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The State of the Art in Thoracic Surgery: Treating Lung Cancer Between Tradition and Innovation

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Abstract: Lung cancer is the second most diagnosed cancer and was the primary cause of cancer death worldwide in 2020. Lung cancer treatment is associated with huge costs for patients and society. Consequently, there is an increasing interest on prevention, early detection with screening, and development of new treatments. Surgical management accounts for at least 90% of the activity of thoracic surgery departments. Surgery is the treatment of choice for stages I and II non-small cell lung cancer. In this chapter, we discuss the state of art of thoracic surgery for surgical management of lung cancer. We start describing the milestones of lung cancer treatment, lobectomy, and lymphadenectomy, followed by a description of the traditional and innovative approaches that are currently available. Open lobectomy, and mini-invasive approaches including video-assisted thoracoscopic surgery and robotic assisted thoracoscopic surgery

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are covered. A brief overview of the innovation and future perspective in thoracic surgery are presented.

Keywords: lobectomy for lung cancer; non-small cell lung cancer; thoracic surgery for lung cancer; video-assisted thoracoscopic surgery; robotic-assisted thoracoscopic surgery

INTRODUCTION

With an estimated 2.2 million new cancer cases and 1.8 million deaths, lung cancer is the second most diagnosed cancer and was the primary cause of cancer death worldwide in 2020 (1). These epidemiological data explain the growing interest in prevention, early detection by screening programs, and development of new treatments for lung cancer (2–4). The surgical treatment of lung cancer is based on accurate diagnosis and staging. Whereas small cell lung cancer (SCLC) is rarely treated by surgery, patients affected with early-stage non–small cell lung cancer (NSCLC) typically undergo curative surgical resection (5). In this chapter, we discuss the state of art of thoracic surgery in the surgical management of early-stage NSCLC. We begin with the principles of surgical therapy followed by various procedures, including, lobectomy and lymphadenectomy (6). We then describe the different approaches developed from classical thoracotomy, and their advantages and disadvantages. Since the first lung resection for a tumor in 1861 by Pean, thoracic surgery has evolved considerably. With the advent of technological innovations, beside traditional thoracotomy, several mini-invasive approaches have been developed to improve short-term outcomes and minimize pain, while maintaining the same oncological outcomes. The most common mini-invasive approaches are video-assisted thoracoscopic surgery (VATS) and robotic assisted thoracoscopic surgery (RATS). We discuss several aspects of these mini-invasive approaches and conclude the chapter with a brief overview of the future perspectives in thoracic surgery.

PRINCIPLES OF RESECTION SURGERY

One of the most important and apparently banal principles in oncological lung thoracic surgery is the multidisciplinary discussion of surgical cases. Lung cancer care should only be performed in lung cancer units or centers with a multidisciplinary team, and an extensive pool of healthcare professionals dedicated to lung disease. Several studies have shown that the best oncological outcomes are directly associated with multidisciplinary approaches (7). Another principle that should be respected in lung cancer surgery is related to the surgical and hospital volume. Several studies have shown that patients undergoing NSCLC resection in hospitals that perform a large number of such procedures survive longer than patients who undergo such surgery in hospitals with a low volume of lung resection procedures. Likewise, the number of procedures performed by the surgeon is an important factor capable of predicting a better surgical outcome (8). Thus, only thoracic surgeons who perform lung cancer surgery in highly specialized centers should be involved in this surgery.

For patients affected by stage I or II NSCLC, surgical resection should be proposed as the treatment of choice (9). In 1962, a landmark paper comparing case series of pneumonectomy and lobectomy for treating a bronchogenic carcinoma showed that survival after lobectomy was equivalent to pneumonectomy with fewer complications (10). Since then, lobectomy for NSCLC has become the gold standard anatomic resection. Sub-lobar resections such as segmentectomy or wedge resection should be performed in patients with poor pulmonary reserve or other major comorbidity that contraindicates lobectomy, or peripheral nodules ≤2 cm presenting with specific characteristics (pure ais histology, ≥50% ground-glass appearance on CT or a long doubling time [≥400 days] confirmed by radiologic surveillance). Current guidelines recommend lobectomy as the standard for NSCLC in patients who can tolerate the size of lung resection (6).

However, some surgeons prefer sublobar resection (SLR) for treating lung cancer and a knowledge gap remains regarding the suitability of segmentectomy in stage I NSCLC patients. Several retrospective studies have demonstrated that SLR (wedge resection or segmentectomy) is equivalent to lobectomy for early-stage lung cancer even in patients with good pulmonary function (11–12). Although the retrospective cohorts and meta-analyses found predominantly no difference in overall survival or disease-free survival in sub-centimeter tumors, this finding is yet to be convinced for tumors >1 cm and <2 cm in size. To provide evidence for the role of SLR in comparison to lobectomy, two prospective randomized, trials are currently being performed (JCOG0802/WJOG4607L; CALGB/Alliance 140503) (13). In summary, definitive management of lung cancer for cure necessitates anatomical resection of the entire involved lobe with hilar and mediastinal lymph node dissection in the patient who has cardiopulmonary reserve to tolerate the resection.

LYMPHADENECTOMY

Adequate intra-operative lymph node sampling (LNS) is a fundamental part of NSCLC surgery. All surgical studies advocate the need for correctly dissecting the LNs; the role and the extension of the lymphadenectomy is currently included in surgical guidelines (14). An accurate mediastinal staging is mandatory for prognostic reasons as well as to determine the need for adjuvant therapies given the possibility of recurrence of occult pathologic nodal disease (pN+) (15). According NCCN guidelines, hilar (N1) and mediastinal (N2) node resection and mapping should be routine components of lung cancer resections. A minimum of three N2 stations should be sampled, or a complete mediastinal lymph node dissection (MLND) should be performed (6). Historically, a complete MLND has been routinely performed as part of the surgical procedure at the beginning of NSCLC surgery. Over the years, MLND has been progressively replaced by LNs sampling due to the fear of increasing the operative risks of the surgical procedure (16). Several studies showed that patients randomized to complete MLND have little added post-operative morbidity compared with those undergoing random-LNS, and generally, MLND does not increase the length of hospital stay (17).

Interestingly, several studies have shown that about 15% of pN+ patients had mediastinal LN metastasis that did not follow a lobe-specific lymphatic drainage. This occurrence justifies a radical dissection of mediastinal nodes to avoid misdiagnosis of metastatic nodes in non-lobe-specific lymphatic stations (18). To conclude, in our opinion, performing a complete MLND is relatively harmless and low risk, and remains the best "sampling" in clinical stage I NSCLC to correctly stage the patients, offer them an evidence-based adjuvant therapy, and a R0 resection.

OPEN SURGERY

Lobectomy is defined as the surgical removal of the entire lobe of the lung. The first lobectomy was described in 1913 (19), but the patient died one week later due to a postoperative infection. Over time, the surgical skills got refined, and with improvement in anesthesia techniques and infection control, lobectomy became more prevalent with better outcomes. Traditionally, lobectomy has been performed through a thoracotomy approach. The outcome of the procedure is largely dependent on patient selection. Patients with forced expiratory volume in 1-second (FEV1) less than 800 cc or diffusion capacity of carbon monoxide (DLCO) less than 40% are considered high-risk patients. In these patients, as mentioned above, sub-lobar resection or non-operative therapy should be proposed (9).

Rib-spreading thoracotomy has been the standard procedure since the first endeavors in thoracic surgery. For conventional lobectomy procedures, a rib retractor (the Finochietto retractor) is the mainstay surgical tool (20). Thoracotomy provides excellent exposure of the pulmonary hilum and allows direct two-handed surgical techniques for exposure, retraction, and sharp dissection. Different sites of skin incision to access to the pleural cavity have been standardized by different surgical groups.

Posterolateral thoracotomy is the historic gold standard of thoracic incisions, offering an excellent exposure for most general thoracic procedures. Posterolateral thoracotomy requires the patient to be positioned in the lateral decubitus position (Figure 1A). Once the patient is properly secured to the operating table, the ipsilateral arm is raised and positioned anteriorly and cephalad to rest above the head. However, it requires transection of large muscles (latissimus dorsi and serratus anterior in addition to the intercostal muscles). The most important advantage of the posterolateral approach is to offer an optimal exposure of all-important structures allowing penetration of the thorax at any level between the 3rd and the 10th rib. The disadvantages of this approach include the division of the major muscles of the chest, resulting in increased potential for blood loss and a significant time requirement for opening and closing the incision, as well as prolonged ipsilateral shoulder and arm dysfunctions, compromised pulmonary function, and chronic post-thoracotomy pain syndromes. About 40% of patients had troublesome chronic chest pain for several years after undergoing a posterolateral thoracotomy and more than 60% required analgesia for pain for one month after surgery (21). Over time, muscle-sparing variants have been introduced to minimize post-operative pain and to limit functional dysfunctions due to muscle transection.

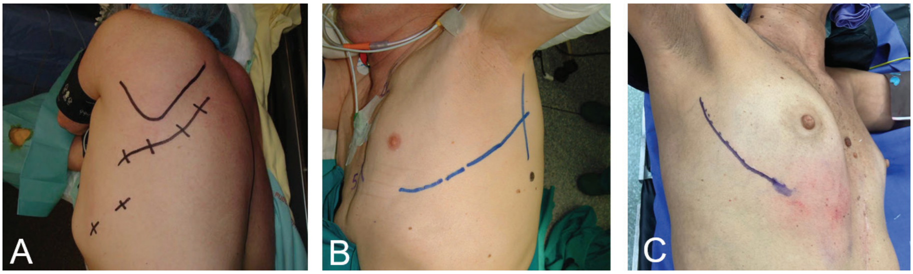

Figure 1. Different approaches to thoracotomy. A, Posterior: it extends from a point located at 3 inches from the mid-spinal line to the anterior axillary line, thus passing below the tip of the scapula. **B,** Lateral: a horizontal line passing below the tip of the scapula to the sub-mammary fold. **C,** Anterior: it begins in the fourth or fifth interspace at the lateral edge of the sternum and curves along the sub-mammary crease to the anterior axillary line.

The first muscle to be spared was the serratus anterior by performing an incision in the so-called fatty triangle along the inferior border of the rhomboideus and the posterior border of the serratus face avoiding its transection. Then, two additional muscle-sparing variants were described allowing to preserve latissimus dorsi. In the partial variant, only the posterior part of the latissimus is severed from back to front until the posterior border of the serratus is reached, while in the complete variant, the serratus is completely preserved thanks to a careful and generous subcutaneous dissection. The principal disadvantages of muscle-sparing techniques are related to the significant limitation of the exposure and the surgical field, requiring longer real surgery time to dissect the mediastinum and to perform lymphadenectomy. Therefore, many surgeons prefer not to use these approaches when chest wall resection or difficult hilar dissection are anticipated; instead, they advocate muscle-sparing only for minor resections (segmentectomies, wedge resections) or 'simple' lobectomies (22).

Lateral thoracotomies include many variants with a common goal—an intercostal incision. To perform this incision. the patient is placed in a lateral position, with a soft rotation of the coxa (15 to 20°) towards the surgeon (behind the patient) (Figure 1B). The homolateral arm is placed on a padded armrest without any tension and with a softly flexed elbow. Though large, this incision is a muscle-sparing thoracotomy because the latissimus dorsi muscle integrity is preserved. Described in 1988 (23), the advantage of lateral thoracotomy is an excellent exposure, even for such extended procedures as sleeve resections of the bronchi or intrapericardial pneumonectomy (24). The lateral position permits the best access to the hilus structures which may be approached by either the anterior or the posterior route. It is a safe procedure, and the preservation of a potential muscle flap (latissimus dorsi) can be useful in cases of postoperative complications. The disadvantage of this incision is that an extension to the upper ribs cannot be safely performed using this approach.

An anterior approach to the pleural cavity has also been described for all types of major pulmonary resections. The patient will need to be positioned with their ipsilateral side elevated approximately 30 to 45 degrees and the ipsilateral arm at the patient's side (Figure 1C**)**. Electrocautery is then used to divide the pectoralis major muscle and serratus anterior muscle. The thoracotomy incision is usually made either in the fourth or fifth intercostal space along the superior border of the inferior rib (25). Anterolateral thoracotomy is our preferred approach for oncological lung surgery. It provides excellent access to upper lobe, the right middle lobe, and the anterior hila. It can be extended across the sternum into the opposite chest (clamshell incision) or prolonged longitudinally through the sternum to achieve a sterno-thoracotomy in challenging cases. Another advantage of this incision is allowing the patient to remain supine avoiding compression of contralateral lung by mediastinum. Furthermore, cosmetic results are superior to a posterolateral thoracotomy. On the other hand, the exposure to the posterior pleural space is more limited than with a posterolateral thoracotomy. Thus, for procedures requiring excellent posterior exposure, this incision should be avoided.

In performing any kind of thoracotomy, it is important choosing the most appropriate and least traumatic surgical incision, adhering to meticulous surgical techniques, and avoiding intercostal nerve injury or rib fractures. Unfortunately, in all these described incisions, rib fracture is a common occurrence. For this reason, for performing the described thoracotomies, the rib spreader should be slowly and progressively opened, to minimize the risk of fracture. To prevent fracturing, the ribs may be intentionally divided or "shingled" posteriorly at the costovertebral angle or anteriorly at costochondral articulations, depending on the type of performed thoracotomy (26).

In conclusion, the first principle in making a thoracic incision is that adequate exposure must be achieved, especially during the most technically challenging part of the operation. The second principle is that chest-wall function and appearance should be preserved to the extent possible. The choice of incision is aided by a thorough understanding of the surface anatomy and a comprehensive review of the radiographic images that are obtained preoperatively. Finally, independent of the chosen approach, the oncological results after anatomical open lobectomy for the early-stage NSCLC are good. The completeness of resection, stage, and lymph node involvement are the primary predictors of survival after resection. The 5-year overall survival rate is between 73.8% and 78.9% (27). Furthermore, open lobectomy is usually associated with a significant risk of postoperative complications occurrence. Up to 35% of patients may experience some form of postoperative complication after an open lobectomy. The most common of these are minor and include atrial arrhythmia and prolonged air leak, but more serious complications including respiratory failure and decreased baseline pulmonary function can occur. The operative mortality following lobectomy is reported to be 1–3%, with pneumonia and respiratory failure as the overwhelming causative factors (28). Currently, more stage I NSCLC are treated by open lobectomy but in the coming years mini-invasive approaches probably will overcome this traditional approach.

VIDEO-ASSISTED THORACOSCOPIC SURGERY (VATS)

Rib-spreading thoracotomy has been the standard procedure since the first attempts in thoracic surgery. However, many studies have reported a higher incidence of morbidity and less favorable outcomes when compared with non-rib-spreading procedures (29). The neuralgic pain caused by irritation of the intercostal nerves, which is naturally exacerbated by rib spreading, is the leading cause of postoperative morbidity after thoracotomy. It usually leads to poor respiratory effort and subsequent atelectasis or pneumonia. The advantages of non-rib-spreading technique are the reduction of acute postoperative pain and the requirement of less analgesics; a higher proportion of patients present very low postoperative pain profile. Furthermore, several studies have confirmed a reduction in the occurrence of chronic pain and long-term better quality of life (30).

VATS is a non-rib spreading thoracic procedure. It differs from the traditional mini- thoracotomy by the lack of rib spreading, and complete thoracoscopic visualization as opposed to visualizing the procedure directly through the incisions (31). The initial thoracoscopic procedures were reported in the early 20th century (32) but widespread use of the VATS technique did not occur until improvements in video technology and the introduction of double-lumen endotracheal tubes to facilitate single lung ventilation in the 1980s. The first VATS lobectomy reports emerged in the 1990s, documenting safety and outlining technical aspects of the approach (33). The VATS approach to lobectomy for NSCLC typically involves a varying number of small incisions (two to four port sites) and a 5- to 8-cm access incision (also defined utility port).

The basic equipment needed to perform a VATS lobectomy are a video system, a 10 mm 30-degree video-thoracoscope, a light source power, energy dissection devices, vascular clips, curved-tipped endoscopic staplers, plastic endobag, wound protectors for the utility port, and 10 mm trocars. Long instrumental is essential to reach the hilar structures and to perform blunt dissection (34). The introduction of the mechanical surgical stapler was a crucial discovery in the development of minimally invasive surgery. This technology enabled surgeons to securely divide pulmonary parenchyma, bronchi, and vessels through small incisions (35). Various approaches to perform VATS lobectomy have been reported in literature. They can be summarized as three ports anterior or posterior approach, two ports approach, and uniport VATS lobectomy (Figure 2).

The Copenhagen anterior approach involves the use of an anterior utility incision at the 4th intercostal space anterior to latissimus dorsi muscle and two lower incisions (Figure 2, A) (36). During this procedure, the structures are usually divided from anterior to the posterior. The major advantages of the standardized anterior approach are: (i) the utility incision is directly over the hilum and the major pulmonary vessels, allowing to easily clamp the major vessels in case of the major bleeding; (ii) the surgeons do not need to change their position or the site of incision if a conversion is required; and (iii) major vessels are the first structures to be transected (IV) reproducibly (36).

The Edinburgh posterior approach was reported by Richards et al (37). The main advantages of this approach are the easy access to posterior hilum including the bronchial branches and the pulmonary arteries, a better visualization of lymph nodes, and a safer dissection due to the tips of the instruments coming towards the camera. In contrast to the anterior approach, the main differences of this technique include: (i) the surgeons are placed posterior to the patient; (ii) utility incision is made at the 6th or 7th intercostal space anterior to latissimus dorsi muscle, instead of the 4th intercostal space; (iii) camera port is made through the auscultatory triangle, instead of lower anterior incision; (iv) thorascoscopy is 0^{o} rather than 30^{o}; and (v) the order of dissection is from the

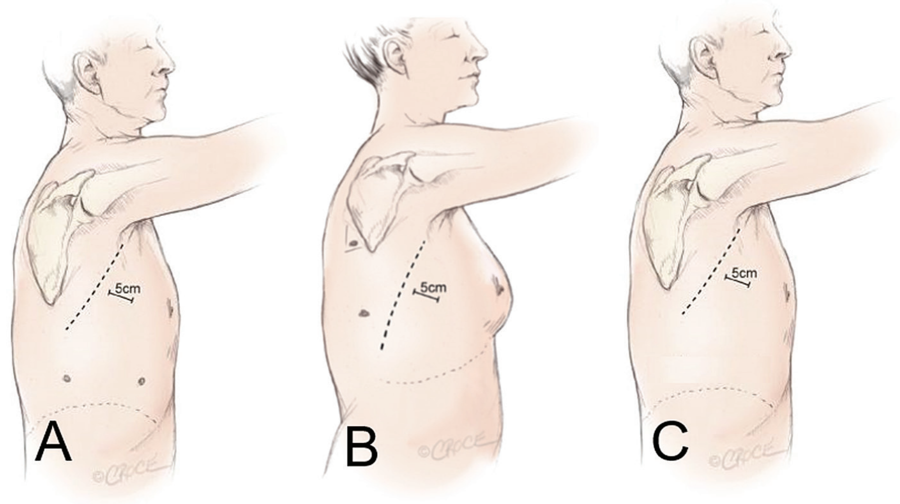

Figure 2. Different VATS approaches. A, Copenhagen three ports anterior approach. **B,** Edinburgh three ports posterior approach. **C,** Gonazales-Rivas uni-portal anterior approach.

posterior to anterior, by opening up the fissure first to identify and isolate pulmonary arterial branches (Figure 2, B).

Other VATS approaches that merit mention is the D'Amico approach that has reported the largest series to date in double-port anterior VATS (Figure 3) (38), and purely thoracoscopic lobectomies with a mini-thoracotomy only for extraction of the lobe (39). However, the posterior VATS approaches are not widely performed, and most centers use a utility incision measuring about 3–5 cm, generally positioned anteriorly, with one or two adjunctive ports (Figure 3) (40).

Independently of the chosen approach, VATS lobectomy is the same oncologic operation as the open approach, with removal of the pulmonary lobe containing the tumor with individual ligation of each of the bronchovascular structures and removal of hilar and mediastinal lymph nodes. Numerous large series have reported recurrence and survival data that are equivalent to open lobectomy. Furthermore, most large series of lobectomy by VATS describe a similar pattern of perioperative complications as the open approach but at reduced rates (41). Other consistent demonstrated advantages of VATS lobectomy over open lobectomy are early recovery, better quality of life, increased delivery of adjuvant therapy, less impact on pulmonary function tests and the immune system, decreased pain, and reduced length of hospital stay (42).

Thus, according to the NCCN guidelines, VATS, or minimally invasive surgery (including robotic-assisted approaches) should be strongly considered for patients with no anatomic or surgical contraindications, as long as there is no compromise of standard oncologic and dissection principles of thoracic surgery (6). VATS lobectomy for the treatment of early-stage NSCLC gained the 'grade 2C' recommendation as a preferred technique over open surgery by the

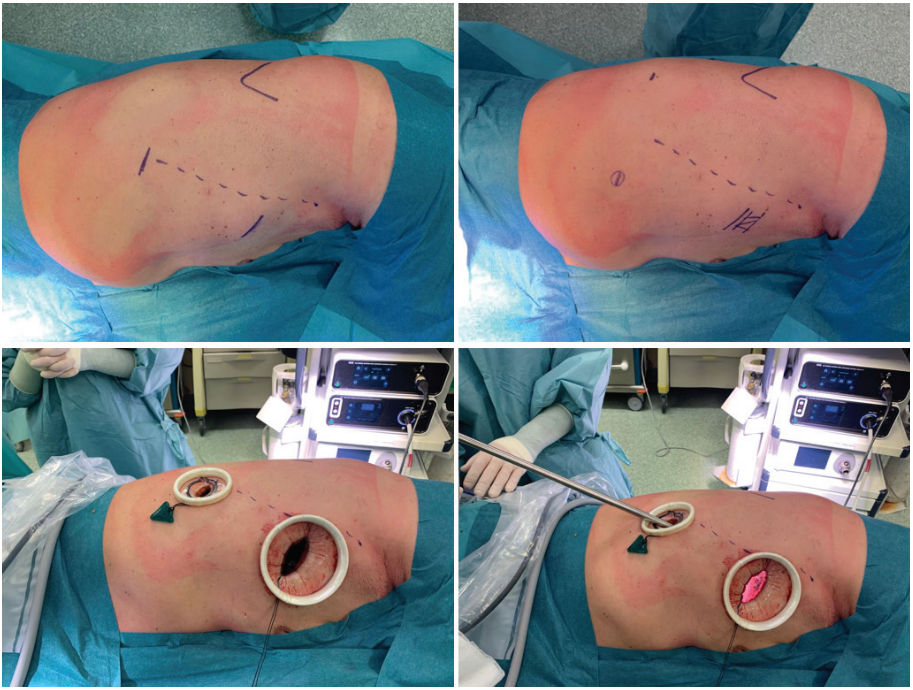

Figure 3. VATS lobectomy. Our anterior VATS lobectomy approach performed by using a utility incision on IVth intercostal space and a 10 mm port.

American College of Chest Physicians evidence-based guidelines in 2013 (43). However, despite the undoubted advantages, VATS lobectomy has not been adopted widely. For example, it is currently estimated that VATS lobectomy rate is 30–40% in the USA, 30% in Europe, 50% in Italy, 65% in Denmark, and 29% in Great Britain and Ireland (44).

ROBOTIC-ASSISTED THORACOSCOPIC SURGERY (RATS)

The introduction of RATS is undoubtedly the most recent significant addition to the field of thoracic surgery that, as “innovative technological bomb”, has changed the entire paradigm of the traditional approach to surgery. Early experience with da Vinci robots (Intuitive Surgical, Sunnyvale, CA, USA) showed that this minimally invasive approach is feasible and safe (45). The results of RATS are comparable to VATS but, at the same time, provide several advantages compared to VATS. Similar to VATS, RATS allows anatomical thoracic resections through smaller non-rib-spreading incisions resulting in less operative trauma for the patient. At the same time, it provides several advantages, which are typical of robotic surgery. The binocular visualization allows an excellent high-definition, three-dimensional view of the operating field. It allows a fine dissection with precision and accuracy in a surgery where safe and careful dissection is essential. Several surgical groups have developed totally portal robotic procedures that do not need a utility incision reducing a possible source of pain. During this procedure, the capnothorax (insufflation of carbon dioxide in the hemithorax), favoring further collapse of the lung, provide a larger working area. The attached instruments to robot arms overcome several technical limitations of VATS due to the poor maneuverability of the straight rigid instruments through the rigid chest wall. Robotic instruments have a greater precision, a superior range of motion (degrees of freedom), and improved ergonomic characteristics compared to VATS instruments. Motion scaling and zoom capabilities allow dexterous dissection and manipulation in a small, confined space. Several authors have also described the use of the robot for more advanced and challenging cases such as sleeve resections or segmentectomies (46).

The current approach for a robotic lobectomy consists of similar lateral decubitus positioning as the open, or VATS approach. The main difference compared to open, or VATS lobectomy, is that during a RATS procedure, the surgeon is not at the bedside and not even sterile. It controls a three-dimensional high-definition camera and instruments that can fit through 8-mm ports from a console that is remote from the patient (Figure 4) (45). A robotic system was used for the first time in performing a lobectomy for treating primary NSCLC in 2002 (47). From this first report, which has demonstrated the feasibility of the procedure, several surgical series have confirmed that this minimally invasive approach is safe.

Similar to VATS, several different techniques of RATS lobectomy have been described, which can be summarized into two groups: without insufflation with a utility thoracotomy or completely portal with carbon dioxide insufflation (capnothorax). The first are hybrid procedures in which the use of a utility thoracotomy does not allow the use of carbon dioxide insufflation. In 2006, Park et al. reported a three-port RATS technique where the port positions were similar to that used by the anterior VATS. They described a technique approach with a utility incision of 3–4 cm in the IV intercostal space on the mid axillary line, and two more trocars for the camera port and for the second instrument (48). In 2011, Veronesi et al. described a modified RATS technique with the use of 4 robotic arms with a 3 cm utility incision (49) (Figure 4, C). The second group of procedure are characterized by the complete portal approach with induction of capnothorax. Cerfolio reported in 2011 a four-arm completely port-based robotic lobectomy technique (CPRL), by using CO_2 insufflation. In this technique, the four arms were positioned along the same intercostal space (usually the 7th), between the mid-axillary and paravertebral lines with no utility incision (50). From this initial experience, several Cerfolio-modified techniques have been described and are routinely adopted today (Figure 4 D).

During RATS lobectomy, independently of the technique adopted, the hilar and fissural dissection is similar to that of VATS and open approaches. The bronchovascular structures are dissected and individually divided with staplers, as with other approaches. The stapler is usually introduced by utility incision or by assistant's port. Finally, the specimen is generally removed from the chest through the utility incision or the assistant's port when completely port-based robotic lobectomy is performed. In the latter case, it needs to be widened to permit egress of the specimen from the chest after the entire operation is conducted with small port incisions (46).

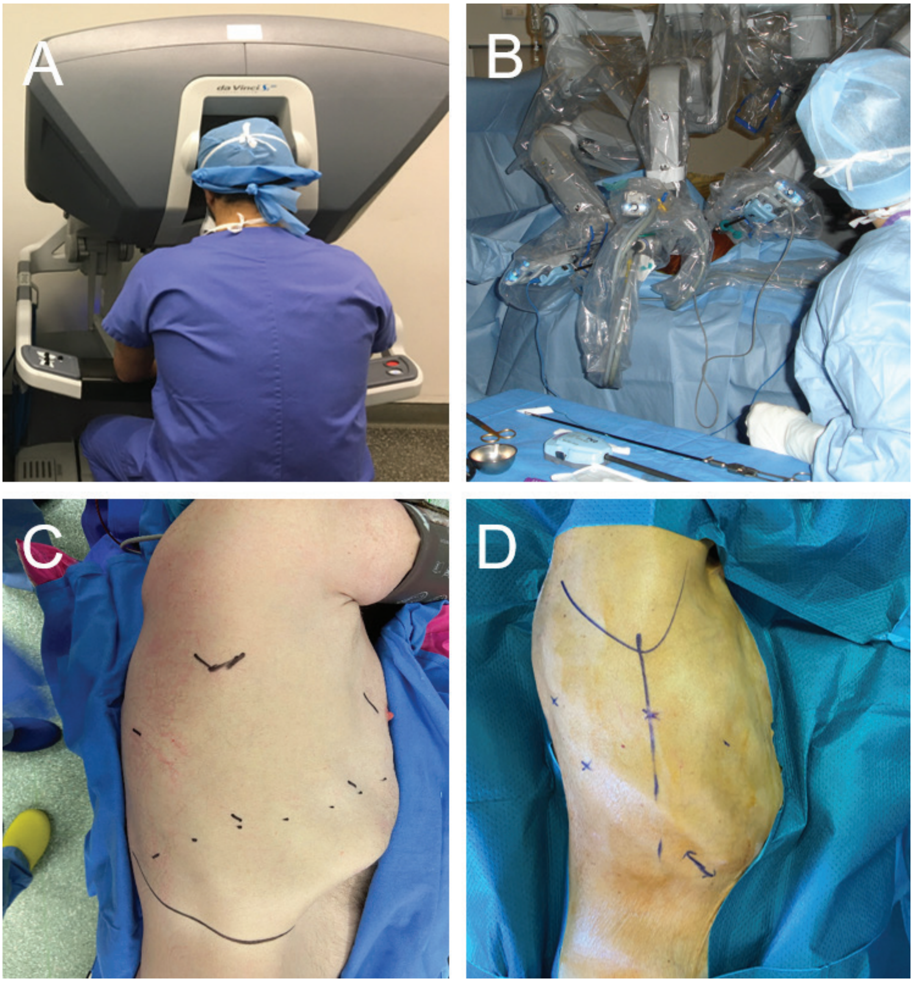

Figure 4. RATS lobectomy. **A,** Surgeon sitting in console. **B,** Surgical filed during RATS lobectomy. **C,** Veronesi approach, without CO_2 insufflation and with a utility mini-thoracotomy on 4^{th} intercostal space. **D,** Total endoscopic portal approach. In this case, the utility port is finally enlarged to remove surgical specimen from the chest cavity.

To date, no randomized controlled studies have compared the different surgical approaches of lung surgery: thoracotomy, VATS, and RATS. Most of the current data is based on case series and comparisons to historical cohorts or databases. Initial series of patients undergoing robotic lobectomy for NSCLC demonstrate safety, feasibility, and similar morbidity and mortality rates compared with open lobectomy or VATS approaches (51). A recent prospective international randomized control trial compared the perioperative outcome and surgical radicality of the robotic approach with those of traditional video-assisted surgery in the treatment of early-stage NSCLC. The results of this trial demonstrated that RATS was not superior to VATS considering the perioperative outcome for early-stage NSCLC, but the robotic approach allowed an improvement of lymph node dissection (52). Concerning the oncological benefits of robotic surgery, longer follow-up data are needed; however, initial reports show comparable stage-specific survival rates between the VATS and robotic approaches (53).

The limitations to the widespread use of robotic surgery are the demanding learning curve and the high costs associated with the procedure. Also, a higher level of evidence based randomized trials are required to justify widespread adoption. On the other hand, it has been demonstrated in several studies that, in comparison with open thoracotomy, robotic approach appears to have an overall cost benefit due to the significant decrease in length of hospital stay (45). It is estimated that, in 2015, approximately 15% of the lobectomies were performed with a robotic system in the USA (54).

INNOVATION AND FUTURE PERSPECTIVE IN THORACIC SURGERY

Several innovations have been recently introduced and will be developed in the coming years. These technological waves probably will favor the wide-spread use of robotic surgery. The introduction of robotic endowrist staplers was the biggest innovation that has been made in the field of robotic surgery. Stapler division of the hilar structures is considered one of the most important and potentially hazardous steps during a lobectomy. For example, with the Si Da Vinci system, many surgeons needed to use a 12-mm assistant port for stapling in addition to specimen retrieval, suction, and exchange of items such as rolled-up sponges and vessel loops. For some surgeons, the delegation of this task to the assistant is considered a risk. With the introduction of Xi Da Vinci System, a 12 mm port can be used for the introduction and firing of the robotic Endowrist stapler. The use of the robotic stapler allows the surgeons to operate in absolute autonomy, enabling them to manage the vascular section by themselves, and seems to be safe and effective. The operating surgeon's ability to control the stapler from the console represents a critical technical advancement, as it can allow surgeons with limited assistance to explore robotic lung resection and perhaps transition from open or video-assisted lobectomy (55).

Another innovation in robotic thoracic surgery is "single site" technology. A thoracic uniportal dispositive is in development and it is expected to be commercialized in a few years (56). Fluorescence is a new technology which has evolved concurrently with robotics. In recent years, a new optical system has been created and incorporated into the da Vinci platform. This device has been utilized in fluorescence-guided surgery using intravenous administration of indocyanine green (ICG) allowing the identification of the intersegmental plane in anatomic lung segmentectomies (46). Finally, we are waiting for the commercialization of new robots developed by companies such as Medtronic and Johnson & Johnson in partnership with Google. Their placing on the market could reduce the costs related to this technology because until now, da Vinci is the only platform available. In the same manner, the introduction of a technology capable of receiving tactile feedback could finally improve the adoption of robotic surgery as mini-invasive approach of choice.

CONCLUSION

Several take home messages should derive from this chapter. Lobectomy is the gold standard surgery that should be proposed for treating early-stage NSCLC in patients who can tolerate anatomical lung resection. The scientific community is waiting for the results of prospective randomized trials (JCOG0802/WJOG4607L; CALGB/Alliance 140503) comparing lobectomy with sub-lobar resection in treating small size (> 1 cm and < 2 cm) NSCLC. Until a clear benefit is known, sub-lobar resection should be proposed exclusively for NSCLC patients who cannot tolerate lobectomy. An adequate intra-operative lymph node sampling is a fundamental part of NSCLC surgery. Performing a complete MLND, even in clinical stage I NSCLC, allows for correctly staging patients and to offer them an evidence-based adjuvant therapy, and furthermore, a R0 resection. Open thoracotomy is the most common approach adopted by most surgeons for treating stage I NSCLC. All possible approaches (anterior, lateral, and posterior) are similar. They are indifferently adopted according to the habits of surgeons. Mini-invasive surgery, such as VATS and RATS, are increasingly being adopted in surgical practice allowing several advantages compared to open lobectomy (less pain, better quality of life) maintaining the same rate of postoperative complications and especially, the same short- and long-term oncological results. Anterior approach in performing VATS lobectomy is the most common practice. RATS lobectomy, thanks to the technological widespread and an expected costs reduction, probably will become the mini-invasive approach of choice in the near future.

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