# ROBOTIC SURGERY FOR LUNG CANCER

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**Abstract**
Major lung resections by minimally invasive surgery (MIS) represent an effective technique for treatment of early stage lung cancer. Many published papers have demonstrated that this approach (Video-Assisted Thoracic Surgery-VATS) may have some advantages over thoracotomy. However, concerns still remain, especially in terms of lack of standardization of operative technique, technical limitations such as impaired vision, restricted instrument-maneuverability and unstable camera platform. Recently, robots have been introduced into surgical practice in an attempt to facilitate minimally invasive surgical performance. The three-dimensional view with depth perception is a marked improvement over the 2 dimensional conventional thoracoscopic camera. Combined with the increased degrees of freedom and enhanced dexterity of the robotic arms, the surgeon's ability is enhanced to render surgical operations feasible that are technically difficult or even impossible by using traditional minimally invasive techniques. This article describes general aspects, indications, advantages and disadvantages of this new technique in thoracic surgery in performing major lung resections for treatment of early lung cancer.
**Key words:** Lung cancer, robotic surgery, thoracoscopy, lobectomy, VATS

## INTRODUCTION

The past two decades have witnessed a revolutionary transition in surgical technique and technology with minimally invasive approaches. Many advantages were obtained by using Video-Assisted Thoracic surgery (VATS): less trauma and pain, shorter hospital stay, better cosmetic results (1, 2). In thoracic surgery, several studies have suggested improvements in postoperative pain control, earlier discharge, lower levels of perioperative inflammatory cytokine levels, lower complication rates and earlier return to normal activities compared with open thoracotomy procedures (3, 4). However, for lung cancer treatment, unanswered questions still remain among surgeons who have not accepted this technique, especially regarding the oncological validity of the procedure. Concerns include: safety of anatomical hilar and mediastinal dissection, adequacy of clearance (oncological resection with a curative intent) and unclear long-term benefits over open surgery (5-8). In addition, limitations of VATS lobectomy still remain due to impaired vision, restricted instrument-manoeuverability, unstable camera platform and poor ergonomics for the surgeon. Some of the more prominent limitations involve the technical and mechanical nature of the equipment such as 2 dimensional imaging (2D), unsteady camera platform and limited instrument manouverability due to the rigid shaft axis fixed to the thorax by the entry trocar. This implies an unnatural operative feel with hands, and miss-aligned and fixed instrument tips inside the patient together with inverted movements.

Robotic-assisted minimally invasive surgery represents an extraordinary technological advance for a broad range of procedures traditionally requiring open surgery. By enabling surgeons to perform complex operations through small incisions, the surgeon's hand movements are scaled and filtered to eliminate hand tremor which are then translated into micro-movements of the proprietary instruments.

These improved ergonomic conditions and instrument mobility at distal articulations seem beneficial in thoracic procedures (3).

Currently, different types of robotic devices are used in clinical practice (8-11). However, the da Vinci™ Robotic System (*Intuitive Surgical*, *Inc*., *CA*, *US*) represents the only complete surgical system currently applied in a wide range of surgical procedures. Although there is a real difference between thoracic surgery and other surgical disciplines, an application in this field seemed realistic. In the last years, an increasing number of thoracic surgeons have been using the robot to perform a wide range of thoracic procedures, ranging from simplest operations to complex ones such as lobectomies for treatment of non-small cell lung cancer (NSCLC) (12-20).

This chapter describes technical aspects, indications and surgical sequences of this new technique for performing robotic major lung resections for treatment of NSCLC patients.

**Historical Notes**

The early robot systems employed in surgery were relatively simple - programmed to handle the scope only or to maintain an endoscopic instrument in a fixed position during surgery.

In 1994, the US Food and Drug Administration (FDA) approved the first Automated Endoscopic System for Optimal Positioning (AESOP) arm to be used in laparoscopic surgery (21). The device is controlled through voice activation to provide a flexible view of the surgical field. Around the same time, the TISKA Endoarm became available, being able to act as a camera guided by electromagnetic friction and it could also work as a tissue retractor (22). While foot pedals were being replaced by voice-activated systems, other manufacturers were designing cameras that moved in synchrony with the movements of the surgeon's head. To combat dexterity problems, the master-slave telemanipulator concept was developed for medical use in the early 1990s. The first master-slave manipulator for medical use was developed at Stanford Research Institute by SRI International, a research and defence contractor in Palo Alto, California. The da Vinci Robotic Surgical System has been cleared by the FDA for laparoscopy, thoracoscopy and intracardiac mitral valve repair surgery. In parallel, the ZEUS Surgical System was developed and cleared for sale by the FDA for general and laparoscopic surgery. The two systems were similar, with some minor differences.

However, after a few years, Zeus was completed replaced by the da Vinci System. In 1995, Intuitive Surgical licensed the rights to patents from SRI, International Business Machines and the Massachusetts Institute of Technology and commenced work on a telerobotic system (23).

The da VinciTM System creates an immersive operating environment for the surgeon by providing both high-quality stereo visualization and a man-machine interface that directly connects the surgeon's hands to the motion of the surgical tool tips inside the patient's body. The surgeon visualizes the stereoscopic images by a 3D display located above the hands, restoring hand-eye coordination and providing an intuitive correspondence with manipulations. Furthermore, the controller transforms the spatial motion of the instruments into the camera frame of reference, so that the surgeon feels as if his hands are inside the patient's body. Lastly, the da Vinci system restores the degrees of freedom lost in conventional laparoscopy by placing a three degrees of freedom (DOF) wrist inside the patient, enabling natural wrist pronation/supination and providing a total of seven DOF for control of the instrument tip (three orientation, three translation and grip). The system also uses its control system to filter out surgeon tremor, making the instrument tips steadier compared to the unassisted hand. Also, the system allows for variable motion scaling from each master (moved by surgeon's hands) to each slave.

Since the first version (robot received FDA approval in 2000) the system has been modified, but the master console and the slave robot mechanisms have remained essentially the same (the changes made relate only to their mechanical design).

Human robotic surgery was introduced by Cadiere's team in March 1997 (24). A thoracic procedure was performed using a voice-controlled robot (ZeusTM, Computer Motion Inc., Goleta, CA, USA) (25, 26), and in the same period, a different robotic device was used by other surgical teams (27, 28). Robotic pulmonary lobectomy was first performed in 2002 (13). Subsequently, other centres confirmed that this technique is feasible and safe, although technical differences from various centres are reported (13-28).

## ROBOT FEATURES

**Surgical Robot System** (the Master-Slave Manipulator)

*At the present time the da Vinci™ Robotic System (Surgical Intuitive, Inc., Sunnyvale, CA) is the only complete surgical robot system applied in surgical practice* ***which can*** *overcome some limitations of conventional minimally invasive surgery. The da Vinci System is a* *sophisticated robotic platform designed to expand the surgeon's capabilities - and for the first time - offer a minimally invasive option for major surgery.*

**The *da Vinci* ® S™ Surgical System**

*With da Vinci, small incisions are used to introduce miniaturized wristed instruments and a high-definition 3D camera. Seated comfortably at the da Vinci console, the surgeon views a magnified, high-resolution 3D image of the surgical site. At the same time, state-of-the-art robotic and computer technologies scale, filter and seamlessly translate the surgeonıs hand movements into precise micro-movements of the da Vinci instruments.*

This system comprises of three different main parts: (Figure 1).

- **The Surgeon Console** (controlled by the surgeon, Figure 2): *is connected to a surgical manipulator with -three instrument-arms and a central arm to guide the endoscope. Two master handles at the surgeon's console are manipulated by the user. The position and the orientation of the surgeon's hands on the handles trigger highly-sensitive motion sensors which transfer the surgeon's movements to the tip of the instrument at a remote location.*
- **The Surgical Cart Figure 3** (of which three arms directly perform the procedures) *provides three degrees of freedom (pitch, yaw, insertion). Attached to the robot arm is the surgical instrument, the tip of which is provided by a mechanical cable-driven wrist (EndoWrist®). This adds four more degrees of freedom (internal pitch, internal yaw, rotation and grip.)*
- **The Vision System** The computer system which controls the whole system resides in the Surgeon Console. *The notable features of the da Vinci Surgical System are: the surgical instruments with the Endo Wrist™ move like human hand motions by artificial articulation and the visualization through a high-quality 3D endoscope is optimal. This system provides surgeons with an intuitive translation of the instrument handle to the tip movement, thus eliminating the mirror-image effect, scaling, tremor filtering, coaxial alignment of the eyes, hand and tooltip image and an internal articulated endoscopic wrist providing an additional three degrees of freedom.*

**Instruments**

*The EndoWrist Instruments are designed to provide surgeons with natural dexterity and full range of motion for precise operation through tiny incisions. EndoWrist Instruments provide enhanced dexterity*

**Figure 1.** the da VinciTM Robotic System (Courtesy of Surgical Intuitive, Inc., Sunnyvale,CA)

**Figure 2.** the console (Master Handles) (Courtesy of Surgical Intuitive, Inc., Sunnyvale,CA)

**Figure 3.** Surgical Cart

*due to the great range of motion that allows precision and control.*

**The features of instruments :**

- 7 degrees of freedom
- 90 degrees of articulation
- *Intuitive* motion and finger-tip control
- Motion scaling and tremor reduction

**Dual console surgical system**

*The newly refined da Vinci Si Surgical System includes a dual console used for both training and collaboration. During a dual console operation, each surgeon sits at his individual console and can see the same high definition images of the anatomy from the 3D endoscope (flexible tube with a camera and light at the tip). When the dual console is used for training, control over instruments can be easily and quickly exchanged during surgery - meaning that the teaching surgeon can hand over control of the instruments to the resident at any time. This enables a see-and-repeat model of instruction designed to accelerate the learning curve.*

*For collaborative surgery with the dual console, two surgeons can operate in concert. While one surgeon performs the primary tasks of the operation, the second surgeon can assist with another task, such as retraction.*

**SURGICAL TEAM**

In order to perform robotic lobectomy in a safe and straightforward manner, it is necessary to standardize procedures and establish operative schemes. This robotic device requires meticulous preparation in terms of set-up of the system and its placement at the operating table.

The main body of the machine (surgical cart) must be placed perpendicularly to the camera port (Figure 4). This is mandatory in order to avoid arm impingement. Only when the robotic cart has been positioned appropriately and the patient placed in the chosen position can the robotic arms be brought into the operative field.

**Robotic Lobectomy (RL)**

**Current indications to perform a robotic lobectomy:**

- Clinical Stage I
- Negative mediastinoscopy
- No evidence of other pulmonary lesions on computed tomography (CT) scan

Dense adhesions are not a real absolute contraindication. Once a space is created when the correct plane in the pleural space is entered, endoscopic adhesiolysis can proceed quickly and safely.

Fused fissure is a technical challenge to robotic surgery. However, with increased experience, successful lobectomy can be accomplished.

This technique is not recommended for tumours larger than 4 cm, not for technical difficulties, but because ribs have to be excessively spread to retrieve the specimen.

**Anaesthesia and Positioning**

A single-lung ventilation is required. The general standards of monitoring are as for a major thoracotomy. Patients are prepared and draped for a formal thoracotomy (posterolateral thoracotomy) (Figure 5) with the operating table flexed at 30° at the level of the scapula tip so that the procedure can be converted in the event of intraoperative complications such as bleeding or for technical reasons.

Insufflation of low pressure of carbon dioxide ($CO_2$=5-8 mmHg) into the pleural cavity can be useful to facilitate lung collapse and wash out intrapleural smoke.

The location of the incisions is critical for a successful procedure. The best positioning of the main body (*surgical cart*) and arms is well established in relation to the site of the lesion in order to have an excellent, unobstructed view of the chest cavity without arm impingement and interference.

If there is no contraindication to proceed, the surgical cart is positioned at the posterior side of the patient's head with the centre column at an approxi-

**Figure 4.** Surgical cart docking

**Figure 5.** Patient's position

mately 45° angle with respect to the longitudinal axis of the patient.

A 30° scope angled down (generally preferred) is introduced through a 12-mm trocar and secured to the camera arm. The positioning of the instrument arms and the remaining access incisions are accomplished under direct vision.

The standard layout is the same for right and left side: the first port is placed in the $7^{th}$-$8^{th}$ intercostal space at the mid-axillary line (over the mid to posterior axillary line), for the camera port (30° 3D scope). The others are inserted in the $6^{th}$-$7^{th}$ intercostal space at the post-axillary line and in the auscultatory area.

The anterior incision is made in the $4^{th}$-$5^{th}$ intercostals space at the anterior axillary line. However, this port mapping varies. Instead of the small anterior incision, a 'service entrance' can also be made.

**Instruments**

**Currently, few robotic instruments are used:**

- *Cadiere Forceps* (*Intuitive R*, *EndoWrist TM*)
- *Fenestrated Bipolar Forceps* (*Intuitive R*, *EndoWrist TM*)
- *Permanent Cautery Hook* (*Intuitive R*, *EndoWrist TM*)
- *Curved Scissors* (*Intuitive R*, *EndoWrist TM*)
- *Large Clip Applier* (*Intuitive R*, *EndoWrist TM*)
- *Endovascular Staplers*

Accessory conventional endoscopic instruments can be used.

## SURGICAL STEPS

Robotic lobectomy follows the standard surgical steps of open thoracic surgery and implies the isolation and resection of the vascular and bronchial hilar elements. Usually the artery is dealt with before the vein and eventually the bronchus is transected; however, priorities are not strictly set.

**Hilar dissection**

The dissection is performed by using a Cadiere forceps and the monopolar Hook Individual isolation of the hilar structures proceeds with dissection around the hilar vessels and bronchi performed through a combination of cautery and sharp and blunt dissection.

**Arterial step**

When the fourth arm is available, a Cadiere forceps-EndoWrist for lung retraction, a bipolar fenestrated forceps-EndoWrist and a monopolar Hook or spatula are used for the artery dissection if the interlobar fissure is complete or nearly complete. Incision of the visceral pleura is done with electrocautery or blunt dissection with a pledget mounted on the Cadiere forceps which allows easy identification of the pulmonary artery. When the vessels are sufficiently dissected, two blunt-tipped Cadiere forceps are used to isolate the pulmonary artery. Then, a sling is passed. The dissection begins after vein isolation for upper and middle lobectomies; the arteries are isolated and often taken separately, for lower lobectomies. Due to the wrist instruments the suture may be performed by using double-tie linen 2.5 or by vascular stapler introduced through the posterior access incision, when an upper or middle lobectomy is performed, or through the anterior utility incision for the lower lobectomy.

**Vein step**

Vein isolation is generally performed with Cadiere forceps on the left arm and hook or spatula on the right arm. For lower lobectomies, the vein identification begins from the pulmonary ligament that is incised. For upper and middle lobectomies, a good exposure of the mediastinum is required to clear the vein from the surrounding tissues. A sling is passed and a double tie (with linen 2.5 or silk) is placed to close the vessel; when necessary, an additional transfected suture can be added. When the vein wall is particularly thick, it is advisable to use a mechanical stapler. Another way of handling the vein is to place a vascular curved clamp through the utility incision and stitch it by using the robot Debakey forceps and a large needle holder (polypropylene monofilament 4/0). This is more difficult and not safe, considering that both the stapler and the clamp have to be placed by the assistant surgeon whose hand-eye orientation (bidimensional vision) is less precise compared with the surgeon who, at the console, has a different depth perception and optical resolution.

Consequently, poor coordination between the surgeon and the assistant can jeopardize the success of the operation.

**Bronchus Step**

The last step consists of dissecting the lobar bronchus so that lobar bronchial nodes can be completely removed with the specimen. A sling is used to encircle the bronchus, which is subsequently stapled (Endopath ATB45 *Ethicon Endo-Surgery*, *INC*). This manoeuvre is necessarily performed by the assistant surgeon. This is the only possible way to transect and suture the bronchus. Although the robot wrists are able to simulate even fine physiologic movements, the surgeon cannot make a running stitch when dealing with the bronchus,

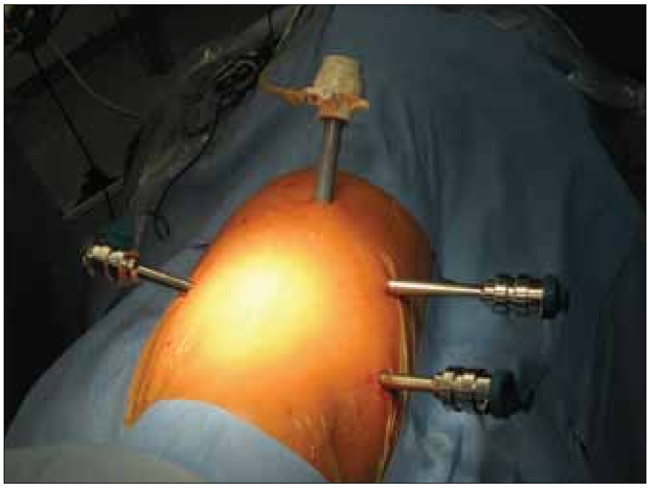

**Figure 6.** Port Mapping

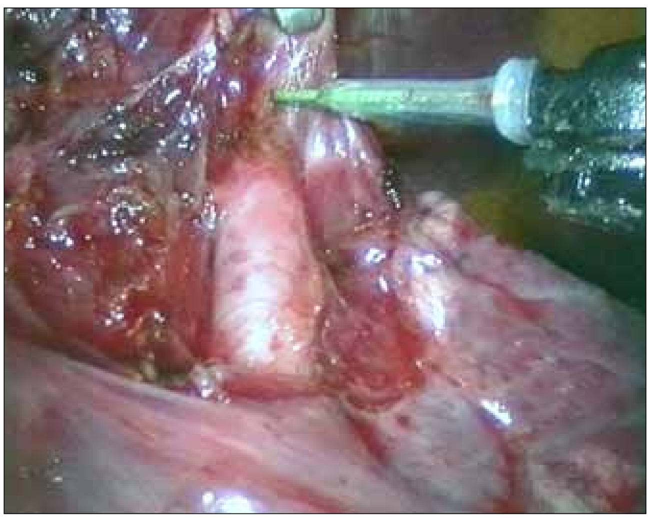

**Figure 7.** Artery dissection

because the robotic instruments in current use are too small to handle such a thick structure.

When feasible, the completion of the fissure is performed last, just before removing the specimen.

Ultimately, the specimen is placed in a sterile plastic bag and removed through the utility incision without rib spreading. The bronchial stump is then tested under water for air leaks with 20 cm positive airway pressure.

**Lymph Node Sampling**

At the end of the operation, all the accessible nodal stations are systematically sampled to ensure proper staging of the lung cancer. Currently, the lymph node samplings are made at stations that are more likely involved by a tumour originating from a particular lobe (Naruke 1999) (29). Right upper lobe (prevascular and tracheal nodal station 2 and lower paratracheal station 4R), middle lobe (stations 2 and 4 and subcarinal 7), right lower lobe (station 7), left upper lobe (subaortic and para-aortic stations 5 and 6) and left lower lobe (station 7). Unlike the VATS approach, there are no limitations regarding accurate lymph node sampling, given that this is carried out at the end of the operation when a part of the lung has been removed. One chest drain, through the previous camera port, completes the operation.

**Personal Experience**

Since February 2001, 382 patients (median age 56 years, range 19-81) were selected to undergo various surgical robotic procedures ranging from the simplest operations, such as benign tumour enucleations and excisions, to very complex procedures, such as major lung resections. Robotic lobectomy was performed in 181 (87 M, 67 F; range 40-85) (mean age 63.5) good-risk patients with cardiopulmonary function demonstrating an adequate pulmonary reserve (forced expiratory volume in 1 s of 1.5 L) and arterial blood gases within normal limits. In accordance with protocols at that time, mediastinoscopy was not performed for small lesions without mediastinal lymphadenopathy identified on CT or PET scan.

The patients were judged to have clinical stage I NSCLC. In all patients, an anatomic major lung resection with lymphadenectomy was performed. Specific consent was obtained to attempt a robotic resection.

**RESULTS**

No technical operative mishaps related to manoeuvres of the instrument arms occurred. None of the patients had problems related to operative bleeding.

Summarizing the results, a median of 22 lymph nodes were removed. Most of the patients had adenocarcinoma (103 pts), and the most representative postoperative stage was stage I (147 pts: 103 IA and 39 IB) in a larger number of the cases. The other postoperative stages were stage II in 24 patients (15 IIA and 9 IIB), stage III in 8 (4 stage IIIA and 4 stage IIIB), and IV in 2 pts.

In ten cases (9.4%), the procedure was converted to thoracotomy because of pleural adhesions in two patients and because of fused fissure in six. In two cases, the lobectomies were begun by isolating and stitching the transected lower vein with the robot. The operations had to be completed using the service entrance (enlarged by about 2 cm) because of hilar calcified lymph nodes which rendered the dissection of the pulmonary artery unsafe. Ten patients had air leaks beyond seven postoperative days. In all patients, mechanical staplers were used to complete the fissure. There was one death on the twelfth postoperative day (not related to the surgical technique) because of pulmonary embolus. After an initial excellent postoperative recovery, the patient had acute kidney failure on the fourth postoperative day, which led to a worsening of the clinical condition.

Operative time (median operative time) was 215 min (range, between 130 and 250 min), of which 60 min was used to do the self-test of the machine and instrument set-up. Chest tubes were removed after a mean of 2.1 postoperative days (range, 2-28), and the patients were discharged after a mean of three postoperative days.

All patients were discharged in good condition and returned to preoperative levels of physical activity within 10 days of the operation.

## COMMENT

Robotic technology has added certain advantages in minimally invasive thoracic surgery and also for anatomic lung resection, especially pulmonary lobectomy. Minimally invasive lobectomy for early stage lung cancer is entering daily clinical practice. In part, it is due to detection of lung cancer of smaller sizes thanks to screening programs, in part it is due to advances in minimally invasive technology, with the development of robotic systems.

As far as is known, only few robotic lobectomies are currently performed; consequently, few surgeons have experience in this field (16-20). At the present time, many of the limitations of robotics surgery are related to the imperfections of the system. Consequently, some procedures become more complicated, especially when dealing with major lung resections.

Other limitations are system-related. The poor tactility impairs the surgeon's ability to judge the amount of tension applied during the manoeuvres of suturing and/ligating (12). In addition, adequate training for surgeons to acquire and master the new skills to improve surgical performance and a perfect knowledge of topographical anatomy and broad experience in conventional surgery and training in specific thoracoscopic skills, are required. Although this technique is still evolving and larger series are required, some studies have demonstrated that robotic procedures may have some advantages over conventional approaches.

In 2002, we reported the encouraging results of pulmonary lobectomies performed with the aid of robotic technology (13). Subsequently other authors reported their experiences with the da Vinci robotic system, in performing mainly right lower lobectomies (16). These very first experiences showed robotic surgery to be feasible and safe, but with this type of approach increased operative times were noted with respect to conventional surgery. Probably, this is due to different factors. First, we have to consider that there is no standard technique that the surgeon has to precisely follow, therefore the surgical sequences still have to be well established. Second, we all know that the incorporation of any new device in surgical practice may yield an inferior performance in the introductory period.

Although this technique is still evolving and larger series are required, some studies have demonstrated that robotic procedures may have some advantages over conventional approaches Especially in thoracic surgery, this new technology offers clear benefits in the treatment of mediastinal lesions, particularly in performing thymectomy (14, 17), and in the treatment of lung cancer, particularly lobectomy in stage I NSCLC patients (9, 10, 13).

We believe that many of the current limitations can be overcome in the near future and that, as the da Vinci System is improved and its instruments better adapted to thoracic surgery, application will be extended to a wider range of operations.

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