Review Article

Superiorities of robotic segmentectomy: a review

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Abstract: Several approaches to the resection of lung cancer are now available within the armamentarium of the thoracic surgeon. Robotic-assisted surgery has emerged as a comparable alternative to both the open and video-assisted thoracoscopic (VATS) approaches. Numerous studies have confirmed equivalent oncologic outcomes and superior postoperative outcomes with robotic resections compared to both the open and VATS approaches. In particular, due to the meticulous anatomical dissection required during segmentectomy, there is heightened interest in outcomes research comparing the 3 approaches. The aim of this review is to study the available data on robotic *vs.* VATS and open segmentectomy and present a thorough comparative analysis including oncologic, postoperative and patient outcomes for and against robotic segmentectomy. In our review, we find robotic segmentectomies to be cost effective and offer improved dexterity resulting in decreased complications and hospital length of stay (LOS). There is promise for this approach especially within the elderly frail patients, and data suggest that the reduction in LOS offsets the higher cost of establishing a robotic program. Ultimately, long-term outcomes from well-designed prospective studied are needed but initial results are promising and have set the acquisition of robotic programs in motion.

Keywords: Robotic; segmentectomy; sublobar or segmental pulmonary resection

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Lung cancer is the leading cause of cancer death in the United States (1,2). With the introduction of low-dose computed tomography (LDCT) for lung cancer screening, an expected two-thirds of all lung cancers in this screening population will be detected in their early-stage, hence will be surgically resectable (3). Pulmonary segmentectomy offers a lung preserving alternative for early-stage lung cancer resection especially for patients with emphysema.

Churchill and Belsey first introduced pulmonary segmental resection in 1939 for the surgical management of bronchiectasis (4). In 1973, Jensik and Faber endorsed segmentectomy to achieve parenchymal preservation for the management of recurrent lung cancer. Oncologic outcomes demonstrated a 56% 5-year survival rate with a rate of local recurrence of 10% following segmentectomy for T1 cancers (5). The North American Lung Cancer Group later found three times the local recurrence rate and 30% increased mortality compared to lobectomy (6). These findings firmly endorsed lobectomy as the continued standard of care and prevented acceptance of the sublobar approach to early NSCLC at that time.

Since then an increased number of reports have demonstrated equivalent outcomes. In 2002, Yoshikawa *et al.* showed improving survival rates for segmentectomy in smaller tumors, with 82% 5-year survival rate for tumors less than 2 cm (7). Additionally, in 2014 Okada *et al.* showed equivalent 5-year disease-free survival when comparing lobectomy and segmentectomy (8). Functional preservation was found to be superior with segmentectomy compared with lobectomy with the extent of parenchymal resection directly proportional to postoperative functional loss persisting up to 6 months postoperatively. Furthermore, in their prospective trial, the Cancer and Lymphoma Group B (CALGB 140503) demonstrated equal rates of survival and recurrence for patients with small peripheral NSCLC undergoing segmentectomy compared to lobectomy (9). Other studies additionally supported the feasibility and safety of segmentectomy (10-12). In 2010, Schuchert *et al.* showed equivalent recurrence rates and overall survival between techniques, specifically for stage 1 NSCLC (13). This would later be endorsed by multiple retrospective studies showing equivalent recurrence and survival in patients undergoing open segmentectomy *vs.* lobectomy who were 75 years or older, had large tumors and even patients with poor pulmonary reserve and associated comorbid conditions (14-17). Some studies have even demonstrated superior outcomes with segmentectomy (18-20). This data has allowed segmentectomy to become a reasonable alternative, with no compromise to oncologic survival while preserving lung parenchyma especially in older patients with small, stage I lung tumors who may not tolerate a lobectomy due to reduced pulmonary function (17,21).

The open thoracotomy approach to lung cancer resection has been challenged by the growing utility and enthusiasm for less invasive techniques first by video-assisted thoracoscopic (VATS) resection and, more recently, robotically assisted approaches (22,23). There is substantial evidence that minimally invasive techniques in the treatment of NSCLC results in superior perioperative results. Several reports have identified a reduction in pain, lower respiratory tract infections, arrhythmias, length of stay (LOS), and inflammatory markers (19-20). This has fueled the shift to a less invasive approach to resections and further studies have shown similar rates of locoregional recurrence, cancer-free survival, as well improved overall morbidity and mortality (22,24-26). A minimally invasive sublobar resection allows anatomic resection with acceptable margins while concurrently preserving lung function (22).

Comparing thoracoscopic segmentectomy to the open technique was first performed by Shiraishi *et al.* in 2004 with no significant difference in complications or perioperative deaths (27) and comparable rate of recurrence, survival, and operative time. Thoracoscopic segmentectomy resulted in reduction of hospital LOS, cost reduction and decreased rates of cardiopulmonary complications (21,28-30).

In the last two decades, the robotic approach has been introduced for a variety of thoracic procedures including lobectomy and segmentectomy. Review of national data have demonstrated increased robotic lung resections by 3.2% between the years 2008 and 2010 (17,31). The robotic approach affords superior visualization in the setting of three-dimensional optics and higher instrument precision with seven degrees of motion. The DaVinci system (Intuitive, Sunnyvale, CA, USA) results in improved dexterity, tremor filtration, and telesurgery (32). This is particularly useful during anatomical pulmonary segmentectomy which requires meticulous intraparenchymal dissection to expose the segmental bronchus and vessels. The robotic approach is also advantageous due to ability to perform dissection sharply using bipolar energy rather than blunt dissection carried out during the VATS approach.

Farivar *et al.* studied all robotic anatomic lung resections from two institutions between 2010 to 2012 (n=181) matched against the same variables for resections via thoracotomy (n=5,913) and VATS (n=4,612) from the STS National Database (33). Their results showed reduced 30-day mortality and perioperative rates of blood transfusion. Hospital LOS was also cut by 2 days *vs.* VATS and 4 days *vs.* thoracotomy (33). A review of the National Cancer Database between 2010 to 2015 found the robotic approach to be associated with significantly decreased conversion rates to open compared to VATS (9% *vs.* 14%) (34). These data further support the robotic approach in achieving comparable survival and reduction in length of hospital stay resulting in earlier return to work.

Many comparative studies have formally compared the two techniques particularly because of the increased resources necessary in the inception of a robotic surgery program and have demonstrated increased cost in establishing a robotic cancer surgery practice (33,35-37). One propensity matched analysis by Bao *et al.* in China noted increased cost and operative time with robotic pulmonary resection compared to thoracoscopic (38). Robotic approach was also noted to be more costly in a retrospective review of 2,868 patients undergoing VATS versus robotic lobectomy (39).

However, after these initial start-up costs, results by Musgrove *et al.* contradict the statement that robotic segmentectomy is more expensive than VATS approach. They compared their early robotic segmentectomy experience with VATS segmentectomy in their single institution retrospective analysis (40). The robotic group achieved a shorter length of hospital stay (2 *vs.* 4 days) and reduction in both air leaks (7% *vs.* 18%) and overall complications (14% *vs.* 36%) (40). Cost analysis was calculated by taking into account the cost of hospital stay per day and intraoperative instrument and resource allocation. This translated to cost savings in the robotic cohort compared to the VATS cohort (40). Although statistical significance was not reached (likely due to the small cohort size), these data suggest that robotic surgery for lung cancer would not certainly result in increased cost or result in poor outcomes. Similarly, Nelson *et al.* found similar cost between robotic and VATS lobectomy (41). Kneuertz *et al.* also found similar cost between robotic and VATS approach to lobectomy between 2012 and 2017 with increased procedural costs compared to open compensated by decreased LOS and improved post-operative outcomes (42).

Nasir *et al.* performed a retrospective review from 2010 to 2013 of 862 robotic lobectomies and segmentectomies and found that despite a median hospital charge of $32,000, the hospital profited $4,750 per patient. Most results were favorable including minimal morbidity and mortality, and reduced postoperative pain. Notably, the authors did find increased capital costs and number of robotic cases required to achieve expertise as downsides of robotic segmentectomy (43). Based on the variation in cost analysis within published literature, prospective studies are needed to accurately discern accurate cost and physician reimbursement associated with setting up and running a thoracic surgery robotic program.

In addition to cost, robotic approach to pulmonary resection does have an important learning curve that must be mastered which includes overcoming the lack of tactile feedback compared to VATS. Glenn *et al.* retrospectively reviewed 2,868 patients between 2010 to 2013 using the National Inpatient Sample (39). Whereas overall morbidity was similar, they noted an increased rate of accidental lung puncture or laceration as well as bleeding complications (39). Some studies also note increased operative time with robotic approach, however these limitations improve with surgeon experience and mastery of the learning curve (41,44).

Our experience in comparing 87 consecutive robotic lobectomies with 72 robotic segmentectomies demonstrated reduction in hospital LOS by 1-day (2 *vs.* 3 days) contradicting belief that segmentectomy is associated with increased air leak and longer LOS compared to lobectomy. Robotic surgery will likely continue to maintain superiority compared to VATS due to the greater precision of intraparenchymal dissection. This likely allows decreased air leak complications and LOS. Other studies have shown similar results. Dylewski *et al.* reported outcomes of 35 patients undergoing robotic thoracoscopic segmentectomy and reported mean operative time of 146 minutes, median lymph node harvest of 5, and zero 60-day mortality (45). Similarly, Pardolesi *et al.* reported outcomes of their initial experience on 17 patients demonstrating a mean operative time of 189 minutes, zero post-operative mortality, and no major intraoperative complications or conversions (46).

Liang *et al.*, performed a meta-analysis analyzing outcomes of 7,438 patients undergoing robotic lobectomy and segmentectomy compared with video-assisted lobectomy and segmentectomy. The meta-analysis showed decreased mortality, decreased conversion to open, and increased completion of the planned segmentectomy in the robotic approach (47). There were similar postoperative complications, operative time, duration of hospitalization, and chest tube duration (47). Another meta-analysis by O'Sullivan *et al.* showed robotic lobectomy compared to VATS and open approaches had decreased 30-day mortality, overall complications, and duration of hospital stay (44).

Cerfolio and colleagues piloted the largest series to date evaluating outcomes after robotic segmentectomies. They reported no conversions to thoracotomy and zero mortality. Between 2010 and 2014, 100 patients underwent robotic segmentectomy with only 7 patients converting to lobectomy, median lymph node harvest of 19, median operative time 88 minutes, median LOS 3 days, and 3.4% recurrence rate with follow up of 2.5 years (48). Using the Society of Thoracic Surgeons General Thoracic Database (STS-GTS), Louie and colleagues demonstrated comparable morbidity and survival despite the fact that the majority of the patients undergoing robotic resection were older with poor functional status compared to patients undergoing VATS (49).

Robotic approach has also been shown in multiple studies to have similar to increased median number of lymph nodes harvested. A retrospective analysis in China of 1,075 patients undergoing robotic versus VATS lobectomies between 2013 to 2016 was performed. They noted increased retrieval of lymph nodes (9.7 *vs.* 8.4) and a decrease in duration of chest tube drainage (50). In 2017, Xie *et al.* compared 166 patients undergoing robotic versus VATS segmentectomy and found that in the robotic approach had statistically significant increased average of 13 *vs.* 10.8 lymph nodes removed (51). Kneuertz *et al.* retrospectively analyzed 1,053 patients between 2011 to 2018 undergoing robotic versus VATS or open lobectomy. They found similar number of lymph nodes removed however an increased number of stations for open and robotic approaches with similar rates of nodal upstaging in the robotic approach (42). Nelson *et al.* also noted robotic approach to lobectomy was associated with decreased blood loss, decreased LOS, and improved nodal harvest (41).

In summary, robotic segmentectomy allows superior precision during intraparenchymal dissection resulting in a decreased rate of air leaks and hospital LOS. The increased lymph node harvest, increased completion of the planned segmentectomy, decreased likelihood of conversion to open, and improved dexterity proffered by this technique are well documented advantages of robotic segmentectomy. Adoption of robotic segmentectomy within the thoracic surgery community will likely continue to grow given its demonstrated utility in older debilitated patients and its ability to achieve equivalent outcomes. These advantages will likely offset the greater resource allocation required for the inception of a robotic program. The authors acknowledge that further analysis and larger prospective studies are needed to validate these findings.

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Footnote

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