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Review Article

Robotic Surgery for Thoracic Disease

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Robotic surgeries have developed in the general thoracic field over the past decade, and publications on robotic surgery outcomes have accumulated. However, controversy remains about the application of robotic surgery, with a lack of well-established evidence. Robotic surgery has several advantages such as natural movement of the surgeon's hands when manipulating the robotic arms and instruments controlled by computer-assisted systems. Most studies have reported the feasibility and safety of robotic surgery based on acceptable morbidity and mortality compared to open or video-assisted thoracic surgery (VATS). Furthermore, there are accumulated data to indicate longer operation times and shorter hospital stay in robotic surgery. However, randomized controlled trials between robotic and open or VATS procedures are needed to clarify the advantage of robotic surgery. In this review, we focused the literature about robotic surgery used to treat lung cancer and mediastinal tumor.

Keywords: robotic surgery, lung cancer, video-assisted thoracic surgery, VATS

Introduction

Robotic surgeries have been reported in the general thoracic field since early 2000. The first report of robotic lobectomy for lung cancer was published in 2002.[1] Since early-stage non-small-cell lung cancer (NSCLC) is a candidate for surgery with curative intent, these cancer surgeries have been performed using video-assisted thoracic surgery (VATS).[2] State inpatient databases (SID) showed that 40% of lung cancers were operated on by VATS and 3.4% by robotic systems in 2010.[3] According to the Japanese Association for Thoracic Surgery annual report, 62.9% of total lung cancer surgeries in 2012 were carried out by VATS,[4] but only a few cases by robotic surgery. This infrequency of robotic surgery may be due to different payment systems and the delayed introduction of this system. Both VATS and robotic surgery are minimally invasive, but several differences have been reported.[5] It seems that VATS has drawbacks including less hand-eye coordination under the two-dimensional imaging system, limited manipulation of instruments, and steep learning curves. In contrast, robotic surgery has several advantages such as natural movement of the surgeon's hands when manipulating the robotic arms and instruments controlled by computer-assisted systems. Furthermore, better hand-eye coordination using the three-dimensional console monitor may provide accurate identification of anatomical landmarks and precise manipulations without haptic feedback. Publications on robotic surgery outcomes have accumulated in the last decade. However, controversy remains about the application of robotic surgery, with a lack of well-established evidence.

The purpose of this review is to evaluate the efficacy of robotic surgery according to the available evidence, and to provide information for patients with thoracic disease.

Lung Cancer

Indications

The candidates for robotic surgery were patients with early-stage non-small cell cancer, similar to VATS.[6]

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Most surgeons offered this to clinical stage I NSCLC patients who met other criteria such as no previous thoracic surgery, without preoperative chemoradiation, and no tracheobronchial or chest wall involvement. The other groups showed similar indications including clinical stage I or II.[5,7] Veronesi et al. limited the maximum size to five centimeters.[5] Cerfolio et al. extended the indications to include larger size or preoperative chemoradiation.[8] Other surgeons allowed more advanced cases which were treated by preoperative chemoradiotherapy.[9–11] Recent reports showed that more complicated cases needing bronchoplastic surgery were feasible for robotic surgery.[12,13]

Technical aspects of major pulmonary resections

Several different techniques have been reported. Park et al. showed three robotic arm techniques manipulated through two thoracoscopic ports and a four centimeter access incision.[14] They applied the VATS technique to robotic surgery regarding port positions and anterior-to-posterior hilar isolation technique. The other groups also reported a three-arm technique with one utility port.[9,15–17] Cerfolio et al. reported a four-arm technique without a utility incision, while Veronesi et al. included the incision.[5,8] Carbon dioxide (CO_2) insufflation to achieve maximal surgical exposure while compressing the lung away from the operative area may provide the benefit for thoracoscopic surgery.[18] Cerfolio et al. named completely portal robotic lobectomy (CPRL) by using CO_2 insufflation.[8] Other groups have published reports of a four-arm technique with all ports approach.[19] In addition, Gharagozloo et al. reported a hybrid robotic surgery consisting of two phases; a robotic hilar isolation phase followed by bronchovascular structure division by VATS technique.[7]

Perioperative outcomes

Perioperative outcomes are shown in **Table 1**. At the beginning of the robotic surgery era, operating time increased compared to conventional surgery.[8,14,15,20] This is due to the initial lack of well-trained operators and initially-available instruments. Most studies were therefore aimed at establishing feasibility and safety. Later in the robotic surgery era, operation times decreased (mean operative time: less than 200 min)[8,10,11] and the conversion rate was less than 10%.[6,9–11,17] Gharagozloo et al. reported 21% morbidity and 3% mortality in robotic lobectomy,[7] while postoperative complications were 16.8% and the conversion rate was 1.6% due to pulmonary artery bleeding.[21] Most complications were due to atrial fibrillation, prolonged air leakage or atelectasis. Veronesi et al. showed similar complication rates of 13% including atrial fibrillation, prolonged air leakage.[5] Veronesi et al. and Cerfolio et al. revealed no significant differences between robotic and open lobectomy in terms of morbidity and mortality.[5,22] Furthermore, other groups reported similar morbidity and mortality rates between robotic and VATS lobectomy.[9,17,23] However, they showed shorter hospital stays after robotic lobectomy than open lobectomy. Pardolesi et al. reported the safety and feasibility of robotic segmentectomy, including a 17.6% morbidity rate.[24] On the other hand, Paul et al. reported that robotic lobectomy was significantly higher risk factor of iatrogenic complication including vessel injury than thoracoscopic lobectomy from the Nationwide Inpatient Sample.[25]

Long-term outcomes

As there has been only one study of long-term prognosis associated with robotic lobectomy, most data come from nonrandomized retrospective analyses of the feasibility and safety of robotic surgery including perioperative outcome. Park et al. reported the long-term outcomes of 325 robotic lobectomies for non-small cell lung cancer in three centers between 2003 and 2010.[6] Overall 5-year survivals were 91% in stage IA, 88% in stage IB, 49% in stage II, and 49% in stage III 3-year survival, respectively. Five-year survival of all patients was 80%. Taken together, these results may suggest that robotic lobectomy is oncologically superior to VATS or open lobectomy in terms of stage specific survivals.

Lymph node evaluation

Two groups (Veronesi et al. and Cerfolio et al.) showed that there were no differences between robotic and open lobectomy regarding the number of dissected lymph nodes as a indicator of oncological efficacy.[5,22] Other groups compared removed lymph nodes in robotic surgery with VATS lobectomy and found no differences between the two procedures.[9,17]

On the other hand, since the frequency of upstaging in clinically node negative lung cancer is a surrogate marker for completeness of lymph nodes dissection, Park et al. reported the upstaging rate in robotic surgery.[6] They found 13% of N1 upstaging in stage I cases, with similar radicality to open surgery reported by Boffa et al. Another group reported 6.6% of N1 and 4.3% in N2 upstaging by robotic major anatomical resection for lung cancer.[26] They concluded that the rate of nodal upstaging for robotic resection appears to be superior to that of VATS

Table 1 Perioperative results

Authors	Year	Patient number	Operation time (min)	Conversion (%)	Morbidity (%)	Mortality (%)	Hospital stay (median, days)
Park et al.[14]	2006	34	218	12	26	0	4.5
Anderson et al.[15]	2007	21	216	0	27	0	4
Gharagozloo et al.[7]	2008	61	240	0	22	4.9	4
Gharagozloo et al.[21]	2009	100	216	1	21	3	4
Giulianotti et al.[20]	2010	38	209	15.8	10.5	2.6	10
Veronesi et al.[5]	2010	54	236	13	20	0	NR
Cerfolio et al.[8]	2011	168	132	11.9	26	0	2
Jang et al.[9]	2011	40	240	0	10	0	6
Dylewski et al.[11]	2011	200	100	1.5	26	1.5	3
Augustin et al.[23]	2011	26	228	19.2	15	3.8	11
Park et al.[6]	2012	325	206	8.3	25.2	0.3	5
Louie et al.[17]	2012	52	213	5.7	43	0	4
Lee et al.[10]	2014	35	161	2.9	11	0	3

NR: not reported

and similar to thoracotomy data when analyzed by clinical T stage.

Learning curve

Melfi et al. and Gharagozloo et al. recommended at least 20 cases of robotic operation for achievement of sufficient skills.[21,27] Jang et al. reported that the learning curve for robotic lobectomy was shorter than that for VATS lobecotmy,[9] while Veronesi et al. suggested that 20 robotic operations are needed for open thoracic surgeons but not for VATS surgeons.[28] Meyer et al. suggested a similar learning curve by calculating operative time, mortality, surgeon comfort, and conversion need.[29] Lee et al. reported that there were no differences between the initial robotic lower lobectomy and mature VATS one in terms of operating times, but not for upper lobectomy.[10] They suggested that 17 cases of robotic lobectomy were necessary for minimizing the difference in operative time between the two procedures.

Mediastinal Tumor

Mediastinal tumors are good candidates for robotic surgery. Several papers have reported mediastinal masses including thymoma, thymic cancer, teratoma, thymic cysts, pericardial cysts, enterogenous cysts, ectopic parathyroid or thyroid tumors, lymphoid tissues, and neurogenic tumor.[30,31] Bodner et al. and Savitt et al. suggested the safety and feasibility of robotic surgery for mediastinal masses from their early experience.[30,31] They showed no conversions, intraoperative complications, or deaths. Weksler et al. compared robotic thymectomy to the trans-sternal approach for thymoma including myasthenia gravis.[32] They suggested that robotic thymectomy is superior to transsternal thymectomy, reducing intraoperative blood loss, morbidity, and hospital stay. Seong et al. also reported a propensity-matched analysis comparing robotic and conventional sternotomy approaches for anterior mediastinal mass resection.[33] They concluded that robotic surgery resulted in better outcomes including less tube drainage, lower blood loss, shorter tube days, length of hospital stay, and less complication rates. Melfi et al. reported long-term experiences of mediastinal robotic surgery with no intraoperative complications and no mortality.[34] Conversion rates were 4.3% and postoperative complication rates were 7.2% including convulsions, pleural effusion, anemia, and biliary colic events. They found no recurrence in cases of thymoma. A European multicenter study revealed that robotic thymectomy for early-stage thymoma was safe and useful. In that study, there was one conversion out of 79 cases, no intraoperative complications, no mortality, 12.7% postoperative complications, and a 3-day hospital stay.[35] Although 1.3% of recurrences were found during their follow-up period, they suggested that long-term oncologic results are needed for comparing between conventional and robotic approaches for thymectomy.

Myasthenia Gravis

Thymectomy is a widely accepted therapeutic option for myasthenia gravis (MG). Rea et al. reported 33 cases of robotic thymectomy with good perioperative outcomes including 6% postoperative complication, 2.6 days in hospital, 16.7% complete remission and 75% clinical improvement.[36] Cakar et al. compared robotic thymectomy to open thymectomy in a small study.[37] They showed significantly longer operation times, shorter hospital stays, fewer surgical complications and lower doses of MG therapeutic drugs in robotic thymectomy than in open thymectomy. A German group showed that the cumulative complete remission rate in robotic thymectomy (39.25%) was superior to non-robotic thoracoscopic thymectomy (20.3%).[38] However, the non-robotic group included a significantly higher number of hyperplasia cases than the robotic group, which may lead to patient selection bias and affect remission rates. In their study, there were no differences in terms of operation time and morbidity between the two groups. Marulli et al. reported similar improved outcomes for 100 consecutive MG patients after robotic surgery.[39] They showed 28.5% complete remission and 87.5% overall improvement in addition to safety (no deaths or intraoperative complications), with 6% postoperative complications in a 67-month median follow up period. Another long-term follow-up study (mean follow-up of 45 months) after robotic thymectomy for MG was reported by Freeman et al.[40] They concluded that robotic thymectomy is safe and effective due to 87% improvement in MG symptoms.

Conclusion

Although there is growing evidence that robotic surgery is associated with minimal invasiveness and an outcome equivalent to that of open or video-assisted thoracic surgery in early-stage NSCLC or mediastinal tumors, prospective randomized controlled trials to evaluate short-term outcomes including complications and long-term outcomes in terms of survival by experienced surgeons may be needed.

Disclosure Statement

The authors declare that no conflicts of interest exist.

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