Robotic Surgery in General Thoracic Surgery

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11.1 Introduction

Minimally invasive surgery (MIS) has been an important treatment modality in many fields of surgery. However, in the field of MIS, the advance of thoracic surgery has been delayed due to limited thoracic space with fixed rib cages, a beating heart, and ventilation of the lungs. The ergonomic discomfort and counter-intuitive instruments have hindered the application of video-assisted thoracic surgery (VATS) to more advanced procedures. Initially, VATS was used as a diagnostic tool. With the development of thoracoscopic instruments and vision systems, VATS has been applied to major thoracic surgery, such as a pulmonary lobectomy. Successful thoracoscopic surgery is highly surgeon-dependent and requires a high degree of dexterity and technical skill. The uncomfortable operative position and the flat, two-dimensional view made it one of the most difficult operations, requiring a long learning curve. Because MIS has been proven to be beneficial to the patients, broadening its use has become an important issue.

Trials to alleviate the shortcomings of VATS have developed the robotic technology. The use of robotic assistance during MIS was first described in 1985 [1], and the technology has evolved to its current state in the form of the *da Vinci* surgical system® (Intuitive Surgical, Sunnyvale, CA, USA) [2]. This technology offers several creative advantages, including a three-dimensional view of the operative field, absence of a fulcrum effect, seven degrees of freedom of movement

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with “wristed” instruments (*EndoWrist*®) that facilitate intracorporeal suturing, elimination of surgeon tremor, and ergonomic benefits. Thus, robotic assistance has consistently reproducible advantages over open approaches, including smaller incisions, reduced intraoperative blood loss, decreased postoperative pain, and shorter hospital lengths of stay (LOS) and convalescence periods. The disadvantages of robot-assisted surgery include the absence of tactile feedback and instrument collisions when traversing wide surgical fields [3–18].

Although the *da Vinci* system was originally intended for cardiac surgeries [19], it has found widespread applications across multiple specialties, with the vast majority of cases dedicated toward oncologic procedures. We present here our robotic surgery for lung cancer and mediastinal tumors using the *da Vinci* Surgical System® with literature reviews.

11.2 Robotic Surgery in Lung Cancer

The standard treatment for stage I non-small cell lung cancer (NSCLC) is a lobectomy with mediastinal lymph node dissection (MLND). This standard of care was effectively established by the landmark publication from the Lung Cancer Study Group in 1995 demonstrating decreased local recurrence rates and a trend toward improved survival after a lobectomy compared with sublobar resections, including anatomic segmentectomies requiring individual pulmonary arterial and bronchial division and nonanatomic pulmonary wedge resections [20]. In 2007, a prospective, multi-institutional study to examine the standardized, truly videoscopic, minimally invasive VATS lobectomy procedure for early-stage lung cancer showed that a VATS lobectomy is feasible. The low complication rates and short duration of chest tube placement suggest there may be a benefit to the patient; furthermore, at early follow-up, the secondary survival end point compared favorably with that in the open lobectomy series [21]. A VATS lobectomy has been reported to be beneficial for patients, with more favorable early postoperative outcomes and long-term oncologic outcomes that are comparable with an open lobectomy [22–28]. Despite these advantages, a recent analysis of the voluntary Society of Thoracic Surgery (STS) database demonstrated that although 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 %, possibly due to the limitations of visualization and maneuverability of the approach [29]. However, the majority of major lung resections performed in the USA are still via thoracotomy.

Some pioneers have challenged to perform robot-assisted video-assisted thoracic surgery (R-VATS) pulmonary resection. Based on the literature review of R-VATS pulmonary resection (Table 11.1), the operative time was 3.3 h. Open conversions were required in 6 %, and the LOS was 5 days. Overall, complications occurred in less than 20 %. Death occurred in 1 %. Conversions, operative times, LOS, complications, mortality, and oncologic outcomes were consistent with previous

Table 11.1 Reviews of R-VATS pulmonary resections

Authors	Year	No.	Conversion	Op. time (h)	LOS (day)	Cx (%)	Mortality (%)
Melfi [16]	2005	23	2	3.2	5 (1.3)	NR	NR
Park [17]	2006	34	4	3.6 (2.6–5.9)	4.5 (2–14)	26	0
Anderson [3]	2007	31	0	3.6 (1.0–6.4)	4 (2–10)	27	0
Gharagozloo [11]	2008	100	0	4.0 (3.0–6.0)	4 (3–42)	21	3
Venonesi [18]	2010	54	7 (13 %)	3.9 (2.4–8.5)	4.5 (3–24)	20	0
Giulianotti [12]	2010	38	6 (15.8 %)	3.5 (1.8–6.3)	10 (3–24)	10.5	2.6
Cerfolio [8]	2011	106	11 (10.4 %)	2.2 ± 0.4	2 (1–7)	27	0
Dylewski [9][a]	2011	200	3 (1.5 %)	1.5 (0.5–4.65)	3 (1–44)	26	1.5
Jang [14][b]	2011	40	0	4.0 ± 0 0	6 (4–22)	10	0
Lee [31][b]	2012	100	2 (2 %)	3.5 ± 1.0	6.3 ± 3.3	9	0
Park [38][c]	2012	325	27 (8.3 %)	3.4 (1.8–6.4)	5 (2–28)	25	0.3
Overall		1,031	62 (6 %)	3.3	4.9	17.6	0.8

R-VATS = robot-assisted video-assisted thoracic surgery
[a]Benign diseases were included in this study
[b]Twenty patients overlapped in these studies
[c]This is a multicenter study from the USA and Italy

reports of VATS outcomes. The robotic approach confers advantages over open surgery similar to VATS [3–5, 7–9, 11, 12, 14, 17, 18, 30, 31]. However, as existing data do not demonstrate superiority over VATS, comparative effectiveness studies are needed to explore short-term outcomes, such as pain and respiratory function, and to assess cost differences.

11.2.1 Robot-Assisted VATS (R-VATS) Lobectomy for Lung Cancer

11.2.1.1 Indication

As in a VATS lobectomy, early-stage lung cancer is the indication for robotic surgery. The indication for robotic surgery can be modified according to different features, such as the tumor size, the extent of pleural adhesion, incomplete fissure, and the presence of calcified and anthracotic lymph nodes (LN).

11.2.1.2 Patient Position

During a thoracotomy, the patient is usually placed in a slightly flexed left lateral decubitus position to widen the intercostal space. During robotic surgery, the patient is more flexed to avoid the collision between the 30° thoracoscope and the pelvis and was then moved to a 10-degree reverse-Trendelenburg position. For a

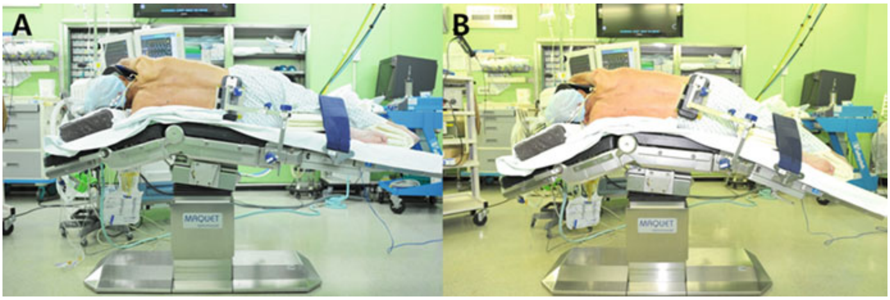

Fig. 11.1 Position of patients. (**a**) During thoracotomy or VATS. (**b**) During R-VATS

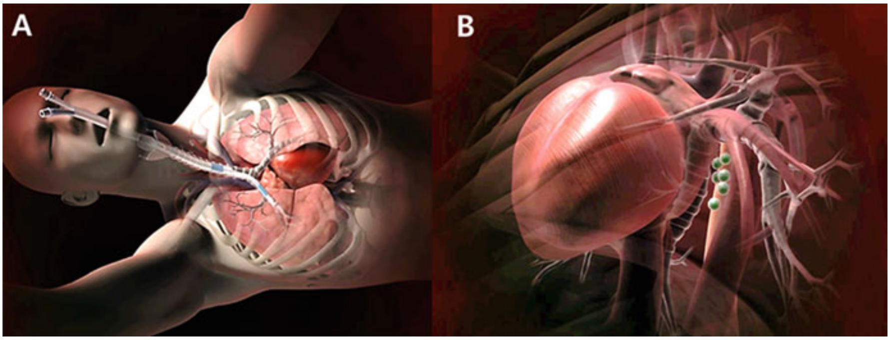

Fig. 11.2 Anterior approach to the subcarinal LNs with right-sided double-lumen endotracheal tube intubation during left sided R-VATS. (**a**) A right-sided double-lumen endotracheal tube is inserted into the right bronchus. (**b**) During R-VATS, subcarinal LNs can be dissected anteriorly

woman with a large pelvis, a 30-degree thoracoscope might be changed to 0° to prevent damage to her pelvis (Fig. 11.1).

The robotic cart approach to the patient in an oblique manner is helpful to reach the inferior pulmonary ligament and to permit enough space for the assistant standing on the anterior side of the patient.

11.2.1.3 Anesthesia

During right-sided R-VATS lobectomy, a double-lumen endotracheal tube was inserted into the left main bronchus. In contrast, during left-sided R-VATS lobectomy, a right-sided double-lumen endotracheal tube was inserted into the right bronchus (Fig. 11.2). This approach enabled the left main bronchus to be easily lifted during subcarinal LN dissection. For full anesthesia, fentanyl and vecuronium were infused continuously.

11.2.1.4 Selection of Robotic Instruments

Despite many diverse instruments, the cost of instruments is very expensive, and the number of uses is limited; thus, the selection should be deeply considered. Also, the insurance reimbursement system can affect the selection of the instruments.

We selected fenestrated bipolar forceps to grasp the lung parenchyma to prevent the injury. Additionally, these forceps are safe to grasp pulmonary veins. A bipolar energy source is added to control the bleeding from small vessels and lymphatics. *Cadiere*® forceps and ProGrasp® forceps have the same shape. However, *Cadiere*® forceps have no energy source, and ProGrasp® forceps have grasping power strong enough to injure the lung parenchyma and vessels.

Robotic ultrasonic devices can be used during robotic surgery. However, the cost is more expensive, and the motion of ultrasonic devices is limited due to the absence of wrist motion. We believe that a bipolar energy source and endostaplers are enough to complete the pulmonary lobectomy. Robotic instruments have continued to evolve, and robotic stapling devices will be launched in the future. However, the cost-effectiveness should be considered.

11.2.1.5 Robot-Assisted Pulmonary Resection with Four Arms

In the case of the right approach, a “utility incision” is made with 3–5 cm length at the fifth ICS along the anterior axillary line through the submammarian line, where the right robotic arm ① is placed. The camera port is placed at the seventh ICS along the mid-axillary line for the 30-degree 3D scope, and the other port is placed at the seventh ICS along the post-axillary line for the left robotic arm ②. An additional 5-mm port is placed at the seventh ICS around the auscultatory triangle at the back side for the robotic arm ③ (Fig. 11.3). Port placement between the right and left sides is consistent regardless of tumor location and tumor site. Occasionally, the submammarian incision in women is located at the sixth ICS. In that case, the other ports should move to the eighth ICS.

Wound protractors (Alexis®, Applied Medical, Rancho Santa Margarita, CA, USA) are inserted into three incision sites except 5-mm port to prevent tumor contamination and port-site bleeding from muscle tears. In addition, the application of wound protractors reduces the docking time because the robotic arm is directly inserted with the robotic trocar already docked.

For the robotic arm ① and ②, bipolar fenestrated forceps and the spatula-type monopolar electrocautery *EndoWrist*® are used. The dissection and anatomical isolation of the hilar structures are performed using two arms of the *da Vinci* system®. For the robotic arm ③, the thoracic grasper is used. This instrument is commonly used when the lung parenchyma is retracted, and the mediastinal pleura is pulled during the LN dissection to provide a better surgical field. The docking of three cannulae and the camera port are performed. The dissection and anatomical isolation of the hilar structures are performed using two arms of the *da Vinci* system®. The vessels and bronchus are usually ligated with thoracoscopic endostaplers (Multifire Endo GIA, Covidien, Mansfield, MA, USA). In some cases, the vessels are ligated with ties.

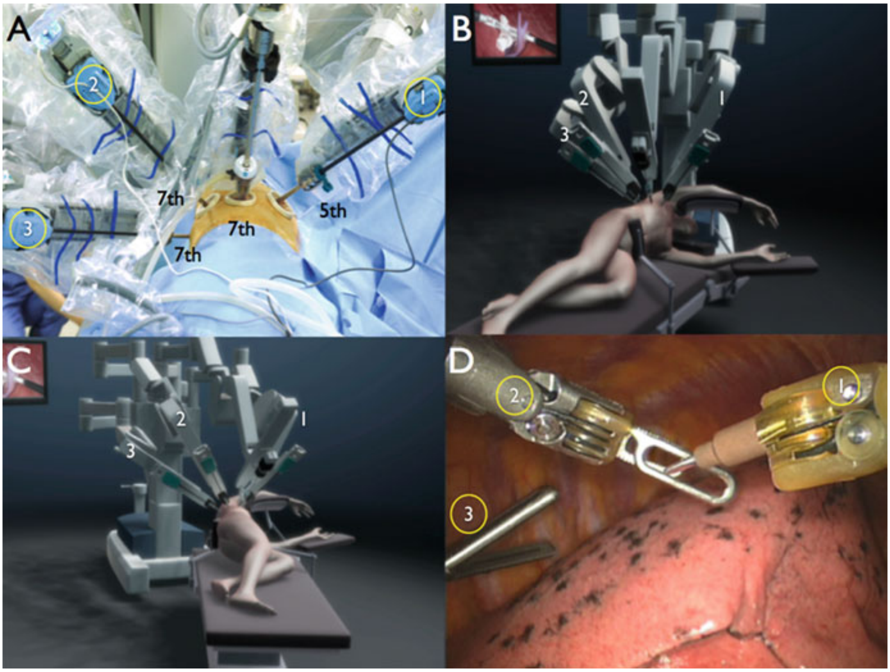

Fig. 11.3 Port placement and the use of instruments during robot-assisted pulmonary resection with four arms. (**a**) Port placement. (**b**) Cart approach (*anterior view*). (**c**) Cart approach (*foot view*). (**d**) Three instruments in the thoracic cavity (Reprinted from [31] with permission from Elsevier)

During upper lobectomies, the endostaplers are inserted through the posterior ports after the removal of the robotic arm. During lower lobectomies, the endostaplers are inserted through the utility port instead of removing the posterior robotic arm. The robotic arm through the utility incision can be removed out to achieve the wide angulation of endostaplers.

Our standard protocol involves complete LN dissection. After cessation of the procedure, an intercostal nerve block is routinely achieved with ropivacaine. After removal of the wound protractor, port-site bleeding is checked. A 24 Fr thoracic catheter is inserted through the camera port.

11.2.1.6 Mediastinal Lymph Node Dissection

Mediastinal LN staging is an important component of the assessment and management of patients with operable NSCLC and is necessary to achieve complete resection. One lingering criticism of the MIS approach is that LN dissection is inadequate compared with the thoracotomy approach. MLND is associated with more accurate staging, but whether MLND is associated with improved survival is not clear [32–37]. However, if the MIS technique is a viable treatment option for early-stage lung cancer, the performance of an equivalent oncologic resection, including adequate LN dissection similar in extent to open thoracotomy, is absolutely necessary.

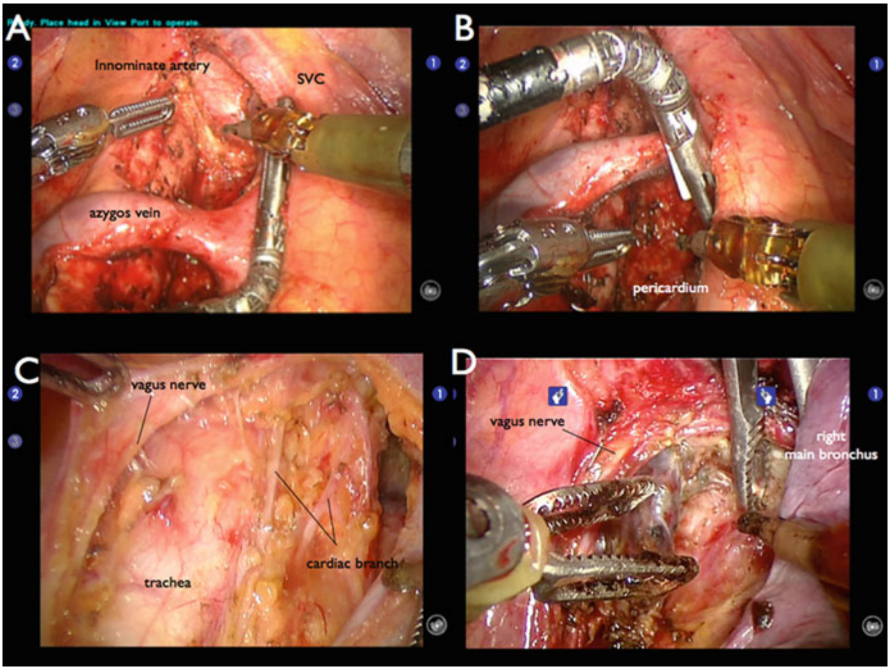

Fig. 11.4 Mediastinal lymph node dissection during a right-sided R-VATS lobectomy. (**a**) 2R. (**b**) 4R. (**c**) Cardiac branch from the vagus nerve in paratracheal space. (**d**) 7 (Reprinted from [31] with permission from Elsevier)

Right Paratracheal LNs (2R and 4R)

During paratracheal lymph node dissection (LND), the robotic arm ③ is very useful for retracting the superior vena cava (SVC) and the azygos vein. The mediastinal pleura, cephalad to the azygos vein (between the trachea and the SVC), is grasped with thoracic graspers and incised to the level of the innominate artery (Fig. 11.4a). A small vein draining from the mediastinal fat pad directly into the SVC is ligated with bipolar electrocautery.

The mediastinal fat pad is removed from the SVC to the trachea and from the cephalad border of the azygos vein to the caudal border of the innominate artery. A thoracic grasper in the robotic arm ③ is used to elevate the azygos vein, and the LNs that are located between its cephalic border and the origin of the bronchus of the right upper lobe are removed (Fig. 11.4b). During dissection at these levels, the lymphadenectomy may be extended to the contralateral LN levels (left paratracheal LN). Care must be taken not to injure the left recurrent laryngeal nerve, which is found in the tracheoesophageal groove. The cardiac branch from the vagus nerve before the trachea is the landmark of left deep border for right paratracheal LND (Fig. 11.4c).

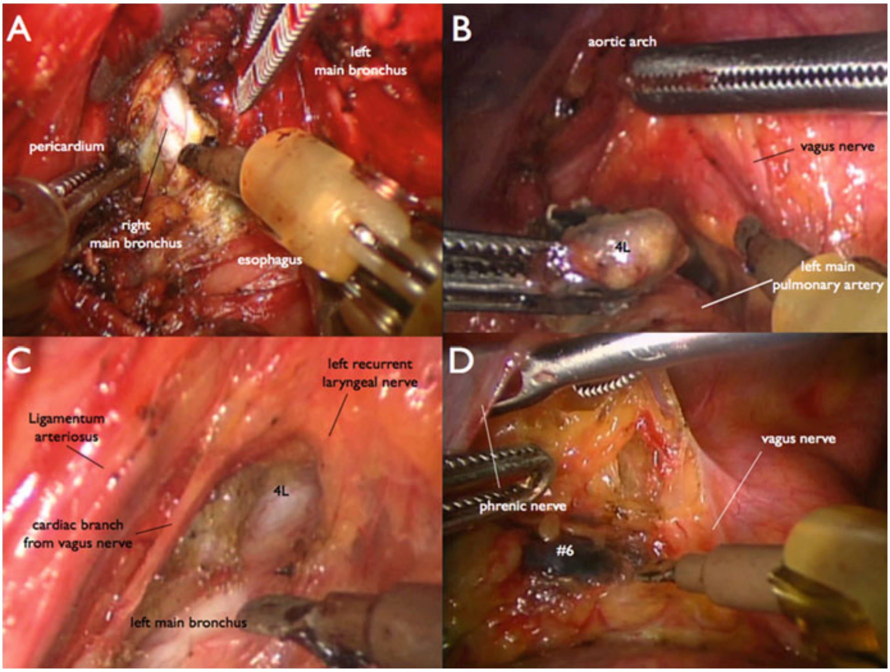

Fig. 11.5 Mediastinal lymph node dissection during a left-sided R-VATS lobectomy. (**a**) 7. (**b**) 4 L (during the removal). (**c**) 4 L (after removal). (**d**) 6 (Reprinted from [31] with permission from Elsevier)

Subcarinal LNs (During Right R-VATS)

The attachments to the right and left main stems of the bronchi are performed with the right main bronchus up and the anterior side lifted using the robotic arm ③ (Fig. 11.4d). The subcarinal LN packet is grasped with bipolar fenestrated forceps. Before transection, vessels course along the anterior border of the trachea and enter the subcarinal LNs from the region of the carina. These arteries and veins must be identified and controlled with bipolar cautery before transection.

Subcarinal LNs During Left R-VATS

The *level 7* subcarinal LNs are approached with the lung retracted posteriorly during robotic surgery. The left main stem bronchus is identified and lifted up and posteriorly with the robotic arm ③. The LNs are grasped with bipolar fenestrated forceps, and the attachments to the left main bronchi are performed. At that time, the first assistant uses only one instrument—a long, curved, thin Yankauer sucker—to press the heart. The arterial vessel that commonly enters the LNs from the anterior border of the trachea at the level of the carina must be identified and ligated with bipolar cautery to avoid postoperative hemorrhage (Fig. 11.5a).

Fig. 11.6 Port placement of R-VATS with three arms

Left Paratracheal LNs (4 L)
The mediastinal pleura and the vagus nerve are lifted up with the robotic arm ③. The first assistant presses the left main pulmonary artery with the suction tip. The 4L LN is excised along the left main bronchus to the trachea with bimanual dissection (Fig. 11.5b, c). Because of the three-dimensional imaging and articulated arms, robotic surgery is very helpful for identifying the recurrent laryngeal nerve so that it is not injured.

Subaortic and Paraaortic LNs (5 and 6)
During the aortopulmonary window dissection, the mediastinal pleura with the phrenic nerve is tented with the robotic arm ③ (Fig. 11.5d).

11.2.1.7 Robot-Assisted Pulmonary Resection with Three Arms

All procedures are the same as the robot-assisted pulmonary resection with four arms except no additional 5 mm instrument is used (Fig. 11.6). Robot-assisted pulmonary resection with three arms depends more on the first assistant than that with four arms.

R-VATS with four arms and with three arms is compared in Table 11.2.

11.2.2 Robot-Assisted VATS (R-VATS) Segmentectomy

A pulmonary segmentectomy can be performed more delicately with robotic systems. Magnification and the articulated wrist are very helpful to approach the distal vascular and bronchial branches.

To determine the segment territory, air insufflation with a butterfly needle is used. Some reports have described air embolisms after air insufflation, but the magnified view can reduce the risk of an air embolism.

11.2.3 R-VATS Bronchoplasty or Sleeve Lobectomy

Intracorporeal suturing during MIS is a merit of robotic surgery. A bronchoplasty or sleeve lobectomy can be performed. In addition, angioplasty can be performed with bull dog clamping of the proximal and distal portion of the vessels. A bronchus

Table 11.2 Comparison between three-arm and four-arm robotic thoracic surgeries

View	Three-arm robotic surgery	Four-arm robotic surgery
Surgeon	– Easy to perform during the initial learning curve – Similar to VATS ports – More dependent on the assistant – Occasionally needs two assistants	– Needs more spatial sense – Less dependent on the assistant – Self-control of tissue retraction by the surgeon – During stapling, can use two robotic instruments
Assistant	– Two instruments in the narrow space – Robotic arm contamination – Injury to the assistant by the robotic arms – Collision between the robotic arms and VATS instrument – Uncomfortable insertion of endostaplers	– Increase in the resting time – Ability to focus on the surgical procedure – Better ergonomics – No physical injury – Reductions in collisions
Patient	– Same or similar number of incisions as VATS – Confined to two intercostal spaces	– Needs one more 5-mm incision and instrument – Meticulous dissection with the stable retraction of adjacent tissue according to the desires of the surgeon – Rare possibility of conversion
Nurse	– Prepares more VATS instruments	– Limited use of VATS instruments – Increased resting time by sitting

anastomosis has more tension, compared with the anastomosis of the intestines. Usually absorbable monofilament suture material is used for bronchial suturing during an open thoracotomy. During MIS, the knot of a monofilament suture can be loosened with ease. We use an interrupted suture with absorbable multifilaments to prevent the loosening of the knot. The robotic arm ③ is very useful for maintaining the tension of the bronchus by pulling up the suturing materials.

11.2.4 Technical Tips

11.2.4.1 Bleeding Control

Most surgeons are afraid of major bleeding during robotic surgery because the surgeon does not stand by the patient. Prevention is a high priority. During the robotic surgery, patience and anatomic knowledge are very important to prevent bleeding.

Once bleeding occurs, calmness without hesitation is very important, followed by compression of the bleeding site with robotic arms using gauze. This status can be maintained without difficulty with the robotic systems. Most bleeding can be controlled without conversion. A sealant such as Tachocomb® is also very useful to control bleeding. Additionally, a suture with prolene after clamping the vessels can be performed with a robotic system.

11.2.4.2 Pleural Adhesion

If there are some spaces to insert the robotic arms, pleural adhesion could be fully detached. During adhesiolysis, a 30-degree upward 3D thoracoscopic view is chosen. After detachment around the port sites, the thoracoscope can be changed to a 30-degree downward view.

Even if ventilation of one lung is unstable, robotic surgery could still proceed to completion within the small space. Thus, in the pediatric field, a robotic system can be applied to remove a mediastinal tumor.

11.2.4.3 Is CO_2 Insufflation During R-VATS Lobectomy Essential?

CO_2 insufflation can make the surgical field cleaner without smoke and bleeding. However, during robotic thoracic surgery, the surgical target is focused with magnification and can be approached more deeply and closely, depending on the control of the surgeon. Additionally, after the en bloc excision of the LN, the size of the excised LN is greater than 2 cm. These LNs would be squeezed during the removal through the 1.5-cm thoracoport, which is not oncologically safe. During the insertion and removal of the staplers, the leakage of CO_2 might be inconvenient. Additionally, a high intrathoracic pressure with CO_2 can cause hemodynamic deterioration. Attention should be paid to the potential of gas embolisms through the vascular stump site. During robot-assisted pulmonary resection for lung cancer, the merit of CO_2 seems to be very limited.

11.2.5 Learning Curves During Robotic Surgery in Lung Cancer

Some authors emphasized the faster learning curve of robotic surgery compared with that of VATS. The cutoff point was 20 cases [18]. However, from our experience, we needed approximately 50 cases to be confident regarding the use of robotic surgery for lung cancer due to the technical achievement of the anatomical complexity of the lungs. Based on our series, the operation time and console time were reduced after 30 cases (Fig. 11.7).

11.2.6 Long-Term Survival After R-VATS for Lung Cancer

Recently, long-term survival after robotic surgery for lung cancer has been reported from the USA and Italy [38, 39]. In 325 patients from three institutes, 310 patients were clinical stage I. The median follow-up was 27 months. The overall 5-year survival was 90 % in pIA, 88 % in pIB, 49 % in pII, and 43 % in pIII. Based on the 190 consecutive patients in our institute with a median follow-up of 26 months, the overall survival and disease-free survival for clinical stage I and II lung cancers were 91.4 % and 80 %, respectively. The overall 3 year survival was 98.1 % in pIA, 96.4 % in pIB, 96.2 % in pIIA, 80 % in pIIB, and 59.7 % in pIIIA (Fig. 11.8).

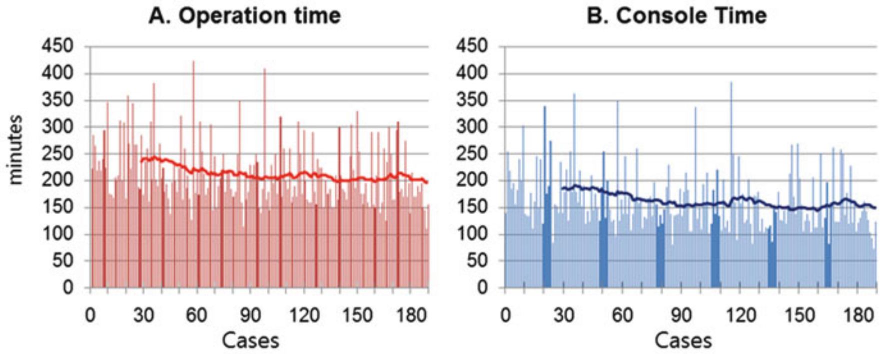

Fig. 11.7 Changes in the operation time (**a**) and console time (**b**) of R-VATS lobectomy for lung cancer

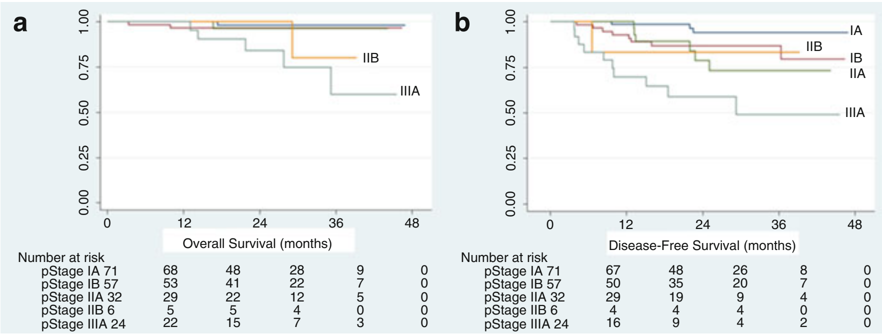

Fig. 11.8 Overall survival (**a**) and disease-free survival (**b**) after R-VATS lobectomy for lung cancer

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 [40].

11.2.7 Comparison Between VATS and R-VATS Lobectomies for Lung Cancer

Two hundred consecutive lung cancer patients who underwent VATS or R-VATS lobectomies for clinical stage I and II NSCLCs were selected for comparison of the VATS and R-VATS lobectomy techniques [14, 31]. R-VATS lobectomies required longer surgical times than VATS lobectomies. However, the console time during the operation was similar to the operation time in the VATS lobectomies. The median length of the postoperative stay was significantly shorter after robotic surgery than after VATS (Table 11.3). Additionally, robotic surgery had a

Table 11.3 Postoperative results between R-VATS and VATS lobectomies for early-stage lung cancer

	R-VATS	VATS	*p*-value
Operation time (min)	209 ± 58	157 ± 40	<0.001
Console time (min)	155 ± 49	–	0.791
Dissected LN numbers	24.8 ± 8.8	23.6 ± 9.2	0.340
Nodal stations	7.3 ± 1.5	6.0 ± 1.4	<0.001
Time until discharge (days)	6.3 ± 3.3	8.9 ± 5.8	<0.001

Values are mean ± standard deviation. Reprinted from [31] with permission from Elsevier

Table 11.4 Postoperative complications between R-VATS and VATS lobectomies for lung cancer

	R-VATS (n = 100)	VATS (n = 100)	*p*-value
Conversion to thoracotomy	2	8	0.101
Postoperative mortality	0	2	0.497
Postoperative morbidity	9	21	0.028
Chylothorax	0	4	
Atrial fibrillation	2	1	
ALI or ARDS	1	3	
Prolonged air leak	4	10	
Sinus tachycardia	4	1	
Pulmonary artery thrombi	4	0	
Stump dehiscence	0	1	
Pericardial effusion	0	1	

ALI acute lung injury, *ARDS* acute respiratory distress syndrome

Table 11.5 Comparison of lymph node dissections between the VATS and R-VATS lobectomies

	VATS right	VATS left	R-VATS right	R-VATS left
Patients (*n*)	60	40	58	42
N2 MLN stations (*n*)	4.9 ± 1.0	4.7 ± 0.6	5.7 ± 1.2	5.3 ± 0.6
Individual LNs (*n*)	24.2 ± 9.8	22.7 ± 8.4	26.2 ± 9.3	22.9 ± 7.9

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significantly lower rate of postoperative complications. In the R-VATS lobectomies, two patients required a conversion to thoracotomy for oncologic reasons. However, in the VATS lobectomies, eight patients required a conversion to thoracotomy for mechanical, technical, and oncologic reasons (Table 11.4). The number of mediastinal LNs exceeded 20 for both the VATS and R-VATS procedures. The number of mediastinal nodal stations was approximately 5 in both procedures (Table 11.5).

11.2.8 Additional Comments

The key steps for performing an R-VATS pulmonary resection and MLND for early-stage lung cancer are as follows: (1) bimanual dissection, (2) dynamic exposure and adequate retraction with the robotic arm ③, (3) meticulous hemostasis, and (4) slow and steady techniques with perseverance.

A merit of robotic surgery is that bimanual dissection can be performed while the surgeon has autonomous control of both the camera and the instruments. To grasp the lung parenchyma and the node without damaging them, *Cadiere* forceps or fenestrated bipolar forceps are recommended. The grasping power is controllable by the surgeon once he has gained experience with the robot.

The dynamic exposure and retraction of tissues by utilizing all of the *da Vinci* instrument arms are essential to perform the en bloc resection of the mediastinal LNs. For right paratracheal LN dissection, the robotic arm ③ is helpful for pulling the SVC. Additionally, a minimal amount of help from an assistant is required for the retraction of the SVC and the azygos vein with the robotic arm ③.

For subcarinal LN dissection in the case of cancer of the right lung, the robotic arm ③ plays a role in lifting the main bronchus up, providing better exposure. The surgical field can be deepened to enable a closer approach, depending on the control of the surgeon.

Another advantage of the robotic system is the magnification. However, small bleeds can be magnified, and the surgical field may appear bloodier. Scrubbing LNs with a suction tip is not recommended because the surgical field becomes bloody. To maintain a clean view, meticulous hemostasis is essential. During robotic surgery, we usually use a monopolar cautery in the right hand and a bipolar cautery in the left hand. Secure control of the vessels and lymphatics is likely associated with decreased postoperative morbidities.

To complete an R-VATS pulmonary resection, the surgeon must have perseverance, which is more necessary during robotic surgery than during VATS or open thoracotomy. A common cause of conversion to thoracotomy during VATS is the presence of benign anthracotic and calcified LNs around the major vessels. However, a surgeon's slow and steady with an advanced robot-assisted system could provide an opportunity for a patient with severe anthracotic hilar LNs to undergo MIS without a conversion to open thoracotomy.

11.3 Robotic Surgery for Mediastinal Tumor

Given the early experiences of robotic surgery, the excision of a mediastinal tumor, such as a pericardial cyst or neurogenic tumor, can be performed. During the excision of mediastinal tumor, CO_2 insufflation is essential to widen the mediastinum and maintain the bloodless clean view. Because there is no need to use the endostaplers, the surgery can be performed by the surgeon alone. A first assistant is needed when the specimen is retrieved.

11.3.1 Anterior Mediastinal Tumor

In a patient with a thymoma, a total thymectomy by a median sternotomy has been universally accepted as the standard treatment. The VATS approach for a thymoma remains controversial, and many surgeons are reluctant to use this technique because of the supposed increased risk of local recurrence, reduced safety margins after minimally invasive resection, possible rupture of the capsule, and seeding of the tumor during endoscopic manipulations.

11.3.1.1 Robot-Assisted Thoracoscopic Thymectomy (R-VATS Thymectomy)

All surgeons have a policy of a “no-touch technique” with an en bloc resection of the thymus and perithymic fat tissue. During this technique, the thymoma is never touched, and normal thymic tissue and perithymic fat are used for grasping and for traction to avoid the direct manipulation of the tumor, capsular damage, and potential seeding. All thymic and perithymic fats are dissected with safe surgical margins, according to the International Thymic Malignancy Interest Group criteria [41], and the completeness of the thymectomy is assessed by the macroscopic inspection of both the thymic bed and the specimen [42].

The upper mediastinum is a delicate and difficult-to-reach anatomic area for a thoracoscopy, with large, vulnerable vessels and nerves. The two-dimensional view of the operative field, enhancement of the surgeon’s tremor by the thoracoscopic instruments, and the inability of the instruments to articulate make it difficult to operate in a fixed, tiny three-dimensional space such as the mediastinum. Moreover, a thoracoscopic thymectomy is considered a technically challenging operation that requires a long learning curve [43]. The introduction of robotic surgical systems has added a new dimension to conventional thoracoscopy, providing additional advantages and overcoming some technical and methodological limits [42].

The main oncologic concerns are related to the possible breach of the tumor capsule, with the risk of tumor seeding locally or in the pleural cavity, and the difficult evaluation of the resection margins with reduced oncologic accuracy and safety. In our opinion, the robotic approach has some clear advantages compared with a conventional thoracoscopy. In fact, a lesser manipulation of the thymic and perithymic tissues is required during the operation, and a better evaluation of the healthy tissue as a result of the high-quality images leads to a more precise, lower risk dissection with wide safety margins and the reduced possibility of tumor breaching, incomplete resection, or iatrogenic injury. The use of carbon dioxide inflation (usually 8–12 mmHg) during the operation is another advantage, which allows enlargement of the mediastinal space with better visualization. The lack of tactile feedback could, theoretically, increase the risk of damaging the tumor tissue; however, this disadvantage appears to be compensated for by the superior three-dimensional visual control of the system.

We will now introduce Dr. Rückert’s approach [42] and our preference for an R-VATS thymectomy. The approaches of R-VATS thymectomy through the right or left can be chosen based on the surgeon’s preference:

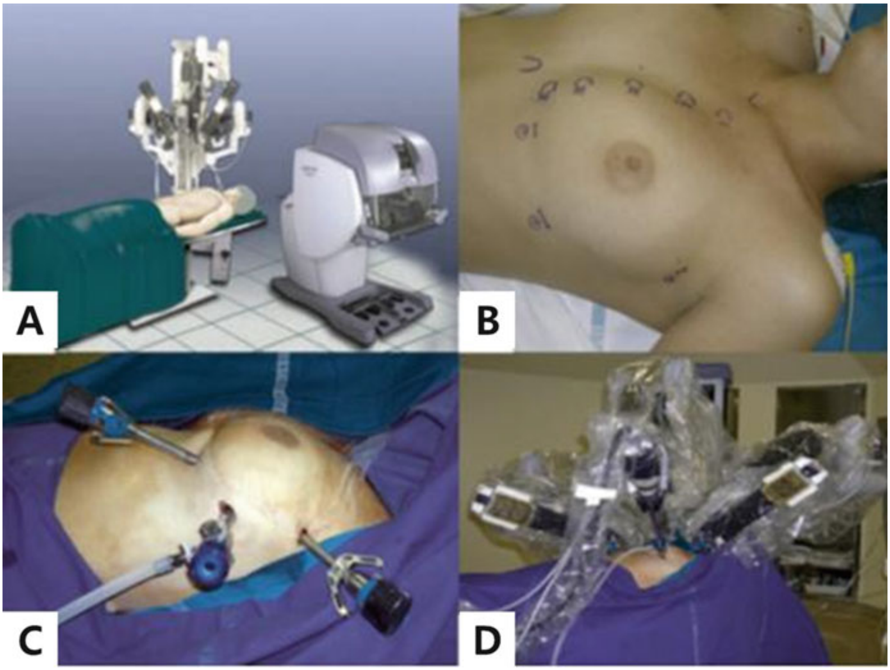

Fig. 11.9 Port placement and patient position during an R-VATS thymectomy (*left approach*). (**a**) In the surgical room, the patient is positioned supine on the surgical table with the left side elevated at 30°. The left arm is flexed on a support to expose the axillary region. The *da Vinci* robotic system with the surgical cart and the surgeon's console is displayed. (**b**) Before surgery, the fifth and third intercostal spaces (incision sites for port placement) are identified. The thoracic ports are placed, (**c**) and the arms of the robot are then attached to the ports and are operative. (**d**) Conflict between the arms should be avoided (Reprinted from [42] with permission from Elsevier)

1. **R-VATS thymectomy with a preference for the left approach by Dr. Rückert [42].** Dr. Ruckert and colleagues prefer the left approach in the left side upward position at a 30° angle using a bean bag. He uses the 0° 3D thoracoscope introduced through a 15-mm incision in the fifth ICS on the mid-axillary line. Care is taken when operating on the left side to avoid the heart, which lies just beneath this area. Thus, under camera vision and CO_2 insufflation to turn away the heart, two additional thoracic ports are inserted: one in the third ICS on the mid-axillary line and another in the fifth ICS between the parasternal and mid-clavicular lines. In women, three ports are lined along the submammarian line and its imaginary extension line to the axilla (Fig. 11.9).

   They prefer a left-sided approach for technical, clinical, and anatomical reasons. First, the left lobe of the thymus gland is usually larger and extends down to the pericardiophrenic area. The aortopulmonary window and the region below the left innominate vein are frequent sites of ectopic thymic tissue. In addition, by using the left-sided approach, they can easily demonstrate the right phrenic nerve to control complete resection [42].

The right-sided approach is reserved mainly for tumors located on the right side.

2. **R-VATS thymectomy with a preference for the right-sided approach.** Despite the several merits of the left approach used by Dr. Rückert, routine left approaches may be avoided due to the fear of heart injury by the trocars and robotic instruments. The approach is instead decided by the tumor location. If the tumor deviates to the right, the right approach is selected; if the tumor deviates to the left, the left approach is selected. If the tumor is located at the midline, the right approach is selected because the right thoracic cavity is larger with minimal chance to injure the heart. In addition, the pericardium might be simultaneously resected for the en bloc resection of the tumor. However, a one-sided approach is insufficient to perform LN dissection and remove the cardiophrenic fat pad on the contralateral diaphragm. Frankly speaking, a one-sided approach can remove approximately two-thirds of the contralateral pericardial fat tissue. Therefore, for a total thymectomy, we prefer a bilateral approach using hybrid techniques (VATS and R-VATS).

   First, in the contralateral side without the tumor, a 5-mm thoracoscope is used with two 5-mm thoracoscopic instruments under CO_2 insufflation (VATS phase). In the supine position with the left side slightly raised, cardiophrenic pericardial fat pad dissection is performed, and the phrenic nerve is identified and marked with clipping around the nerve, which is necessary to examine the margin of dissection from the contralateral approach. The 5-mm ultrasonic device is useful. During VATS, the upper part dissection can be skipped because the dissection of both upper parts of the thymus can be easily performed with R-VATS. During the dissection of the upper part of the thymus, the contralateral phrenic nerve can be identified. On the left side, the paraaortic and subaortic LNs are detached from the pericardium and the phrenic nerve; however, these are extracted during R-VATS from the right side. Three 5-mm stab wounds remain without chest tube insertion.

   For R-VATS thymectomy (R-VATS phase), a patient is turned to the lateral decubitus position. The port placement is the same as that in an R-VATS lobectomy. A robotic thymectomy with four arms is performed. The fourth arm is very useful to press the lung parenchyma and innominate vein and to retract the SVC. After all procedures, a utility incision is made to retrieve the tumor specimen. For the retrieval of the tumor, a strong plastic bag is needed. A chest tube is inserted on the R-VATS side.

11.3.2 Posterior Mediastinal Tumor

Neurogenic tumors are the most common posterior mediastinal tumor. Neurogenic tumors located on the mid or lower portion of the thorax are easily excised with VATS or R-VATS. The merit of R-VATS is remarkable during the removal of the neurogenic tumor in the upper portion. Even a posterior tumor in the apex is approachable with a robotic system, saving sympathetic chains. Robotic magnification is likely

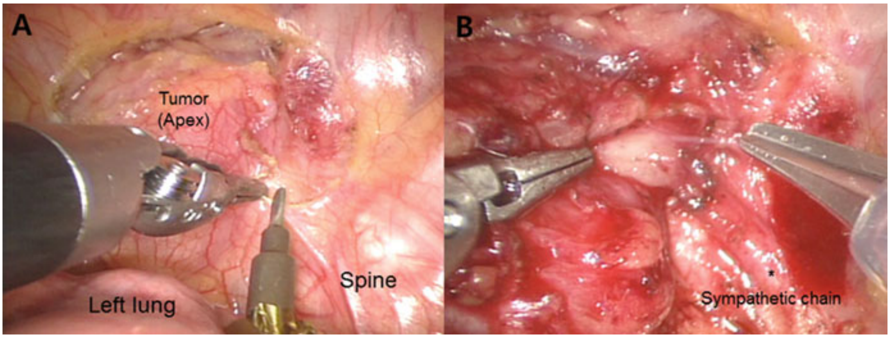

Fig. 11.10 R-VATS excision of a mediastinal tumor in the left apex in a child. In a child, robotic surgery can be performed under bilateral ventilation with intrathoracic CO_2 insufflation

more helpful to prevent Horner's syndrome compared with VATS or an open thoracotomy.

The port placement is the same as that in an R-VATS lobectomy with four arms. R-VATS with three arms can be applied to pediatric cases. R-VATS with three arms with CO_2 insufflation can provide enough space to excise the mediastinal tumor under bilateral lung ventilation with diminished tidal volume (Fig. 11.10).

11.4 Summary

Leonardo da Vinci said, "Simplicity is the ultimate sophistication." During the setup of robotic surgery in the field of thoracic surgery, we have simplified and standardized the port placement and the use of the instruments. Therefore, lung cancer and mediastinal tumors can be managed with the same port placement and instruments. Even for esophageal cancer, a thoracic phase with intrathoracic anastomosis can be performed with the same port placement.

One of the most important aspects of the R-VATS is the depth and accuracy of the hilar and mediastinal nodal dissections. R-VATS provides articulated movement, elimination of physiologic tremor, and a three-dimensional view of the limited space through a small incision. Another strong benefit of robotic surgery is the stable camera platform, which is held by the robotic arm. Because minor movements of the camera can result in image movement, the capacity to provide a steady image is an important benefit of robotic surgery. These merits facilitate LN dissection by enabling more precise instrument movements around the vessels. We found that the dissection of the LNs around major vessels was easier with a magnified three-dimensional view and articulated. These advantages could prevent injury to several nerves, such as the pulmonary and cardiac branches of the vagus nerve. Robotic surgery represents an easy way to expand the indications of MIS towards advanced lung cancer.

From the perspective of the patient, concrete and statistical data are lacking; nevertheless, because the robotic surgeries are performed in a stable setting, postoperative recovery is easier. The magnified operative field and ability to control the surgical view resulted in a low conversion rate related to the experience and dexterity of the surgeon and reduced trauma to the heart and lungs during the robotic surgery, which might be related to the decreased rate of postoperative morbidity.

There is little comparative evidence from randomized controlled trials, and any outcomes from such study designs are affected by variations in surgeon training and experience, which is difficult to assess and adjust for statistically. Consequently, the influence of intra-surgeon technical heterogeneity may outweigh the differences in the surgical approach. However, population-based, observational studies have demonstrated fewer complications for robotic-assisted procedures, such as a pulmonary lobectomy, than those without robotic assistance. The results of this systematic review suggest that R-VATS is feasible and can be performed safely for selected patients in specialized centers [30]. The perioperative outcomes, including postoperative complications, were similar to historical accounts of conventional VATS [14].

In general, robotic surgery has been reported to require more time than thoracoscopic or conventional open surgery. The prolonged operation time is caused by the additional setup time required for the robotic arms. The time spent docking and setting up the robotic arms, which is the main reason for the time delay in other reports, decreases with experience [8, 14, 18]. Robert McKenna suggested that the time limit for the VATS procedure of approximately 3 h in general should be set in advance so that the general anesthesia is not excessive [44]. However, the console time was reduced to less than 3 h after 60 cases based on our series. After achieving the learning curve, the operative times for a robotic lobectomy are comparable with those for a VATS lobectomy.

The lack of tactile feedback could result in excessive pressure and stress on fragile intrathoracic structures. Robotics removes the surgeon from the field and requires a highly trained assistant in the operative theater. These factors necessitate a highly organized and rehearsed approach to the operation, especially in the event of complications such as catastrophic bleeding. In the beginning, we had used three incisions, similar to VATS lobectomy [14]. We used three arms to keep the same number of ports as in VATS lobectomy. However, this approach depends on the experience of the assistant. The use of four arms allows less dependence on the assistant. The role of the assistant is merely to perform the suction, use the endostaplers, and remove the specimen. Four-arm robotic surgery requiring more spatial conception must be performed by a experienced surgeon with the three-arm version of the technique.

Park et al. reported that the cost of open thoracotomy for lung cancer in the USA was high due to the longer hospital stay than that required by VATS or robotic surgery [45]. VATS was the least expensive option. However, this issue depends on each country's insurance system. For example, in Korea, as the reimbursement system is supported by the National Health Insurance system, an open thoracotomy is the least expensive option, despite the extended hospital stay, due to the 95 % reimbursement to cancer patients. The total hospital costs are similar between VATS and robotic surgery, approximately US$11,000. However, there is no reimbursement for the robotic operation from the reimbursement system. Patients who undergo robotic surgery have to pay all costs, which amount to approximately US $10,000. The decision to pursue a particular surgical method is therefore a reflection of socioeconomic status. The excessive costs urge close scrutiny of the benefits of robotic surgery with respect to the patient and the surgeon as well as social and hospital-related considerations.

Robotic surgery is the starting point in the field of thoracic surgery. However, surgeons are enthusiastic about the outstanding merits of the robotic system, which differ from those of VATS. Robot-assisted surgery may provide a good alternative to conventional open or thoracoscopic surgery for lung cancer, provided that the cost-effectiveness and long-term prognosis are confirmed.

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