Original Article

Learning curve for robot-assisted lobectomy of lung cancer

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Background: Robotic lobectomy is widely used for lung cancer treatment. So far, few studies have been performed to systematically analyze the learning curve. Our purpose is to define the learning curve to provide a training guideline of this technique.

Methods: A total of 208 consecutive patients with primary lung cancer who underwent robotic-assisted lobectomy by our surgical team were enrolled in this study. Baseline information and postoperative outcomes were collected. Learning curves were then analyzed using the cumulative sum (CUSUM) method. Patients were divided into three groups according to the cut-off points of the learning curve. Intraoperative characteristics and short-term outcomes were compared among the three groups.

Results: CUSUM plots revealed that the docking time, console time and total surgical time in patients were 20, 34 and 32 cases, respectively. Comparison of the surgical time among the 3 phases revealed that the total surgical time (197.03±27.67, 152.61±21.07, 141.35±29.11 min, $P<0.001$), console time (150.97±26.13, 103.89±18.04, 97.49±24.80 min, $P<0.001$) and docking time (13.53±2.08, 11.95±1.10, 11.89±1.49 min, $P<0.001$) were decreased significantly. Estimated blood loss differed among groups (90.63±45.41, 87.63±59.84, 60.29±28.59 mL, $P=0.001$) and was associated with shorter operative time. There was no conversion or 30-day mortality. No significant differences were observed among other clinic-pathological characteristics among the groups.

Conclusions: For a surgeon, the learning time of robotic lobectomy was in the 32th operation. For a bedside assistant, at least 20 cases were required to achieve the level of optimal docking.

Keywords: da Vinci; robotic lobectomy; lung cancer surgery; short-term outcomes; learning curve

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Introduction

Robot-assisted thoracoscopic surgery (RATS) is a minimally invasive lung surgery method for early stage non-small cell lung cancer (NSCLC). Since the first report on robot-assisted lobectomy which was performed using a da Vinci surgical system in 2002 (1), utility incision assisted robotic lobectomy, performed with one utility incision and several ports, has been widely used for lung surgery (2-4). Park *et al.* (5) and Veronesi *et al.* (6) described their experience in robot-assisted lobectomy with two thoracoscopic ports and a 4-cm utility incision in 2006 and 2011, respectively. In addition, robotic lobectomy has been reported to be a feasible and safe approach (3,7,8), with clinical outcomes similar to those of open and video-assisted thoracoscopic surgery (VATS) (9,10). However, the da Vinci system is still not covered by the national health insurance of China, and it has only been used in few patients. Up to now, few studies

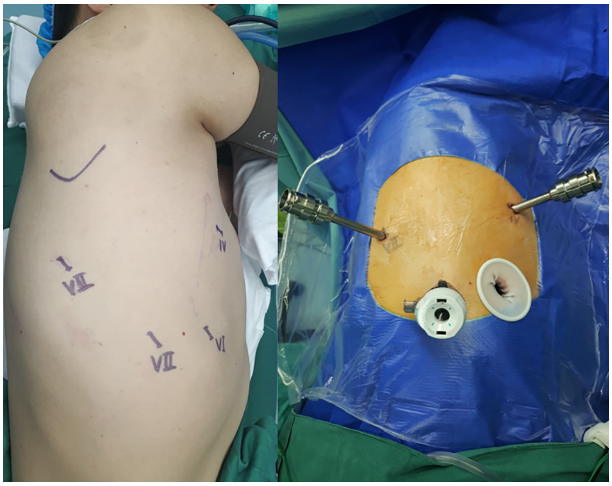

Figure 1 Intraoperative view of port placement for utility incision robotic lung surgery. The camera port is usually performed at the seventh intercostal space in the midaxillary line. The two operative ports for arm 1 and arm 2 equipped with permanent cautery hook and fenestrated bipolar forceps, are usually placed in the fourth and the seventh intercostal space. A 3–4 cm utility incision with no rib spread is created at the sixth intercostal. The utility incision provides enough space to introduce the instruments controlled by the bed assistant, such as suction, sponge stick and staple.

have systematically analyzed the learning curve of robotic lobectomy.

Initially, the cumulative sum (CUSUM) technique was successfully used to monitor the trend of continuous variation in the industrial sector, and it was later adopted in medicine to analyze the learning curve in the 1970s (11,12). It has already been used in several types of surgical processes, including laparoscopic surgery (13,14), robotic laparoscopic surgery (15,16), and esophagectomy (17,18). Our purpose is to define the learning curve to provide training guideline of RATS lobectomy by reporting our experience using the CUSUM technique.

Methods

Study population

Lung cancer patients who underwent robot-assisted lung surgery by a single team in the Department of Thoracic Surgery of the Affiliated Hospital of Qingdao University between October 2014 and October 2016 were included in this study. All patients who underwent R0 resection and radical lymph node dissection were pathologically confirmed as having NSCLC. Patients under preoperative chemoradiotherapy were excluded. A total of 208 patients were ultimately enrolled. Informed consent for robotic assistance was obtained from all patients, and all surgeries were performed constantly during the study period. This study was approved by the institutional review board of our center.

The data collected included age, sex, FEV1, ECOG performance status, tumor size, histopathological results, operative procedure, tumor site, clinical TNM stage, operative time, intraoperative estimated blood loss, conversion rates to open surgery, length of postoperative hospital stay, chest tube duration, perioperative complications, total number of dissected lymph nodes (LNs), and number of dissected LN stations. Definitions of operation duration are as followed: (I) docking time, the time from creation of portal incisions to the end of the docking; (II) surgeon console time, the time the surgeon spent at the console performing operations; (III) total surgical time, from the start of incision open to the end of closure (skin to skin).

Surgical technique

All robotic lung surgeries were performed with da Vinci Si surgical robotic system (Intuitive Surgical, Inc., Santa Clara, CA, USA). Patients received general anesthesia with double-lumen endotracheal intubation to achieve single-lung ventilation. Three ports and a utility incision were used in the robotic assisted lobectomy using 3 arms of the system (RAL-3) (19): a 12-mm camera port in the 7th intercostal space (ICS) at the midaxillary line and two 8-mm working ports in the 4th ICS at the anterior axillary line and the 7th ICS at the posterior axillary line. A 2.5-cm auxiliary incision was finally created in the 6th ICS without rib spreading, using an applicable wound protector (*Figure 1*). Specimen were obtained through the auxiliary incision at the end of the procedure.

All surgeries were carried out by the same surgeon, who had already performed more than 500 conventional video-assisted pulmonary resections before the RATS technique was adopted in our center.

Statistical analysis

The cumulative summation (CUSUM) which was calculated on the basis of the mean operative time, was used to analyze the learning curves of RATS lobectomy. Firstly, the cases were arranged in chronological order. Next, the CUSUM of the first case was the difference between the value for the first case and the mean for all cases. The CUSUM of the second case was the CUSUM of first case added to the difference between the second case and the mean for all cases. This recursive process continued until CUSUM for the last case was calculated as zero (15,17). A learning curve is deemed to be complete when a decreasing time-point is observed from the CUSUM plot.

SPSS software (v.22.0 for Windows; SPSS Inc., Chicago, IL, USA) was used for statistical analysis. Continuous variables are expressed as mean value ± standard deviation, and categorical variables are expressed as percentages. We performed a comparison among the three groups, in which the independent sample and paired t-test were used for continuous variables. The Fisher exact test was applied for dichotomous variables. P<0.05 was considered a significant difference. Learning curves were analyzed with MATLAB 2014.

Results

A total of 252 patients who underwent RATS lung resection were included in this study. Among the included patients, 44 patients who received robotic assisted wedge resection or segmentectomy were excluded, 208 patients who received robot assisted lobectomy were finally enrolled. None of the patients was under preoperative neoadjuvant therapy. The study participants consisted of 99 men (47.6%) and 109 women (52.4%), with an average age of 60.09 years. Baseline characteristics of patients are summarized in *Table 1*. No significant differences were found in gender, age, preoperative comorbidities and FEV1%, histology, clinical stage among the groups.

According to the cross point of the cumulative plots, the first 32 patients who underwent robotic lobectomy were assigned to Group 1, and the other 33rd to 70th patients were assigned to Group 2, while the remaining 71st to 208th cases were assigned to Group 3. We analyzed the learning curve for surgical time using the CUSUM method and found that a decreasing point for total surgical time begun at the 32nd operation (*Figure 2A*). Meanwhile, a similar trend at the 34th operation was observed for surgeon console time by visually inspecting the CUSUM plots (*Figure 2B*). Docking time decreased at the 20^{th} operation (*Figure 2C*). Among the three groups, the surgical time (197.03±27.67, 152.61±21.07, 141.35±29.11 min, P<0.001), console time (150.97±26.13, 103.89±18.04, 97.49±24.80 min, P<0.001) and docking time (13.53±2.08, 11.95±1.10, 11.89±1.49 min, P<0.001) were decreased. There was no case of conversion to VATS or open thoracotomy in the 208 consecutive cases.

Additionally, multiple intraoperative variables and short-term postoperative outcomes were compared as shown in *Table 2*. The number of dissected LNs (17.59±6.27 *vs.* 18.39±6.92 *vs.* 18.74±7.69, P=0.743) and dissected LN stations (5.63±0.75 *vs.* 5.55±0.76 *vs.* 5.59±0.77, P=0.923) were not significantly different among the groups. However, compared with Group 1, Group 2 and Group 3 displayed low blood loss (90.63±45.41, 87.63±59.84, 60.29±28.59 mL, P=0.001) and had shorter operative time (197.03±27.67, 152.61±21.07, 141.35±29.11 min, P<0.001). Drainage duration (3.91±1.53, 3.26±1.45, 3.10±1.99 d, P=0.087) and length of postoperative stay (6.31±1.69, 5.58±1.18, 5.46±2.20 d, P=0.097) were not different among the three groups. The postoperative complications and the incidence rate for each cohort were also assessed. There was no 30-day mortality in any cohort.

Discussion

Previous studies have shown several advantages of RATS lobectomy and demonstrated good short-time outcomes, including a reduction in the length of hospital stay and generally few post-operative complications (20,21). In the present study, none of the 208 consecutive patients who underwent robotic lobectomy was converted to open thoracotomy. In addition, although a significant decrease in the surgical time was noted after the first 32 cases, the length of hospital stay, estimated blood loss, conversion rate, and the frequency of major comorbidities were not significantly different among the three groups. Furthermore, there was no 30-day mortality in any group, which suggests that RATS lobectomy is safe and feasible.

At the initial stage of applying the robotic system, low availability and high costs may render surgeons unable to gain sufficient learning experience. Therefore, some of the initial operations are considered as the learning phase for the surgeon. By analyzing the learning curve, a novice surgeon can train and evaluate the benefits of the robotic lobectomy.

According to the CUSUM plots, we observed that the cutoff point of the surgical time learning curve of robotic lobectomy was the 32nd case, which implies that 32 cases are needed for surgeons who are experienced in open thoracotomy and VATS to achieve early proficiency.

Table 1 Baseline characteristics of patients

Characteristics	Group 1 (n=32)	Group 2 (n=38)	Group 3 (n=138)	P
Gender				0.556
Male	17	20	62	
Female	15	18	76	
Age, years	60.75±9.27	60.36±7.48	59.86±8.85	0.203
FEV1 (% of predicted)	2.63±0.69	2.55±0.53	2.54±0.58	0.331
Tumor size (cm)	2.25±0.92	2.31±1.16	2.28±1.09	0.292
Pathology				0.857
AC	24	30	118	
SCC	6	5	15	
Other	2	3	5	
Tumor location				0.274
RUL	10	16	39	
RML	2	4	16	
RLL	7	6	31	
LUL	6	4	30	
LLL	7	8	22	
Comorbidities				0.456
COPD	4	5	15	
Hypertension	5	7	28	
Diabetes	2	3	12	
Hepatic cirrhosis	1	0	3	
Atrial fibrillation	2	1	4	
Coronary artery disease	2	3	8	
Clinical TNM stage				0.255
I	20	20	83	
II	5	12	31	
III	7	6	20	

Clinical TNM stage was classified according to the AJCC, 8th edition. Data are represented as mean ± SD or number (percentage). AC, adenocarcinoma; SCC, squamous cell carcinoma; COPD, chronic obstructive pulmonary disease; FEV1, forced expiratory volume in 1 s; RUL, right upper lobe; RML, right middle lobe; RLL, right lower lobe; LUL, left upper lobe; LLL, left lower lobe.

However, in a report comprising 185 patients treated with robotic lobectomy using 3 arms, the learning curve based on operative times, mortality and surgeon comfort was 15, 20 and 19 cases, respectively according to the slope of the curve corresponding to the beginning of the plateau (22). Veronesi suggested that 18 cases may be the learning curve for robotic lobectomy using a four-armed robotic way, based on decreased operating time trends in 54 lung cancer patients (23). Baldonado *et al.* (24) argued that experienced surgeons in VATS may not have a definite learning curve for robotic lobectomy.

By making comparisons among these studies, our results can be interpreted as follows. Firstly, this study evaluates the in the initial stage of the learning curve of a single surgeon

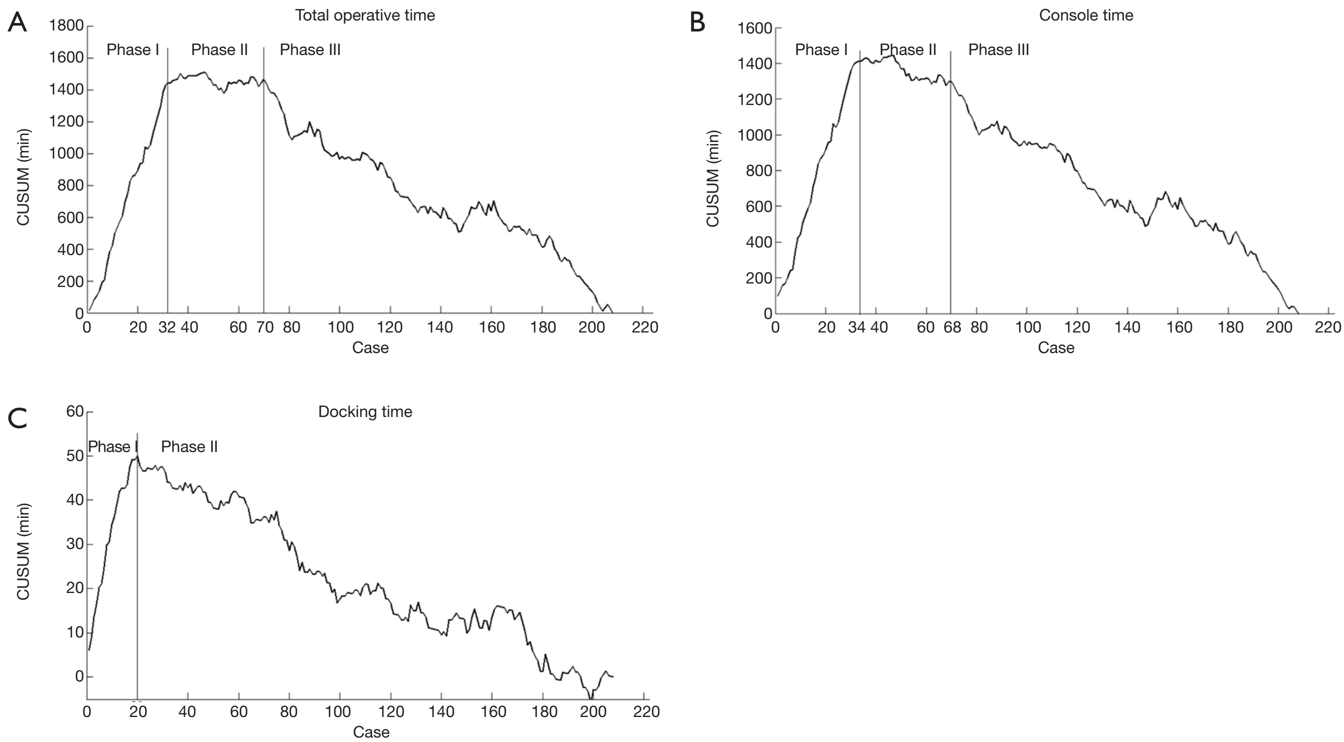

Figure 2 The CUSUM plot for RATS lobectomy. (A) A decreasing point for total surgical time begins at the 32nd operation; (B) a decreasing point for console time begins at the 34th operation; (C) a decreasing point for docking time begins at the 20th operation. RATS, robot-assisted thoracoscopic surgery.

and his team in 208 consecutive cases, using the CUSUM technique which is a more accurate statistical method (25). The learning curve may change from surgeon to surgeon. Additionally, we focus on surgical time in the analysis since it is the most widely used marker for the learning curve in this report. We speculate that the learning period of 32 operations is due to the difficulties associated with communication during the surgical procedure, since the surgeon sits away from the bed implying that the assistant must help the surgeon through the utility incision to expose the hilum structure. Nevertheless, a surgeon with an extensive VATS lobectomy experience and familiarity with the thoracoscopic appearance of pulmonary anatomy will have a short learning curve of the surgical procedure and a low rate of conversion.

The phase I, phase II and phase III periods were the 1st–32nd, 33rd–70th and 70th–208th operations, respectively. Phase I was the initial learning period, in which the CUSUM of the operative time increased. Phase II was the consolidation period, in which the operative time reached a mean value and remained stable. At the beginning of this phase, the operator was considered to have reached the learning point. This result suggested that the surgeon attained deeper understanding of anatomy and better collaboration with the teammates. Phase III was the experienced period in which CUSUM decreased continuously without increased morbidity or mortality in the cohort. This may explain the decreased estimated blood loss after the different phases. In phase I of the initial learning period, multiple factors such as the stress of role of the surgeon (primary operator or assistant) and the skilled degree may influence the cooperation and exposure of anatomical structure with increased risk of vascular injury. After the learning period, better understanding and cooperation result in less intraoperative injuries. The whole surgical time contains console time that requires cooperation between the surgeon and the bedside assistant, and docking time that requires incision design, portal set-up, docking, undocking and changing instruments. Therefore, the proficiency of the bedside assistant is crucial in the entire operation process. After 20 cases, the docking time decreased and it was significantly different among

Table 2 Intraoperative and postoperative variables

Characteristics	Group 1 (n=32)	Group 2 (n=38)	Group 3 (n=138)	P
Operative time (min)				
Total time	197.03±27.67	152.61±21.07	141.35±29.11	<0.001
Console time	150.97±26.13	103.89±18.04	97.49±24.80	<0.001
Docking time	13.53±2.08	11.95±1.10	11.89±1.49	<0.001
Blood loss (mL)	90.63±45.41	87.63±59.84	60.29±28.59	0.001
Postoperative hospital stays (day)	6.31±1.69	5.58±1.18	5.46±2.20	0.097
Chest tube duration (day)	3.91±1.53	3.26±1.45	3.10±1.99	0.087
Complication, n (%)	2 (6.25)	3 (7.89)	6 (4.35)	0.668
Arrhythmia	0 (0.0)	0 (0.0)	2 (1.45)	
Postoperative bleeding	1 (0.79)	0 (0.0)	0 (0.0)	
Pulmonary air leakage	1 (0.79)	2 (5.26)	2 (1.45)	
Dyspnea	0 (0.0)	0 (0.0)	0 (0.0)	
Pneumothorax	0 (0.0)	0 (0.0)	0 (0.0)	
Chylothorax	0 (0.0)	0 (0.0)	0 (0.0)	
Pulmonary infection	0 (0.0)	1 (2.63)	2 (1.45)	
Myocardial infarction	0 (0.0)	0 (0.0)	0 (0.0)	
Cerebral infarction	0 (0.0)	0 (0.0)	0 (0.0)	
Thirty-day mortality	0 (0.0)	0 (0.0)	0 (0.0)	
Number of LNs dissected	17.59±6.27	18.39±6.92	18.74±7.69	0.743
Number of LN stations dissected	5.63±0.75	5.55±0.76	5.59±0.77	0.923

the groups (13.53±2.08, 11.95±1.10, 11.89±1.49, P<0.001), which implies that the learning curve for a skilled bedside assistant requires 20 cases.

However, there are several limitations in this study. Since it is a retrospective study design that evaluated the learning curve of a single surgeon and his team. Other parameters including tube drainage duration, length of hospital stay and long-term oncology outcomes should be analyzed in future prospective multicenter studies involving several surgeons. In conclusion, robotic lobectomy is safe and feasible for patients with lung cancer based on its short-term outcomes. For a surgeon who is experienced in open thoracotomy and VATS, 32 operations are needed to attain early proficiency.

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Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

Ethical Statement: The protocol for data collection was approved by the Institutional Review Board of the Affiliated Hospital of Qingdao University, and informed consent was waived.

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