Robotic-assisted videothoracoscopic pulmonary lobectomy appears to be as safe as conventional videothoracoscopic surgical lobectomy.

**Background:** Despite initial concerns about the general safety of videothoracoscopic surgery, minimally invasive videothoracoscopic surgical procedures have advantages over traditional open thoracic surgery via thoracotomy. Robotic-assisted minimally invasive surgery has expanded to almost every surgical specialty, including thoracic surgery. Adding a robotic-assisted surgical system to a videothoracoscopic surgical procedure corrects several shortcomings of videothoracoscopic surgical cameras and instruments.

**Methods:** We performed a literature search on robotic-assisted pulmonary resections and compared the published robotic series data with our experience at the H. Lee Moffitt Cancer Center & Research Institute. All perioperative outcomes, such as intraoperative data, postoperative complications, chest tube duration, hospital length of stay (LOS), and in-hospital mortality rates were noted.

**Results:** Our literature search found 23 series from multiple surgical centers. We divided the literature into 2 groups based on the year published (2005–2010 and 2011–2014). Operative times from earlier studies ranged from 150 to 240 minutes compared with 90 to 242 minutes for later studies. Conversion rates (to open lung resection) from the earlier studies ranged from 0% to 19% compared with 0% to 11% in the later studies. Mortality rates for the earlier studies ranged from 0% to 5% compared with 0% to 2% for the later studies. Since 2010, our group has performed more than 600 robotic-assisted thoracic surgical procedures, including more than 200 robotic-assisted pulmonary lobectomies, which we also divided into 2 groups. Our median skin-to-skin operative time improved from 179 minutes for our early group (n = 104) to 172 minutes for our later group (n = 104). The overall conversion rate was 9.6% and the emergent conversion rate (for bleeding) was 5% for our robotic-assisted lobectomies. The most common postoperative complications in our cohort were prolonged air leak (> 7 days; 16.8%) and atrial fibrillation (12%). Hospital LOS for the early series ranged from 3 to 11 days compared with 2 to 6 days for the later series. Median hospital LOS decreased from 6 to 4 days. Our mortality rate was 1.4%; 3 in-hospital deaths occurred in the early 40 cases. Mediastinal lymph node (LN) dissection and detection of occult mediastinal LN metastases were improved during robotic-assisted lobectomy for non–small-cell lung cancer, as demonstrated by an overall 30% upstaging rate, including a 19% nodal upstaging rate, in our cohort.

**Conclusions:** Robotic-assisted videothoracoscopic pulmonary lobectomy appears to be as safe as conventional videothoracoscopic surgical lobectomy, which has decreased perioperative complications and a shorter hospital LOS than open lobectomy. Both mediastinal LN dissection and the early detection of occult mediastinal LN metastatic disease were improved by robotic-assisted videothoracoscopic surgical compared with conventional videothoracoscopic surgical or open thoracotomy.

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Surgery for Primary and Secondary Lung Malignancies

With more than 221,000 new cases of lung cancer estimated for 2015 in the United States, lung cancer is the second most diagnosed cancer, behind only prostate and breast cancers in men and women, respectively.\textsuperscript{1} However, with approximately 158,000 deaths from primary lung cancer in the United States estimated to occur in 2015, primary lung cancer remains the leading cause of cancer-related deaths in the United States, causing 28% and 26% of all cancer deaths in men and women, respectively, and causing more deaths than breast, prostate, and colorectal cancers combined.\textsuperscript{1} One reason for this high mortality rate for lung cancer is that the 5-year overall survival (OS) rate for lung cancer is 17% (32% at the H. Lee Moffitt Cancer Center & Research Institute, Tampa, Florida) compared with 85% for breast cancer (88% at Moffitt Cancer Center).\textsuperscript{1} This low OS rate for lung cancer is among the worst survival rates for any cancer, including pancreatic cancer (7.2%), mesothelioma (9.0%), liver cancer (17.4%), and esophageal cancer (17.9%).\textsuperscript{3} Another reason for low survival rates is that most primary lung cancers (> 75%) are stage 3 or 4 at initial diagnosis.\textsuperscript{3} The Surveillance, Epidemiology, and End Results Program of the National Cancer Institute established that all patients with lung cancer initially diagnosed with localized disease have a 5-year relative survival rate of 54%, and those initially diagnosed with regional disease or those initially diagnosed as stage 4 have 5-year relative survival rates of 27% and 4%, respectively.\textsuperscript{2}

In 2010, the financial cost of caring for patients with lung cancer was $12.1 billion; if the 2,373,200 person-years of life lost in 2009 are added to that number, then the indirect cost was $36.1 billion.\textsuperscript{4,5} Thus, the societal burden has prompted the need and importance of medical advancements in the prevention, screening, and treatment of lung cancer.\textsuperscript{6}

Tobacco smoking accounts for the majority of deaths caused by lung cancer and contributes to at least 30% of all cancer deaths, which makes tobacco smoking prevention and cessation programs an integral part of any lung cancer management program.\textsuperscript{1} Those with a relatively greater tobacco smoking history (≥ 30 pack-years), those with advanced age (55–74 years), and those who either currently smoke or recently quit (≤ 15 years) are at high risk for developing lung cancer.\textsuperscript{6}

For this high-risk group, lung cancer screening with low-dose computed tomography (CT) of the chest has shown a 20% reduction in lung cancer mortality as well as a 6.7% reduction in deaths from any causes.\textsuperscript{6} Results from low-dose CT screening for lung cancer revealed 8-mm solid or 10-mm ground-glass lung opacities, which led to the patients being referred to pulmonologists, interventional radiologists, thoracic surgeons, or all 3 specialists for diagnostic procedures, therapeutic procedures, or both.\textsuperscript{6} However, of the 24.2% of low-dose lung cancer screening CT scans found to be positive for a lung abnormality, 96.4% were false-positive findings eventually diagnosed as benign lung nodules.\textsuperscript{6}

Thus, given their lung abnormality, the patients undergoing these scans are now at risk of morbidity or mortality related to the obligate diagnostic — sometimes surgical — biopsy procedure or the deemed necessary “therapeutic” — oftentimes surgical — procedure. The subcentimeter size of these lung nodules and, oftentimes, the location of these nodules away from central airways as well as the visceral pleura made such procedures more difficult. For example, bronchoscopic biopsy procedures, risk of pneumothorax due to transthoracic needle biopsy, and risk from unnecessary lung resection (eg, lobectomy) are increased with these smaller lung nodules that, although they may be suspect for early stage lung cancer, are likely to be benign.\textsuperscript{7-9}

Minimally Invasive Lung Surgery

Traditionally, lung surgery for suspected or confirmed primary or secondary lung malignancies was performed via a maximally invasive “open” approach through a large thoracotomy incision involving a division of the latissimus dorsi and serratus anterior muscles, and this procedure historically involved removal of the entire fifth rib for exposure. The development of endostaplers then allows for the use of slightly less-invasive muscle-sparing thoracotomy approaches that spared either or both of the latissimus and serratus muscles, thus preserving the long-term function of these muscles but without minimizing the trauma and pain associated with still relatively large incisions.

The first endoscopes were invented in the 19th century, but it was not until the early 1900s that the first laparoscopic procedures emerged; during the decades that followed, these procedures evolved into routine minimally invasive abdominal and pelvic procedures (eg, laparoscopic cholecystectomy, laparoscopic hysterectomy).\textsuperscript{10} Jacobaeus, a Swedish internist, performed the first diagnostic thoracoscropy in 1910, leading to the development of dedicated laparoscopic and, subsequently, thoracoscopic surgical instruments in the 1960s and 1970s and performance of the first thoracoscopic lung biopsy in 1976.\textsuperscript{11-13} During the early 1990s, improvements in laparoscopic and thoracosco- pic video camera technology led to the development of videothoracoscopic surgical procedures, and the first videothoracoscopic pulmonary lobectomy was performed in 1991.\textsuperscript{14}

Long, narrow surgical instruments were then developed so that surgeons could reach the farthest recesses of the relevant body cavities through small “keyhole” incisions; however, use of these straight,
nonarticulating instruments was akin to operating with chopsticks. Although few instruments with articulating tips had been designed, articulation often required complicated manipulation, with wheels and levers, to realize the articulation. Moreover, use of these instruments was counterintuitive, because the need to move the working internal end of the instrument in one direction required that the surgeon move the external handle of the instrument in the opposite direction. For example, to move the working internal end of the instrument up, a surgeon must move his or her hands down; to move the working internal end to the left, the surgeon must move his or her hands to the right. Other issues, such as limited visual field, 2-dimensional visualization, lack of articulating thoracoscopic instruments, and lack of scaling down of movements, have limited the widespread adoption of videothoracoscopic surgery.15

Despite initial concerns over the general safety of videothoracoscopic surgery, minimally invasive videothoracoscopic surgical procedures have advantages over traditional open thoracic surgery via thoracotomy that have been well-established in the medical literature, including less intraoperative bleeding, less need for perioperative blood transfusions, smaller surgical incisions, less postoperative pain, less need for postoperative narcotics, reduced exposure to internal organs, less perioperative inflammatory response, shorter length of stay (LOS) in the hospital, shorter recovery times, faster return to routine activities of daily living, reduced infection risk, and less postoperative scarring.16-20

In addition, initial concerns about whether videothoracoscopic lobectomy — in particular, for primary lung cancer — might result in inferior oncological outcomes due to inadequate lymph node (LN) evaluation are unwarranted. Preliminary experience supported the use of videothoracoscopic pulmonary lobectomy for patients with small peripheral lesions.21 Since then, the debate regarding benefits, outcomes, and costs has been addressed in multiple studies. In 2009, Yan et al22 published a systematic review and meta-analysis about the controversy and concluded that videothoracoscopic lobectomy for early-stage non–small-cell lung cancer (NSCLC) may be a valid alternative to open surgery if the procedure is performed in qualified centers. Supporters of minimally invasive surgery (MIS) now promote expanding the use of videothoracoscopic surgery to special populations, such as those with advanced age (> 70 years of age) and patients with pulmonary compromise or poor physical performance.23

However, videothoracoscopic lobectomy is not routinely performed. Estimates are as high as 44.7% of lobectomies, according to The Society of Thoracic Surgeons National Database; as low as 6% in the Healthcare Cost and Utilization Project’s National (Nation-wide) Inpatient Sample database; and 80% of these videothoracoscopic lobectomies are performed at specialized academic centers.24-27

Robotic-Assisted Surgical Systems

The first reported use of robotic assistance during surgery was during stereotactic neurosurgical biopsy in April 1985.28 Since then, robotic assistance during surgery has expanded to almost every surgical specialty. The da Vinci Surgical System (Intuitive Surgical, Sunnyvale, California) was first introduced in the late 1990s and approved by the US Food and Drug Administration for general laparoscopic surgery (ie, for gallbladder disease and gastroesophageal reflux) in 2000, urological procedures in 2001, mitral valve repair in 2002, and gynecological conditions in 2005.29 In the early 2000s, some thoracic surgeons began to adopt robotic-assisted videothoracoscopic surgery as an option for pulmonary resections. In 2001, investigators reported the first series of robotic lobectomies, including 2 right lower lobectomies and 3 left lower lobectomies, with 1 right lower lobectomy and 1 left lower lobectomy converted to an open procedure due to calcified hilar nodes in 1 case and inability to determine extent of disease in the other.30

With the surgeon sitting at the surgeon console (Fig 1A), the robotic system binocular cameras (Fig 2A) provide the surgeon with a high-definition, 3-dimensional view of the operating field, which provides improved depth of perception compared with the 2-dimensional image provided by conventional videothoracoscopic surgical cameras.31 The robotic system computer translates hand movements of the surgeon at the surgeon console (Figs 1B and 2B), via cables and pulleys through the arms of the robotic patient cart (Fig 3A) and through the robotic surgical instruments inserted through port incisions through the patient’s chest (Fig 3B), to equivalent movements of the robotic surgical instrument working tips within the patient (this is contrary to the popular misconception that the robot itself performs the surgery). The surgeon manipulates the hand controls within the console, just as he or she would control surgical instruments during a traditional open surgical procedure via a thoracotomy incision. When the surgeon needs to move the robotic instrument working tips up, the surgeon moves the controls up, and, when the surgeon needs to move the robotic instrument tips to the left, the surgeon moves the controls to the left. Moreover, the robotic system has the capacity to scale down the surgeon’s hand movements and reduce hand-related tremors.

The articulating robotic instrument working tips have at least the same or more degrees of motion than the human hand (Fig 4), and these improve the ability of the surgeon to complete surgical procedures that require operating around and behind structures, such
as around the pulmonary artery and vein and around the bronchus within the pulmonary hilum during lung resection, as well as within deep, narrow spaces (eg, within the mediastinum during mediastinal LN dissection).

For minimally invasive thoracic procedures, such as videothoracoscopic lobectomies, these advancements in instrumentation should allow for precise hilar dissection, decreased risk of intraoperative complications, and decreased risk of conversion to open-completion lung resection via large thoracotomy — in which case, the patient will lose the benefits of MIS. Thus, robotic-assisted surgery would allow MIS procedures to be within reach of more thoracic surgeons, particularly among those primarily performing open thoracic surgical procedures, and to be available to more patients who might benefit from the advantages of videothoracoscopic surgery.

At the time of publication, the da Vinci Surgical System is the only complete robotic system on the mar-
ket, although this da Vinci robotic system has been through 4 different generations, including the original “standard” system, the second-generation S System, the third-generation Si System, and the fourth-generation Xi System. Since 2010, our group has used the S and Si systems (a typical operating room setup appears in Fig 5) to perform more than 600 robotic-assisted pulmonary resections, including wedge resections, segmentectomies, lobectomies, bilobectomies, and complete pneumonectomy after prior right lower lobectomy, via 3 small port incisions (Fig 6).

For oncological procedures, robotic-assisted thoracic surgery may improve mediastinal LN dissection and detection of mediastinal LN metastases, such that patients with clinically occult pathological stage 2 or stage 3 lung cancer may be offered adjuvant chemotherapy or adjuvant chemoradiotherapy in combination with radiation therapy, respectively, which would, in turn, be expected to improve cancer-related survival rates.\(^2\) Many consider robotic-assisted videothoracoscopic surgery to be the leading edge of the paradigm.

Fig 3A–B. — (A) During a typical right lung resection, the patient cart of the da Vinci Surgical System (Intuitive Surgical, Sunnyvale, CA) holds up to 3 surgical instruments and a video telescope and (B) docks to the patient on the operating room table. Its robotic arms are covered with plastic sleeves for sterility. Panel A: ©2014 Intuitive Surgical, Inc. Panel B: Photography by Eric M. Toloza, Moffitt Cancer Center, Tampa, FL.

Fig 4A–B. — Typical da Vinci Surgical System (Intuitive Surgical, Sunnyvale, CA) instrument with the EndoWrist instrument (Intuitive Surgical) showing its (A) size compared with a human hand and (B) range of motion compared with a human wrist. ©2014 Intuitive Surgical, Inc.

Fig 5. — Typical OR setup for robotic-assisted right lung surgery. Surgical instruments (foreground) with robotic instruments (left foreground), scrub nurse (right foreground), robotic video cart (far left), surgeon (left background, sitting at surgeon console) partially hidden by the robotic patient cart (left center) docked to patient on OR table, and surgical assistant standing by OR table (right center). OR = operating room. Photography by Nicholas Gould, Moffitt Cancer Center, Tampa, FL.

Fig 6. — Typical port incisions after 3-port robotic-assisted right lung surgery with pleural chest tube drain through the most caudal port incision. Photography by Eric M. Toloza, Moffitt Cancer Center, Tampa, FL.
shift toward minimally invasive thoracic surgery.\textsuperscript{35}

**Outcomes Intraoperative**

In 2008, Melfi et al\textsuperscript{34} delineated and compared the advantages and disadvantages of the 2 most common MIS approaches, conventional videothoracoscopic surgery and robotic-assisted videothoracoscopic surgery. The main advantages they found for robotic-assisted surgery were 3-dimensional imaging, dexterity, 7 degrees of freedom, lack of fulcrum effect and physiological tremors, scaled-down motions, and ergonomic position. They also noted disadvantages, including lack of tactile feedback, costly equipment and maintenance, and, at the time of their review, no proven benefit.\textsuperscript{34}

An important aspect of robotic-assisted videothoracoscopic lobectomy is the depth and accuracy of hilar and mediastinal nodal dissection.\textsuperscript{35} As a result of 3-dimensional visualization and the “wrist-like” action of the instruments, use of the surgical robot has been hypothesized to facilitate precise dissection in a confined space, such as the mediastinal nodal dissection phase of the videothoracoscopic lobectomy procedure.\textsuperscript{36}

During our review of the literature, we found 23 series — retrospective analyses made up the majority — that addressed the early experiences and outcomes of robotic-assisted anatomical pulmonary resection (lobectomy and segmentectomy) at multiple surgical centers. We divided these series into 2 groups based on the year of publication as follows: 2005 to 2010 and 2011 to 2014 (Table 1).\textsuperscript{27,34–55} Operative times from the 2005–2010 series ranged from 150 to 240 minutes compared with 90 to 242 minutes for the 2011–2014 series. No significant difference in change

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\textsuperscript{a}Data from the Healthcare Cost and Utilization Project’s State Inpatient Databases.

\textsuperscript{b}Two groups compared (standard da Vinci Surgical System [Intuitive Surgical, Sunnyvale, CA] vs da Vinci Surgical S/Si systems [Intuitive Surgical]).

NA = not applicable.
in operative times was seen, and this was most likely related to the inclusion of minor resections in the 2005–2010 series. Conversion rates from the 2005–2010 series were between 0% and 19% compared with 0% and 11% in the 2011–2014 series. Mastering of the robotic-assisted surgical technique resulted in decreased conversion rates; however, this mastery also resulted in the extension of this approach to more difficult cases, larger-sized tumors, more advanced-stage cancer, patients who received prior induction therapy, and patients with hilar adenopathy.

The major intraoperative outcomes from our cohort (N = 208) are comparable with what have been described in these previous robotic series. Comparing our early series of pulmonary lobectomies (n = 104) with our subsequent later series (n = 104), our skin-to-skin operative time improved from 179 minutes to 172 minutes. Our overall conversion rate for the entire cohort was 9.6%; a higher overall conversion rate (13.0%) was seen during the later series of robotic-assisted lobectomy cases compared with the early series (7.0%). The higher overall conversion rate in the later series can be explained by the increased level of difficulty of the cases performed. As our level of proficiency and confidence increased, pulmonary lobectomies for advanced-stage lung cancer cases and for more complex cases, such as hybrid procedures combining lung resection with chest wall resections, were performed with the robotic approach. Our emergent conversion rate for bleeding control was 2% for the early series and 5% for the later series. These higher conversion rates did not appear to affect overall postoperative outcomes. In comparison, Park et al published a large series on robotic-assisted pulmonary lobectomy and found that the median operative time was 206 minutes and the conversion rate to open approach was 8%.

Based on operative times, rates of mortality, and surgeon comfort, the overall learning curve has been described as 18 to 20 cases. In a case series comparing robotic-assisted lobectomies with conventional videothoracoscopic lobectomies, Jang et al concluded that a robotic approach can be rapidly adapted by experienced videothoracoscopic surgeons. The outcomes for robotic-assisted videothoracoscopic lobectomy in terms of operative times, intraoperative estimated blood loss, and hospital LOS were similar to those with conventional videothoracoscopic lobectomy when surgeons had at least 2 years of experience with videothoracoscopic lobectomy.

**Postoperative**

The 5 most commonly reported postoperative complications are atelectasis or mucous plugging (1%–22%), atrial fibrillation (3%–19%), prolonged air leak (defined as an air leak lasting > 5–7 days; 3%–13%), acute respiratory distress syndrome or respiratory failure (1%–13%), and pneumonia (1%–5%; Table 2). Table 3 shows the most common postoperative complications in our cohort; prolonged air leak longer than 7 days and atrial fibrillation were the 2 most frequent complications seen in our series.

Likely related to the relatively flat learning curve for videothoracoscopic lobectomy, morbidity rates ranged from 11% to 39% in the 2005–2010 series compared with 11% to 44% in the 2011–2014 series. Morbidity rates did not change between our 2 series (43% vs 38%). In comparison, Park et al reported an overall morbidity rate of 25% and a median hospital LOS of 5 days. Hospital LOS for the 2005–2010 series ranged from 3 to 11 days compared with 2 to 6 days for the 2011–2014 series (see Table 1). The median hospital LOS for our entire cohort was 5 days, which had decreased from 6 days in our early subgroup to 4 days with our later subgroup.

A comparative study analyzing the Healthcare Cost and Utilization Project’s State Inpatient Databases demonstrated the superiority of robotic-assisted lobectomy and segmentectomy compared with conventional videothoracoscopic lobectomy and open lobectomy. Robotic-assisted lobectomy was associated with reductions in the overall complication rate (43.8% vs 54.1%), hospital LOS (5.9 vs 6.3 days), and overall mortality rate (0.2% vs 2.0%) when compared with open resections. The overall complication rate, LOS, and mortality were also lower among the robotic group compared with videothoracoscopic surgery; however, none of these differences reached statistical significance. Adams et al compared their experience with The Society of Thoracic Surgeons National Database. They found that robotic-assisted surgery was equivalent to videothoracoscopic surgery on all intraoperative and postoperative outcomes and also resulted in significantly lower postoperative blood transfusion rates (0.9% vs 7.8%), air leaks for more than 5 days (5.2% vs 10.8%), and hospital LOS (4.7 vs 7.3 days) compared with open thoracotomy.

Mortality also appeared to improve with surgeon experience; we found that mortality rates for the 2005–2010 series ranged from 0% to 5% compared with 0% to 2% for the 2011–2014 series (see Table 1). Our in-hospital mortality rate for our entire cohort was 1.4%; 3 in-hospital deaths occurred during the early series.

**Oncological**

One of the main benefits of robotic-assisted techniques is the meticulous dissection that can be conducted in a nearly bloodless field. Supporters of robotic surgery promote the potential superiority of the robotic approach in LN dissection, and we recently presented our LN dissection and upstaging data at the CHEST World Congress Annual Meeting. Current guidelines suggest that the assessment of at least 3 mediastinal (N2) nodal
Our overall mean of N1 + N2 stations reported was 5.6 ± 0.1 stations, with a total of 13.4 ± 0.4 individual N1 + N2 LNs retrieved. In comparison, a review of the NCCN NSCLC Database reported that the mean number of N2 LN stations dissected via the videothoracoscopic surgical approach was 3.1 N2 LN stations and 2.9 N2 LN stations via the open approach. Another study suggested that 40% to 50% of lobectomies performed for lung cancer in the United States had no mediastinal LN dissection documented at all.61

Our mean number of N2 LN stations dissected was 3.7 ± 0.1 stations. We had a mean number of 7.2 ± 0.3 individual N2 LNs retrieved. Our overall mean of N1 + N2 stations reported was 5.6 ± 0.1 stations, with a total of 13.4 ± 0.4 individual N1 + N2 LNs retrieved. In comparison, a review of the NCCN NSCLC Database reported that the mean number of N2 LN stations dissected via the videothoracoscopic surgical approach was 3.1 N2 LN stations and 2.9 N2 LN stations via the open approach. Another study suggested that 40% to 50% of lobectomies performed for lung cancer in the United States had no mediastinal LN dissection documented at all.61

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<th>Prolonged Air Leak, n (%)</th>
<th>Pleural Effusion Requiring Drainage, n (%)</th>
<th>PE, n (%)</th>
<th>Pneumonia, n (%)</th>
<th>ARDS/Respiratory Failure, n (%)</th>
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*Divided as major and minor complications.
*Data from the Healthcare Cost and Utilization Project’s State Inpatient Databases.
*Two groups compared (standard da Vinci Surgical System [Intuitive Surgical, Sunnyvale, CA] vs da Vinci Surgical S/Si systems.
AF = atrial fibrillation, ARDS = acute respiratory distress syndrome, NA = not applicable, PE = pulmonary embolus.
recurrence, and 0% to 3.8% for both local and systemic recurrence rates ranging from 0% to 9.8%, including outcomes performed by Cao et al, and 1B, respectively. A meta-analysis of robotic-assisted 5-year survival rates were 91% and 88% for stages 1A with NSCLC undergoing robotic-assisted lobectomy; 80% among individuals undergoing robotic-assisted lobectomy for lung cancer. A large cohort series by Park reported an overall upstaging rate of 21%. Our cohort had an overall 30% upstaging rate and a 19% nodal upstaging rate, with a cN0-to-pN2 upstaging rate of 8.2% and a cN0-to-pN1 + cN0-to-pN2 upstaging rate of 16.4%, indicating the improved efficacy of LN dissection using the robotic approach. The meticulous and detailed LN dissection provided by robotic-assisted surgery improves the early detection of metastatic disease. Robotic-assisted thoracic surgery has the potential to become the gold standard for NSCLC management, because more patients can be more accurately staged and receive appropriate adjuvant chemotherapy without or with radiation — and this is not likely to happen without an effective LN dissection.

A study by Melfi et al showed a 5-year OS rate of 80% among individuals undergoing robotic-assisted lobectomy for lung cancer. A large cohort series by Park et al also showed a 5-year OS rate of 80% for persons with NSCLC undergoing robotic-assisted lobectomy; 5-year survival rates were 91% and 88% for stages 1A and 1B, respectively. A meta-analysis of robotic-assisted outcomes performed by Cao et al showed overall recurrence rates ranging from 0% to 9.8%, including 0% to 4.8% for local recurrence, 0% to 6% for systemic recurrence, and 0% to 3.8% for both local and systemic recurrence at the time of the latest follow-up.

### Costs

Several disadvantages of robotic-assisted surgery exist, including cost (several countries cannot afford any type of robot), the need for a bedside assistant to use an endostapler across pulmonary vessels, and lack of a consistent platform, tactile feedback, standardized credentials, and training programs for surgeons and technical assistants. In a retrospective analysis by Dylewski et al, lobectomies performed using a robotic-assisted approach reduced direct cost by $560 per case. The majority of cost savings occurred from reduced hospital LOS and lower overall nursing care cost. However, in the Japanese health care system, for any institution willing to acquire the robotic technology, Kajiwara et al notes that at least 300 robotic operations must be performed each year to avoid financial deficit with the current process of robotic surgical system management.

In addition to the challenges of acquiring a robotic surgical system, Lee et al analyzed intraoperative and postoperative costs between videothoracoscopic surgery and robotic-assisted videothoracoscopic surgery. Intraoperative costs include disposable instrumentation, operative time, and personnel. Compared with the videothoracoscopic surgery group, robotic-assisted cases in the series by Lee et al required approximately 30 minutes of additional operative time, and no additional personnel were required. Robotic-specific instruments were an additional cost, but no difference was seen in endostapler cartridge usage. The postoperative care that both groups received was identical. The difference in cost was realized in the hospital LOS.

The optimization of patient care and the early identification of potential complications could decrease the overall costs even further. Decreasing operating time, minimizing the number of robotic instruments needed, eradicating unnecessary laboratory work, and minimizing stays in the intensive care unit will help decrease direct hospital costs for anatomical lung resection. The robotic system allows the surgeon to perform a minimally invasive operation while reducing the need for routine arterial catheters, epidural catheters, Foley catheters, and other items that impart additional fixed costs — thus resulting in a lower direct cost. The most significant cost benefit to patients and their caregivers is derived from faster recovery times and a quicker return to work as well as less expenditure for the management of postoperative complications and outpatient services (eg, home health care, rehabilitation).

### Extended Use: Complex Surgery

Robotic-assisted surgery has been proposed to provide an MIS approach for routine lung resections,
more accurate LN dissections, and more complex surgical procedures. Two robotic-assisted pneumonectomies were reported by Spaggiari and Galetta. Both cases were completed in 200 minutes or less, and the patients were discharged home 6 to 7 days after uneventful hospital stays. At Moffitt Cancer Center, we performed completion pneumonectomy and mediastinal LN dissection on a patient aged 57 years diagnosed with recurrent NSCLC in the right upper lobe and right hilar lymphadenopathy and a history of previous right lower lobectomy for pT1N0M0 adenocarcinoma (6 years ago) with adjuvant chemotherapy. Due to the patient’s history of prior lobectomy, pleural adhesions and scar tissue were additional challenges in this procedure. He was discharged 8 days following the operation; his hospital stay was complicated by sinus tachycardia and urinary tract infection. This successful robotic-assisted completion pneumonectomy confirmed the safety of the technology, and further evaluation of this procedure should be conducted.

Chest wall resection en bloc with lung resection potentially incurs higher morbidity rates than pulmonary resection alone. One hybrid technique includes robotic-assisted pulmonary resection and LN dissection prior to freeing the chest wall through an additional incision smaller than what would be necessary had both lung and chest wall resections been performed via thoracotomy. In this setting, the goal is to minimize injury to the overlying chest wall musculature without jeopardizing the oncological element of the procedure. If the tumor is higher in the chest where extensive periscapular extrathoracic musculature is present, then new minimally invasive techniques to resect the tumor with en bloc chest wall resection compared with open surgery might benefit patients because the periscapular extrathoracic muscles would be spared. At Moffitt Cancer Center, we have performed this hybrid, robotic-assisted thoracoscopic lobectomy with en bloc chest wall resection on 5 patients with primary NSCLC during a 1-year period; of those cases, 1 was converted to open lobectomy due to pulmonary artery segmental branch bleeding. Despite some complicated hospital stays, the median days for chest tube duration and hospital LOS were 5 and 7 days, respectively. Thus, from our experience, hybrid, robotic-assisted pulmonary lobectomy with en bloc chest wall resection and reconstruction is feasible and safe in select patients.

The robotic approach appears well suited for the precise dissection required for anatomical segmentectomy, and this is particularly true among patients with single-lesion, early-stage lung cancer or those whose cancer has metastasized from an extrapulmonary site and when the lung lesion is less than 2 cm in diameter. A retrospective study of 35 patients showed a mean operation time of 146 minutes; 5 LN stations were sampled and there was no 60-day mortality. Based on these studies, robotic-assisted surgery may be feasible for skilled and trained surgeons performing pulmonary segmentectomies. At Moffitt Cancer Center, more than 45 robotic-assisted pulmonary segmentectomies have been performed, including right and left lower lobe superior segmentectomies, right or left lower lobe basilar segmentectomies, lingulectomy, and lingula-sparing left upper lobectomy (also known as left upper lobe apical bisegmentectomy).

**Conclusions**

Robotic-assisted videothoracoscopic lobectomy appears to be at least as safe as traditional open and conventional videothoracoscopic lobectomy approaches. Benefits in decreased perioperative complications and shorter hospital length of stays have been demonstrated in the case series we reviewed. Based on the data provided by our experience at Moffitt Cancer Center, mediastinal lymph node (LN) dissection via robotic-assisted videothoracoscopic surgery is more effective than the conventional videothoracoscopic surgical approach and open thoracotomy. The meticulous and detailed LN dissection provided by robotic assistance during surgery improves the early detection of metastatic disease. Overall, the improved efficacy of LN dissection is the most important benefit of robotic technology. Improved intraoperative efficiency, fewer numbers of instruments used, shorter operative times, practical perioperative management, early identification of potential complications, and limiting unnecessary tests and procedures can make robotic-assisted surgery a cost-effective approach. Large multidisciplinary centers can also share the economic burden among specialties, thereby decreasing individual costs. Thus, we expect an increase in surgical procedures of the lung through the use of minimally invasive techniques (particularly robotic assistance), improved instrumentation, better understanding, and the broader acceptance of thoracoscopy among chest surgeons.

**References**


