Robot assisted thoracic surgery: a review of current literature.

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Abstract

Background: Minimally invasive surgical approaches are generally desired and recommended for many thoracic procedures as they preserve function and allow for more rapid recovery of patients. Despite these advantages, the adaptation has been poor. The robotic approach allowing more intuitive movement, greater flexibility, and high definition 3D vision appears to encourage surgeons to adapt the technique.

Methods: This review examines the recent English lit of the early surgical experience of the da Vinci robotic system in the treatment of lung cancer, esophageal resection and mediastinal pathology.

Conclusion: The application of robotic technology to thoracic surgery has proven to be at least comparable to open or video assisted thoracoscopic techniques in several areas and in some, possibly superior. If the widespread application of robotic technology allows greater access to minimally invasive thoracic surgery, with equivalent or superior oncological and perioperative outcomes, then it seems logical that robotic technique will become the standard for many general thoracic surgical procedures.

Keywords: Robotic assisted, Mminimally invasive, Lung resection, Esophagectomy, Mediastinal tumors.

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Introduction

Minimally invasive surgical approaches are generally desired and recommended for many thoracic procedures as they preserve function and allow for more rapid recovery. Despite these advantages the adaptation has been poor with Video Assisted Thoracoscopic Surgical (VATS) technique for lung resection. This is due to limited vision, and imprecise dissection using rigid instruments that need to be manipulated from a long distance. The robotic approach allowing more intuitive movement, greater flexibility, and high definition 3D vision appears to overcome these limitations. This review examines the recent literature and the early thoracic surgical experience of the da Vinci robotic system in the treatment of lung cancer, esophageal resection and mediastinal pathology.

Review

Lung resection

Lung cancer accounts for one quarter of all cancer related deaths in the United States [1]. As low dose CT screening becomes more prevalent, as it is adopted by national organizations, the incidence of early stage lung cancers will likely increase [2,3]. Surgical lobectomy along with lymph node dissection has long been the mainstay of treatment for early stage lung cancer. There are currently three commonly used surgical approaches to lung cancer: open thoracotomy, Video Assisted Thoracic Surgery (VATS), and robot assisted. Each of these approaches has proponents and purported benefits. Open surgery is the oncological gold standard for lobectomy and lymph node dissection. VATS lobectomy offers the promise of a minimally invasive approach with reduction in post-operative pain, length of stay, and morbidity [4,5]. VATS surgery has a steep learning curve and has not been widely implemented; in a 2010 study of data from the Nationwide Inpatient Sample Database Gopaldas et al. found that VATS was used in less than 6% of lobectomies [6]. Robot assisted surgery seems to address some of the limitations of VATS surgery by providing three dimensional imaging, magnification, and more freedom of movement. There have been a number of studies attempting to address the risks and benefits of the different approaches to lung resection.

Louie et al. reported on a case control analysis of 52 robot cases and 35 VATS resections. Their study consisted of four surgeons early in their learning curve of robotic surgery. Clinical outcomes including tumor size, operative time, blood loss, and length of stay were similar between the two groups, as were the rate of complications, and number of nodal stations sampled [7]. Augustin et al. reported on the perioperative outcomes of a practice switching from robotic to VATS approaches. In their group of 26 robotic cases and 26 VATS cases there was no significant difference in complications, mortality, LOS, or conversion to open. There was a significant difference in operative time with robotic surgery taking on average 215 min *vs.* 183 min in the VATS group [4]. These early studies demonstrate clinical non inferiority of robotic lung resection when compared to VATS. Swanson et al. reported on a propensity matched cohort study derived from a large multi-institutional database comparing robot assisted and VATS lung resections [8]. The final cohorts after matching contained 590 Lobectomies and 650 wedge resection in each group. They demonstrated no difference in LOS and major adverse events. They did demonstrate a significantly higher rate of minor adverse events in patients undergoing robotic lobectomy compared to those undergoing VATS (odds ratio 4.24). There was also a significantly higher operative time in the robotic wedge resection group. They also analyzed the cost of robot assisted surgery vs VATS demonstrating a significant increase in cost associated with robot assisted surgery in both lobectomy and wedge resection. From this data they conclude that robotic lung resection has no clinical benefit and increases cost [8]. This has been challenged by Nasir et al. reported on a single surgeon experience of the cost of robotic surgery in combination with lean methods and concluded that robot assisted surgery could remain a profitable option for hospital systems with appropriate changes to perioperative management to reduce waste and cost [9].

As to the long term oncological outcomes Park et al. reported on 325 patients in three centers in the United States and Italy undergoing robotic resection for early stage lung cancers. They demonstrated a similar 5 year survival to previous studies of VATS and open resections [3]. Lymph node dissection is also a key component to an adequate oncological procedure for lung cancer. Pathological upstaging after resection can be used as an indicator of the completeness of node dissection and the radical nature of the surgical approach. Zirafa et al. compared the rate of pathological upstaging between 212 (106 open, 106 robot assisted) patients undergoing lobectomy. They found similar overall rates of pathological upstaging but a significant increase in upstaging specifically in the mediastinum. There was a significant increase in the number of lymph node stations assessed, particularly in the mediastinum. This suggests that lymph node dissection with a robot assisted technique is at least as good at detecting lymph node spread as open surgery and is possibly superior to VATS approach when looking at mediastinal stations specifically [10].

Current literature shows that robot assisted lung resection is a safe option when compared to VATS or open approaches. The benefits of three dimensional vision, magnification, and increased freedom of movement when compared to VATS surgery seem to be most clear when looking at lymph node dissection. There are still substantial limitations to the widespread use of robot assisted lung resection most importantly cost particularly including the institutional cost of procuring and maintaining the robotic system. This may be overcome by shortened length of stay and increasing experience with the technique. It is also possible that robotic surgery will allow for wider implementation of minimally invasive approaches to lung resection than VATS due to a possibly easier learning curve.

Esophageal resection

The American Cancer Society estimates that there will be 17290 new cases of esophageal cancer in the United States in 2018, and 15850 deaths [1]. Surgical resection with curative intent offers many of these patients their best hope of survival. Minimally invasive esophageal surgery offers decreased rates of pneumonia, shorter length of stay, decreased pain while providing an appropriate resection and lymph node dissection and similar short term survival to open esophagectomy [11-13].

Given the narrow confines of the posterior mediastinum, robotic assisted esophageal surgery would seem a well suited approach with its magnification and three dimensional vision. An early series of 18 patients by Galvani et al. demonstrated feasibility of a transhiatal robot assisted technique. In comparing their robot assisted transhiatal technique to other techniques of MIE they demonstrate comparable results for operative time, EBL, LOS, and mortality [14]. Dunn et al. published a 3-year experience with 40 patients undergoing transhiatal resection, of which 38 were for cancer. They were able to achieve 94.7% R0 resection rate with similar operative time, EBL, LOS, and hospital mortality to other MIE series [15]. In 2016, the same group reported on a separate cohort of 100 patients undergoing transhiatal robot assisted MIE. This demonstrated a lower operative time than their initial 40 patient series (264 min *vs.* 311 min), similar rates of perioperative complications, and a 97.8% R0 resection rate [16].

Other centers have used a transthoracic approach for robot assisted MIE. Van Hillengersberg et al. reported the first series of patients treated with robot assisted trans-thoracic esophagectomy in 2006. They report 76% R0 resection rate in their initial series which is comparable to open transthoracic series. They did report a higher than expected rate of pulmonary complications but associate this with management of ventilation of the right lung which improved after changing to pressure controlled ventilation and adding continuous positive airway pressure to the operative lung [17]. de la Fuente et al. presented the outcomes of 50 patients undergoing robot assisted Ivor Lewis esophagogastrectomy. They report a hospital length of stay 2 days shorter than the historic outcomes reported in their institution as well as lower postoperative morbidity and a higher number of nodes retrieved. They also report a significant decrease in operative times when comparing the second 25 patients in their cohort to the first, suggesting a relatively short learning curve [18]. Cerfolio et al. reported on their series of 85 patients undergoing robotic Ivor Lewis esophageal resection. They reported similar operative time, blood loss and conversion rates to other series of robot assisted esophagectomy. They did have an unfavorable rate of anastomotic or conduit related complications (7.1%), which prompted a change from a totally hand sewn anastomosis to the use of a linear stapler on the posterior wall and hand sewn two layer closure of the anterior wall. Overall they did demonstrate early survival comparable to the Eastern Cooperative Oncology Group E2202 study [19]. Wee et al instead propose using a circular end-to-end stapler during robot assisted esophagectomy in their series from 2016. In their group 20 patients underwent stapled end-to-end anastomosis with no anastomotic leakage [20].

The long term oncological results of robot assisted minimally invasive esophagectomy have been reported by two groups, both using a trans-thoracic approach. Park et al. followed 115 patients with squamous cell carcinoma for a mean of 32.4 months and demonstrated a 6.3% local recurrence rate, and 85% overall survival at 3 years [21]. Van der Sluis et al. who reported on a series of 108 patients (78% adenocarcinoma) undergoing robot assisted minimally invasive esophagectomy with a median disease free survival of 21 months and with 52% of patients free of recurrence at a median of 34 months of follow up. They also report a low rate of locoregional recurrence (6%) [22].

The same group also reported in 2018 on the learning curve for two surgeons initiating a robotic assisted esophagectomy program. Their assessment suggests that by using a structured proctoring system they were able to reduce the number of operations needed to reach proficiency in their second surgeon by 66% when compared to the first. They report a learning curve in this environment of structured proctoring of only 15 supervised and 9 independent cases, compared to 70 cases in the first surgeon [23].

The available literature at this point suggests that robot assisted esophagectomy has good short term and long term outcomes, which are comparable to both minimally invasive and open techniques. Most studies have focused on the Ivor Lewis technique and this appears to be the most feasible, though early studies also show some promise in the transhiatal approach. There is a paucity of randomized controlled data on the best technique for esophagectomy. Van der Sluis et.al have undertaken a randomized controlled study to compare robot assisted esophagectomy to open. The results of this study have yet to be published but should provide an interesting perspective on the benefits of robot assisted surgery compared to open [24]. Similar studies to compare the outcomes of robot assisted and thoracoscopic surgery are also needed.

Mediastinal surgery

The diagnosis and treatment of mediastinal pathology remains a common problem for thoracic surgeons. Thymoma is the most common anterior mediastinal mass and is typically treated with surgical resection which can also improve symptoms of myasthenia gravis. Historically thymectomy has been performed via a median sternotomy which remains the gold standard. Other mediastinal masses including cysts, neural tumors, parathyroid tissue, and lymph nodes have been resected via thoracotomies or other open techniques as well as traditional video assisted techniques. Yoshino and colleges described the first robot assisted resection of an anterior mediastinal tumor [25].

Bodner et al. described an early series of 14 patients with various mediastinal pathologies who underwent robot assisted resection. These lesions were in a variety of locations with 10 in the anterior, 1 in the middle, and 3 in the posterior mediastinum. Nine of these patients had thymomas for which complete thymectomy was performed with resection of all thymic tissue and anterior mediastinal fat en-bloc. There were no significant postoperative complications in this early series [26].

Giuseppe et al. have published several multicenter studies on resection of thymoma using a robot assisted technique. In 2012 they published a cohort of 79 patients at 4 centers using a variety of robotic approaches; 82.3% from the left, 12.6% from the right, and 5.1% from both sides. They reported a 12.7 % complication rate, with a median hospital stay of 3 days. After a median follow up 40 months the 5 year survival was 90%, and 97% for thymoma-related survival [27]. In 2016 they reported on a cohort of 134 patients from 3 centers in Europe with a 17.1% postoperative complication rate, and a median hospital stay of 4 days. Most of the tumors were Masaoaka stage I and II (34.4%, and 52.9%). At conclusion of the study, (median follow up 42 months) overall survival rate was 97%, and five year thymoma-specific survival was 100% [28]. These two studies show generally acceptable outcomes but do not provide comparison to open or vats techniques or long term (10+year) follow up data.

Seong et al. compared a robotic approach to conventional sternotomy using propensity score matching. They matched 34 patients treated with robotic surgery with an equal number of patients treated with sternotomy during the same time period. They demonstrate a statistically significant reduction in the number of drains, 24 hour drain output, hemoglobin decrease, chest tube days, and length of stay. There was no difference in operative time and there were more complications in the open sternotomy group. When they evaluated operative time they did see a tendency toward shorter operative times in the second half of their series. This study clearly suggests superior perioperative outcomes when robotic surgery is compared to open sternotomy in a small cohort [29].

With the limited data at hand it appears that robot assisted resection of thymomas and other mediastinal masses is feasible and safe with the robot system. It also appears that the surgical and perioperative outcomes are superior to those seen with open sternotomy. Long term follow up for these slow growing tumors is still needed as is randomized controlled data comparing robot assisted surgery to traditional video assisted surgery though it seems logical that three dimensional view as well as freedom of view afforded by the robot system will provide superior exposure and dissection of delicate mediastinal structures. A recent report by Wilshire et al suggests thymic tumors that are larger than 3 cm can be robotically resected with low perioperative morbidity and mortality [30].

Conclusion

The application of robotic technology to thoracic surgery has proven to be at least comparable to open or thoracoscopic techniques in several areas and in some possibly superior. It is unclear if the cost of robot assisted surgery is justified by the outcomes; but if the widespread application of robotic technology allows greater access to minimally invasive techniques, with equivalent or superior oncological and perioperative outcomes, then it seems logical that this will become the standard for general thoracic surgery. The benefits of robot assisted surgery still need to be better evaluated by randomized controlled trials and large multi institutional populations to ensure that the good initial outcomes seen are generalizable to centers that are not pioneers in robotic thoracic surgery. Cost versus benefit analysis is always difficult with new surgical procedures and will be even more complicated with the high upfront and ongoing cost of maintaining the robotic surgical system. The robot surgical market is currently dominated by a single system and company; hopefully as the technology spreads more competitive systems and more widespread adaptation will drive down cost. Robot assisted general thoracic surgery has a bright future and will hopefully continue to develop in the coming decades.

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