multiple lymph nodes around the inferior bronchus in the middle lobe of right lung became swollen. We dissociated the azygos vein arch and then thoroughly dissected the lymph nodes. In addition, the stapler inserted via the auxiliary port made in the 7th ICS at midaxillary line can conveniently handle the lobar fissures, arteries, and bronchus. However, since there is a large angle in handling the middle lobe vein, we need to move the camera to the auxiliary port and then insert the stapler via the camera port. This is a routine step in endoscopic surgeries but seems a bit complicated in the robotic surgeries. Thus, a skillful assistant who is familiar with the performances of the robotic arms is critically important.

## Acknowledgements

*Disclosure:* The authors declare no conflict of interest.

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# Robotic-assisted left upper lobectomy

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## Clinical data

### *Medical history*

The patient, a 53-year-old woman, was admitted due to "lesion in the left lung found during health check-up 2 years ago" and "a space-occupying lesion in the upper lobe of left lung". Two years ago, chest CT during health check-up showed a ground-glass opacity (GGO) at the edge of the upper lobe of left lung. However, no special treatment was given. Ten days ago, the patient visited our hospital due to spinal joint conditions. Chest CT showed a space-occupying lesion in the upper lobe of left lung. The lesion has slightly irregular border and unclear margin, with mild pleural retraction. The lesion was slightly enlarged compared with that in the CT image 2 years ago. The patient's complaints did not include cough/expectoration, chest tightness, shortness of breath, low fever, night sweats, nausea, vomiting, abdominal distension, diarrhoea, heart palpitations, or discomfort of precordial area. His mental status, physical performance, appetite, and sleep were normal, and the body weight did not obviously change. Urination and defecation were normal.

### *Physical examination*

Physical examinations upon admission showed no obviously positive signs. The cervical and supraclavicular lymph nodes were not abnormally enlarged.

### *Auxiliary examination*

Chest X-ray had no abnormal findings in both lungs (*Figure 1*).

Chest CT showed a space-occupying GGO sized 1.0 cm in the upper lobe of left lung (near the pleural membrane). The lesion has slightly irregular border and unclear margin, with mild pleural retraction. The mediastinal lymph nodes were slightly swollen (*Figure 2*).

Epigastric ultrasound and bone ECT did not find the evidence of remote metastasis. Other surgical contraindications including thyroid nodules and breast nodules were ruled out after multidisciplinary consultations.

No obvious abnormality was found in ECG, echocardiography, pulmonary function test, blood gas analysis, and other biochemical tests.

## Pre-operative preparation

Based on the imaging results, "a space-occupying lesion in the upper lobe of left lung" was considered, and the lesion showed no change during the follow-up visits; however, the possibility of malignancy could not be ruled out. Lesion inspection and wedge resection were planned. The subsequent surgical protocol was determined based on the results of intraoperative frozen section biopsy. (If the lesion was found to be malignant in the frozen biopsy, resection of the upper lobe of left lung and lymph node dissection would be performed). The surgery was planned to be completed using da Vinci robotic system. Since the lesion was small and thus difficult to locate during the surgery, CT-guided puncture of the lesion was performed before the surgery, and methylene blue solution was injected at the pleural membrane to assist lesion-locating. The patient was directly sent to the operation room after the lesion was located.

## Procedures

### *Anesthesia and body position*

After the induction of general anesthesia, the patient was

**Figure 1** Chest X-ray had no abnormal findings in both lungs.

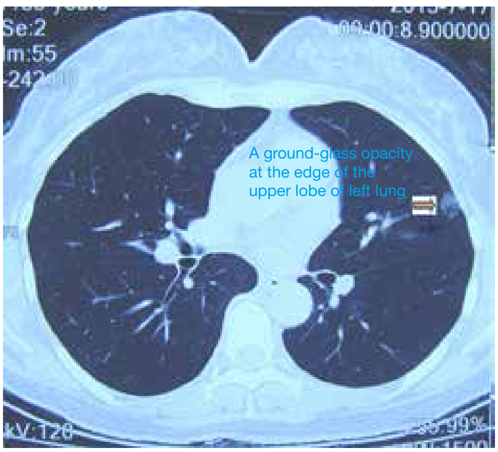


**Figure 2** Arrow shows a ground-glass opacity at the edge of the upper lobe of left lung.

**Figure 3** The patient's position: in the right lateral decubitus position and in a Jackknife position.

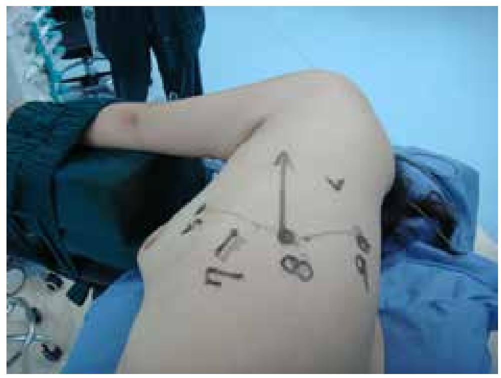

**Figure 4** A camera port was created in the 8th intercostal space at posterior axillary line, and two working ports were separately made in the 5th intercostal space at anterior axillary line and the 9th intercostal space at scapular line. An auxiliary port was made in the 7th intercostal space at midaxillary line.

under double-lumen endotracheal intubation and directly underwent left-sided one-lung ventilation, so as to avoid the aggravation of pneumothorax caused by puncture. With the patient lying on her right side and with her hands put in front of head, he was fixed in a Jackknife position with single-lung (right) ventilation (*Figure 3*).

### *Surgical procedures*

#### Incisions

A 1.5-cm camera port was created in the 8th intercostal space at left posterior axillary line, and two 1.0-cm working ports were separately made in the 5th intercostal space at left anterior axillary line and the 9th intercostal space at scapular line. A 4-cm auxiliary port was made in the 7th intercostal space at midaxillary line (*Figure 4*).

During the thoracic cavity inspection, the camera was inserted via the camera port and found no obvious adhesion in the thoracic cavity; however, a small amount of coagulated bloody fluid was visible, which might be caused by puncture. The puncture site was located at the lateral side of the upper lobe (near the oblique fissure), which was clearly visible after subpleural blue-staining (*Figure 5*).

The robot Patient Cart were connected over the patient's

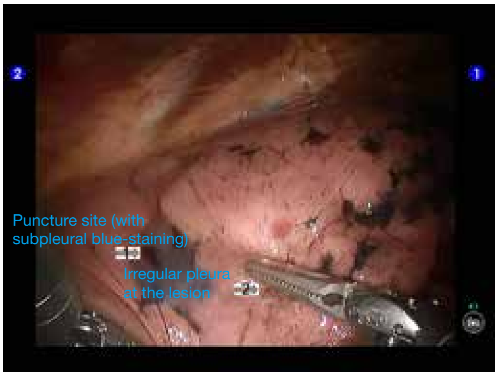


**Figure 5** Arrow 1 indicates the puncture site (with subpleural blue-staining), and arrow 2 indicates the lesion.

**Figure 8** Transect the inferior vena cava.

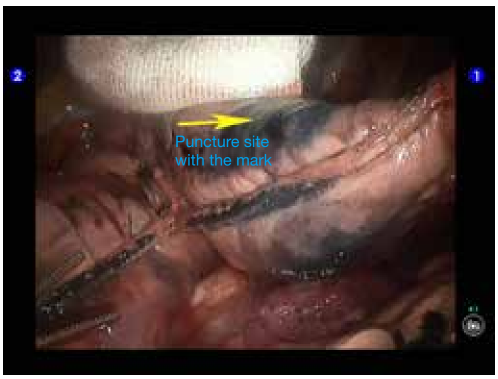


**Figure 6** Wedge resection of the lesion along the inner side of the puncture site using an endoscopic cutter/stapler.

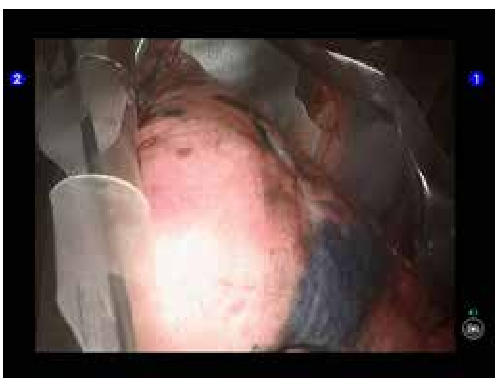

**Figure 7** Removed the lesion from the auxiliary port device with endoscopic extract.

head. A 12-mm trocar was placed at the camera port in the 8th intercostal space at posterior axillary line to be attached with the camera arm. The robot metal trocars were respectively attached to the 2# arm (left hand) and 1# arm (right hand) at the incisions in the 5th ICS at anterior axillary line and the 9th ICS at scapular line. Incision protector was applied in the auxiliary port.

Pulmonary wedge resection: After the puncture site and lesion were located, the lesion was found to be with small size and good mobility and without external invasion. Wedge resection was decided. An endoscopic linear cutter/stapler (Ethicon Echelon Flex 60) was inserted via the auxiliary port. Wedge resection of the lingular segment of the upper lobe of left lung was performed using two blue reloads 2 cm away from the tumor (*Figure 6*). An endoscopic retriever was inserted via the auxiliary port to harvest the divided specimen (*Figure 7*), which was a soft mass, gray-white in color and sized about 1cm. It was immediately sent for frozen pathology.

Quick frozen pathology indicated that it was an atypical alveolar type II epithelial cell hyperplasia; cancer.

### Lobectomy

The right arm was re-connected with unipolar cautery hook. After the inferior pulmonary ligament was divided till the inferior lung vein level, the lymph nodes at the pulmonary ligament were removed (*Figures 8,9*).

Inspection showed that the oblique fissure was well developed. Open the oblique fissure with the cautery hook, dissociate several branches of the pulmonary artery (two in lingular segments and two in posterior segments), and remove the lymph nodes among fissures (*Figures 10-13*).

Dissociate the upper pulmonary vein (3 branches) (*Figures 14-16*), which was further suspended and pulled with elastic cuffs (*Figure 17*). Move and insert the camera arm via the auxillary port (*Figure 18*). The stapler was


**Figure 9** Remove the lymph nodes at the pulmonary ligament.


**Figure 10** Dissect the oblique fissure.

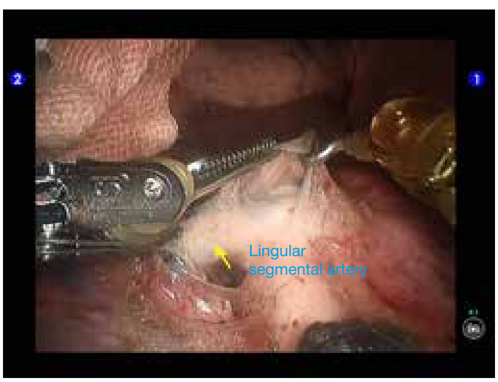


**Figure 11** Dissect the branches of pulmonary upper lobe artery within the oblique fissure.

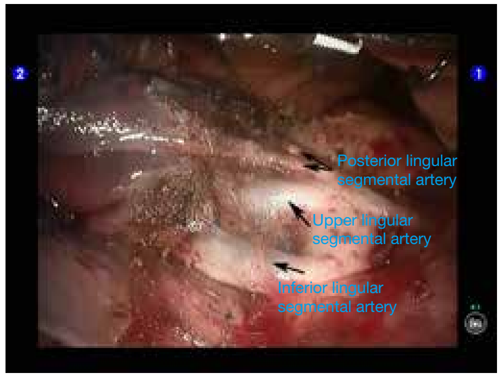


**Figure 12** Dissociate the branches of upper lobe artery within the oblique fissure.


**Figure 13** Remove the inter-lobar lymph nodes.

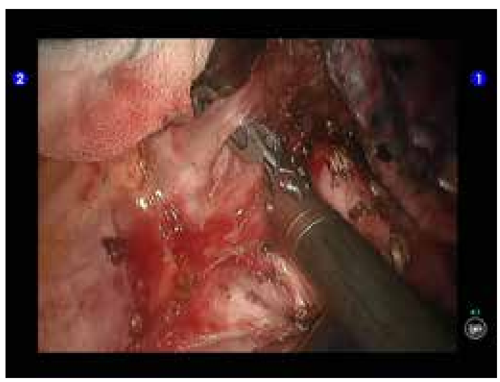


**Figure 14** Dissociate the branches of upper lung vein [1].

inserted through the camera port, and the vein was transected using a white reload (*Figure 19*).

Move the camera arm back to the camera port. Insert the cutter/stapler via the auxiliary port. Transect one branch of the sublingular artery using a white reload, and then remove the lymph nodes behind the vessel (*Figures 20-22*).

The superior lingular segmental artery, together with the inferior branch of the posterior segmental artery, was transected with a white reload (*Figures 23,24*), and the superior branch of the posterior segmental artery was

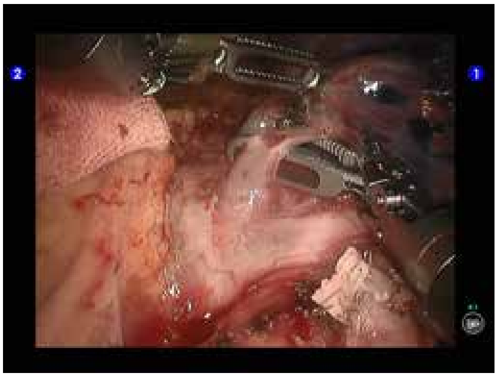

**Figure 15** Dissociate the branches of upper lung vein [2].

**Figure 16** Dissociate the branches of upper lung vein [3].

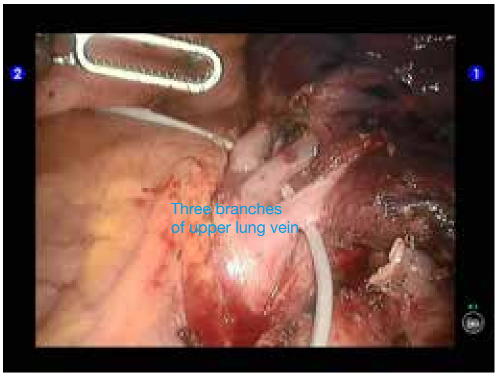


**Figure 17** Pull these three branches using elastic cuffs.


**Figure 18** Insert the camera arm via the auxiliary port.

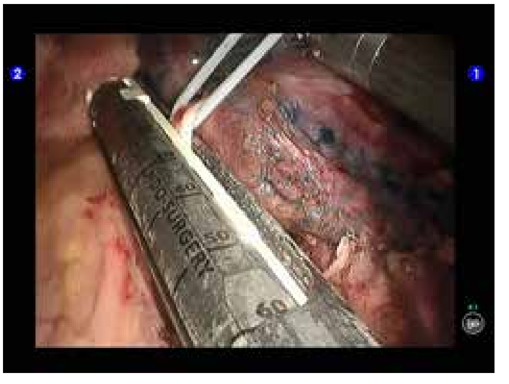

**Figure 19** Insert the cutter/stapler via the camera port to transect the upper lung vein.


**Figure 20** Thoroughly dissociate the inferior branch of the lingular segmental artery.

transected with a white reload (*Figures 25,26*).

Dissociate the apical anterior segmental artery, and then transect it using a white reload (*Figures 27,28*).

Remove lymph nodes (*Figures 29-32*).

Clamp the upper lobe bronchus using a golden reload. An anesthesiologist was asked to suction sputum and ventilate the operated lung. After CXR revealed good expansion of the lower lobe, transect the bronchus and then divide the upper lobe. An endoscopic retriever was inserted via the auxiliary port to harvest the divided specimen (*Figures 33,34*).

 

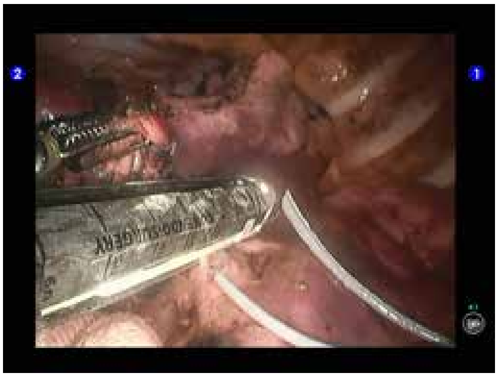

**Figure 21** Transect the inferior branch of the lingular segmental artery.

**Figure 22** Remove the lymph nodes behind the vessels.

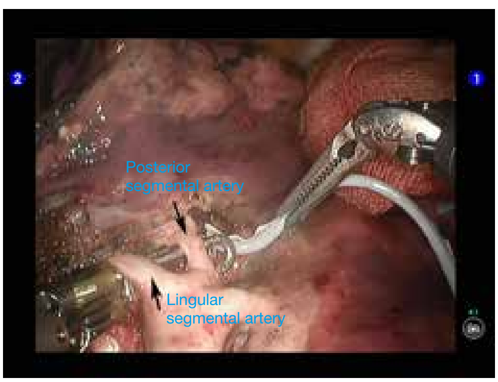


**Figure 23** Dissociate and pull the superior lingular segmental artery and the superior branch of the posterior segmental artery.

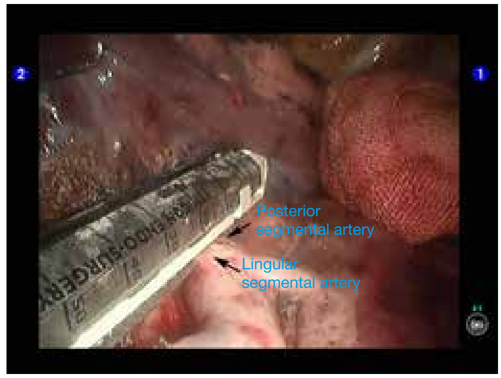


**Figure 24** Handle these two vessels using a white reload.

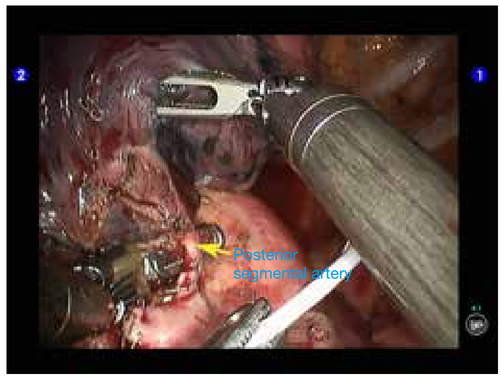


**Figure 25** Thoroughly dissociate the superior branch of the posterior segmental artery.

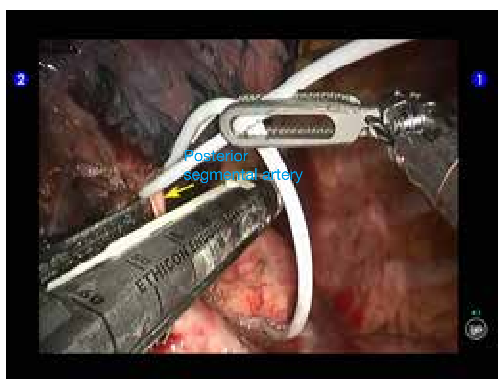


**Figure 26** Transect using a white reload.

Open the posterior mediastinal pleura to remove the subcarinal and subaortic lymph nodes. Remove the interlobar lymph nodes. No swollen lymph node was found during aorta inspection (*Figures 35,36*).

When no obvious bleeding was observed at all the trauma surfaces, wash the thoracic cavity. If no air leakage was observed during lung recruitment and the inferior lobe was well expanded, suction all the rinsing water.

The hilar trauma surfaces and the subcarinal area were sprayed and covered with the sol of TISTAT absorbable

**Figure 27** Thoroughly dissociate the apical anterior segmental artery.

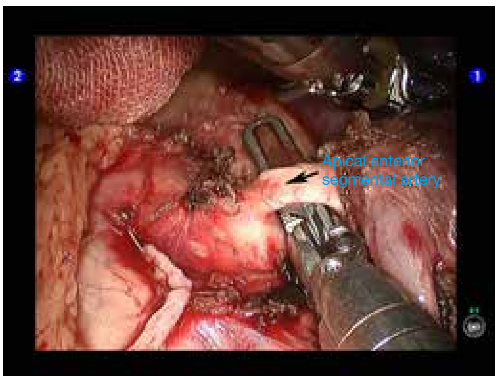


**Figure 28** Transect the apical anterior segmental artery.

**Figure 29** Remove the lymph nodes among arteries and veins.

hemostatic gauze.

The thoracic drainage tube was indwelled at the working port at the 5th ICS and at the camera port, respectively. Close the chest after lung recruitment (*Figure 37*).

**Figure 30** Remove the lymph nodes near the bronchus.

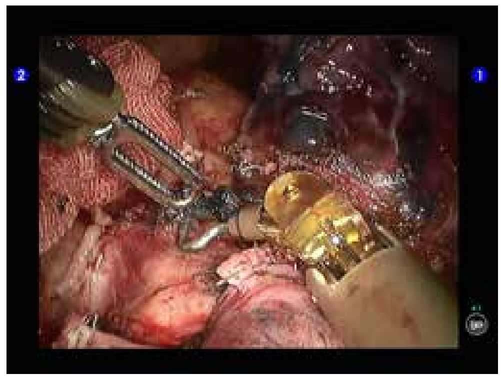

**Figure 31** Remove the lymph nodes near the arteries.

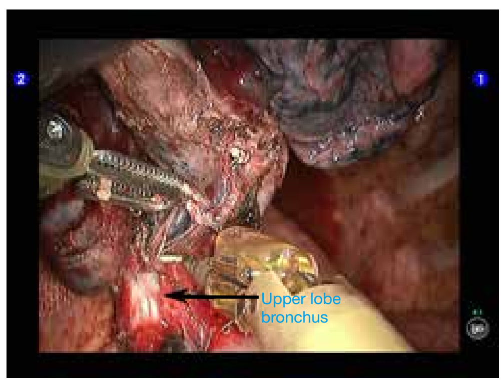


**Figure 32** Remove the lymph nodes near the bronchus, and then dissociate the bronchial wall.

## Postoperative treatment

Postoperative treatment is similar to that after the conventional open lobectomy. The thoracic drainage tube was withdrawn 7 days after the surgery. The post-operative

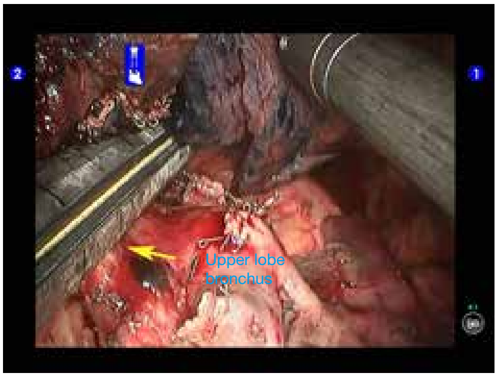


**Figure 33** Clamp the upper lobe bronchus.

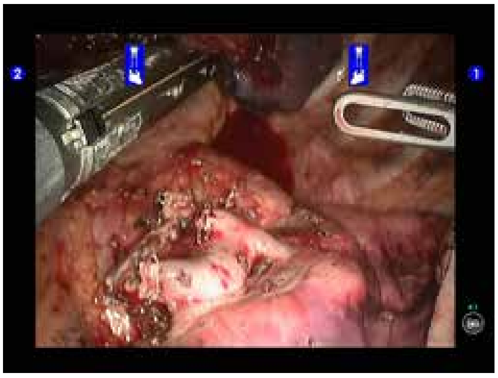

**Figure 34** Transect the bronchus and then divide the upper lobe.

**Figure 35** Remove the subcarinal and subaortic lymph nodes.

pathological stage was $pT_1aN_0M_0$. Currently the patient was under follow-up visits.

## Pathological diagnosis

Well-differentiated adenocarcinoma in the upper lobe of

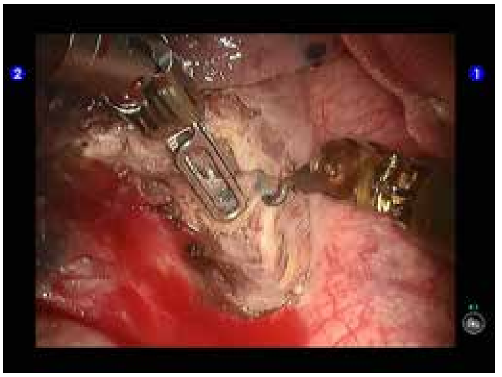

**Figure 36** Remove the interlobar lymph nodes.

**Figure 37** Placement of drainage tube: the thoracic drainage tube was indwelled at the working port at the 5th ICR and at the camera port, respectively.

left lung, sized about 1 cm. No cancer cell was detected at the bronchial stump or the hilar/mediastinal lymph nodes.

## Comment

Resection of the upper lobe of left lung is the most difficult procedure in lobectomy. The vessels in this area have multiple branches and variations. Thus, resection of the left upper lobe is particularly challenging either under endoscope or using the robotic system. A successful surgery is often based on the factors including proper one-lung ventilation, appropriate body position and incision selection, clear exposure and anatomic relationships, as well as the skills and teamwork of operator and assistants. In our current case, the patient had well developed lung fissures. Thus, the vessels were dissociated firstly and then handled one by one. In patients with poorly developed lung fissures, the dissection of lung fissures and vessels will be difficult.

A single direction procedure then can be adopted, during which the upper lung vein, apical and anterior segmental branches of lung artery, and upper lobe bronchus were transected one by one, followed by the handling of the lung fissures and the remaining arteries. Notably, during the handling of the bronchus, the cutter/stapler may hurt the pulmonary trunk or posterior segmental artery by mistake because the posterior segmental artery is not transected and the gap behind the bronchus is small. Clear exposure is particularly important to avoid such unnecessary injuries. In addition, the cutter/stapler can easily handle the oblique fissure, arteries, and bronchus via the auxiliary port created in the 7th intercostal space at midaxillary line. However, since there is a large angle in handling the upper lung vein, we need to move the camera to the auxiliary port and then insert the cutter/stapler via the camera port. This is a routine step in endoscopic surgeries but seems a bit complicated in the robotic surgeries. Thus, a skillful assistant who is familiar with the performances of the robotic arms is critically important.

## Acknowledgements

*Disclosure:* The authors declare no conflict of interest.

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# Robotic-assisted left upper lingual segmentectomy

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## Clinical data

### *Medical history*

The patient, a 50-year-old woman, was admitted due to "repeated hemoptysis for more than half a year" and "bronchiectasis". The patient began to cough up blood without obvious causes about 6 months ago. The blood was bright red in color, and the patient spitted about 6 times during each attack. No special treatment was given. She spitted up 9 times of fresh blood again 1 month ago and then visited a local hospital. Chest CT showed that the lingular bronchus of left upper lobe showed cystic and cylindrical dilatation, along with thickened walls. Small dotted and patchy intensities were visible around it. Left bronchial dilation accompanied with peribronchitis was considered. The condition was not remarkably improved after anti-inflammatory and hemostatic treatment. She then visited our hospital for further management. After outpatient consultation, she was admitted due to "bronchiectasis". The patient's complaints did not include cough, chest tightness, shortness of breath, low fever, night sweats, nausea, vomiting, abdominal distension, diarrhea, heart palpitations, or discomfort of precordial area. His mental status, physical performance, appetite, and sleep were normal, and the body weight did not obviously change. Urination and defecation were normal.

Initial physical examination findings included HR of 75 bpm, breath rate of 20 times per minute, and BP of 125/79 mmHg. The thoracic cage was symmetric and showed no deformity. The respiratory movement in both lungs was symmetric. The respiratory movement and respiratory frequency was normal. The vocal fremitus and voice transmission were normal in both lungs. Pleural friction fremitus was not palpable. There was no chest wall and rib tenderness. The sternum was not sensitive to percussion. Resonance was heard during percussion in both lungs. Cardiopulmonary examination showed no abnormal results.

The preliminary diagnosis was bronchiectasis.

### *Physical examination*

The body temperature was 36.3 ℃. Auscultation revealed harsh breath sounds in the left upper lung field; however, no dry or wet rales or pleural friction rubs were heard. No such abnormality was heard in other lobes. No other positive sign was detected.

### *Auxiliary examination*

Chest CT: The lingular bronchus of left upper lobe showed cystic and cylindrical dilatation, along with thickened walls. Small dotted and patchy intensities were visible around it. Left bronchial dilation accompanied with peribronchitis was considered (*Figure 1*).

No obvious abnormality was found in ECG, echocardiography, pulmonary function test, blood gas analysis, and other biochemical tests.

## Pre-operative preparation

Bronchiectasis was considered based on the symptoms, signs, and imaging findings.

The symptoms were remarkably alleviated after medical treatment; however, a clear lesion persisted and was confined to the lingular bronchus. Resection of lingual segment of the left upper pulmonary lobe or wedge resection of the upper lobe was then decided. Tests including sputum culture were

 

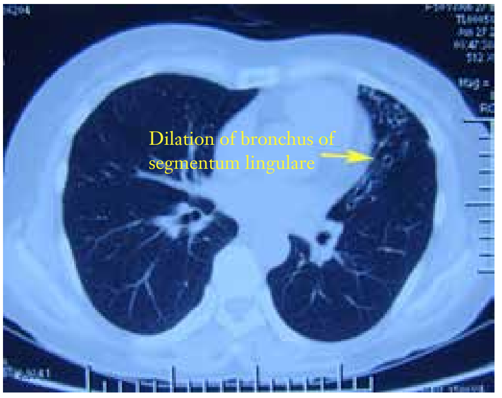


**Figure 1** On chest CT, the lingular bronchus of left upper lobe showed cystic and cylindrical dilatation, along with thickened walls. Small dotted and patchy intensities were visible around it. Left bronchial dilation accompanied with peribronchitis was considered. (Dilation of bronchus of segmentum lingulare)

**Figure 2** The patient was placed in a right lateral decubitus position; with his hands put in front of head, he was fixed in a Jackknife position.

**Figure 3** Incisions. A camera port was created in the 8th intercostal space at posterior axillary line, and two working ports were separately made in the 5th intercostal space at anterior axillary line and the 8th intercostal space at scapular line. An auxiliary port was made in the 7th intercostal space at midaxillary line.

performed before the surgery. Also, oral administration of anti-inflammatory and phlegm-eliminating drugs as well as atomization for sputum discharge was applied to control the amount of phlegm.

## Surgical procedures

### *Anesthesia and body position*

After the induction of general anesthesia, the patient was placed in a right lateral decubitus position under double-lumen endotracheal intubation. With her hands put in front of head, he was fixed in a Jackknife position with single-lung (right) ventilation (*Figure 2*).

### *Surgical procedures*

Incisions. A 1.5-cm camera port was created in the 8th intercostal space (ICS) at left posterior axillary line, and two 1.0-cm working ports were separately made in the 5th ICS at left anterior axillary line and the 8th ICS at scapular line. A 4-cm auxiliary port was made in the 7th ICS at midaxillary line (*Figure 3*).

The robot Patient Cart were connected over the patient's head. A 12-mm trocar was placed at the camera port in the 8th ICS at posterior axillary line to be attached with the camera arm. The robot metal trocars were respectively attached to the 2# arm (left hand) and 1# arm (right hand) at the incisions in the 5th ICS anterior axillary line and the 8th ICS scapular line. Incision protector was applied in the auxiliary port.

Inspection of the thoracic cavity showed that there were many cord-like structures adhered in the upper lobe. Under the endoscopic monitoring, the robot trocars were separately inserted via the two working ports. Incision protector was applied in the auxiliary port. The robot Patient Cart is positioned directly above the operating table and then connected. Its left hand was attached to bipolar cautery forceps, and its right hand was attached to a unipolar cautery hook. The cord-like structures were then dissected. Inspection also showed that the lesion was localized inside the lingual segment of the upper lobe.

Segmentectomy. Divide the pleural adhesions (*Figure 4*).

Cut open the oblique fissure to dissociate the lingular branch of the upper lobe pulmonary artery (*Figures 5,6*). The anterior mediastinal pleura were cut open to dissociate the lingular branch of the upper lobe pulmonary vein. The vein was handled firstly. Endoscopic cutter/stapler

 

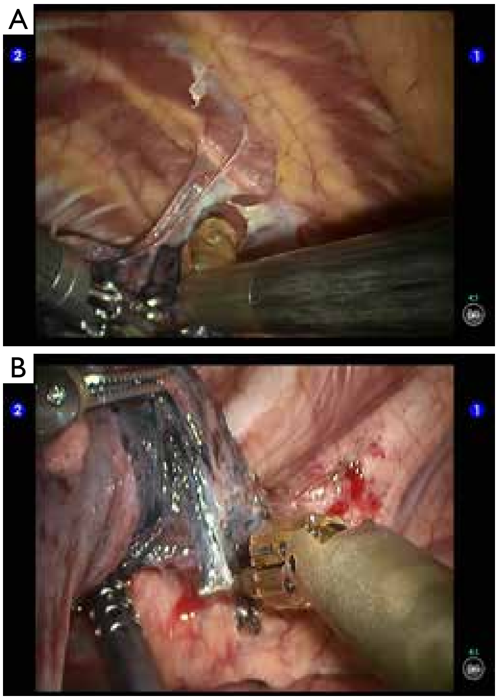


**Figure 4** Divide the pleural adhesions using the unipolar cautery hook.

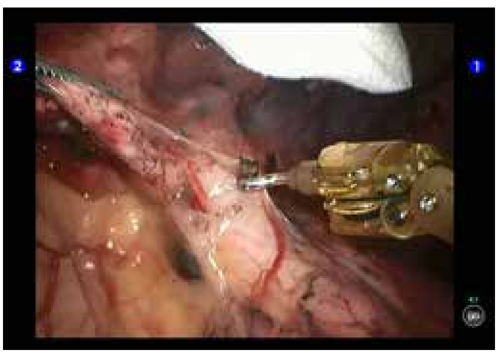

**Figure 5** Open the oblique fissure.

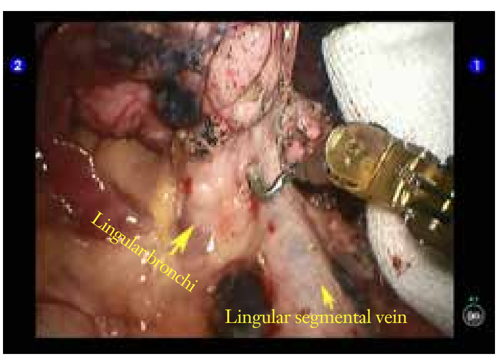


**Figure 6** Dissociate the lingular segmental artery.

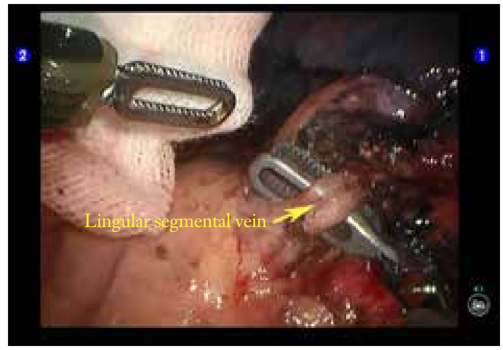


**Figure 7** Dissociate the lingular segmental vein.

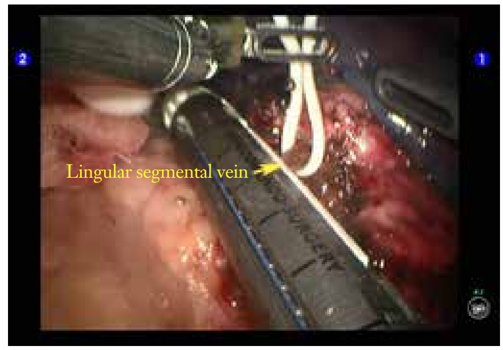


**Figure 8** Transect the lingular segmental vein with a white reload.

was inserted through the auxiliary port, and the vein was transected using a white reload (*Figures 7,8*), and then transect the lingular segmental artery using a white reload (*Figure 9A,B*).

Dissociate the lingular segmental bronchus (*Figure 10*). Behind it there were small vascular branches, which were handled using cautery devices (*Figure 11*). Clamp the lingular segmental bronchus with a blue reload. An anesthesiologist was asked to suction sputum and ventilate the operated lung, so as to identify the borders of the lingular segment and ensure the proper segments of the upper lobe were well ventilated (*Figures 12,13*). Divide the bronchus. The inter-segmental gap was separated using two golden reloads and one blue reload, and thus the lingual segment was removed (*Figures 14,15*). A specimen bag was inserted via the auxiliary port to harvest the specimen. Wash the thoracic cavity. The residual lungs were well dilated, without air leakage. The trauma surfaces and the post-operative lung surfaces were sprayed and covered with the sol of Tistat absorbable hemostatic gauze. After the robot system was withdrawn, the thoracic drainage tube was indwelled at the camera port before closing the chest. Close

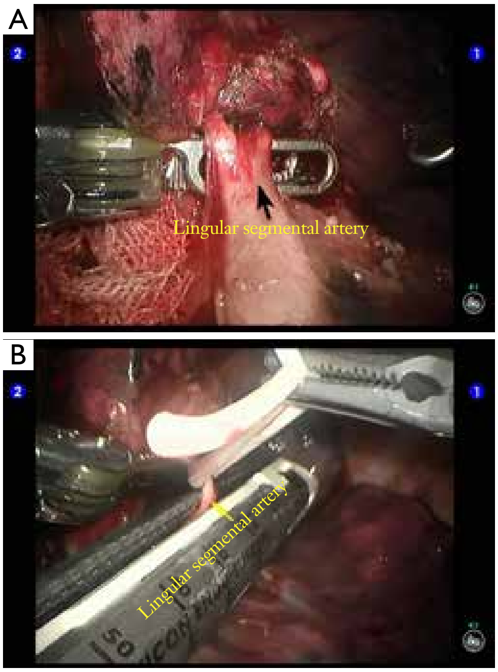


**Figure 9** (A) Thoroughly dissociate the lingular segmental artery; (B) transect the lingular segmental artery with a white reload.

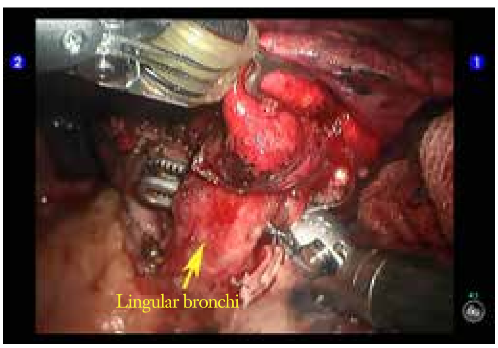


**Figure 10** Dissociate the lingular segmental bronchus.

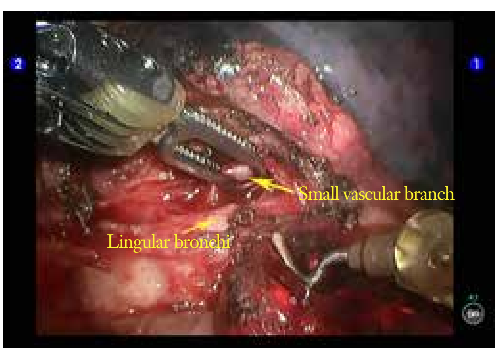


**Figure 11** Handle the small vascular branches behind the bronchus using cautery devices.


**Figure 12** Clamp the lingular segmental bronchus.

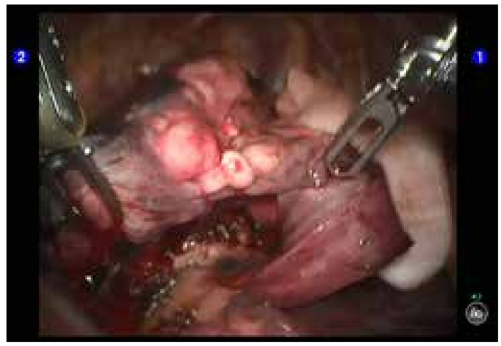

**Figure 13** Ventilate the operated lung to identify the borders of the lingular segment.

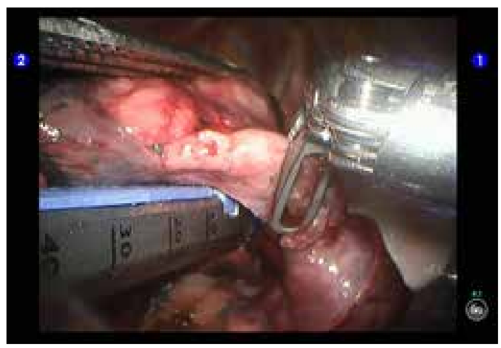

**Figure 14** Place the stapler along the borders of the lingular segment.

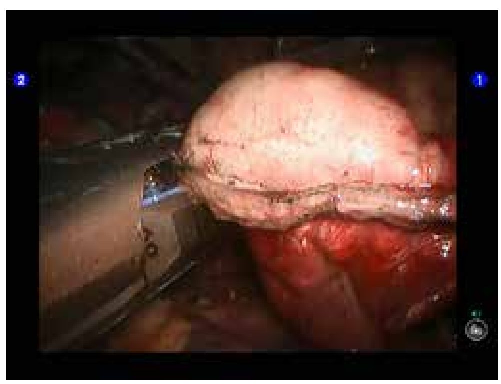

**Figure 15** Dissect and remove the lingular segment.

the chest after lung recruitment.

## Postoperative treatment

Postoperative treatment is similar to that after the conventional open lobectomy. The thoracic drainage tube was withdrawn 7 days after the surgery.

## Pathological diagnosis

Bronchiectasis.

## Comment

Anatomic segmentectomy is quite difficult. It may be considered in patients with begin tumors and with well-developed lung fissures. The key to a successful surgery includes: the operator is familiar with the anatomy of the segmental vessels and bronchus and can appropriately handle these structures after adequate dissociation; ventilating the lung after clamping the bronchus will not hurt the nearby bronchus; the borders among segments can be clearly identified. Some authors prefer to clamp the bronchus while the lung is half ventilated, so as to keep the inflation of the resected lung tissues, which is helpful to identify the segmental borders and thus make the transection using stapler easier. Their practices warrant further investigation in clinical settings.

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# Robotic-assisted left inferior lobectomy

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## Clinical data

### *Medical history*

The patient, a 52-year-old woman, was admitted due to “space-occupying lesion in the inferior lobe of lung found during health check-up 3 weeks ago”.

The patient complained of an occasional cough but had no signs/symptoms such as fever, phlegm production, difficulty in breathing, chest tightness, shortness of breath, fatigue or night sweats. She had been treated with azithromycin and levofloxacin in a local hospital for 1 week, but the condition was not remarkably improved.

### *Physical examination*

No bilateral supraclavicular lymph node enlargement was detected. Chest examination showed no positive sign.

### *Auxiliary examination*

(I) Chest CT showed a lobulated and spiculated dorsal high-density shadow sized 1.8 cm × 2.0 cm in the inferior lobe of left lung. It has uneven density and an enhancement was evident after contrast application. The bilateral pulmonary hilar and mediastinal lymph nodes were not remarkably swollen (*Figures 1,2*).

(II) Metastasis was not detected on head CT, bone ECT, and abdominal ultrasonography.

## Pre-operative preparation

Same as the conventional open thoracic surgery.

## Surgical procedures

### *Anesthesia and body position*

After the induction of general anesthesia, the patient was under double-lumen endotracheal intubation and underwent right-sided one-lung ventilation.

The patient was placed in the right lateral decubitus position and in a Jackknife position (*Figure 3*).

### *Surgical procedures*

(I) Incisions. A 1.5-cm camera port was created in the 8th intercostal space at left posterior axillary line, and two 1.0-cm working ports were separately made in the 5th intercostal space at anterior axillary line and the 8th intercostal space at scapular line. A 4-cm auxiliary port was made in the 7th intercostal space at midaxillary line (*Figure 4*).

(II) Connection of robot Patient cart. The robot Patient cart is positioned directly above the operating table and then connected. Its left hand was attached to bipolar cautery forceps, and its right hand was attached to a unipolar cautery hook. Incision protector was applied in the auxiliary port.

(III) The inferior pulmonary ligament was dissociated using the unipolar cautery hook till the inferior pulmonary vein level (*Figure 5*).

(IV) Remove the lymph nodes in the inferior pulmonary vein (*Figure 6*).

(V) Dissociate the inferior pulmonary vein (*Figure 7*).

(VI) Pull the inferior pulmonary vein elastic cuffs (*Figure 8*).

(VII) Cut off the inferior pulmonary vein, and then the vein of the left inferior lobe of the lung was clamped

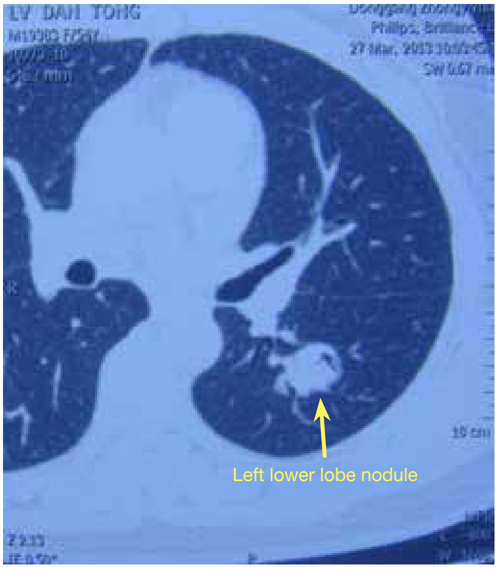


**Figure 1** CT image: markings.

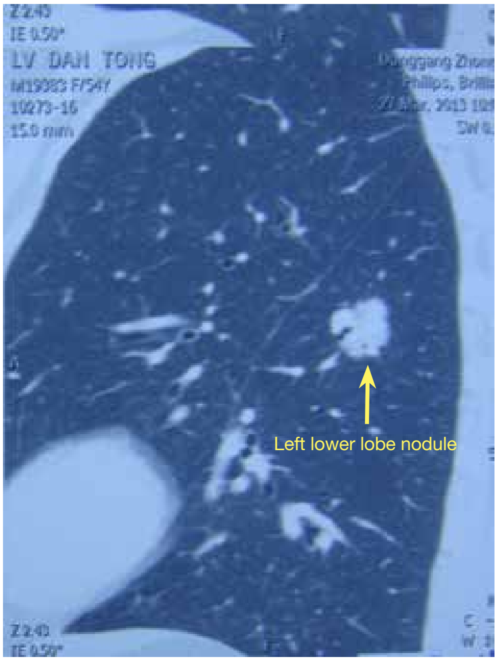


**Figure 2** CT image 2: markings.

**Figure 3** Surgical position.

**Figure 4** Incisions.

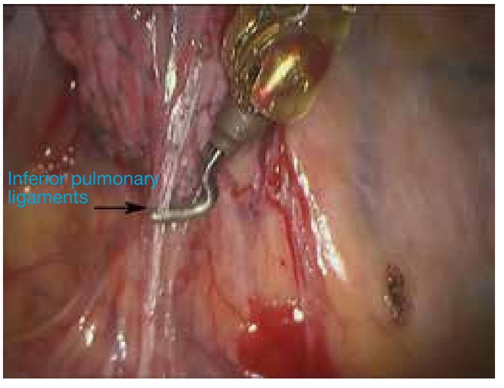


**Figure 5** Dissociate the inferior pulmonary ligament.

and divided using the single-use endoscopic linear cutter/stapler (white reload) (*Figures 9,10*).

(VIII) Remove several subcarinal lymph nodes (*Figure 11*).

(IX) Remove the interlobar lymph nodes (*Figure 12*).

(X) Dissociate and transect the branches of the upper lobe artery (*Figures 13,14*).

(XI) Dissociate the upper lobe bronchus. Then, the bronchus was clamped using the single-use endoscopic linear cutter/stapler (golden reload) for lung ventilation test, and was transected after the test (*Figures 15,16*).

(XII) An extraction bag was inserted to harvest the

 

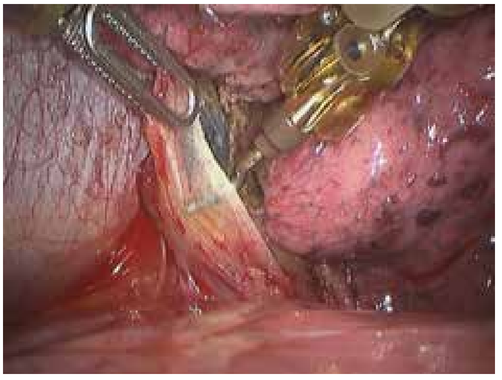

**Figure 6** Remove the lymph nodes in the inferior pulmonary ligament.

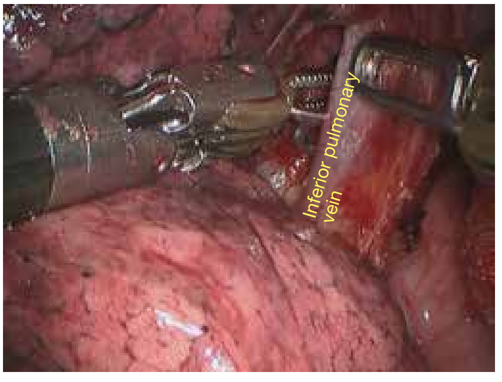


**Figure 7** Sharply dissect the inferior pulmonary ligament: markings.

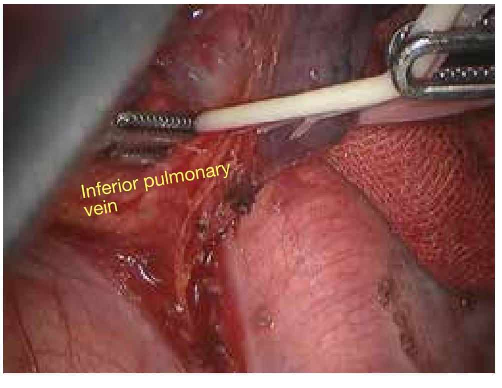


**Figure 8** Pull the inferior pulmonary ligament using an elastic cuff: markings.

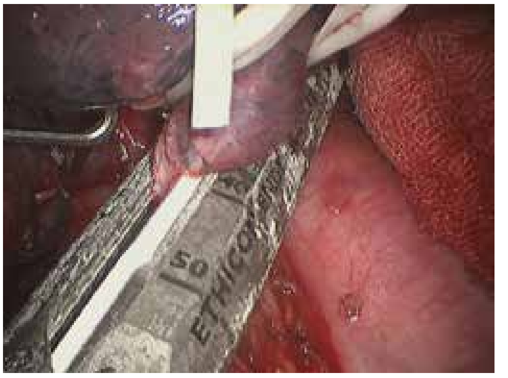

**Figure 9** Transect the inferior pulmonary vein.

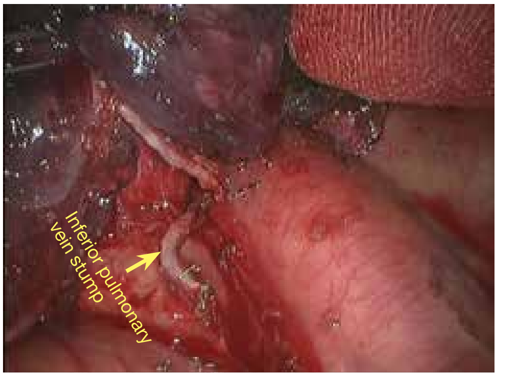


**Figure 10** After the transection of the inferior pulmonary vein: marking.

**Figure 11** Remove the subcarinal lymph nodes.

 

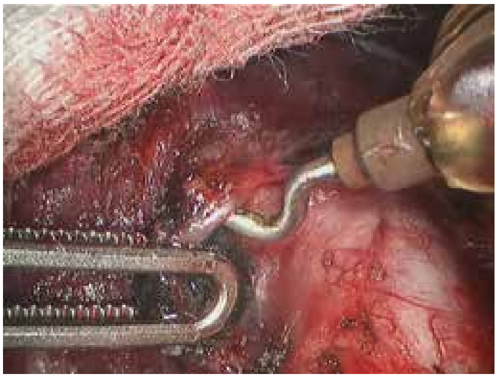

**Figure 12** Remove the interlobar lymph nodes.

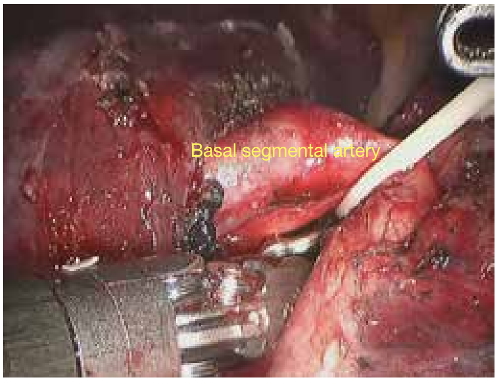


**Figure 13** Dissociate the arteries in the basal and dorsal segments of lower lobe: markings.

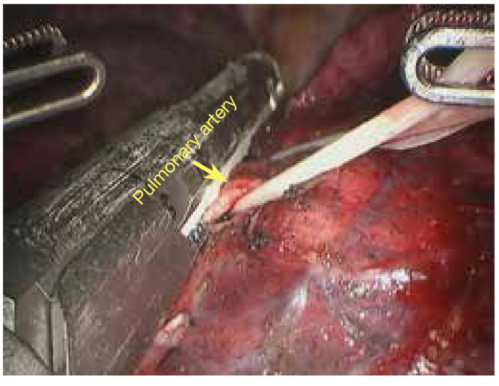


**Figure 14** Transect the branches of lower lobe artery: markings.

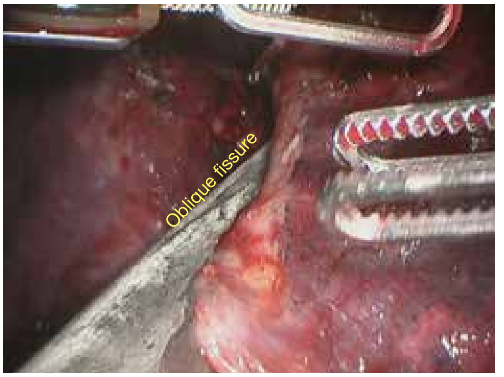


**Figure 15** Clamp the lower lobe bronchus and part of undifferentiated lobar fissures: markings.

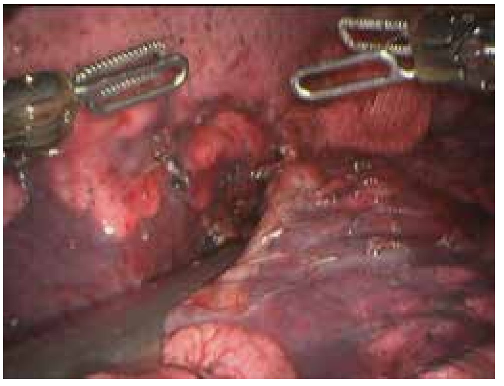

**Figure 16** Transect the bronchus after the full ventilation of the upper lobe.

**Figure 17** An extraction bag was inserted to harvest the completely resected lobe via the incision.

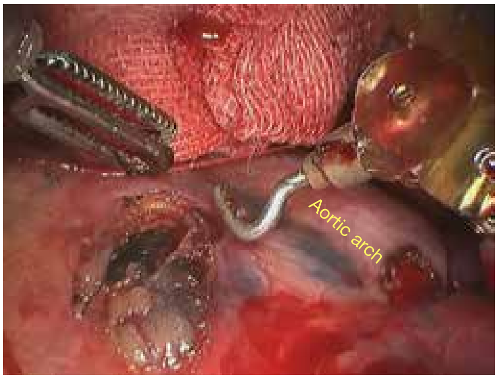


**Figure 18** Remove the lymph nodes under the aortic arch: markings.

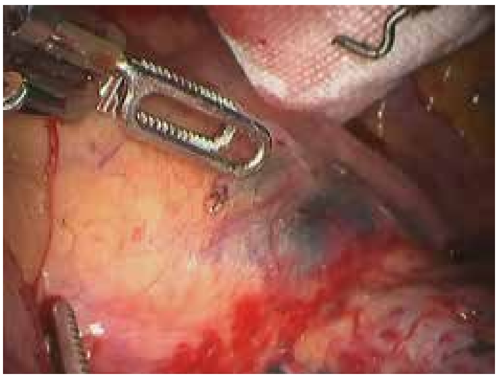

**Figure 19** Remove the lymph nodes near the ascending aorta.

completely resected left inferion lobe via the incision (*Figure 17*).

(XIII) Remove the lymph nodes under the aortic arch (*Figure 18*).

(XIV) Remove the lymph nodes near the ascending aorta (*Figure 19*).

(XV) Saline is then injected to expand the lungs to identify potential leakage of the bronchial stumps (*Figure 20*).

(XVI) Wash the thoracic cavity with warm saline. The robotic arms were withdrawn after the bleeding was stopped. Close the chest after a closed chest drainage tube was placed at the camera port.

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**Figure 20** Bronchial stump leak test showed negative result.

### *Postoperative treatment*

Postoperative treatment was similar to that after the conventional open lobectomy.

## Pathological diagnosis

A moderately-well differentiated adenocarcinoma sized 2.0 cm × 1.5 cm × 1.0 cm in the lower lobe of the left lung. No metastasis was seen at the bronchial stump or the sampled lymph nodes. Postoperative pathologic staging: $pT_1N_0M_0$.

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*Disclosure:* The authors declare no conflict of interest.

 

# Technical highlights of robotic-assisted mediastinal tumor resection

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## Technical highlights of anterior upper mediastinal tumor resection

### *Anesthesia, intubation, position*

The operation uses general anesthesia, double-lumen endotracheal intubation, contralateral decubitus with slight backward bending, contralateral one-lung ventilation, upper limb buckling and head crossing.

### *Incision design—the "6-3-5" incision design method*

An incision is made in the sixth intercostal space on the posterior axillary line of the affected side to place a 12-mm-diameter trocar, which is used to insert a thoracoscope. Incisions are made in the third and fifth intercostal spaces on the ipsilateral anterior axillary line to place an 8-mm-diameter trocar for the insertion of equipment connected to the instrument arm. If necessary, during the operation, another incision is made in the sixth intercostal space on the midaxillary line to place an 8-mm-diameter trocar to assist in the operation. An artificial 6-10 mmHg pneumothorax (usually 8 mmHg) is established in the ipsilateral pleural cavity during the operation to fully collapse the lung to facilitate the operation.

### *Technical highlights of the surgical operation*

#### Careful observation

After the insertion of the lens, the relationship between the lesion and its surrounding tissue structures is carefully confirmed, including the relationship between the lesion and superior vena cava, as well as the relationship between the lesion and left and right innominate veins and heart, to avoid accidental injury.

#### Device selection

The left hand uses a bipolar coagulation forceps, and the right hand uses a monopolar coagulation hook.

### *Operation procedures*

If the tumor is obvious and protruding to the affected side, a monopolar coagulation hook is used to make a sharp separation of mediastinal pleura at about 0.5 cm proximal to the mediastinal pleura on the surface of the tumor. The tumor is then completely isolated and excised by cutting the inherent tumor capsule from top to bottom, front to back and ipsilateral side to contralateral side. One of the incisions used for equipment insertion is extended appropriately to insert a disposable specimen retriever to remove the specimen, and then, the wound is given a complete hemostasis. If there is no obvious bleeding and oozing of the wounds during the operation, after the anesthesiologist has fully expanded the lung, each operation incision is sutured and closed without maintaining a thoracic drainage tube, and the operation is complete. Otherwise, a thoracic drainage tube, which is connected to an external water-sealed drainage bottle, is inserted through the incision for a thoracoscope. After the lung is fully expanded, all of the incisions for the operation are sutured, and the surgery is complete.

If the tumor is relatively small, and the lesion is not seen after the lens is inserted, a coagulation hook is used to isolate and excise the whole anterior mediastinal tissue (thymus and adipose tissue) in front of the phrenic nerve and superior vena cava and below the innominate vein. Next, one of the incisions used for the equipment insertion is extended appropriately to insert a disposable specimen retriever to remove the excised specimen, carefully examine it and search for the lesion. After confirming an accurate and complete excision of the lesion tissue, the wound is given a complete hemostasis. If no lesion is found in the excised tissue, the same method is used to expand the excision of the anterior mediastinal tissue until an accurate and complete excision of the lesion tissue is confirmed, and then, the wound is given a complete hemostasis. A thoracic drainage tube, which is connected to an external water-sealed drainage bottle, is inserted through the incision for a thoracoscope. After the lung is fully expanded, all of the incisions for the operation are sutured, and the surgery is complete.

If, during the operation, the ipsilateral lung does not show a satisfactory collapse, or the tumor has abundant blood vessels and too much oozing interfering with the operation, an incision in the sixth intercostal space at the midaxillary line is made on the affected side to place an 8-mm trocar to assist in the operation, which is performed by an assistant.

## Technical highlights of anterior lower mediastinal tumor resection

### *Anesthesia, intubation, position*

The operation uses general anesthesia, double-lumen endotracheal intubation, contralateral decubitus with slight backward bending, contralateral one-lung ventilation, upper limb buckling and head crossing.

### *Incision design—the "6-3-6" incision design method*

An incision is made in the sixth intercostal space on the posterior axillary line of the affected side to place a 12-mm-diameter trocar, which is used to insert a thoracoscope. Incisions are made in the third and sixth intercostal spaces on the ipsilateral anterior axillary line to place an 8-mm-diameter trocar, which is used for the insertion of equipment connected to the instrument arm. If necessary, during the operation, another incision is made in the sixth intercostal space on the midaxillary line to place an 8-mm-diameter trocar to assist in the operation. An artificial 6-10 mmHg pneumothorax (usually 8 mmHg) is established in the ipsilateral pleural cavity during the operation to fully collapse the lung to expose the operative field and facilitate the operation.

### *Technical highlights of the surgical operation*

**Careful observation**

After the insertion of the lens, the relationship between the lesion and its surrounding tissue structures is carefully confirmed, including the relationship between the lesion and lungs, as well as that between the lesion and the phrenic nerve and heart, to avoid accidental injury.

**Device selection**

The left hand uses bipolar coagulation forceps, and the right hand uses a monopolar coagulation hook.

### *Operation procedures*

If the tumor is obvious and protruding to the affected side, a monopolar coagulation hook is used to make a sharp separation of the mediastinal pleura at about 0.5 cm proximal to the mediastinal pleura on the surface of the tumor. The tumor is then completely isolated and excised by cutting the inherent tumor capsule from top to bottom, front to back and ipsilateral side to contralateral side. One of the incisions used for the insertion of equipment is extended appropriately to insert a disposable specimen retriever to remove the specimen, and then, the wound is given a complete hemostasis. If there is no obvious bleeding and oozing of the wounds during the operation, after the anesthesiologist fully expands the lung, each operation incision is sutured and closed without maintaining a thoracic drainage tube, and the operation is complete. Otherwise, a thoracic drainage tube, which is connected to an external water-sealed drainage bottle, is inserted through the incision for a thoracoscope. After the lung is fully expanded, all of the incisions for the operation are sutured, and the surgery is complete.

If the tumor is relatively small, and the lesion is not seen after the lens is inserted, a coagulation hook is used to isolate and excise the whole anterior mediastinal tissue from the lower mediastinum (estimated tumor location) in front of the phrenic nerve and pericardium. Next, one of the incisions used for the equipment insertion is extended appropriately to insert a disposable specimen retriever to remove the excised specimen, carefully examine it and search for the lesion. After confirming an accurate and complete excision of the lesion tissue, the wound is given a complete hemostasis. If no lesion is found in the excised tissue, the same method is used to expand the excision of the anterior lower mediastinal tissue until an accurate and complete excision of the lesion tissue is confirmed, and then, the wound is given a complete hemostasis. A thoracic drainage tube, which is connected to an external water-sealed drainage bottle, is inserted through the incision for a thoracoscope. After the lung is fully expanded, all of the incisions for the operation are sutured, and the surgery is complete.

If, during the operation, the ipsilateral lung does not show a satisfactory collapse, or the tumor has abundant blood vessels and produces too much oozing that interferes with the operation, an incision in the sixth intercostal space at the midaxillary line is made on the affected side to place an 8-mm trocar for to assist in the operation, which is performed by an assistant.

## Technical highlights of posterior upper mediastinal tumor resection

### *Anesthesia, intubation, position*

The operation uses general anesthesia, double-lumen endotracheal intubation, contralateral decubitus, contralateral one-lung ventilation, upper limbs buckling and crossing the head.

### *Incision design—the "6-4-7" incision design method*

An incision is made in the sixth intercostal space on the ipsilateral posterior axillary line to place a 12-mm-diameter trocar, which is used to insert a thoracoscope. Next, 0.8-cm-long incisions are made, respectively, in the seventh intercostal space at the posterior axillary line and infrascapular line and in the fourth intercostal space at the anterior axillary line and midclavicular line on the ipsilateral side for the operation. If necessary, during the operation, another incision is made in the fifth or sixth intercostal space on the midaxillary line of the ipsilateral side to place an 8-mm-diameter trocar to assist in the operation. An artificial 6-10 mmHg pneumothorax (usually 8 mmHg) is established in the ipsilateral pleural cavity during the operation to fully collapse the lung to expose the operative field and facilitate the operation.

### *Technical highlights of the surgical operation*

**Careful observation**

After the insertion of the lens, the relationship between the lesion and its surrounding tissue structures is carefully confirmed, including the relationship between the lesion and superior vena cava, as well as that between the lesion and left and right innominate veins, azygos vein, esophagus and trachea, to avoid accidental injury.

**Device selection**

The left hand uses a bipolar coagulation forceps, and the right hand uses monopolar coagulation hook.

### *Operation procedures*

At about 0.5 cm from the base and on the surface of the tumor, a monopolar coagulation hook is used to make a sharp and circumferential separation of the parietal pleura on the surface of the tumor. The tumor is then completely isolated and excised by cutting the inherent tumor capsule from top to bottom and from front to back (during the operation, the relationship between the tumor and its surrounding tissue structures is carefully confirmed, particularly paying attention to the relationship between the tumor and intervertebral foramen, to avoid secondary injury). One of the incisions used for the insertion of equipment is extended appropriately to insert a disposable specimen retriever to remove the specimen, and then the wound is given a complete hemostasis. If there is no obvious bleeding and oozing of the wounds during the operation, after the anesthesiologist fully expands the lung, each operation incision is sutured and closed without maintaining a thoracic drainage tube, and the operation is complete. Otherwise, a thoracic drainage tube, which is connected to an external water-sealed drainage bottle, is inserted through the incision for a thoracoscope. After the lung is fully expanded, all of the incisions for the operation are sutured, and the surgery is complete.

If, during the operation, the ipsilateral lung does not show a satisfactory collapse, or the tumor has abundant blood vessels and produces too much oozing that interferes with the operation, an incision in the fifth or sixth intercostal space at the midaxillary line on the affected side is made to place an 8-mm trocar to assist in the operation, which is performed by an assistant.

## Technical highlights of posterior lower mediastinal tumor resection

### *Anesthesia, intubation, position*

The operation uses general anesthesia, double-lumen endotracheal intubation, contralateral decubitus with slight forward bending, contralateral one-lung ventilation, upper limb buckling and head crossing.

### *Incision design—the "6-4-7" incision design method*

A 1.2-cm incision is made in the fifth intercostal space on the right anterior axillary line to insert a thoracoscope. Next, 0.8-cm-long incisions are made, respectively, in the third intercostal space at the right midaxillary line and in the eighth intercostal space at the right posterior axillary line and infrascapular line for the operation. If necessary, during the operation, another incision is made in the sixth or seventh intercostal space on the midaxillary line of the ipsilateral side to place an 8-mm-diameter trocar to assist in the operation. An artificial 6-10 mmHg pneumothorax (usually 8 mmHg) is established in the ipsilateral pleural cavity during the operation to fully collapse the lung to expose the operative field and facilitate the operation.

### *Technical highlights of the surgical operation*

#### Careful observation

After the insertion of the lens, the relationship between the lesion and its surrounding tissue structures is carefully confirmed, including the relationship between the lesion and esophagus, and that between the lesion and the heart and trachea, to avoid accidental injury.

#### Device selection

The left hand uses bipolar coagulation forceps and the right hand uses monopolar coagulation hook.

### *Operation procedures*

At about 0.5 cm from the base and on the surface of the tumor, a monopolar coagulation hook is used to make a sharp and circumferential separation of the parietal pleura on the surface of the tumor. The tumor is then completely isolated and excised by cutting the inherent tumor capsule from top to bottom and from front to back (during the operation, the relationship between the tumor and its surrounding tissue structures is carefully confirmed, particularly paying attention to the relationship between the tumor and intervertebral foramen, to avoid secondary injury). One of the incisions used for equipment insertion is extended appropriately to insert a disposable specimen retriever to remove the specimen, and then the wound is given a complete hemostasis. If there is no obvious bleeding and oozing of the wounds during the operation, after the anesthesiologist fully expands the lung, each operation incision is sutured and closed without maintaining a thoracic drainage tube, and the operation is complete. Otherwise, a thoracic drainage tube, which is connected to an external water-sealed drainage bottle, is inserted through the incision for a thoracoscope. After the lung is fully expanded, all of the incisions for the operation are sutured, and the surgery is complete.

If, during the operation, the ipsilateral lung does not show a satisfactory collapse, or the tumor has abundant blood vessels and produces too much oozing that interferes with the operation, an incision in the sixth or seventh intercostal space at the midaxillary line on the affected side is made to place an 8-mm trocar to assist in the operation, which is performed by an assistant.

## Technical highlights of full thymectomy and anterior mediastinal adipose tissue removal

### *Anesthesia, intubation, position*

The operation uses general anesthesia, double-lumen endotracheal intubation, contralateral decubitus with slight backward bending, contralateral one-lung ventilation, upper limb buckling and head crossing.

### *Incision design—the "6-3-6" incision design method*

If the thymoma is on the right side, or there is no thymoma, the right thoracic cavity entrance is normally chosen because it is convenient and safe for the operation. An incision is made in the sixth intercostal space on the right posterior axillary line to place a 12-mm-diameter trocar, which is used to insert a thoracoscope. Incisions are made in the third and sixth intercostal spaces on the right anterior axillary line to place an 8-mm-diameter trocar, which is used for the insertion of equipment connected to the instrument arm. If the patient has the complication of myasthenia gravis and thymoma (i.e., the thymoma is larger, ≥3 cm), the left thoracic cavity entrance is chosen, and incisions are made the same way as those on the right side. If necessary, during the operation, another incision is made in the sixth intercostal space on the midaxillary line of the operative side to place an 8-mm-diameter trocar to assist in the operation. An artificial 6-10 mmHg pneumothorax (usually 8 mmHg) is established in the pleural cavity of the affected side during the operation to fully collapse the lung to expose the operative field and facilitate the operation.

### *Technical highlights of the surgical operation*

#### Careful observation

First, the lens is inserted to observe whether there are any adhesions in the pleural cavity and to separate them if there are any. The anatomical positions of the superior vena cava, right and left innominate veins, heart and phrenic nerve are carefully confirmed to avoid accidental injury. The operation arm is then connected.

**Device selection**

The left hand uses bipolar coagulation forceps, and the right hand uses a monopolar coagulation hook.

### *Operation procedures*

After the clarification of the lesion area, a monopolar coagulation hook is used to make a sharp opening of the mediastinal pleura in front of the phrenic nerve. Starting from the right bottom end of the thymus (including the adipose tissue at the right bottom, in front of the pericardium), the right lobe of the thymus is isolated by moving along the surface of the pericardium, moving from the right bottom to the top until the right top end of the thymus, and care should be taken when moving to the superior vena cava and left and right innominate veins to avoid injury. After the isolation of the right lobe, movement is made from the left bottom end of the thymus to the top (adjacent to the pericardium, the mediastinal adipose tissue is isolated as well), closely against the left mediastinal pleura, and then movement is continued from the bottom to the top until the left top end of the thymus to isolate the left lobe of the thymus. Because the top end of thymus is adjacent to the innominate vein and other large vessels, extreme care should be taken during the operation. During the isolation, care should also be taken to avoid heat loss from blood vessels that will result in blood vessel rupture and bleeding. Normally, there are two to three thymus veins to merge to the left innominate vein. First, the thymus veins are carefully identified and confirmed. Bipolar coagulation forceps, which are placed far from the left innominate vein, are used to perform multiple electrocoagulations of the thymus veins. A monopolar coagulation hook is then used to sever the thymus vein from the distal end of the coagulated position so that the thymus and anterior mediastinal adipose tissues can be removed altogether completely. Finally, the residual thymus tissue and anterior mediastinal adipose tissues are cleaned and removed to empty the anterior mediastinum so that the contralateral mediastinal pleura are clearly observed. One of the incisions for the operation is extended to approximately 2 cm, and the specimen is removed using a disposable specimen retriever bag. The wound is given a complete hemostasis. A thoracic drainage tube, which is connected to an external water-sealed drainage bottle, is inserted through the incision for a thoracoscope. The anesthesiologist is then instructed to fully expand the lungs and close the incisions for the operation; the surgery is then complete.

Oral administration of a preoperative dosage of pyridostigmine bromide should be continued after the surgery, and the dosage can be gradually reduced according to the patient's clinical symptoms.

If, during the operation, the lung does not show a satisfactory collapse, an incision in the sixth intercostal space at the midaxillary line on the operative side can be made to place an 8-mm-diameter trocar to assist in the operation.

## Technical highlights of tumor resection at the top of the pleura

### *Anesthesia, intubation, position*

The operation uses general anesthesia, double-lumen endotracheal intubation, contralateral decubitus, contralateral one-lung ventilation, upper limbs buckling and both hands holding together and crossing the head with a jackknife position.

### *Incision design—the "8-8-5-7" incision design method*

An incision is made in the seventh or eighth intercostal space on the posterior axillary line of the affected side to place a 12-mm-diameter trocar, which is used to insert a thoracoscope. Incisions are made in the seventh or eighth intercostal space at the infrascapular line and in the fifth intercostal space at the anterior axillary line to place an 8-mm trocar, which is used for the insertion of equipment connected to the instrument arm. If necessary, during the operation, another incision is made in the sixth intercostal space on the midaxillary line to place an 8-mm-diameter trocar to assist in the operation. An artificial 6-10 mmHg pneumothorax (usually 8 mmHg) is established in the pleural cavity of the affected side during the operation to fully collapse the lung to facilitate the operation.

### *Technical highlights of the surgical operation*

**Careful observation**

After the insertion of the lens, the relationship between the lesion and its surrounding tissue structures is carefully confirmed, including the relationship between the lesion and esophagus, trachea, azygos vein and subclavian artery and vein, to avoid accidental injury.

**Device selection**

The left hand uses bipolar coagulation forceps, and the right hand uses a monopolar coagulation hook.

### *Operation procedures*

At a position on the tumor, which is approximately 0.5 cm from the tissues of the top of the pleura, a coagulation hook is used to make a sharp separation of the mediastinal pleura outside the tumor. The tumor is then completely isolated and excised through sharp and blunt isolation of the tumor from outside of the inherent tumor capsule. One of the incisions used for the insertion of the equipment is extended appropriately to insert a disposable specimen retriever to remove the specimen, and then the wound is given a complete hemostasis. A thoracic drainage tube, which is connected to an external water-sealed drainage bottle, is inserted through the incision for a thoracoscope. After the lungs are fully expanded, all of the incisions for the operation are sutured, and the surgery is complete.

If, during the operation, the lung at the affected side does not show a satisfactory collapse, or the tumor has abundant blood vessels and produces too much oozing that interferes with the operation, an incision in the sixth intercostal space at the midaxillary line is made on the ipsilateral side to place an 8-mm trocar to assist in the operation, which is performed by an assistant.

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Mediastinal Surgery

# Robotic thoracic surgery of the anterior superior mediastinal bronchogenic cyst

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## Clinical data

### *Medical history*

The patient, a 48-year-old man, was admitted due to “chest pain for 20 days” and “presence of anterior superior mediastinal mass”. He suffered from chest pain 20 days ago, which became severer when coughing. However, no tenderness or heart palpitations were noted. Chest CT at the local hospital showed a roundish hypodense lesion at the anterior superior mediastinum. Further abdominal ultrasound in a medical university-affiliated hospital showed no other abnormality. He then visited our hospital for further management. His general conditions were acceptable. The chest pain persisted, which became severer when coughing. He also had chest tightness and mildly irritating dry cough. However, he had no fever, night sweats, heart palpitations, or precordial discomfort. His mental status, physical performance, appetite, and sleep were normal, and the body weight did not obviously change. Urination and defecation were normal.

### *Physical examination*

Physical examinations upon admission showed no obviously positive signs. The cervical and supraclavicular lymph nodes were not abnormally enlarged.

### *Auxiliary examination*

Chest X-ray had no abnormal findings in both lungs (*Figure 1*).

Chest CT: a roundish hypodense lesion sized 2.0 cm × 2.0 cm was visible in front of the ascending aorta in the anterior mediastinum. The lesion was somehow calcified, had smooth margin, and could be clearly distinguished from the surrounding tissues/vessels (*Figure 2*).

No obvious abnormality was found in abdominal/urinary ultrasound, ECG, echocardiography, pulmonary function test, blood gas analysis, and other biochemical tests.

## Pre-operative preparation

Based on the imaging results, “a space-occupying lesion in the anterior mediastinum” was considered, and a benign lesion was highly possible. The patient had specific symptoms, and there were clear indications for a surgery, which was planned to be completed using da Vinci robotic system. Since the operations might be affected by the aortic arch and the lesion was located slightly near the right side, anterior mediastinal mass resection through the right chest would be performed.

## Procedures

### *Anesthesia and body position*

After the induction of general anesthesia, the patient was under double-lumen endotracheal intubation and directly underwent left-sided one-lung ventilation, so as to avoid the aggravation of pneumothorax caused by puncture. With his hands put in front of head, he was fixed in the left lateral decubitus position, with the head slightly tilted back (*Figure 3*).

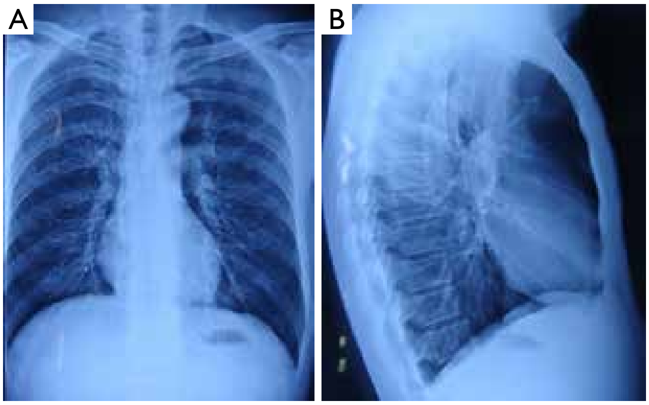


**Figure 1** Chest PA and LAT.

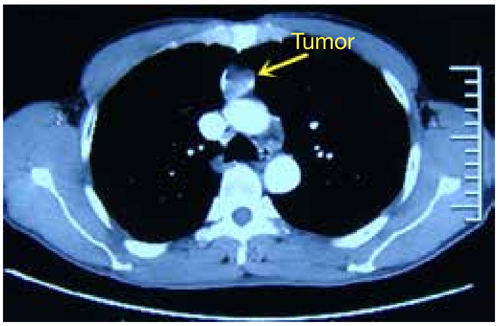


**Figure 2** Enhanced chest CT (note: arrow indicates the tumor).

### *Procedures*

Incisions: a 1.2 cm camera port was created in the 6th intercostal space (ICS) right posterior axillary line, and two 0.8 cm working ports were separately made in the 4th ICS right posterior axillary line and the 5th ICS anterior axillary line (*Figure 4*).

During the thoracic cavity inspection, the camera was inserted via the camera port and found no obvious adhesion or effusion in the thoracic cavity.

The robot manipulators were connected from the left upper side over the patient's head. A 12 mm trocar was placed at the camera port in the 6th ICS at posterior axillary line to be attached with the camera arm. The robot metal trocars were respectively attached to the bipolar coagulation forceps of the 2# arm (left hand) and the unipolar cautery hook of the 1# arm (right hand) at the incisions in the 4th ICS at posterior axillary line and 5th ICS at anterior axillary line.

Inspection: the mass was located at the anterior superior mediastinum and below the mediastinal pleura. The mediastinal pleura were not involved. Tumor had smooth surface, without outward infiltration (*Figure 5*).

**Figure 3** Operation position: left lateral decubitus position, with the head slightly tilted back.

**Figure 4** Incisions. The marks in the figure were made during the pre-operative discussion, and they were somehow moved away after the patient positioning.

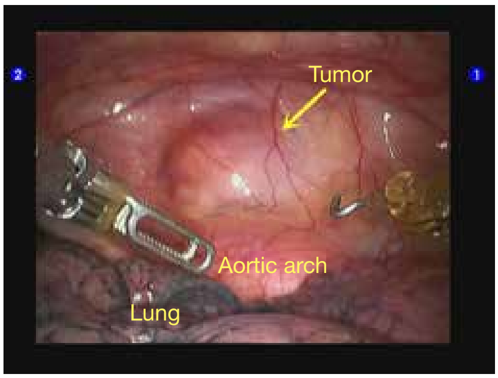


**Figure 5** The tumor is located at the anterior superior mediastinum (yellow arrow) (1: unipolar cautery hook; 2: bipolar coagulation forceps).

### *Surgical steps*

(I) Open the mediastinal pleura (*Figure 6*);

(II) Dissociate the tissues alongside the tumor capsule

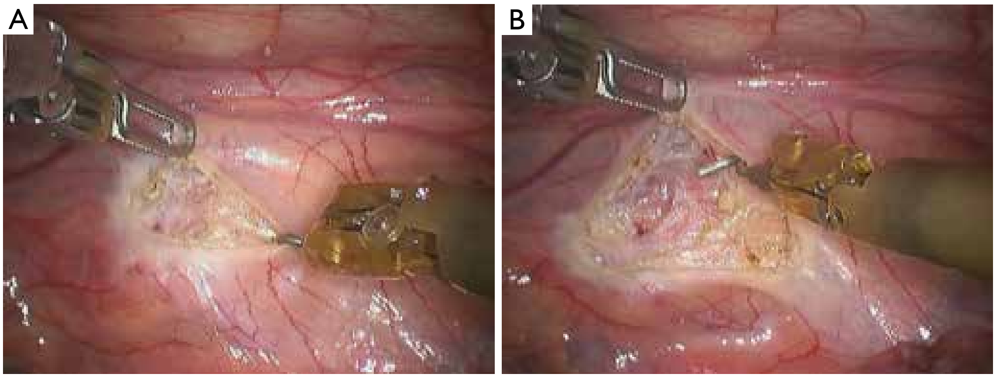


**Figure 6** Open the mediastinal pleura.

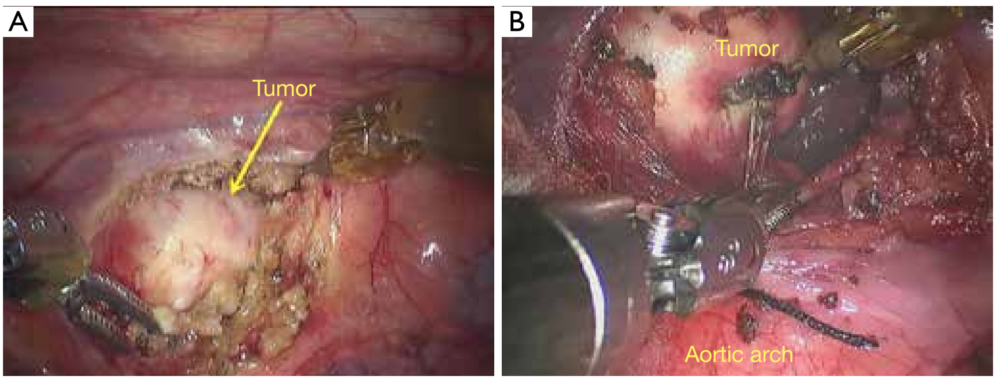


**Figure 7** Dissociate the tissues alongside the tumor capsule using the cautery hook.

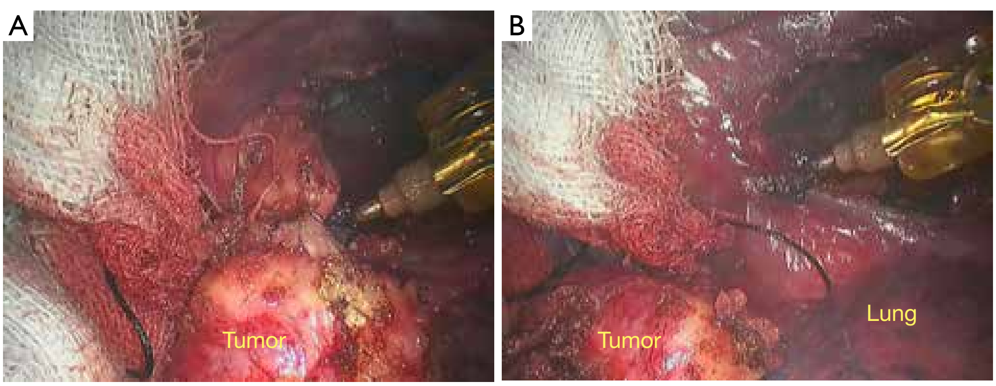


**Figure 8** The tumor capsule was completely peeled off.

using the cautery hook (*Figure 7*);

(III) The left side of the tumor is close to the mediastinal pleura and the left lung. The tumor was completely peeled off after careful separation (*Figure 8*);

(IV) There was no bleeding or exudate on the wound surface (*Figure 9*);

(V) The dissolved hemostatic gauze glue was sprayed (*Figure 10*);

(IV) After the right arm of the robot was withdrawn, the working port was enlarged to about 2.0 cm, via which the endoscopic retriever was inserted (*Figure 11*).

After the specimen was harvested, the tumor was

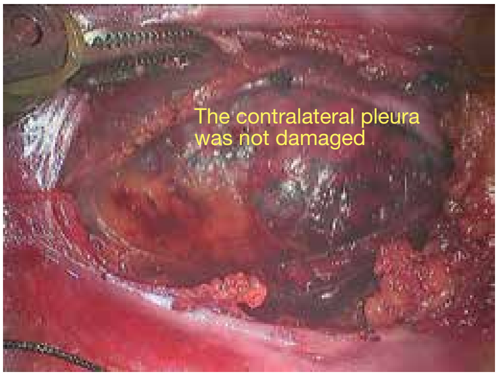


**Figure 9** There was no bleeding or exudate on the wound surface, and the contralateral pleura was not damaged.

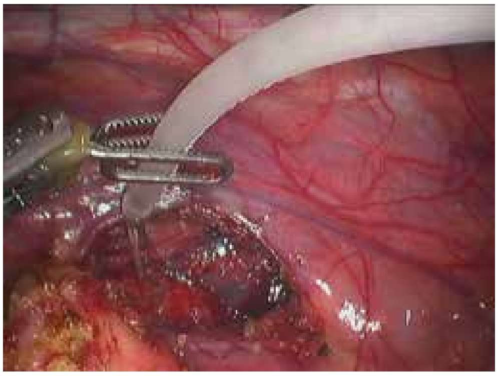

**Figure 10** Dissolved hemostatic gauze glue was sprayed on the wound surface.

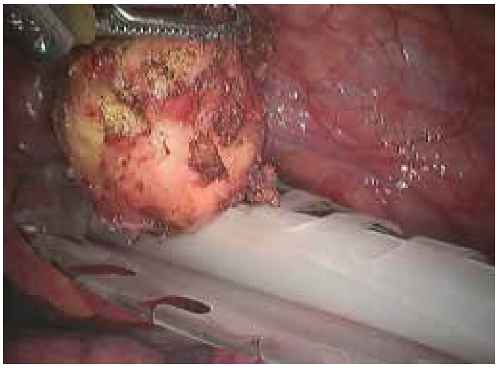

**Figure 11** Harvest the tumor with the endoscopic retriever.

complete, with intact capsule.

Frozen pathology suggested the possibility of teratoma, and the possibility of bronchogenic carcinoma needed to be ruled out.

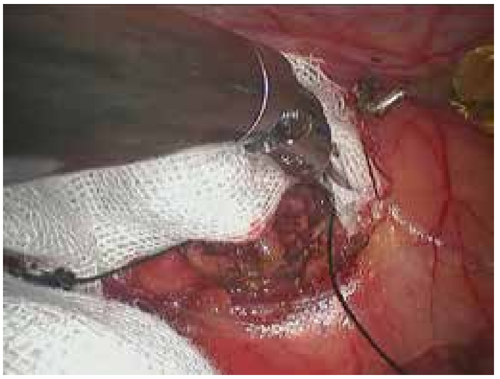

**Figure 12** Clean the visual field with gauze.

Inspection showed that there was no obvious bleeding or exudate on the wound surface. The amounts of equipment, blood pads, and gauzes were correct.

The thoracic drainage tube was indwelled at the camera port and then well fixed. Close the chest after lung recruitment.

Note: if the visual field was affected by blood or exudate during the surgery, gauze can be used to clean it (*Figure 12*).

## Postoperative treatment

The postoperative treatment was same as the conventional resection of mediastinal tumors. Symptomatic treatment was applied. The thoracic drainage tube was withdrawn 3 days after the surgery. Post-operative pathology: together with the immunohistochemical findings, a diagnosis of "bronchogenic cyst" was made.

## Pathological diagnosis

### *Morphology*

A roundish mass sized 2.5 cm × 2.0 cm × 2.0 cm was found at the right anterior mediastinum. It had capsule, with cystic sections. Bean dreg-like substances were found inside the cyst. The wall thickness was 0.2-0.4 cm. The mass was pale or grayish-yellow in color. It was moderately hard, although in some parts was hard.

### *Microscopy*

Microscopy showed that the cyst wall contained fibrous tissue, which was lined with ciliated columnar epithelium, along with lymphocyte infiltration.

### *Immunohistochemistry*

CK5/6 (+), CK8/18 (+), S-100 (-), SMA (+), CK7 (+), CK20 (+), CD34 (vascular +), CEA (+), Ki67 (+), and P53 (-).

## Comment

The da Vinci system has been confirmed to a safe, accurate, and minimally invasive approach with promising clinical value. This technique is featured by small trauma, mild pain, quick recovery, and good cosmesis. Also, it can thoroughly remove the lesions with high safety and success rate. It has been gradually recognized and well accepted by patients. Now it has totally replaced the open surgeries or the conventional video-assisted thoracoscopic surgeries in treating the majority of anterior mediastinal lesions. As a promising technique, it will increasingly become a leading surgical approach along with the development of technology and know-hows over time.

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# Robotic thoracic surgery of the posterior superior mediastinal mass

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## Clinical data

### *Medical history*

The patient, a 34-year-old woman, was admitted due to "a mediastinal mass found during health check-up 3 months ago". She underwent health check-up in a local hospital 3 months ago, during which CT displayed a mediastinal mass. No specific treatment was provided. One week ago, she received a second CT, which showed that the mediastinal mass did not change obviously. She then visited our hospital for surgical treatment. She had no previous history of relevant conditions.

### *Physical examination*

No positive sign was detected during the physical examination at admission.

### *Auxiliary examination*

Chest CT: there was a roundish soft-tissue opacity in the right posterior superior mediastinum. It was sized about 5.0 cm × 4.5 cm, with homogeneous density and smooth margin (*Figure 1*).

## Pre-operative preparation

Conventional skin preparation was performed. Body markers were made for port creation.

## Procedures

### *Anesthesia and body position*

After the induction of general anesthesia, the patient was placed in a left lateral decubitus position under double-lumen endotracheal intubation. With her hands put in front of head, she was fixed in a jackknife position.

### *Surgical procedures*

(I) Incisions: a 1.2 cm camera port was created in the 6$^{th}$ intercostal space at right middle axillary line. Two 0.8 cm working ports were created in the 7$^{th}$ intercostal space between the right posterior axillary line and the subscapular line and in the 4$^{th}$ intercostal space between the anterior axillary line and midclavicular line, respectively (*Figure 2*);

(II) Inspection of the thoracic cavity and insertion of the robot arms: the endoscopic airtight trocar was inserted through the camera port to establish 8 mm artificial pneumothorax, then the robotic endoscope was inserted for inspecting the thoracic cavity. Under the endoscopic monitoring, the robot trocars were separately inserted via the two working ports, so as to place the #2 robotic arm (left hand) and the #1 robotic arm (right hand). The #2 robotic arm was connected with the bipolar cautery forceps, and the #1 robotic arm with unipolar cautery hook (*Figure 3*);

(III) Inspection of the lesion and its relationship with the neighboring tissues/organs: the lesion was located in the right posterior superior mediastinum and pleural cupula, with smooth localized capsule (*Figure 4*);

(IV) Open the mediastinal pleura (*Figure 5*);

(V) Dissociate the tumor (*Figure 6*);

(VI) Resection of tumor (*Figure 7*);

(VII) Hemostasis of the tumor bed (*Figures 8,9*);

(VIII) Harvest the dissected tumor (*Figures 10,11*);

(IX) After the robot system was withdrawn, the thoracic

 

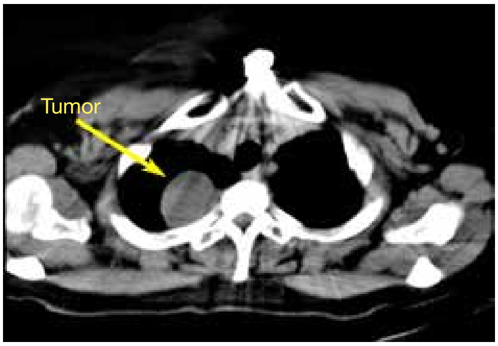


**Figure 1** Chest CT shows a mass in the in the right posterior superior mediastinum.

**Figure 2** Location of each port.

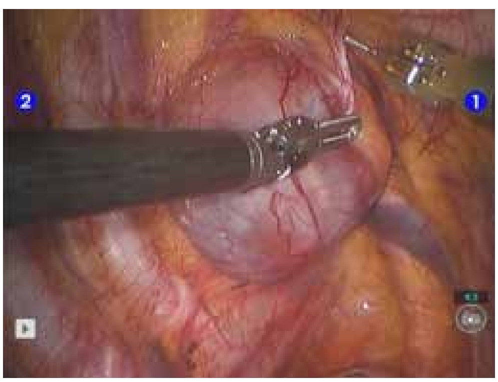

**Figure 3** The #1 robotic arm (right hand) and the #2 robotic arm (left hand) under the endoscope.

drainage tube was indwelled at the camera port. Close the chest after sputum suctioning and lung recruitment. The intraoperative blood loss was about 5 mL; no blood was transfused.

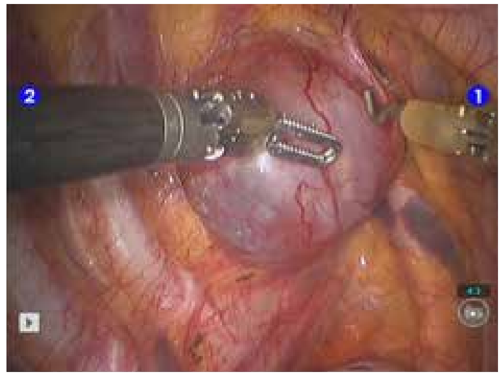

**Figure 4** The smooth lesion protrudes into the thoracic cavity.

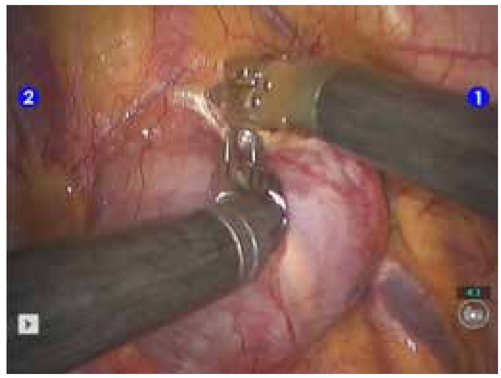

**Figure 5** Cut open the mediastinal pleura on the tumor surface with the unipolar cautery hook.

**Figure 6** Separate the capsule alongside the proper capsule of the tumor.

## Postoperative treatment

After the surgery, the patient received symptomatic treatment under routine general anesthesia. No antibiotic or hemostatic agent was applied.

 

**Figure 7** Lift the tumor and cut off the tumor root, thus completely dissociating and dividing the tumor.

**Figure 8** After the #1 robotic arm was withdrawn, the tumor bed was cleaned with gauzes, and the bipolar coagulation forceps were applied to stop bleeding.

**Figure 9** The wound surface was covered with a hemostatic gauze.

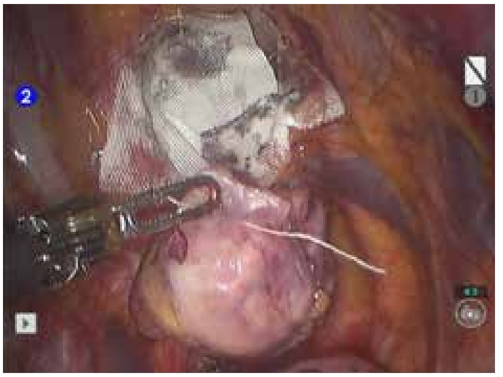

**Figure 10** The dissected tumor.

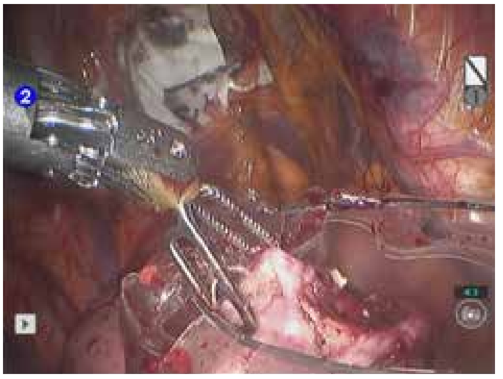

**Figure 11** An endoscopic retriever was inserted via the trocar connected with the #1 robotic arm to harvest the dissected tumor.

## Pathological diagnosis

Morphology: the specimen was sized 5.0 cm × 4.0 cm × 4.0 cm. It was moderately hard and contained Tofu skin-like substance. The pathological diagnosis was a giant nerve sheath tumor in the right posterior superior mediastinum.

## Acknowledgements

*Disclosure:* The authors declare no conflict of interest.

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# Robotic thoracic surgery of the right posterior inferior mediastinal mass

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## Clinical data

### *Medical history*

The patient was admitted due to "a mediastinal mass found during health check-up four months ago". Four months ago, she was admitted in a local hospital due to gas poisoning, during which CT showed a right posterior mediastinal mass. Later she was then discharged after the gas poisoning was resolved. She then visited our hospital for surgical treatment. She has a previous history of hypertension for 20 years and diabetes for 7 years. She underwent resection of uterine myoma 10 years ago.

### *Physical examination*

No positive sign was detected during the physical examination at admission.

### *Auxiliary examination*

Chest CT: an ovoid cystic mass sized 5.5 cm × 4.0 cm was found at the right posterior inferior mediastinum. The lesion had homogenous density and smooth margin (*Figure 1*).

## Pre-operative preparation

Conventional skin preparation was performed. The potential locations of the ports were marked on the skin.

## Procedures

### *Anesthesia and body position*

After the induction of general anesthesia, the patient was placed in a left lateral decubitus position under double-lumen endotracheal intubation. She was fixed in a Jackknife position, with the head slightly leaned forward.

### *Surgical procedures*

(I) Incisions: a 1.2-cm camera port was created in the 5th intercostal space at right anterior axillary line. Two 0.8-cm working ports were created in the 3rd intercostal space between the right middle axillary line and the posterior axillary line and in the 8th intercostal space between the posterior axillary line and the subscapular line, respectively (*Figure 2*).

(II) Exploration of the thoracic cavity and insertion of the robot arms: the endoscopic airtight trocar was inserted through the camera port to establish 8-mmHg artificial pneumothorax, then the robotic endoscope was inserted for inspecting the thoracic cavity. Under the endoscopic monitoring, the robot trocars were separately inserted via the two working ports, so as to place the #1 robotic arm (right hand) and the #2 robotic arm (left hand). The #1 robotic arm was connected with the unipolar cautery hook, and the #2 robotic arm with fenestrated bipolar forceps (*Figure 3*).

 

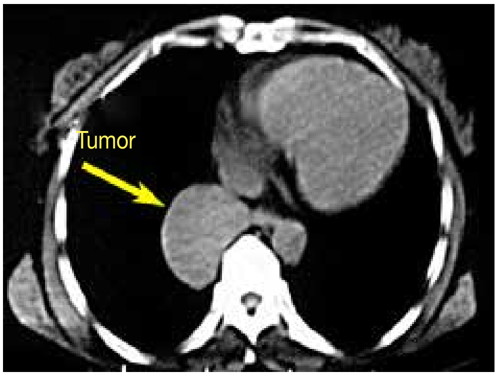


**Figure 1** Chest CT shows a mass in the in the right posterior inferior mediastinum.

**Figure 2** Location of each port.


**Figure 3** The #1 robotic arm (right hand) and the #2 robotic arm (left hand) under the endoscope.

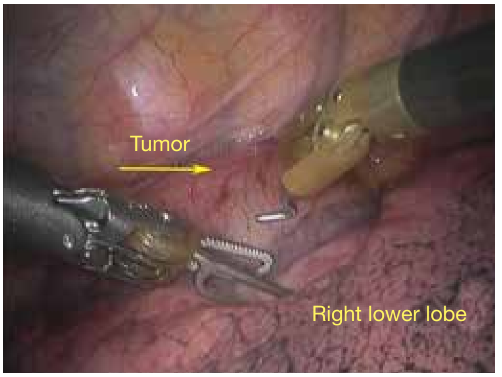


**Figure 4** Lesion and lung adhesion.


**Figure 5** Cut open the mediastinal pleura on the tumor surface with the unipolar cautery hook.


**Figure 6** Dissociate lung adhesions with cautery devices.

(III) Inspection of the lesion and its relationship with the neighboring tissues/organs: there was no adhesion or effusion inside the pleural cavity. The lesion was located in the right posterior inferior mediastinum and adhered to the posterior basal segment of the lower lobe of the right lung (*Figure 4*).

(IV) Open the mediastinal pleura (*Figure 5*).

(V) Dissociate the tumor (*Figures 6-8*).

**Figure 7** The tumor capsule was ruptured during the dissociation, releasing light-yellow thick cystic liquid.

**Figure 8** Suction the cystic liquid with a suction apparatus.

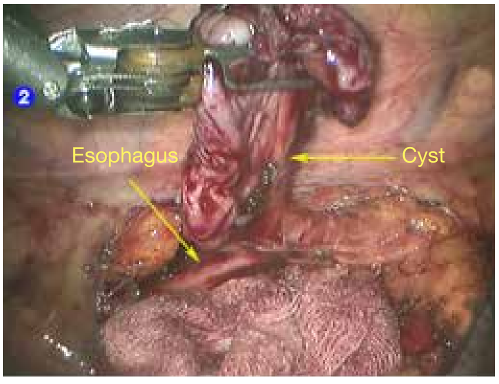


**Figure 9** Divide the adhesions till the basal part of the cyst, which had a close relationship with the esophageal wall.

**Figure 10** Clamp the basal part of the cyst with absorbable hem-en-lock.

**Figure 11** The clamped basal part of the cyst.

**Figure 12** Lift the tumor and cut its basal part, thus completely resecting the tumor.

(VI) Handle the esophagus adhesions (*Figures 9,10*).
(VII) Resection of tumor (*Figures 11,12*).
(VIII) Hemostasis of the tumor bed (*Figures 13,14*).
(IX) After the robot system was withdrawn, the thoracic drainage tube was indwelled at the camera port. Close the chest after sputum suctioning and lung recruitment. The intraoperative blood loss was about 10 mL; no blood was transfused.

 

**Figure 13** The tumor bed after resection.

**Figure 14** The wound surface was covered with a hemostatic gauze.

## Postoperative treatment

After the surgery, the patient received symptomatic treatment under routine general anesthesia. No antibiotic or hemostatic agent was applied.

## Pathological diagnosis

The specimen was sized 4.0 cm × 2.0 cm × 1.0 cm. It had a grey-red surface, with cystic cutting margin. The cyst had smooth walls and was moderately hard. Pathological diagnosis was the right posterior mediastinal bronchogenic cyst.

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## Acknowledgements

*Disclosure:* The authors declare no conflict of interest.

 

# Robotic thoracic surgery of the left pleural cupula mediastinal mass

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## Clinical data

(I) Medical history: the patient, a 67-year-old women, was admitted due to "thoracic back pain accompanied with chest tightness and shortness of breath for over 5 months". She suffered from thoracic back pain 5 months ago, which was accompanied with chest tightness and shortness of breath after physical activities. Chest CT displayed the presence of a mediastinal mass. She then visited our hospital for surgical treatment. She complained that she had a previous history of angina pectoris for 2 years, which had not received any formal diagnosis or treatment. She had no previous history of other conditions.

(II) Physical examination: no positive sign was detected during the physical examination at admission.

(III) Auxiliary examination: thoracic contrast-enhanced CT scan showed that the lesion had a close relationship with the left subclavian artery (*Figure 1*). Thyroid radionuclide scan suggested that the lesion was not originated from the thyroid.

## Pre-operative preparation

Conventional skin preparation was performed. The planned ports were marked on body surface.

## Procedures

### *Anesthesia and body position*

After the induction of general anesthesia, the patient was placed in a right lateral decubitus position under double-lumen endotracheal intubation. With his hands put in front of head, he was fixed in a Jackknife position.

### *Surgical procedures*

(I) Incisions: a 1.5-cm camera port was created in the 7th intercostal space at left middle axillary line. Two 0.8-cm working ports were created in the 3rd intercostal space between the left anterior axillary line and the midclavicular line and in the 6th intercostal space between the posterior axillary line and scapular line, respectively (*Figure 2*).

(II) Exploration of the thoracic cavity and insertion of the robot arms: the endoscopic airtight trocar was inserted through the camera port to establish 8-mmHg artificial pneumothorax, then the robotic endoscope was inserted for inspecting the thoracic cavity. Under the endoscopic monitoring, the robot trocars were separately inserted via the two working ports, so as to place the #2 robotic arm (left hand) and the #1 robotic arm (right hand). The #2 robotic arm was connected with the fenetrated bipolar forceps, and the #1 robotic arm with unipolar cautery hook (*Figure 3*).

(III) Inspect the lesion and its relationship with the neighboring tissues/organs: the lesion was located in the oriface of the left upper mediastinal thoracic cavity, with its upper side deep inside the neck. It had normal morphology and smooth surface (*Figures 4,5*).

(IV) Open the mediastinal pleura (*Figure 6*).

(V) Dissociate the tumor: sharp dissection of the tumor was performed along the tumor surface. The cautery hook should be close to the tumor surface to avoid hurting the nerves and vessels (*Figure 7*).

After the sympathetic nerve was carefully dissected, the sympathetic nerve was found to be with an unclear margin with the tumor (*Figure 8*). A

 

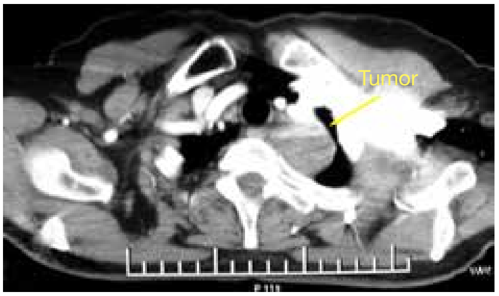


**Figure 1** Chest CT shows a mass at the top of the left posterior superior mediastinum.

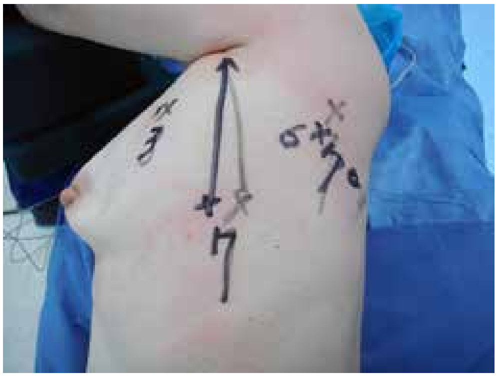

**Figure 2** Location of each port.

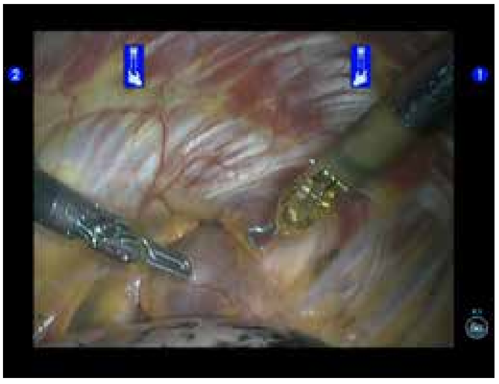

**Figure 3** The #1 robotic arm (right hand) and the #2 robotic arm (left hand) under the endoscope.

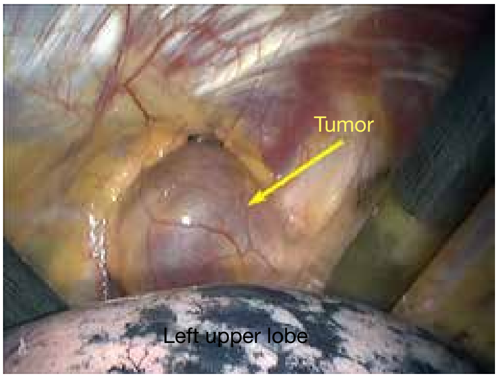


**Figure 4** The lesion is located at the top of the left upper mediastinum.

**Figure 5** The tumor is located at the sympathetic trunk, which is approximately at the stellate ganglion.

**Figure 6** Cut open the mediastinal pleura on the tumor surface with the unipolar cautery hook.

 

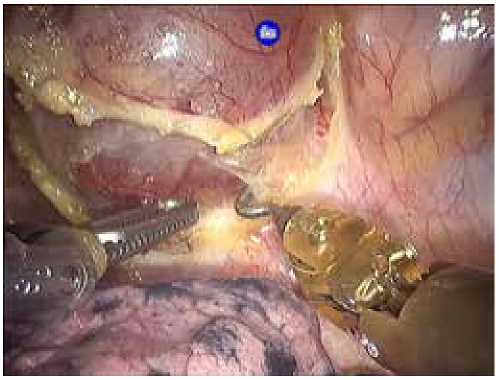

**Figure 7** Separate the capsule alongside the proper capsule of the tumor.

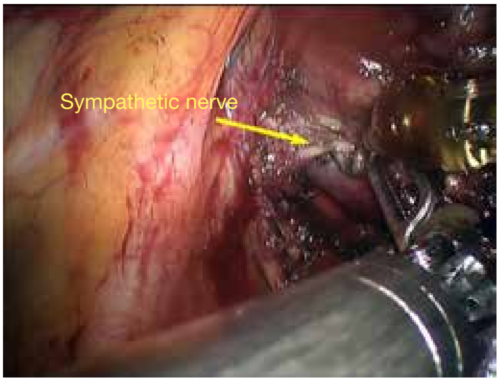


**Figure 8** Expose the sympathetic nerve.

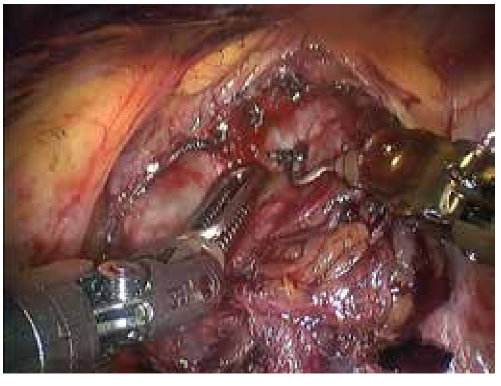

**Figure 9** Generally press the tumor downwards to inspect the upper pole of the tumor.

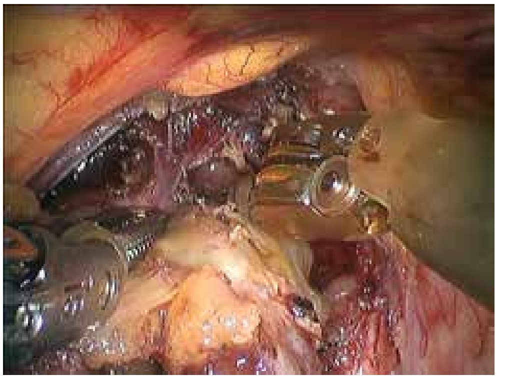

**Figure 10** After the upper pole of the tumor is exposed, divide it with the cautery hook.

**Figure 11** Cut off the upper pole of the tumor, and thus completely dissociate and divide the tumor.

tumor from the sympathetic nerve was considered.

After generally pressing the tumor downwards, the operator could inspect and expose the upper side of the tumor, which was cautiously divided (*Figures 9,10*).

(VI) Resection of tumor (*Figure 11*).

(VII) Hemostasis of the tumor bed (*Figures 12,13*).

(VIII) Harvest the dissected tumor: an endoscopic retriever was inserted via the trocar connected with the left robotic arm to harvest the dissected tumor. After the robot system was withdrawn, the thoracic drainage tube was indwelled at the camera port. Close the chest after sputum suctioning and lung recruitment.

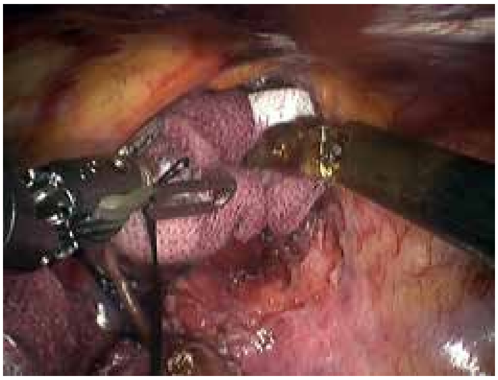

**Figure 12** Gently pat the wound dry using dry gauze pads.

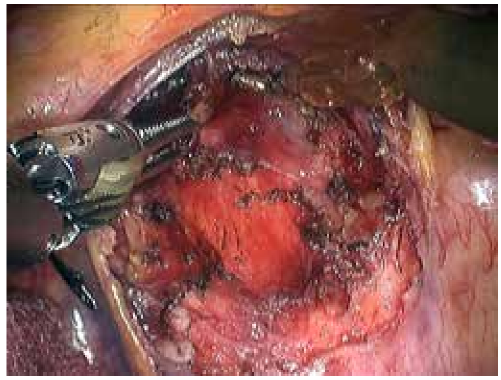

**Figure 13** Electrocoagulation of the wound to stop bleeding.

The intraoperative blood loss was about 30 mL; no blood was transfused.

## Postoperative treatment

After the surgery, the patient received symptomatic treatment under routine general anesthesia. No antibiotic or hemostatic agent was applied.

## Pathological diagnosis

The lesion was pathologically diagnosed as a ganglion cell neuroma at the left posterior upper mediastinum.

## Acknowledgements

*Disclosure:* The authors declare no conflict of interest.

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# Robotic thoracic surgery of the right lower anterior mediastinal mass

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## Clinical data

(I) Medical history: the patient visited our outpatient department after he was found to be with a mediastinal mass during health check-up ten days ago. Then, he was admitted in our hospital with a diagnosis of "mediastinal mass". He had no symptom such as chest tightness, shortness of breath, fever, or heart palpitations. His mental status, physical performance, appetite, and sleep were normal, and the body weight did not obviously change. His urination and defecation were normal.

(II) Physical examination: no positive sign was detected during the physical examination at admission.

(III) Auxiliary examination: chest CT showed a cystic mass at the right anterior mediastinum (near the right heart). The tumor had homogeneous density and was sized 4 cm × 3 cm, with smooth margin (*Figure 1*).

## Pre-operative preparation

Conventional skin preparation was performed. The planned ports were marked on body surface.

## Procedures

### *Anesthesia and body position*

After the induction of general anesthesia, the patient was placed in a left lateral decubitus position under double-lumen endotracheal intubation. With his hands put in front of head, he slightly leaned backwards.

### *Surgical procedures*

(I) Incisions: a 1.2-cm camera port was created in the 6th intercostal space at right posterior axillary line. Two 0.8-cm working ports were created in the 3rd intercostal space at the right middle axillary line and in the 6th intercostal space at the anterior axillary line, respectively (*Figure 2*).

(II) Inspection of the thoracic cavity with the camera and insertion of the robot arms: the endoscopic airtight trocar was inserted through the camera port to establish 8-mmHg artificial pneumothorax, and then the robotic endoscope was inserted for inspecting any adhesion in the thoracic cavity. Under the endoscopic monitoring, the robot trocars were separately inserted via the two working ports, so as to place the #2 robotic arm (left hand) and the #1 robotic arm (right hand). The #2 robotic arm was connected with the bipolar cautery forceps, and the #1 robotic arm with unipolar cautery hook (*Figure 3*).

(III) Inspect the lesion and its relationship with the neighboring tissues/organs: the mass was a cystic lesion in the mediastinum, with limited scope (*Figure 4*).

(IV) Cut open the mediastinal pleura around the cyst, and then separate the lesion closely alongside the cyst wall (*Figure 5*).

(V) Lift the cyst to expose the base of the cyst, and then completely divide and remove the cyst (*Figure 6*).

(VI) After the #1 robotic arm (right hand) and the trocar were removed, the endoscopic retriever was inserted to harvest the cyst (*Figure 7*).

(VII) Inspection showed that there was no obvious bleeding or exudate on the wound surface. The

 


**Figure 1** Chest CT shows the mass has homogeneous density and is located near the pericardium.

**Figure 2** With the patient's body slightly leaned backwards, the gravity facilitates the separation and exposure of the mass; meanwhile, the adequate extension of the intercostal spaces is helpful for the insertion of mechanical arms.

**Figure 3** No adhesion was found inside the thoracic cavity. The #2 robotic arm is connected with bipolar cautery forceps, and #1 robotic arm with unipolar cautery hook.

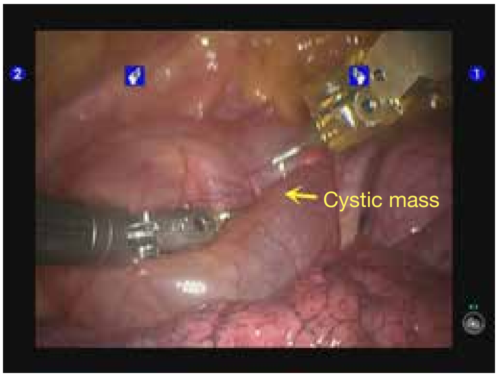


**Figure 4** The lesion is cystic and has intact capsule.

**Figure 5** Separate the cyst along the proper capsule.

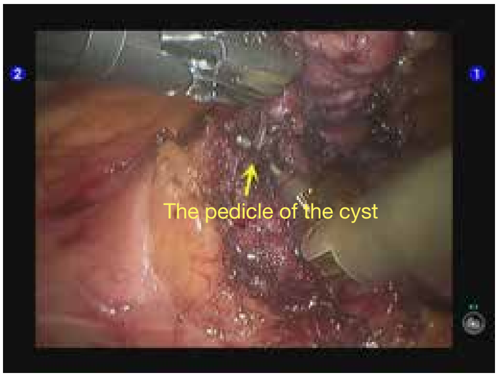


**Figure 6** The pedicle of the cyst is connected with the bottom of the pericardium.

**Figure 7** An extraction bag was inserted to harvest the specimen.

**Figure 8** The dissolved hemostatic gauze glue was sprayed on the wound surface inside the mediastinum.

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dissolved hemostatic gauze glue was sprayed on the wound surface, and then the robotic system was withdrawn (*Figure 8*).

(VIII) The thoracic drainage tube was indwelled at the camera port. Close the chest after sputum suctioning and lung recruitment. The intraoperative blood loss was 10 mL. While no blood was transfused, and 600 mL of fluid was transfused.

## Postoperative treatment

Routine phlegm-resolving and hemostatic treatment was applied after the surgery.

## Pathological diagnosis

The tissue sent for pathological examination was sized 3.5 cm × 2.0 cm × 1.0 cm, grey-white or grey-red in color, and moderately hard. It was pathologically diagnosed as an epithelial cyst at the right anterior mediastinum.

## Acknowledgements

*Disclosure:* The authors declare no conflict of interest.

# Robotic thoracic surgery of total thymectomy

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## Clinical data

(I) Medical history. The patient, a 28-year-old woman, was found to be with the drooping left eyelid half a year ago, but did not receive special treatment. A few months later, the symptom gradually worsened and then the patient visited a local hospital. Chest CT showed thymic hyperplasia in the anterior mediastinum. The diagnosis was "thymic hyperplasia accompanied with myasthenia gravis". She was then orally administered with pyridostigmine bromide 60 mg tid, and the symptoms were controlled. Then, she visited our hospital for further management. The patient's general condition was acceptable, and there were no symptoms such as chest tightness, shortness of breath, difficulty in breathing or swallowing, or fatigue.

(II) Physical examination showed slightly drooping left eyelid.

(III) Auxiliary examination. Chest CT showed a soft-tissue shadow in the anterior upper mediastinum, which had relatively clear margin and homogeneous density (*Figure 1*).

## Pre-operative preparation

Conventional skin preparation was performed. The planned ports were marked on body surface.

## Procedures

### *Anesthesia and body position*

After the induction of general anesthesia, the patient was placed in a left lateral decubitus position under double-lumen endotracheal intubation. With his hands put in front of head, he slightly leaned backwards (*Figure 2*).

### *Surgical procedures*

(I) Incisions (*Figure 3*). A 1.2-cm camera port was created in the 6th intercostal space at right posterior axillary line, and two 0.8-cm working ports were separately made in the third intercostal space at middle axillary line and the 6$^{th}$ intercostal space at anterior axillary line.

(II) Inspection of the thoracic cavity with the camera and insertion of the robot arms. The endoscopic airtight trocar was inserted through the camera port to establish 8-mmHg artificial pneumothorax, and then the robotic endoscope was inserted for inspecting any adhesion in the thoracic cavity. Under the endoscopic monitoring, the robot trocars were separately inserted via the two working ports, so as to place the #1 robotic arm (right hand) and the #2 robotic arm (left hand). The #1 robotic arm (right hand) was connected with the unipolar cautery hook, and the #2 robotic arm (left hand) with fenestrated bipolar forceps.

(III) Inspect the lesion and its relationship with the neighboring tissues/organs. The anterior mediastinum had a full appearance, with a large amount of adipose tissue (*Figure 4*).

(IV) After the lesion scope was identified, the mediastinal pleura were cut open in front of phrenic nerve (*Figures 5-7*).

(V) Beginning from right lower pole of the thymus, dissociate along the pericardial surface upwards till the right upper pole of the thymus, so as to divide the right lobe of thymus (*Figures 8-11*).

 

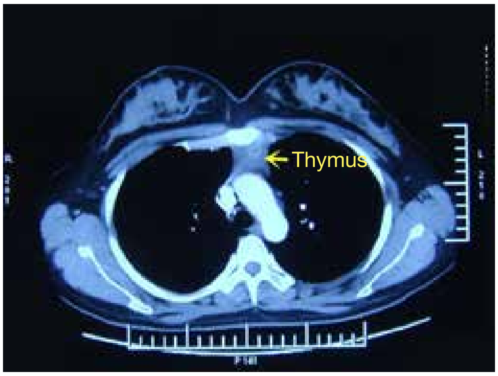


**Figure 1** CT showed a soft tissue shadow in the anterior upper mediastinum.

**Figure 2** Body position.

**Figure 3** Incisions position.

**Figure 4** Inspection: the anterior mediastinum had a full appearance.

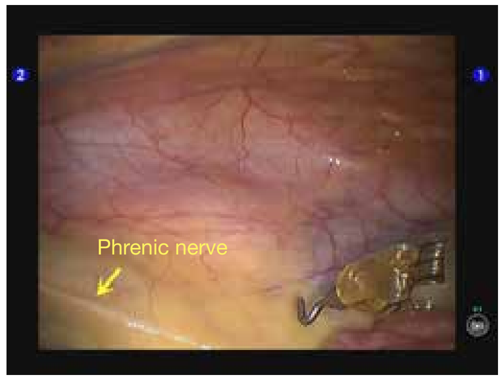


**Figure 5** The thymus and phrenic nerve.

**Figure 6** Cut open the mediastinal pleura front of phrenic nerve.

(VI) After the division of the right lobe of thymus, dissociation was performed upwards from the left lower lobe of thymus till the left upper lobe of thymus. Thus, the left lobe of thymus was divided (*Figures 12-14*).

(VII) The upper pole of the thymus is adjacent to the large vessels such as venae anonyma. Therefore, special attention should be paid during the division of the upper pole; in particular, any thermal damage to the vessels as well as vascular rupture/bleeding should be avoided. Two or three thymic veins may enter the lower edge of the venae anonyma

**Figure 7** Dissociate the thymus.

**Figure 8** Dissociate upward from right side.

**Figure 9** Dissociate along the pericardial surface.

**Figure 10** Remove the adipose tissues in the right lower mediastinum.

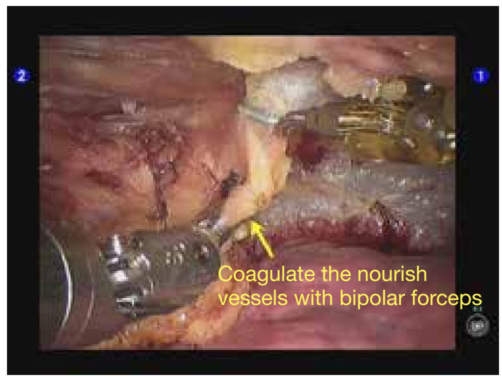


**Figure 11** Dissociate the right upper pole.

**Figure 12** Dissociate close to the thymus.

(*Figure 15*). In our current case, the upper part of the lesion was adjacent to the front of the left side of venae anonyma, with the thymic veins clearly visible, which was then sealed with bipolar cautery forceps (*Figures 16,17*).

(VIII) The whole thymus was removed, and meanwhile the adipose tissues in the anterior upper and anterior lower mediastinum were removed (*Figure 18*).

(IX) Inspection showed that there was no obvious bleeding or exudate on the wound surface (*Figure 19*). After the #2 robotic arm (left hand) was withdrawn, the incision was extended to 2 cm. The

 

**Figure 13** Dissociate upward from left side.

**Figure 14** Look out for the vessels.

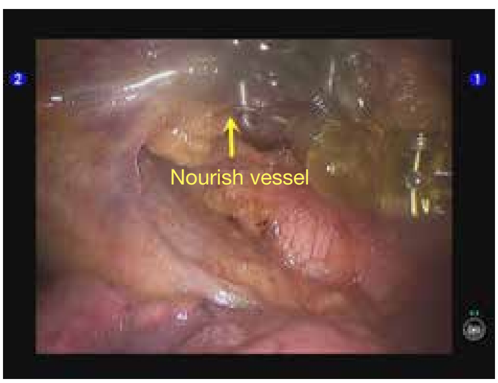


**Figure 15** A nurish vessel in the hook.

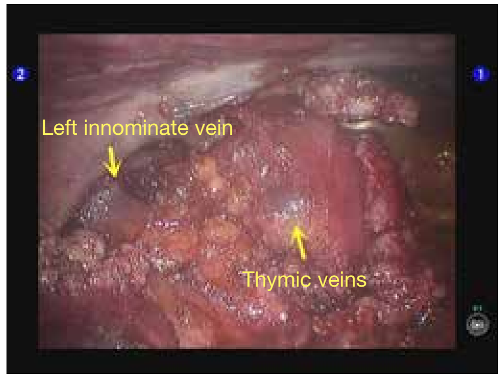


**Figure 16** The thymic vein.

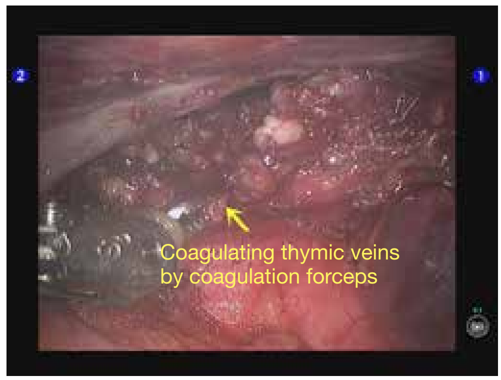


**Figure 17** Coagulate the thymic veins by bipolar forceps.

**Figure 18** Remove the adipose tissues in the lower mediastinum.

**Figure 19** Inspection showed that there was no obvious bleeding or exudate on the wound surface.


**Figure 20** Adipose tissue and mass.

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muscle tissue was divided bluntly. An endoscopic retriever was inserted to harvest the dissected specimen (*Figure 20*).

(X) The wound surfaces were sprayed and covered with the sol of Tistat absorbable hemostatic gauze.

(XI) After the robotic arm was withdrawn, any possible incision bleeding was observed under the endoscope. The thoracic drainage tube was indwelled at the camera port before closing the chest.

## Postoperative treatment

The endotracheal tube was smoothly removed after the surgery, and then the patient safely returned to her ward. She was orally administered with pyridostigmine bromide 60 mg tid, and its dose was reduced gradually according to her clinical symptoms.

## Pathological diagnosis

It was pathologically diagnosed as thymic hyperplasia.

## Acknowledgements

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# Robotic thymectomy in patients with myasthenia gravis by vascular skeletonization

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Surgical resection of the thymus is indicated in the presence of myasthenia gravis (MG) and thymectomy is frequently used in the treatment of MG.

The traditional invasive surgical approach was median sternotomy. The patients showed a slow recovery for the trauma. Robot-assisted thymectomy is a safe and minimally invasive operation.

## Surgical technique

The patient was intubated with a left-side double-lumen tube and was placed supine with the middle part of the right side lifted up with a cushion to 30 degrees. A 12-mm port in the 5$^{th}$ intercostal space in the midaxillary line was made for camera. Other two incisions 8 mm and 25 mm were made in the 3rd intercostal space in the midaxillary line for arm 2, in the 6$^{th}$ intercostal space in the anterior axillary line for arm 1 and an assistant instrument, respectively. The three incisions formed an isosceles and obtuse triangle with at least 8cm per side.

Resection of all the thymic and fat tissue started from the right phrenic nerve up to the left. The bodies and the hind parts of the thymus were dissected in the jugular direction until the brachiocephalic vein was reached (*Figure 1*). Vascular skeletonization followed by reaching the upper poles of the two sides. Thymic veins were cut with cautery. The branches of internal thoracic vein may be clipped to get a better visualization (*Figure 2*). Lift the specimen up from the major vessels to complete dissection. The specimen was removed en bloc in gloves through the anterioraxillary incision.

## Comment

Since the totally endoscopic robotic thymectomy was initially reported by Dr. Ashton in 2003, this new procedure for patients with MG has been gradually accepted among the world. Some series show that it is safe to perform robotic thymectomy in patients with an early stage thymoma. While the issue that whether video-assisted thoracoscopic surgery (VATS) is appropriate to the patients with MG is still under discussion, the robotic procedure has brought dawn to the future. With the extremely flexible Endowrist and high definition 3D images, the matters which are the potential disadvantages for the VATS compared to the sternectomy, such as the incidence of uncompleted resection, the small space for manipulation would have opportunities to turn off by the robotic techniques. The 3D visualization also facilitates an easy, safe and precise dissection of thymic tissue from the major vessel structures and phrenic nerve to reduce the intraoperative complications even in vascular skeletonization.

More positive evidences have been published by the researchers from the North American, the Europe and China. However, as the initial etiology of the MG it is, whether the robotic thymectomy could replace the VATS or even open surgery should be critically evaluated. A long term follow-up is needed to consider this new procedure as a standard approach definitively. The neurologic outcome and prognosis for the patients with MG is still in the top priority instead of the fashion of technique.

 

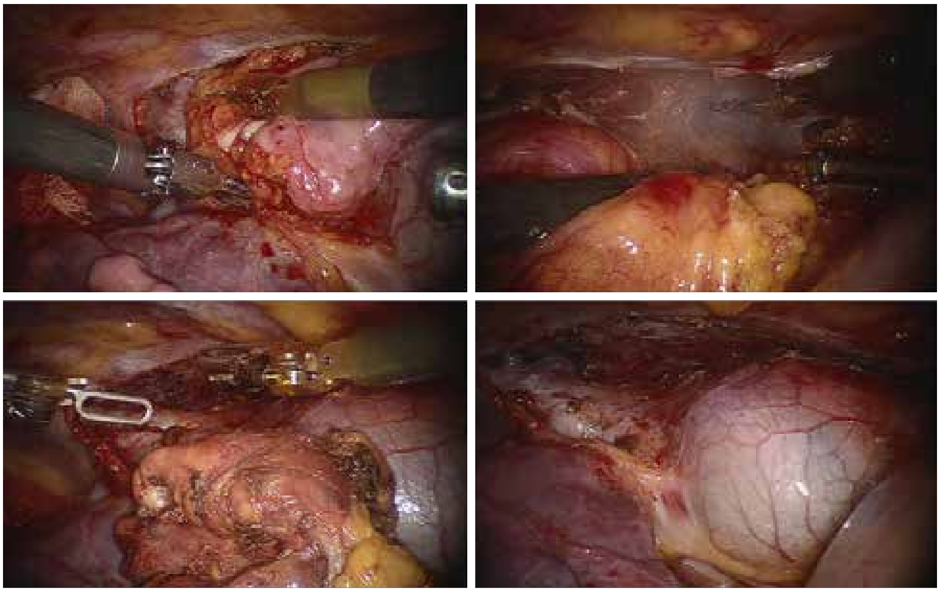

**Figure 1** A completion of robotic thymectomy.

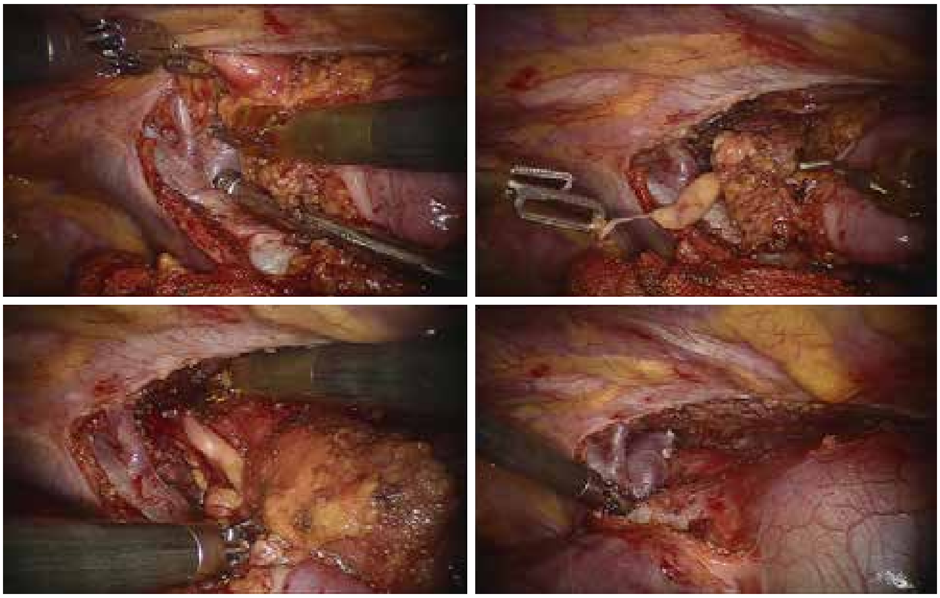

**Figure 2** Vascular skeletonization and excision of the upper poles of thymus.

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# Minimally invasive and robotic Ivor Lewis esophagectomy

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**Abstract:** Esophageal cancer is the eighth most common malignancy and the sixth most common cause of cancer-related death worldwide. Esophagectomy provides a curative treatment but carries significant morbidity and mortality. Ivor Lewis esophagectomy (ILE) is one of the most commonly employed open techniques of esophagectomy. Minimally invasive approaches have been explored in ILE in an effort to reduce operative morbidity. This article reviews recent literature of minimally invasive Ivor Lewis esophagectomy (MI-ILE), discusses its clinical outcomes, and introduces the robotic approach in MI-ILE. MI-ILE has demonstrated comparable postoperative outcomes to open ILE, and it has shown potential to reduce blood loss and length of hospitalization. Due to limited studies, no significant improvement of long-term survival has been reported in MI-ILE. Robotic ILE is safe and feasible, but more studies are needed to prove identifiable benefits. Randomized controlled trials comparing MI-ILE or robotic ILE with conventional open ILE are warranted to determine the optimal surgical procedure for the treatment of esophageal cancer.

**Keywords:** Esophageal cancer; Ivor Lewis esophagectomy (ILE); minimally invasive surgery

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## Introduction

Esophageal cancer is the eighth most common malignancy and the sixth most common cause of cancer-related death in the world. An estimated 482,300 new cases and 406,800 cancer deaths occurred in 2008 worldwide (1), showing a high mortality-to-incidence rate ratio of 0.84. Incidence rates vary internationally, and China has the fourth highest rate of esophageal cancer according to the GLOBOCAN 2008 Database. In the United States, approximately 17,990 patients are diagnosed with esophageal cancer in 2013 with a mortality of 15,210 (2). The overall 5-year survival rate for esophageal cancer remains poor, despite the modest improvement from 5% between 1975 and 1977 to 19% between 2002 and 2008 (2). Several surgical techniques are available, and the choice of technique depends on tumor location, extent of lymphadenectomy, the patient's overall condition and surgeon's preference. The two most frequent open techniques are transhiatal esophagectomy (THE) and transthoracic esophagectomy (TTE). THE involves laparotomy with blunt dissection of the esophagus (without thoracotomy) and cervical esophagogastric anastomosis (3). Ivor Lewis esophagectomy (ILE) is the classic TTE, which consists of laparotomy and right thoracotomy with intrathoracic anastomosis (4). The 3-incision McKeown approach is a modified TTE, which utilizes the right thoracic and abdominal portions of ILE with an added left cervical anastomosis. Compared to THE, TTE allows the removal of the intrathoracic esophageal tumor with a wider radial margin, and the oncologic resection of extensive mediastinal lymph nodes (5), but is associated with significant in-hospital morbidity (but not mortality), predominantly respiratory complications (6,7). THE carries a lower complication rate, but only a limited lymphadenectomy can be performed with no dissection of the carinal and paratracheal lymph nodes (6,7). Although no significant difference in 5-year survival was seen between the THE and TTE groups, there was a trend towards survival benefit: overall survival was 29% in the THE group, as compared with 39% in the TTE group (6).

To reduce the surgical morbidity and mortality, multiple minimally invasive approaches have been explored in esophagectomy. Several studies have shown a substantial decrease in blood loss, complication rate and hospital stay when minimally invasive esophagectomy (MIE) was applied (8,9). However, MIE has several intrinsic limitations, including 2-dimensional view, reduced eye-hand coordination and a decrease in degrees of freedom of movement (10). These may create difficulties in mediastinal dissection and anastomosis during thoracoscopic esophagectomy. Robotic systems have been designed to overcome some disadvantages of standard minimally invasive surgery. The *da Vinci®* robotic system (Intuitive Surgical, Inc. California, USA) provides a magnified 3-dimensional vision system and special wristed instruments that offer more degrees of freedom (10). It translates the surgeon's hand movement into precise real-time movements of surgical instruments, filters the tremor and restores the natural eye-hand coordination. These technical improvements facilitate precise dissection in a confined operating filed, and may benefit mediastinal dissection of esophagus and surrounding lymph nodes.

This article reviews development and techniques of minimally invasive ILE (MI-ILE), and introduces robotics in the management of esophageal cancer.

## Minimally invasive Ivor Lewis esophagectomy (MI-ILE)

The conventional ILE consists of a laparotomy and a right thoracotomy for esophageal resection (and lymphadenectomy) followed by an intrathoracic anastomosis of the gastric conduit with the proximal esophagus at the level of the proximal mediastinum (4). The following components of ILE may differ from surgeon to surgeon: technique of pyloric drainage (pyloromyotomy versus pyloroplasty versus Botox injection versus none); inclusion of jejunostomy; width of the gastric tube; technique of anastomosis (mechanical versus hand sewn). The advantages of ILE include excellent visualization of all parts of the operation, ability to perform 2-field lymphadenectomy, and potential prevention of cervical dissection of the esophagus and consequent complications, such as stenosis, leakage and recurrent laryngeal nerve injury. The disadvantages are the need for single lung ventilation, morbidity associated with a thoracotomy, higher risk for respiratory complications, and the potential danger caused by a postoperative anastomotic leak (11).

To reduce surgical trauma and overcome some of the disadvantages, various minimally invasive approaches have been explored in ILE, including any combination of laparoscopy instead of laparotomy, thoracoscopy instead of thoracotomy and intrathoracic anastomosis. Watson *et al.* first described a totally endoscopic ILE in two patients, which incorporated a hand-assisted laparoscopy for gastric mobilization and a right thoracoscopy for esophageal dissection and anastomosis (12). Nguyen *et al.* then reported a series of three patients receiving a completely MI-ILE of combined laparoscopic and thoracoscopic resection of the distal esophagus with an intrathoracic anastomosis reconstruction (13,14). All patients had an uneventful postoperative course. In 2006, Bizekis and colleagues described their experience in 50 patients who underwent MI-ILE from 2002 to 2005 (15). Thirty five patients (70%) underwent a hybrid ILE (laparoscopic gastric mobilization combined with a minithoracotomy); the remainder (30%) had a completely MI-ILE (laparoscopy and thoracoscopy). A circular stapled anastomosis was performed in all patients. The operative mortality rate was 6% (3/50). Three patients (6%) developed an anastomotic leak; all were successfully managed nonoperatively. Four patients (8%) developed postoperative pneumonia (15). There were no recurrent laryngeal nerve injuries. They concluded that a MI-ILE is technically feasible. MI-ILE approach could minimize the gastric mobilization, avoid recurrent laryngeal nerve injury, and allow a more extensive gastric resection in the case of cardia extension of gastroesophageal junction tumors (15). Similarly, Nguyen and coworkers later reported a series of 104 MIE procedures performed between 1998 and 2007, in which 51 cases were MI-ILE and 47 cases were combined laparoscopic and thoracoscopic McKeown esophagectomy (MI-McKeown, cervical anastomosis) (16). In the MI-ILE group, the mortality rate was 1.96% (1/51) and leak rate was 9.8%, which was comparable to the other group. Interestingly, the MI-ILE group had significant shorter operative time and less blood loss (16). They again showed MIE is feasible with acceptable morbidity and low mortality. They also preferred MI-ILE due to the important advantages of constructing a tension-free intrathoracic anastomosis and the ability to resect the tip of the gastric conduit (16). Other groups also reported successful completion of MI-ILE procedures with comparable outcomes (17-24). In a recent review of Luketich *et al.*, they compared the results of 481 patients undergoing MIE-McKeown to 530 patients undergoing MI-ILE (25). Both approaches resulted in acceptable lymph node resection, postoperative outcomes and low mortality. They proposed MI-ILE as their preferred approach because

 

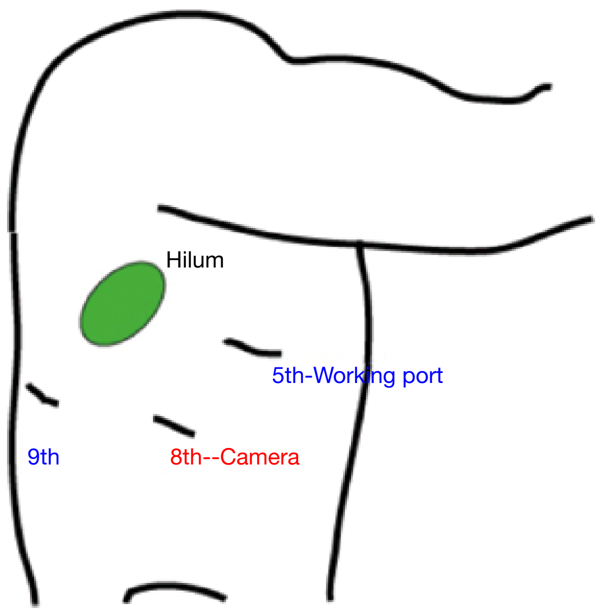


**Figure 1** Port positions for right thoracoscopic esophageal mobilization, lymph node dissection, and anastomosis.

it was associated with decreased recurrent laryngeal nerve injury and mortality rate of 0.9%.

## Techniques of the MI-ILE

As pioneers in MIE, Luketich and the Pittsburgh group described the modified MI-ILE procedures in recent publications (26,27). For the laparoscopic portion of the procedure, the patient is initially positioned in a steep reverse Trendelenburg position, and a double lumen endotracheal tube is placed in preparation for the later thoracoscopic stage. Five abdominal ports are used. A 10-12 mm port is first placed via a Hasson technique in the epigastrium between the xiphoid and umbilicus to the right of midline. Subsequent ports are placed under direct laparoscopic visualization. A 5 mm camera port is placed just to the left of the midline at the same level as the 10 mm port. Two additional 5 mm ports are inserted at the right and left subcostal margins. The final 5 mm port is placed at the right flank for liver retractor. After an abdominal inspection to rule out advance disease, the gastrohepatic ligament is divided. The exposed right crus is dissected, followed by dissection of the left crus until the gastroesophageal junction is freed. The greater curvature of the stomach is mobilized by dividing the short gastric vessels using the ultrasonic coagulation shears. The gastrocolic omentum is then divided, with care taken to preserve the right gastroepiploic arcade. Posterior gastroesophageal attachments are divided after retraction of the stomach anteriorly. A complete celiac node dissection can be performed before division of the left gastric vessels with a vascular stapler. Next, Luketich *et al.* perform a pyloroplasty whereas some other groups do not. A gastric tube is created with a stapling device from the lesser curvature towards the fundus of stomach, preserving the right gastric vessels. There are some variations regarding the diameter of the gastric tube. Luketich *et al.* reported an increase of ischemia and high leak rate with a too narrow tube (3-4 cm in diameter), and hence they emphasized the importance of creating a gastric tube of 5-6 cm in diameter (8). Berrisford *et al.* also observed a high gastric tube ischemia and leak rate by using a 4 cm gastric tube (28). Currently, creating a 5 cm wide gastric tube is recommended in MIE by Wee and Morse (29). Next, a jejunostomy tube is placed before division of the phrenoesophageal membrane. The abdomen is inspected and the incisions are closed.

In the thoracoscopic phase, the patient is placed in a left lateral decubitus position. The position of the double-lumen tube is verified, and single-lung ventilation is used. In our hands, three thoracoscopic ports are used (*Figure 1*). A 10 mm camera port is placed in the eighth intercostal space, just posterior to the posterior axillary line. Access incisions are placed in the $5^{th}$ and $10^{th}/11^{th}$ intercostal spaces. After division of the inferior pulmonary ligament, the mediastinal pleura is divided up to the level of the azygous vein to expose the thoracic esophagus, and the vein is divided with an endovascular stapler. The esophagus is circumferentially mobilized from the diaphragm to the level about 2 cm above the carina, and a Penrose drain is placed around it. Mediastinal lymph node dissection is performed. The distal esophagus and previously constructed gastric conduit are brought up into the chest. The proximal esophagus is then transected above the azygous vein. The eighth posterior interspace port is enlarged to 5 cm to remove specimen and complete construction of intrathoracic anastomosis. The redundant portion of the gastric conduit is then excised with endostapler and the thoracic cavity is drained. There are various intrathoracic anastomotic techniques in MI-ILE, including handsewn and stapled techniques. The stapled techniques varied with regard to transthoracic circular stapled, transoral circular stapled and side-to-side liner stapled. Anastomotic leak rates ranged from 0% to 10%, and anastomotic stenosis rates ranged from 0% to 27.5% (30).

**Table 1** Review of MI-ILE operative parameters

| Study | Surgical type | No. patients | Total operative time (min) | Estimated blood loss (mL) | No. lymph nodes | Length of hospital stay (day) |
|---|---|---|---|---|---|---|
| Watson *et al.* [1999] (12) | HAL, T | 2 | 210, 300 respectively | 50, 300 respectively | NR | 10 |
| Nguyen *et al.* [2001] (13) | MI-ILE | 1 | 450 | 200 | 11 | 8 |
| Bizekis *et al.* [2006] (15) | L, mini-T | 35 | NR | NR | 16* | 9 |
| | MI-ILE | 15 | | | | 7 |
| Thairu *et al.* [2007] (22) | MI-ILE | 18 | NR | NR | NR | NR |
| Nguyen *et al.* [2008] (16) | MI-ILE | 51 | 249±72 | 146±117 | 13.8±8.6 | 9.7±8.1 |
| Campos *et al.* [2010] (19) | L, mini-T | 23 | 275* | NR | 15* | 10* |
| | MI-ILE | 14 | | | | |
| Cadière *et al.* [2010] (31) | MI-ILE | 1 | 337 | 170 | 25 | 6 |
| Ben-David *et al.* [2010] (20) | MI-ILE | 6 | 360 | NR | 18 | 8 |
| Gorenstein *et al.* [2011] (21) | MI-ILE | 31 | NR | NR | NR | NR |
| Ben-David *et al.* [2011] (17) | MI-ILE | 16 | 330-420* | 125-150* | 14* | 7.5-10* |
| | MI-McKeown | 82 | | | | |
| Tapias *et al.* [2011] (24) | MI-ILE | 40 | 364±46 | 205±68 | 21 | 7 |
| Merritt [2012] (32) | MI-ILE | 15 | 468±54 | 182±67 | 11.4±1.1 | 10 |
| Thomay *et al.* [2012] (23) | MI-ILE | 30 | 535±120 | 278 | 27.1±11.4 | 10.7±4 |
| Luketich *et al.* [2012] (25) | MI-ILE | 530 | NR | NR | 23.5 | 7 |

HAL, hand-assisted laparoscopy; T, thoracoscopy; MI-ILE, minimally invasive Ivor Lewis esophagectomy; L, laparoscopy; mini-T, minithoracotomy; MI-McKeown, combined laparoscopic and thoracoscopic McKeown esophagectomy; NR, not reported; *, data is evaluated based on total cases of both approaches.

## MI-ILE outcomes

As with many novel procedures, the initial publications involving MI-ILE were mostly institutional series. Operative parameters, including operating time, estimated blood loss, number of lymph nodes harvested and length of hospital stay, were evaluated in MI-ILE (*Table 1*). Post-operative mortality and major complications of MI-ILE were also reviewed in *Table 2*. Theoretically, obviating the need of the thoracotomy, laparotomy, or both may reduce surgical pain, wound infections, cardiopulmonary complications, intensive care unit and hospital stays, and mortality rates. Although MI-ILE has been shown to be safe and feasible, a clear advantage with MI-ILE over conventional ILE has not been demonstrated. The ultimate answer to this important question is complicated by the lack of well-designed trials, the small number of institutional series, publications bias of satisfactory outcomes and the technical variations. Recently, there are several studies aiming to compare open transthoracic with MIE (33-36) (*Tables 3,4*). Patients in both groups underwent similar pre-operative and post-operative protocols. Operative data and post-operative data were collected. These studies demonstrate the feasibility and safety of MI-ILE, and show its potential of reducing blood loss, pulmonary complications and length of hospital stay. Prospective multi-center, randomized and controlled studies would be needed to draw definite conclusions.

Another controversial issue with MI-ILE is whether its long-term survival rate is comparable with the open procedure, because the extent of lymphadenectomy may be compromised. Many series did not report on lymph node dissention, and the quality of lymph node dissection is difficult to evaluate. From the studies comparing open and MIE (*Table 3*), lymph node dissection is comparable between two groups. However, most of the major complications of MI-ILE were described within the perioperative period, and the long-term survival and disease progression data from large patient cohorts is absent (*Table 4*). Therefore, the potential of MI-ILE may not have been fully realized.

 

**Table 2** Review of MI-ILE post-operative outcomes

| Study | Surgical type | No. patients | 30-day mortality | Pneumonia | Leak | Stricture | RLN injury |
|---|---|---|---|---|---|---|---|
| Watson *et al.* [1999] (12) | HAL, T | 2 | 0 | 0 | 0 | 0 | 0 |
| Nguyen *et al.* [2001] (13) | MI-ILE | 1 | 0 | 0 | 0 | 0 | 0 |
| Bizekis *et al.* [2006] (15) | L, mini-T | 35 | 2 (5.7%) | 4 (11.4%) | 3 (8.6%) | 6 (12%)* | 0 |
| | MI-ILE | 15 | 1 (6.7%) | 0 | 0 | | 0 |
| Thairu *et al.* [2007] (22) | MI-ILE | 18 | NR | NR | 0 | NR | NR |
| Nguyen *et al.* [2008] (16) | MI-ILE | 51 | 1 (1.96%) | NR | 5 (9.8%) | 14 (27.5%) | NR |
| Campos *et al.* [2010] (19) | L, mini-T | 23 | 0 | 3 (8.1%)* | 1 (2.7%)* | 5 (13.5%)* | NR |
| | MI-ILE | 14 | | | | | |
| Cadière *et al.* [2010] (31) | MI-ILE | 1 | 0 | 0 | 0 | 0 | 0 |
| Ben-David *et al.* [2010] (20) | MI-ILE | 6 | 0 | NR | 0 | 0 | NR |
| Gorenstein *et al.* [2011] (21) | MI-ILE | 31 | NR | NR | 1 (3.2%) | NR | NR |
| Ben-David *et al.* [2011] (17) | MI-ILE | 16 | 1 (1%)* | 9 (9%)* | 8 (8%)* | 4 (4%)* | 7 (7%)* |
| | MI-McKeown | 82 | | | | | |
| Tapias *et al.* [2011] (24) | MI-ILE | 40 | 0 | 1 (2.5%) | 0 | 6 (15%) | 0 |
| Merritt [2012] (32) | MI-ILE | 15 | 0 | 0 | 1 (6.7%) | 0 | 0 |
| Thomay *et al.* [2012] (23) | MI-ILE | 30 | 0 | 2 (6.7%) | 3 (10%) | NR | 1 (3.3%) |
| Luketich *et al.* [2012] (25) | MI-ILE | 530 | 5 (0.9%) | NR | 23 (4.3%) | NR | 5 (1%) |

RLN injury, recurrent laryngeal nerve injury; HAL, hand-assisted laparoscopy; T, thoracoscopy; MI-ILE, minimally invasive Ivor Lewis esophagectomy; L, laparoscopy; mini-T, minithoracotomy; MI-McKeown, combined laparoscopic and thoracoscopic McKeown esophagectomy; NR, not reported; *, data is evaluated based on total cases of both approaches.

**Table 3** Studies comparing ILE and MI-ILE operative parameters

| Study | Surgical type | No. patients | Operative time (min) | Estimated blood loss (mL) | No. lymph nodes | Length of hospital stay (day) |
|---|---|---|---|---|---|---|
| Pham *et al.* [2010] (33) | MI-ILE | 44 | 543[a] | 407[a] | 13[a] | 15 |
| | ILE | 46 | 437 | 780 | 8 | 14 |
| Sihag *et al.* [2012] (34) | MI-ILE | 38 | 360.5 | 200[c] | 19 | 7[b] |
| | ILE | 76 | 365.5 | 250 | 21 | 9 |
| Biere *et al.* [2012] (35) | MIE | 59 | 329[a] | 200[b] | 20 | 11 |
| | Open | 56 | 299 | 475 | 21 | 14 |
| Noble *et al.* [2013] (36) | MI-ILE | 53 | | 300[c] | 19 | 12 |
| | ILE | 53 | | 400 | 18 | 12 |

MI-ILE, minimally invasive Ivor Lewis esophagectomy; ILE, conventional Ivor Lewis esophagectomy; MIE, minimally invasive esophagectomy; open, open esophagectomy; [a], P<0.01; [b], P<0.001; [c], P<0.05.

## Robotic ILE

Some limitations of the minimally invasive approaches to esophagectomy include the 2-dimensional view, decreased freedom of movement, narrow field of the mediastinum and reduced eye-hand coordination. Robotic system provides the possibility to overcome some of these limitations by offering 3-dimensional camera with 10× magnification and wristed instruments (37). The robotic system can be used during the thoracic dissection of the esophagus, gastric mobilization and intrathoracic anastomosis. It can also

 

**Table 4** Studies comparing ILE and MI-ILE post-operative outcomes

| Study | Surgical type | No. patients | 30-day mortality | Pneumonia | Leak | Stricture | RLN injury |
|---|---|---|---|---|---|---|---|
| Pham *et al.* [2010] (33) | MI-ILE | 44 | 3 (6.8%) | 11 (25%) | 4 (9%) | 3 (6.8%) | 6 (13.6%) |
| | ILE | 46 | 2 (4.3%) | 7 (15%) | 5 (10.9%) | 0 | 0 |
| Sihag *et al.* [2012] (34) | MI-ILE | 38 | 0 | 0[a] | 2 (5.3%) | NR | NR |
| | ILE | 76 | 2 (2.6%) | 16 (21.1%) | 4 (5.3%) | NR | NR |
| Biere *et al.* [2012] (35) | MIE | 59 | 1 (2%) | 7 (12%)[a] | 7 (12%) | NR | 1 (2%)[b] |
| | Open | 56 | 0 | 19 (34%) | 4 (7%) | NR | 8 (14%) |
| Noble *et al.* [2013] (36) | MI-ILE | 53 | | | 5 (9%) | | |
| | ILE | 53 | | | 2 (4%) | | |

RLN injury, recurrent laryngeal nerve injury; MI-ILE, minimally invasive Ivor Lewis esophagectomy; ILE, conventional Ivor Lewis esophagectomy; MIE, minimally invasive esophagectomy; open, open esophagectomy; NR, not reported; [a], $P<0.01$; [b], $P<0.05$.

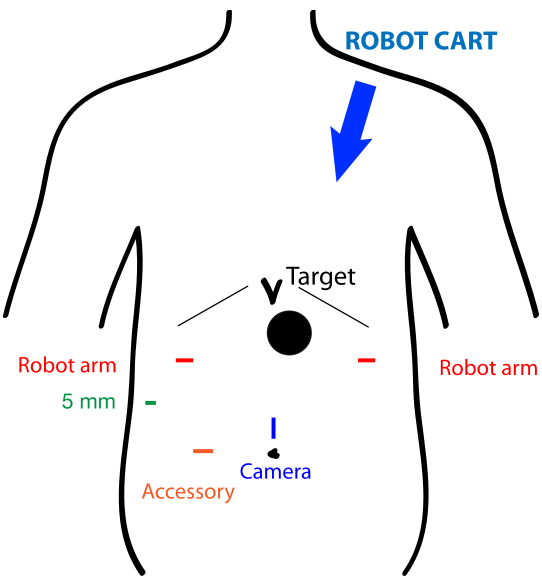


**Figure 2** Port positions for laparoscopic robotic gastric mobilization and lymph node dissection.

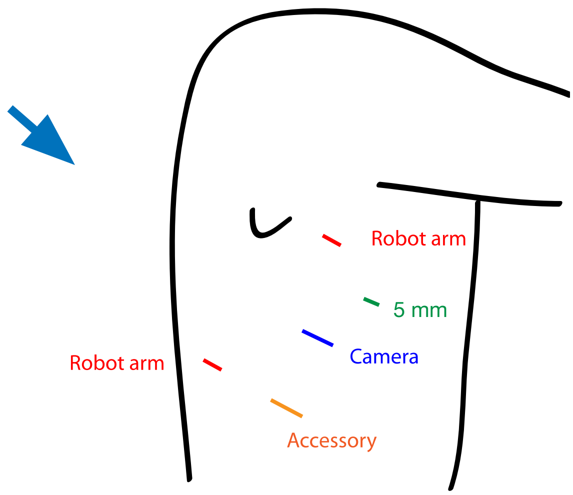


**Figure 3** Port positions for right thoracoscopic robotic esophageal mobilization, lymph node dissection, and anastomosis.

be used in combination with laparoscopy, hand-assisted laparoscopy or thoracoscopy. Several groups have reported their early experience with robot-assisted ILE (38-40).

At our institution, we have begun to utilize the robotic system with MI-ILE. *Figure 2* illustrates the port placement for the robotic abdominal procedure. The patient is placed in the supine position. A camera port is placed above the umbilicus, and a 12 mm accessory port is placed to the right of umbilicus. A liver retractor is placed through a 5 mm port in the low right subcostal space. Two additional ports for robot arms are placed in the right and left subcostal space at least a handbreadth from the camera port. The robotic cart comes over the patient's left shoulder. The abdominal operation for gastric mobilization, gastric tube construction and jejunostomy tube placement is performed as described in MI-ILE procedure. In the robotic thoracoscopic stage, the patient is turned to the left lateral decubitus position and the right lung is deflated. Chest port placement is shown in *Figure 3*. The camera port is placed in the eighth intercostal space, posterior to the posterior axillary line. One robot instrument port is placed a handbreadth superior and a handbreadth anterior to the camera port. The other robot port is placed a handbreadth inferior and a handbreadth posterior to the camera port. A 5 mm port is placed between superior incisions, and a 12 mm port is placed between inferior incisions. The robotic cart comes over the patient's right shoulder posteriorly. The thoracic operation for esophageal mobilization, lymphadenectomy and intrathoracic anastomosis is performed as in the above-mentioned MI-ILE procedure. However, we have preferred to use a stapled side-to-side anastomosis using an endoGIA stapler (45 mm purple load) and then to oversew the resulting defect with two layers of running suture (using the wristed robotic instruments).

## Robotic ILE outcomes

As a relatively new technology, data regarding the safety and the oncologic efficacy of robotic ILE are limited. de la Fuente *et al*. reported their initial experience with robotic ILE in 50 patients, which were comparable to open ILE and MI-ILE approaches (39): the mean operative time was 445±85 min. The estimated blood loss was 146±15 mL. The mean number of lymph nodes retrieved during surgery was 20±1.4. The mean length of hospitalization was 10.9±6.2 days. Mortality was 0 and main postoperative complications included pneumonia (10%) and anastomosis leak (2%). Study of Cerfolio *et al*. described similar results in 22 patients with robotic ILE with 40 mL blood loss, 18 lymph nodes harvested, 7 days of hospitalization, 0% mortality, and 4.5% anastomosis leak (40). These data suggest robotic ILE is safe, feasible and associated with perioperative outcomes similar to open ILE and MI-ILE. However, no evidence to date demonstrates improved outcomes of robotic over MI-ILE. The cost of equipment, specialized training, prolonged set up time and limited instrumentation are barriers to more widespread use. The fact that the surgeon is separated from the patient and the lack of tactile feedback raise potential safety concerns. For this procedure to be ultimately widely adopted, future studies are needed to prove identifiable benefit of robotic ILE relative to other approaches to offset inherent disadvantages and financial concerns.

## Conclusions

MI-ILE has proven to have equivalent postoperative outcomes to open ILE, and thus represent a safe and feasible alternative for the surgical management of esophageal cancer. It also shows potential to reduce blood loss, postoperative pain and length of hospitalization. Improved long-term survival has not been documented in MI-ILE compared to conventional ILE. Prospective and randomized controlled trials comparing open ILE with MI-ILE are necessary if a definite conclusion is to be made about the superiority of one surgical technique over the other. Robotic approach may offer advantages to MI-ILE over conventional procedure. Further studies of MI-ILE and robotic ILE are warranted to determine the ideal esophagectomy procedure.

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# Hybrid Ivor Lewis esophagectomy with robotic assisted gastric mobilization and thoracoscopic esophageal dissection and anastomosis

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Minimally invasive Ivor Lewis esophagectomy (ILE) is one of the most commonly adopted technique which can be performed a variety of ways for the anastomosis. We developed a hybrid Ivor Lewis esophagectomy with robotic system and thoracoscopy.

## Operative techniques

### *Gastric mobilization with robotic system*

The patient is positioned supine. The robot was positioned on the head side, with one assistant on the patient's left. A transumbilical approach was used for insertion of the trocar for camera. The two robotic instrument arms 1 and 2 were placed two sides of the flanks for operation, and another one arm 3 on the right midaxillary line for tissue grasped. A 10 mm port was placed on the left flank for suction or other instruments (*Figure 1*). Carbon dioxide insufflation was used for pneumoperitoneum to a pressure of 15 mmHg.

Then we proceed with gastric mobilization. A harmonic scalpel was used to mobilize the greater curvature of the stomach while carefully preserving the right gastroepiploic arcade, followed by the short gastric vessels. The gastrohepatic ligament was divided, and the right crura of the diaphragm is identified. The left gastric artery was clipped with hemlocks by assistant and divided by harmonic scalpel. Then the right and left cruras of the diaphragm are dissected to enlarge the hiatus (*Figure 2*).

### *Esophageal dissection and anastomosis with thoracoscopy*

The patient was then placed in the left lateral decubitus position. A 4 cm major port in the 4$^{th}$ intercostal space was made on the median axillary line. A 1-cm port in the 7$^{th}$ intercostal space on posterior axillary line for observation. The division of the azygos vein followed by the esophagus was dissected free circumferentially (*Figure 3*). A single circular stapler endo-GIA anvil was placed into the proximal esophagus. The specimen was free to pulled up into the chest carefully to avoid any rotation.

A port was made around the cardia to allow the stapler inserted into stomach. The anvil at the esophageal stump was stabilized while the anastomoses was completing. Transthoracic anastomoses was done followed by the gastric conduit constructed using multiple fires of staplers (*Figure 4*).

## Comments

Esophageal cancer has becoming one of the most common malignancy that related to death worldwide. Esophageal resection can provide a curative treatment. With the development of surgical techniques, esophagectomy have continued to evolve with an increasing trend toward the minimally invasive approach. Robot-assisted thoracoscopic esophagectomy has been published. In the current study and practice, a hybrid Ivor Lewis esophagectomy with robotic system and thoracoscopy can be performed safely. Inconventional laparoscopic procedures, gastric mobilization is technically hindered by a two-dimensional view. The robot system offers a three- dimensional vision and articulating instruments, which avoids the limitation of a narrow vision and the rigid instruments. The precise dissection of the short gastric vessels and the left gastric

**Figure 1** The robot position and trocars arrangement.

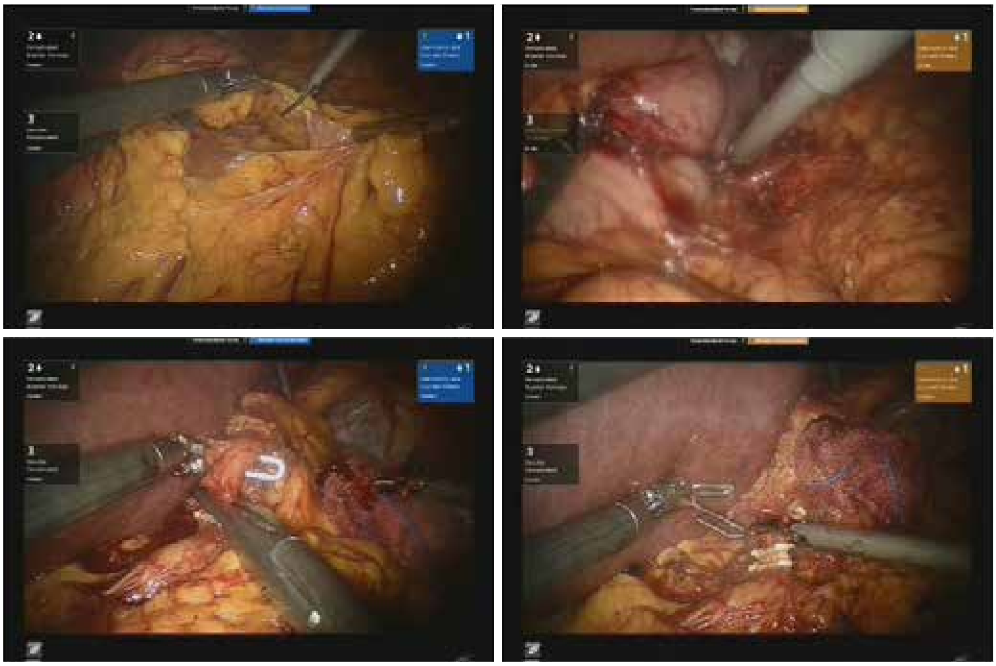

**Figure 2** Robotic assisted gastric mobilization and clipping of the left gastric artery.

 

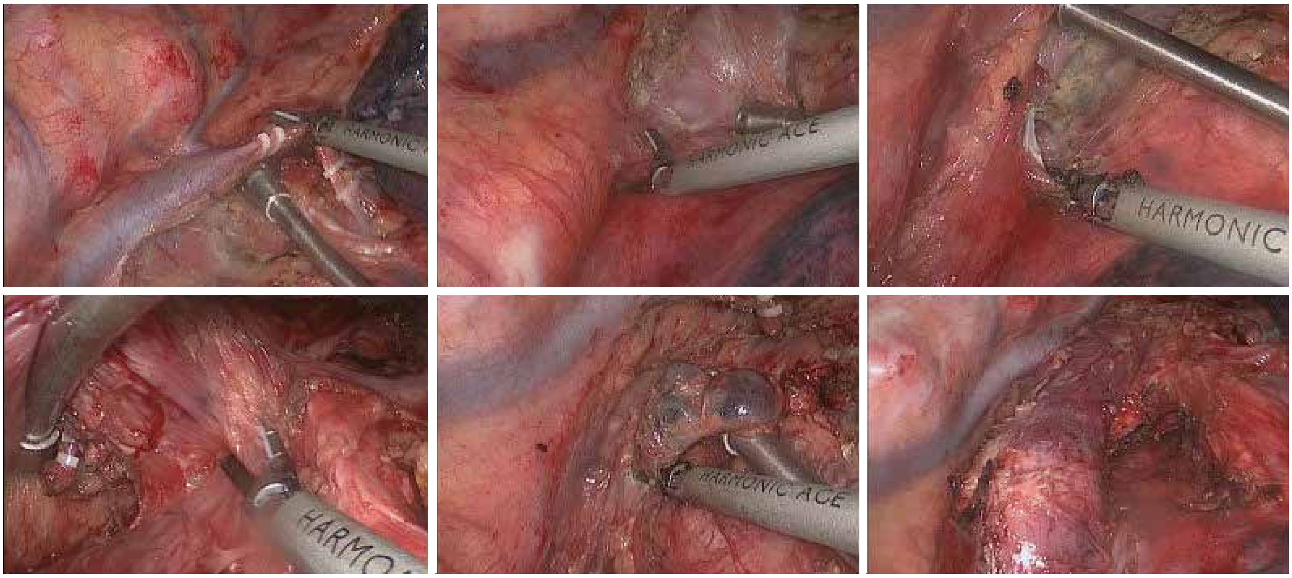


**Figure 3** Thoracoscopic esophageal dissection.

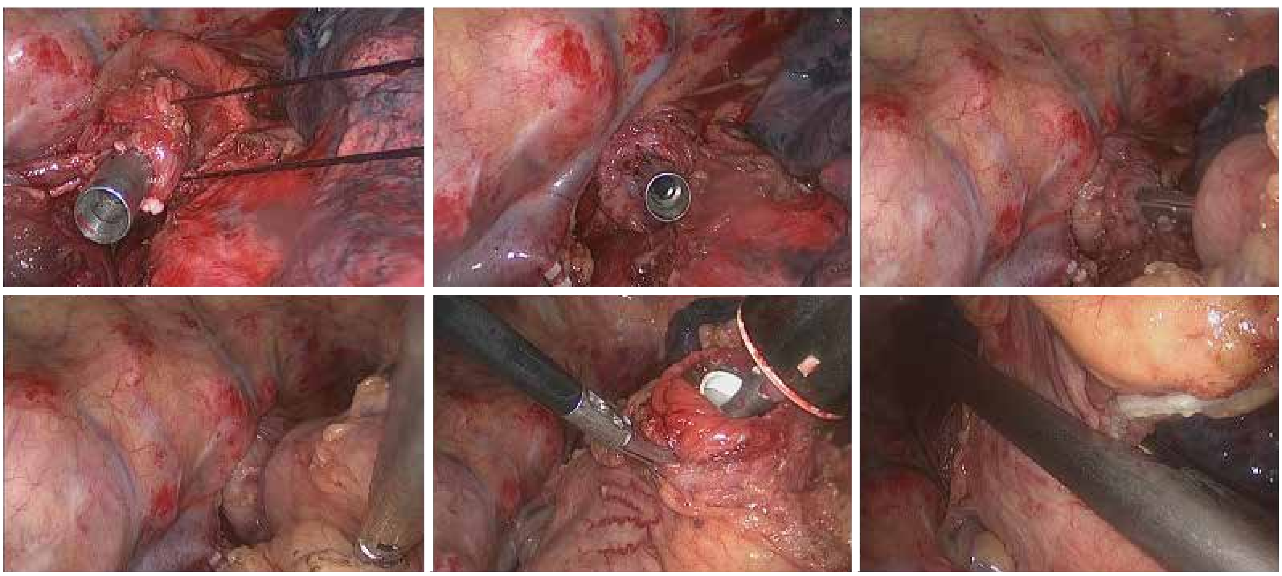

**Figure 4** Transthoracic anastomoses and gastric conduit constructed.

artery is helpful to protect the spleen and the gastroepiploic arcade. We can find that the approach has the potential to improve safety and reduce postoperative complications.

The hybrid procedure is a complex surgical operation. The thoracoscopy portion can be performed in variety of ways using different techniques. However, it's technically demanding for there are technical challenges of transthoracic anvil placement. The major advantages of anastomosis is tension-free. And we chose a 25-mm stapler for utility of placement through the subaxillary major port. A pilot study has covered two cases and the morbidity was acceptable. The precise data of the hybrid technique needs more deep investigation.

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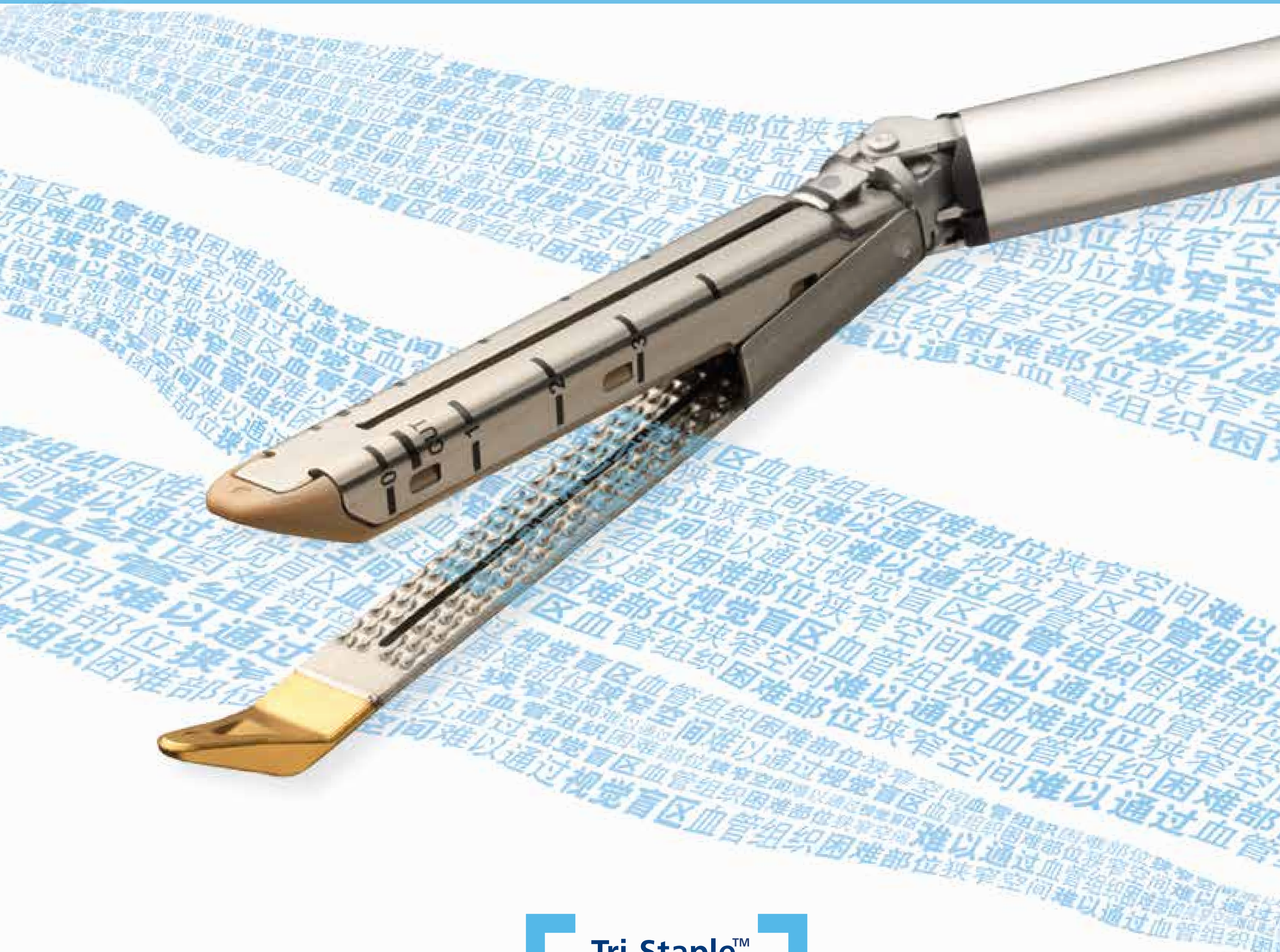

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