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Robotic Surgery for Lung Cancer

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During the last decade the role of minimally invasive surgery has been increased, especially with the introduction of the robotic system in the surgical field. The most important advantages of robotic system are represented by the wristed instrumentation and the depth perception, which can overcome the limitation of traditional thoracoscopy. However, some data still exist in literature with regard to robotic lobectomy. The majority of papers are focused on its safety and feasibility, but further studies with long follow-ups are necessary in order to assess the oncologic outcomes. We reviewed the literature on robotic lobectomy, with the main aim to better define the role of robotic system in the clinical practice.

Key words: 1. Robotocs
2. Lung neoplasms
3. Carcinoma, non-small-cell lung
4. Minimally invasive surgery

INTRODUCTION

Lobectomy with lymph node sampling or dissection remains the cornerstone of treatment for early stage non-small cell lung cancer (NSCLC) since the only randomised prospective study of the Lung Cancer Study Group [1]. Over the years, changes have happened in the thoracic approach with the intent has been to make surgery less invasive. In 1992, Lewis et al. [2] firstly reported the utilisation of video assisted thoracic surgery (VATS) to perform 40 lobectomies. Many advantages were obtained by using VATS: less trauma and pain [3], short chest drainage duration, short hospital stay [4,5], and preservation of pulmonary function [6]. Although there are clear benefits, VATS has also some disadvantages for the surgeon. Long instruments placed through fixed entry points creating a fulcrum effect, with the surgical field viewed on a bi-dimensional screen and with the camera under an assistant's control, creating an unnatural environment where the surgeon can lose orientation, the eye–hand–target axis, and visual depth perception.

In order to overcome these limitations, some robotic systems were developed during the last decades. For the purposes of this document, we define robotic surgery as a surgical procedure that comprehends a computer technology enhanced device, which is under the direct control of the surgeon, during the interaction between surgeon and patient. The Automated Endoscopic System for Optimal Positioning, was the first robotic arm approved by the US Food and Drug Administration (FDA) to be used in laparoscopic surgery [7]. Subsequently, the same company (Computer Motion Inc., Goleta, CA, USA) developed the ZEUS system to assist surgeons in minimally invasive surgery [8,9]. At the same time,

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Table 1. Main features of the three generations of robotic system

Variable	Feature
First generation (standard)	3D image 3 robotic arms 0^{o} scope (12 mm)
Second generation (s)	3D HD vision Digital zoom 0^{o} and 30^{o} stereo endoscopes (12 and 8 mm) 4 robotic arms Large range of motion robotic instruments Extended length instruments
Third generation (si)	Advanced 3D HD visualization with up to ×10 magnification Dual console capability

3D, 3-dimensional.

the da Vinci Surgical System was developed by Intuitive Surgical (Sunnyvale, CA, USA) and cleared by the FDA for laparoscopy, thoracoscopy and intracardiac mitral valve repair. Currently, the da Vinci Robotic system is the only complete surgical system applied in a wide range of surgical procedures.

The aim of this review is to evaluate the application of robotic system in the field of thoracic surgery, in particular, of robotic lobectomy, analysing the perioperative and long-term outcomes. A systematic review of the literature was performed by accessing the MEDLINE database for entries from 1990 through January 2014. We selected and reviewed relevant original articles and case reports published in English language, excluding abstracts, and the reference lists from those sources were searched for additional trials. Data investigation included different techniques, patients' selection criteria, operative time, conversion rate, mortality, morbidity, postoperative stay, and oncologic results. Additionally, we focused on the costs management of the robotic system.

ROBOTIC SYSTEM

The robotic system consists in a master remote console, in a computer controller, and in a manipulator with fixed remote centre kinematics connected via electrical cables and optic fibres. The camera used in the system provides a true stereoscopic picture (3-dimensional) transmitted to a surgeon's console. The master console is connected to the surgical manipulator with the camera arm and three instrumental arms. The surgeon manipulates two master handles and the movements are transmitted to the tips of the instruments thanks to trigger highly sensitive motion sensor, which is able to filter up to 6 Hz of the surgeon hands tremor. The surgical arm cart provides three degrees of freedom (pitch, yaw, and insertion), while the tip of the instrument is characterized by a mechanical cable-driven wrist (EndoWrist), providing four more degrees of freedom (internal pitch, internal yaw, rotation, and grip). These seven degrees of freedom of the instrumentation allow to replicate the human wrist inside the chest cavity. Three generation of robotic systems (standard, s, and si) have been developed during the last decade (Table 1). Recently the first generation was discontinued.

TECHNIQUES

Different surgical techniques were described over these years. The number of ports used in each study, as well as the size of the access port/additional incision varied between institutions and sometimes within an institution in different time periods. Herewith we briefly report the different techniques used by several authors. Gharagozloo et al. [10] described a hybrid technique: three robotic arms are positioned at the 8th (camera), 6th, and 5th intercostal space for the dissection of hilar structures. After the dissection phase, the robot is removed, and the surgeon returns to the operating table for vascular, bronchial and parenchymal division [11,12]. Ninan and Dylewski [13] described a robotic lobectomy with three arms: the robotic camera port is placed in the 5th or 6th intercostal space, directly over the mid-fissure area. The two other ports are placed in the same intercostal space anteriorly and posteriorly, in order to avoid multiple intercostal neurovascular bundles. An utility port is inserted over the 11th rib and bluntly tunneled over the 9th rib, entering in the chest cavity through the 8th intercostal space [13]. Also Jang et al. [14] used a 3 arms-technique with the camera placed in the 7th intercostal space along the midaxillary line, another arm placed in the 6th or 7th intercostal space along the posterior axillary line and the other one positioned through a

Table 2. Pantient' features and surgical details of robotic procedures

Authors	Year	Patient no.	Non-small cell lung cancer	Stage	Robotic arms	Utility incision	Utility port	Lobectomy/ pneumonectomy	Segmentectomy
Anderson et al. [15]	2007	21	20	NR	3	No	2	16/0	5
Gharagozloo et al. [11]	2009	100	100	I II	3	No	1	100	-
Veronesi et al. [18]	2010	54	54	I II	4	Yes (3 cm)	No	54/0	-
Jang et al. [14]	2011	40	40	I[a)]	3	Yes	No	40/0	-
Louie et al. [16]	2012	52	52	I II	3	No	1	40/0	5
Dylewski et al. [24]	2011	200	125	I II[b)]	3/4	No	1 (12 mm)	164[c)]/1	35
Cerfolio et al. [19]	2011	168	168	I II[d)]	4	No	1 (15 mm)	106/0	16
Park et al. [23]	2012	325	325	I	3/4	Yes	NR	325/0	-
Melfi et al. [21]	2012	181	181	I	4	No	1 (12 mm)	181/0	-
Augustin et al. [34]	2011	26	24	I	3	Yes	No	26/0	-
Lee et al. [22]	2014	35	35	I II IIIA IVB	4	No	1	35/0	-

NR, not reported.
a)Three patients with solitary recurrence after chemo-radiotherapy included.
b)Five patients underwent neoadjuvant chemotherapy for locally advanced IIIA disease.
c)Including 4 bilobectomy, 3 sleeve lobectomies, and 3 en bloc lobectomies.
d)Six patients underwent neoadjuvant chemotherapy.

'utility incision' made at the fifth intercostal space along the submammary line. Anderson et al. [15] in 2007 and Louie et al. [16] in 2012 described the application of a three arms-robotic system for lobectomy, with one additional 12 mm-utility port for stapler positioning, suction or lung retraction. Veronesi et al. [17] reported robotic lobectomy with 4 arms, using an utility thoracotomy through which the anterior robotic arm is inserted [18]. Also Cerfolio et al. [19] described robotic lobectomy with 4 robotic arms all positioned along the 7th rib space, between the mid-axillary line and the paravertebral line, at a minimum distance of 9 cm from each other, with no utility incision [20]. Melfi et al. [21] recently reported a totally endoscopic approach with a 4 arms robotic system: the camera port is placed in the 7th to 8th intercostal space on the mid-axillary line, the other port incisions are performed in the 5th to 6th intercostal space on the anterior axillary line, in the 6th to 7th intercostal space on the posterior axillary line, and in the ausculatory area (for the 4th arm). An additional 12-mm port is used for suction or stapler positioning [21]. Also Lee et al. [22] reported the application of four arms robotic system for lung lobectomy, with no utility incision, with an additional 12 mm port. In these abovementioned studies, the specimen is removed through the anterior port that was expanded with blunt dissection, with no rib spreading.

PATIENT SELECTION

In most of cases robotic surgery was offered to patients with early stage NSCLC or carcinoid tumours or metastatic disease located in the hilar region that could not be removed with a limited resection, in addition to an adequate cardiopulmonary functional reserve. However, especially with regard to NSCLC, selection criteria differed amongst institutions. In the largest studies, Melfi et al. [21] and Park et al. [23] offered robotic surgery to clinical stage I NSCLC, with no previous thoracic surgery, no neoadjuvant chemo-radiotherapy, no bronchial involvement, and no chest wall involvement. Gharagozloo et al. [10-12] assumed similar criteria: stage I or II NSCLC, and also Jang et al. [14] selected early stage NSCLC. Veronesi et al. [18] added a dimensional criteria to the abovementioned ones: lesion larger than 5 cm were excluded.

Cerfolio et al. [20] applied robotic surgery to patients with stage I or II NSCLC, with no chest wall involvement, but neither the size of the lesion, nor the use of preoperative chemo-radiotherapy contoindicated the propsal of robotic pulmonary surgery. Also other authors, Jang et al. [14], Lee et al.

Table 3. Results of the most recent papers published in the field of robotic lobectomy

Authors	Year	Operative time (min)	Conversion rate (%)	Mortality (%)	Morbidity (%)	Stay
Gharagozloo et al. [11]	2009	216±27	1.0	3.0	21.0	4 (3–42)
Veronesi et al. [18]	2010	146–513	13.0	0	20.0	3–24
Park et al. [23]	2012	206 (110–383)	8.3	0.3	25.0	5 (2–28)
Fortes et al. [35]	2011	238 (156–323)	4.0	0	39.0	3 (1–13)
Cerfolio et al. [19]	2011	132±60	11.9	0	26.0	2 (1–7)
Dylewsky et al. [24]	2011	100 (30–279)	1.5	1.5	26.0	3 (1–44)
Jang et al. [14]	2011	240±62	0	0	10.0	6 (4–22)
Melfi et al. [21]	2012	215 (130–250)	9.4	0.5	NR	4 (3–22)
Louie et al. [16]	2012	213	5.7	0	43.0	4 (2–21)
Augustin et al. [34]	2011	228 (162–375)	19.2	3.8	15.0	11 (7–53)
Lee et al. [22]	2014	161 (104–272)	2.9	0	11.0	3 (2–6)

Values are presented as mean±standard deviation or median (range).

[22], and Dylewski et al. [24], offered robotic approach also to a small number of patients with stage IIIA that underwent neoadjuvant chemo-radiotherpy. A summary of patient baseline characteristics are summarised in Table 2. However, recently, some case reports describe the successful application of robotic system for sleeve lobectomy in case of tumour invading the orifice of the right upper lobar bronchus. Schmid et al. [25] reported a clinical hybrid VATS-robotic minimally invasive sleeve right upper lobectomy in a 30-year old female with a low grade neuroendocrine tumour, underlining that the robotic system facilitate the technical challenging bronchial end-to-end anastomosis. Subsequently, Nakamura et al. [26] performed robotic bronchoplastic upper lobectomy in a 56-year old man with a squamous cell carcinoma of the right hilum of the lung, narrowing the bronchial orifice of the right upper lobe. These studies empathised that the use of the robotic system in thoracic surgery field is still evolving, and thus also the indications to its application.

SURGICAL OUTCOMES

In 2002 Melfi et al. [27] firstly reported the application of robotic system on thoracoscopic procedures, including 5 lobectomies, reporting variable operative time ranging between 2.5 and 5 hours. Subsequently Ashton et al. [28] described a lower lobectomy performed with robotic surgical system, reporting a global operative time of 530 minutes, including bronchoscopy, mediastinoscopy, and pathology times. Then other authors described the application of robotic system to perform pulmonary lobectomies [29,30], while in 2006 Park et al. [31] reported a mean operative time of 218 minutes (range, 155 to 350 minutes) on 34 lung cancer lobectomies with a conversion rate of 12%. Anderson et al. [15], in 2007, reported 20 robotic lobectomies with an operative time of 3.6 hours (range, 1 to 6.4 hours), including also the time necessary for mediastinoscopy or frozen section analysis. Giulianotti et al. [32] described 38 robotic anatomic lung resection with a mean operative time of 200 minutes (range, 93 to 300 minutes), and with a conversion rate of 15.8%. These first experiences were focused on safety and feasibility of robotic lobectomy for early stage lung cancer, however they were associated with increased operative time in respect to conventional surgery. This was partly related to the necessity of an adequate surgical training to acquire new skills [12] and to the instrumentations initially available, that were designed for use on coronary vessel, resulting often inadequate for thoracic surgery [33]. In addition, the three cases of bilobectomies, performed due to the lack of the fissure, reported by Giulianotti et al. [32], resulted at least perplexing, leading to the belief that robotic lung lobectomies should be done in qualified thoracic divisions.

During the successive years several studies were published on larger series (Table 3). Gharagozloo et al. [10] updated a previous study of 2008, reporting 100 consecutive lobectomies performed with a hybrid technique (as abovementioned) with a mean operative time of 216, with a mortality rate of 3% not associated to the robotic technique and explained as attributable to the inclusion of high risk patients. The complication rate was reasonable (21%), and, in the majority of cases, it was due to atrial fibrillation, atelectasis, and prolonged air leaking [11]. The same group from Washington in 2012, again updated the previous studies, reporting 185 consecutive patients with a mean operative time of 211 minutes and a conversion rate of 1.6% for bleeding from pulmonary artery [12]. Postoperative complications occurred in 16.8% of patients, most frequently atrial fibrillation, prolonged air leaking and atelectasis. However the highlight of this last paper was the fact that the authors created a regression trend-line for independent variables, calculating the learning curve for a robotic lobectomy, that was estimated in 15, 20, and 19 cases for operative time, mortality, and surgical comfort, respectively.

Veronesi et al. [18] reported the first comparison of propensity scores matched series of open muscle-sparing thoracotomy and robotic lobectomy. Complication rates were similar between the two groups, atrial fibrillation and prolonged air leaking in most of cases. Hospital stay was shorter with robotic than open surgery, but robotic operating times were significantly longer. However, the authors emphasized that after the first tertile of robotic series, the duration of intervention decreases [18].

Augustin et al. [34] in 2011 compared posterior (first five patients) and anterior robotic techniques. In this initial experience on 26 patients the median operating time was 228 minutes, the mortality rate was 3.8% (one death for respiratory failure) [34]. However, the same authors in a subsequent paper of 2013 compared this initial robotic experience with initial VATS one [34]. The conversion rate and the postoperative complications were not statistically-significant different between the two groups, but the operative time resulted significantly longer (215 minutes for the robotic group in respect to 183 minutes for the VATS group). These facts led the authors to underline that the technical advantages of robotic system were not yet transformed in clinical benefit for the patients, but probably they will be useful in more complex procedure such as segmentectomy and sleeve lobectomy, as well as then reported by the same institution in a case report of a sleeve right upper lobectomy [25,26].

In 2011, Dylewski et al. [24] reported 200 anatomic lung resections using robotic approach, with a short mean operative time of 100 minutes (range, 30 to 279 minutes), with a conversion rate of 1.5% (required for bleeding, central tumour invasion or completion of a sleeve lobectomy). They observed a 60-day mortality rate of 1.5% and a morbidity rate of 26%, most frequently related to prolonged air leaking or pleural effusion requiring drainage [24].

In the same year, a study from Cerfolio et al. [20] described a retrospective comparative study results between 106 robotic lobectomy and 318 propensity-matched cases undergoing nerve-sparing and rib-sparing thoracotomy. The operative time resulted significantly longer for the robotic group (2.2 hours vs. 1.5 hours), with no difference in terms of operative mortality and morbidity. However the robotic group had improved mental quality of life and shorter hospital stay than the thoracotomy group. Although they did not directly compare robotic and VATS approach, the authors asserted that many of their robotic patients would not have been offered VATS (usually reserved for stage I) while their series did not exclude cases with larger tumours, N1 disease or previous chemoradiation for nodal involvement.

Fortes et al. [35], in 2011, reported an operative time of 238 minutes for 18 consecutive lobectomies, with an acceptable rate (4%) of conversion to open surgery. Also in this study the most frequent complications were atrial fibrillations (17%) and prolonged air leaking (13%) [35].

In 2011, Jang et al. [14] published an interesting comparative study between 40 initial robotic lobectomies and 40 initial VATS and 40 recent VATS lobectomies performed by the same surgeon. The operative time resulted similar in the robotic and in the initial VATS group, even though it was shorter in the recent VATS group. No conversions occurred in the robotic group, while conversion rate was 7.5% and 5% in the initial VATS and recent VATS groups, respectively. Postoperative complication resulted similar between the three groups, suggesting that even during the initial attempts, robotic lobectomy was not inferior to the recent VATS approach in terms of postoperative parameters.

Louie et al. [16], in a paper of 2012, described their early experience with 46 robotic anatomic lung resections, compared with 34 VATS segmentectomies/lobectomies. Operative time and postoperative complications were similar in both groups.

Pardolesi et al. [36] reported the results of 17 consecutive patients that underwent robotic segmentectomy in three different institutes, with a mean operative time of 189 minutes, no conversion to VATS or open surgery, and low morbidity rate (17.6%). The authors underlined that robotic surgery for anatomic segmentectomy was safe and feasible, and reproducible in three different centres.

In 2014, Lee et al. [22] compared 35 robotic and 34 VATS lobectomies performed by the same surgeon. The operative time was longer for the robotic group in respect to the VATS one (161 minutes vs. 126 minutes), while morbidity and mortality were not statistically significant different [22]. The authors highlighted that the features of robotic system may facilitate the minimally invasive resection of locally advanced tumour, leading to an extension of the indications of the robotic approach over the VATS one.

LIMPH NODE ASSESMENT

The potential benefits of robotic-assisted lung surgery include the ability to visualize and dissect small delicate structures, such as lymph nodes near arterial or venous branches, accomplishing an adequate lymph node dissection. For this reason the number of lymph nodes removed and the number of lymph node station examined were generally assumed as an indicator of oncological radicality. Dylewski et al. [24] reported a median number of lymph node stations removed of 5, with no distinction between the hilar or the mediastinal ones. Cerfolio et al. [20] compared the robotic and the thoracotomic groups, in terms of number of hilar and mediastinal lymph nodes removed (5 vs. 4 N1-lymph nodes and 12 vs. 11 N2-lymph node, respectively) and hilar and mediastinal stations assessed (3 vs. 3 N1-stations and 5 vs. 5 N2-stations, respectively), observing no significant difference. The same results were obtained by Veronesi et al. [18] in a comparative study between robotic and open approaches. Fortes et al. [35] reported a similar number of lymph nodes removed (median of 12). In the comparative study between robotic and VATS approach Louie et al. [16] separately analysed, lobe by lobe, the percentage of expected nodal stations sampled, which resulted similar between both groups.

Jang et al. [14] compared the number of lymph nodes removed and the number of station dissected between robotic, initial VATS and recent VATS approach, observing no difference in terms of stations assessed (7, 8, and 7.5 stations per group, respectively). In addition the authors found no differences in terms of lymph nodes dissected between the robotic and the recent VATS group (22 vs. 26) [14]. Lee et al. [22], which compared robotic and VATS approach lobe by lobe, reported similar results: the median number of lymph nodes removed was 18 and 16, respectively, while the median number of stations dissected was 3 and 2, respectively, with no statistically-significant difference.

SURVIVAL DATA

The majority of papers published with regard to robotic lobectomy were focused on technical aspects, analysing safety and feasibility of this new approach. Little data is available about survival with adequate follow-up period. In the study of Gharagozloo et al. [11] on a series of 100 consecutive cases of patients affected by stage I–II NSCLC, with a median follow-up of 32 months, 1 patient died of cancer and 6 had distant metastases. However, in this study, no survival analysis was reported. In 2011 Augustin et al. [34] reported a 5-year disease specific survival of 63% for patient with stage I, with a median follow-up of 27 months. In a paper of Giulianotti et al. [32] 66.7% of patients affected by primary lung tumour lived without recurrence, after a median follow-up of 60 months. This percentage increased up to 80% if stage I was considered [32]. The only study on a large cohort evaluating robotic lobectomy in terms of long-term survival is the one of Park et al. [23]. They obtained a 5-year overall survival rate of 80% with a median follow-up of 27 months, and it increased up to 91% and 88% if Stage IA and IB, respectively, were considered.

LEARNING CURVE

The term ‘learning curve’ has been used with increasing frequency in publications about surgical and diagnostic procedures as a reference to the process of gaining experience and improving skills in performing such procedures. Since the beginning of XX century, it is outward that the learning curve for robotic surgery is shorter than that needed for traditional laparoscopic surgery [37]. This difference was explained by the increased dexterity related to wristed instrumentation, motion scaling, tremor filtration, absence of 'fulcrum effect,' and depth perception. However, little exists about learning robotic lobectomy. Park et al. [31] reported that before implementation of robotics into clinical practice, the authors and the operating room team attended an intensive, 2-day certifying course given by Intuitive Surgical. Then they used a human cadaver model and, once the team became confident with the surgical system, two staff surgeons working together (one at the console and one at the table) applied it in practice. Melfi et al. [33] recommended to start the robotic surgical program with simple procedures, such as pleuro-pericardial cyst removal, and then pass to more complex procedures such as lobectomy. They also suggested a minimum of 20 operations in order to acquire new skills for the whole surgical team (surgeons and nurses). In a subsequent paper, Gharagozloo et al. [11], based on the retrospective analysis of 100 consecutive cases, observed that the first 20 patients had a longer operative time and length of stay in respect to the last 80 patients, reasoning that 20 operations are necessary in order to acquire sufficient skills.

Similar results were reported in a study of Veronesi et al. [17], where the first 18 patients had significantly longer operative time than the later cases. They suggested a learning curve of 20 robotic lobectomies, for a surgeon experienced in open thoracic surgery but not with VATS [17].

Jang et al. [14] compared a series of 40 robotic lobectomies with two VATS groups: the initial 40 VATS and the most recent 40 VATS. In this study the operative time for the robotic group and the initial VATS groups were similar but lasted longer than the recent VATS one. However, the complication rate and length of stay were significantly lower in the robotic group in respect to the initial VATS group, and similar to that of the recent VATS group. This fact supported the idea that the learning curve of the robotic lobectomy was shorter than the one of the VATS lobectomy.

In a paper of 2012, the group from Washington designed a study to calculate the learning curve for lung lobectomy, on a series of 185 consecutive patients [12]. They created different graphs, comparing operative time, conversion rate, morbidity, mortality, length of stay, and surgeon comfort with the number of consecutive cases. In each graph, a regression trend-line was drawn and the change in the slope of the curve, corresponding to the beginning of the plateau, defined the learning curve. They calculated that the learning curve based on operative times, mortality and surgeon comfort was 15, 20, and 19 cases, respectively, finding no relation between the need for conversion and number of consecutive cases. Thus, the authors suggested an overall learning curve of 18±3 cases, that results quite similar to those reported by the aforementioned studies [11,12,18,33], and shorter in respect to those described for VATS technique [38,39]. A recent study of Li et al. [40] suggested a range of cases between 100 and 200 necessary to achieve efficiency in VATS lobectomy (Table 4).

Table 4. The learning curves for robotic lobectomies and for VATS lobectomies defined as the number of cases necessary to achieve efficiency and consistency

Author	Year	Surgical approach	Learning curve
Melfi et al. [33]	2008	Robotic	20
Veronesi et al. [18]	2010	Robotic	20
Meyer et al. [12]	2012	Robotic	18±3
Lee et al. [22]	2014	Robotic	15–17
Petersen and Hansen [38]	2010	VATS	50
Li et al. [40]	2014	VATS	100–200

Values are presented as number, mean±standard deviation, or range.
VATS, video assisted thoracic surgery.

Lee et al. [22] analysed the transition from a mature VATS technique to the initial robotic one for lobectomy, comparing the two approaches based on operative times, stratifying them by tumour location. The authors found no difference in median operative time for lower lobectomies between the mature VATS technique and the initial robotic one. For upper lobectomies, the operative time resulted longer for robotic approach, but the authors observed that after the 17th consecutive case, the operative time for robotic upper lobectomies approached the VATS time, suggesting that once robotic learning curve is completed, minimal difference in operative time exists [22].

COST ANALYSIS

The financial impact of employing a new expensive technology must be considered when it is applied in clinical practice, as it has happened for robotic lobectomy. The cost of the robotic procedures is the sum of the robotic surgical system (ranging from $1 million to $2.5 million), of annual maintenance and of disposable materials. In 2008 Park and Flores [41] conduced a retrospective review using International Classification of Diseases-9 codes for thoracotomy, video-assisted thoracic surgery (VATS), and robotic VATS lobectomy to determine total average costs associated with the resultant hospital stay. Robotic lobectomy had higher associated costs than VATS only, primarily attributed to increased costs of the first hospital day, but was still less expensive than thoracotomy. The average cost of VATS is substantially less than thoracotomy primarily because of a decreased length of stay. The cost of robotic is still less than thoracotomy, but greater than VATS alone [41]. More recently, Turchetti et al. [42] published a systematic review on 11 papers that included some form of cost analysis of da Vinci robot-assisted operations in different surgical fields. They concluded that the higher costs of robotic surgery are mainly due to the high purchase and maintenance costs for the robot and, to a lesser extent, to the longer operating room time, but emerging evidence shows that operating room time decreases with acquired experience in using the robot. However, further studies are necessary in order to obtain a health technology assessment for the application of robotic system.

CONCLUSION

Several studies suggested that the robotic approaches for lung lobectomy are feasible, safe, and reproducible. Robotic system overcame the limitations of VATS technique, thanks to the intuitive movements, the wristed instrumentations and the three-dimensional vision. Longer operative times are reported for robotic lobectomy, but the most important limitation is represented by the costs. However, two key-points rose from this review. The first one is that the robotic system is still evolving. New wristed instruments were recently introduced in the clinical practice, such as suction/irrigation or bipolar coagulation plus mechanical transection for small vessel. Nevertheless, robotic staplers, that greatly enhance surgical intervention, are still lacking. In addition, from the technical point of view, the tactile feed-back is still missing, even if it is partly overcome with gained experience, thanks to enhanced vision.

The second key-point is that the features of robotic system, mostly wristed instrumentation and depth perception, lead us to suppose that it would be even more useful in more complex minimally invasive procedures requiring anastomosis, such as sleeve lobectomies, overcoming weak points of the thoracoscopic approach. However, large randomized trials will be necessary to compare different surgical approaches in order to assess the quality of life, morbidity, oncological outcome and cost-effectiveness.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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