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The learning curve for laparoscopic-assisted single-port mediastinoscopic esophagectomy: an analysis of proficiency

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Abstract

Background Laparoscopic-assisted single-port mediastinoscopic esophagectomy is a safe and effective emerging minimally invasive esophagectomy, but little has been reported about the learning curve for this technology. The goal of the study was to determine the number of procedures to achieve different levels of proficiency on the learning curve.

Methods This study retrospectively analyzed data from consecutive surgeries performed by the same surgeon at the same center from 2016 to 2021. Learning curves were quantitatively assessed by unadjusted cumulative sums, different segments were derived using jointpoint linear regression analysis, and variables were compared between subgroups using trend analysis.

Results The learning curve could be divided into 3 different proficiency stages: the 1st-91st, 91st-125th, and 125th-182nd procedures comprised the preliminary, transition, and proficient stages, respectively. Compared with the preliminary stage, the procedure time [275 (250–300) vs 178.5 (161.5–205.0) min, $P<.001$], bleeding volume [100 (100–200) vs 50 (50–80) mL, $P<.001$], postoperative hospital stays [15 (13–31) vs 13 (11–17) d, $P=.006$], and the incidence of anastomotic fistula(20.9% vs 5.2%, $P=.017$) were significantly lower in the proficiency stage, whereas the number of harvested total lymph nodes [17 (12–23) vs 22 (16–29), P = .002], total mediastinal lymph nodes [7 (5–11) vs 13 (9–18), $P<.001$] and the rate of recurrent laryngeal nerve lymph node harvest (71.4% vs 96.6%, $P<.001$) was significantly higher.

Conclusions There may be 3 stages of varying proficiency in the learning curve of laparoscopic-assisted single-port mediastinoscopic esophagectomy. Approximately 91 consecutive procedures were required to overcome the preliminary stage, whereas proficiency in this technique required approximately 125 consecutive procedures.

Keywords LASPME, Learning curve, Esophagus cancer, Esophagectomy, CUSUM

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Introduction

Surgical treatment is one of the basic treatment strategies for esophageal cancer [1]. Minimally invasive esophagectomy (MIE) is a preferred method for the surgical treatment of esophageal cancer because of its excellent prognosis [2–4]. However, conventional MIE involves interference with the thoracic organs, which is an important independent risk factor for the development of postoperative pulmonary complications [5]. The conventional transhiatal approach requires a high surgical indication for squamous esophageal carcinoma and its oncologic outcome is considered to be poor due to its limited surgical field of view and inadequate mediastinal lymph node clearance [3, 6–8]. Therefore, it is less frequently used in esophageal squamous cell carcinoma. To overcome the problems, Fujiwara and colleagues proposed a new mediastinoscopic technique for dissecting the upper mediastinal lymph nodes through a cervical incision in 2015, which improved the surgical cure rate and expanded the surgical indications for transhiatal esophagectomy for esophageal cancer in the thoracic segment [9]. In 2016, we improved the procedure based on Fujiwara and colleagues' work and proposed laparoscopic-assisted single-port mediastinoscopic esophagectomy [LASPME] [10]. This surgical approach is a mediastinoscopic lymph node dissection via a left cervical incision along the bilateral recurrent laryngeal nerve (RLN), reducing trauma and avoiding double cervical incisions [11].

LASPME is an emerging technique in esophagectomy because of its minimally invasive nature and lower rate of postoperative chest complications; moreover, previous experience with this procedure has demonstrated that it is feasible in esophagectomy with good therapeutic efficacy and safety [12–14]. Compared with the previous trans-thoracic approach to esophageal surgery, this new procedure requires spatial thinking on the part of the operator to reconstruct the mediastinal structures and places higher technical demands on the operator, which has limited its development and dissemination to some extent. Learning curves are widely used to evaluate the learning process of surgeons for new technologies, but nothing has been reported about the learning curve for this technology either. The goal of this study was to perform a detailed analysis of more than 4 years' learning curve for LASPME at our center to help improve surgeons' understanding of the learning process of this new technique and to provide important lessons for establishing a better training program for surgeons.

Methods

Study population

We conducted a retrospective review of a prospectively recorded database of 182 consecutive patients who underwent LASPME among 226 MIEs performed by a single surgeon (QC) at our institution for esophageal cancer from October 2016 to August 2021. The inclusion criteria for this study were as follows: (i) preoperative endoscopic and biopsy specimens were pathologically diagnosed as clinical stage I-III esophageal cancer; (ii) the function of major organ systems met the requirements for esophagectomy; (iii) regardless of preoperative neoadjuvant therapy; and (iv) patients were not comorbid with other cancers. The exclusion criteria were as follows: (i) patients had previously undergone open or MIE for esophageal cancer; (ii) patients had previously undergone major gastrectomy or total gastrectomy; (iii) the tumour located in the cervical segment of the esophagus or the gastroesophageal junction, and; (iv) patients were also involved in other clinical trials with success.

Data collection and definitions

Our database was queried for age, sex, body mass index (BMI), smoking status [15], age-adjusted Charlson Comorbidity Index (aCCI) [16], Eastern Cooperative Oncology Group (ECOG) performance status, tumour location, histopathology, tumour stage, and neoadjuvant treatment. The tumour stage was defined according to the eighth edition of the TNM stage of esophageal and esophagogastric junction cancer jointly published by the International Union Against Cancer (UICC) and the American Cancer Society (AJCC) [17]. Surgical outcomes included operative time, bleeding volume, conversion to open surgery, total lymph nodes, mediastinal lymph nodes, and lymph nodes of the RLN. The operative time was recorded from the beginning of the skin incision to the end of the suture incision. Bleeding volume was defined as the amount of blood loss recorded from the beginning of the operation to the end of the operation. The rate of RLN lymph node harvest was defined as the rate at which the lymph nodes of the RLN were dissected intraoperatively and the presence of lymph nodes of the RLN was confirmed in the postoperative pathology. Postoperative data included postoperative length of stay, intensive care unit (ICU), and surgery-related complications. The definition of all surgical complications and the severity of 3 surgical complications including anastomotic leak, chyle leak, and vocal cord injury/palsy were designated based on the Esophagectomy Complications

Consensus [18]. Pneumonia is defined as "new lung infiltrates plus clinical evidence that the infiltrate is of an infectious origin, which include the new onset of fever, purulent sputum, leukocytosis, and decline in oxygenation" [18].

Surgical technique

All procedures were performed by the same surgical team, which had sufficient experience with approximately 60 + minimally invasive esophagectomies and 10 + open esophagectomies per year prior to this. All staff involved in this procedure must undergo rigorous training beforehand. In the first step, the team of surgeons involved in this technique must have extensive experience in open esophagectomy and thoracoscopic combined laparoscopic MIE before performing this technique. In the second step, all members of this team should carefully study the literature content of single-port mediastinoscopic lymph node dissection along the left recurrent laryngeal nerve proposed [1] by Prof. Fujiwara's team to get an initial grasp of the procedure. In the third step, a site visit to the Department of Surgery and Digestive Surgery, Kyoto Prefectural University of Medicine, Japan to Prof. Fujiwara's team was conducted in order to learn the specific surgical details of this technique. The fourth step is to repeatedly watch the surgical video from Prof. Fujiwara's team at least 3 times to master every detail of the surgical procedure. The fifth step is to learn the cadaver dissection performed in the cadaver lab and simulate the surgical procedure. The entire training process was supervised by the hospital's Ethics Committee, which hired an external, nationally renowned esophageal surgery expert to evaluate the results of the training and provide feedback before performing the first human surgery.

After training in video and cadaver dissection, we summarized this technique and found that the mediastinoscopic part of the procedure can be divided into six parts: the first part is the establishment of the left cervical incision; the second part is the freeing of the posterior and left walls of the esophagus and the clearing of the surrounding lymph nodes; the third part is the freeing of the anterior and right walls of the esophagus and the clearing of the surrounding lymph nodes; and the fourth part is the clearing of the left laryngeal reentrant nerve lymph nodes; In the fifth part, the right recurrent laryngeal nerve lymph nodes are cleared; in the sixth part, the subglottic lymph nodes and the right and left main bronchial lymph nodes are cleared.

Dangerous situations that may arise intraoperatively and responses to them are listed below: a. In the event of carbon dioxide accumulation, if the partial pressure of carbon dioxide is greater than 70 mmHg, the operation should be aborted, the pressure of the pneumoperitoneum machine should be reduced, and the operation should not be performed again until the ventilation has been relieved; b. For patients with hemorrhage during the operation, the operation should be changed to an open thoracotomy or an open abdominal operation, and the patient should be actively rescued and hemostatized, so that the patient can be saved; c. For patients with extensive and tight adhesions found during surgery, the surgical approach should be changed to open thoracic or open abdominal surgery, so as to avoid separation of adhesions leading to damage of large blood vessels and other injuries; d. For patients with tumors found to be unresectable due to tumor invasion during surgery, the continuation of surgery should be abandoned, and the patients' lives should be prolonged by using radiotherapy or other measures to improve the quality of life after surgery.

During the procedure, the patient was placed in the supine position and received single-lumen tracheal intubation and general anesthesia. The surgeons' station is shown in Fig. 1. The procedure consisted of two parts: a mediastinoscopic operation through a left cervical incision and a conventional laparoscopic operation, performed simultaneously by surgeons from the mediastinal and abdominal groups, respectively. The mediastinal group, whose instruments enter the mediastinum through a single left cervical incision, was responsible for completing the dissection of the middle and upper thoracic esophagus and the upper mediastinal lymph nodes including lymph nodes of the bilateral RLN (Fig. 2), while the laparoscopic group completed the remaining esophagus, the lower mediastinal lymph nodes, the stomach, and the abdominal lymph nodes. Finally, the esophagus was dissected at the neck, the distal esophagus and stomach were removed through a subxiphoid incision and the distal esophagus was resected, and an approximately 4 cm wide tubular stomach was reconstructed using a cutting and suturing tool, and the tubular stomach was elevated to the neck through the mediastinal esophageal bed to the neck and then the end-lateral anastomosis between the cervical segment of the esophagus and the stomach was performed with an anastomotic instrument, followed by local suturing of the gastric muscle layer and the esophageal muscle layer at the anastomosis to encapsulate the anastomosis, thus forming a new esophageal tract. The jejunum was exposed through a subxiphoid incision, and a nutrient tube was placed and fixed in the jejunum. Laryngoscopic examination of the vocal cords by an otolaryngologist was routinely performed in all patients on postoperative days 2–4 at our centre. Patients were usually examined by upper gastrointestinal imaging on the seventh postoperative day, and oral intake was initiated after no significant anastomotic leakage was

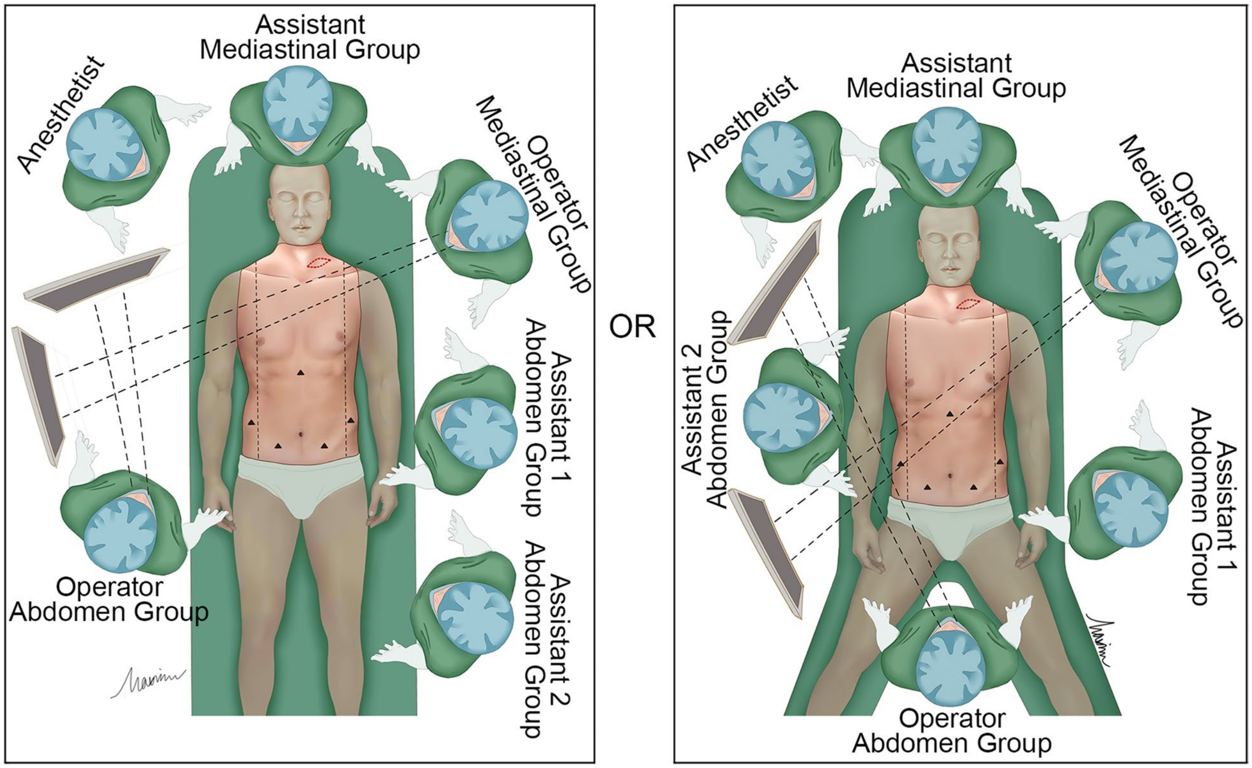

Fig. 1 The working position of the operators, assistants, and anesthesiologists during a new procedure

detected. The detailed technical aspects of LASPME in our institute have been reported previously [10–12, 19] (Video 1).

Statistical analysis of data

All collected clinical data were ordered sequentially by date of procedure, with procedure time used as an indicator of efficiency. The cumulative sum (CUSUM) procedure was used to construct learning curves due to it being one of the most well-known monitoring methods for sequential data [20]. This study used linear regression analysis in attempt to adjust the CUSUM for the following potential variables: age, gender, BMI, smoking status, ECOG performance status, neoadjuvant therapy, pathology types, and pathology stages. However, the learning curve of this study was used to quantitatively assess by unadjusted CUSUM values, as the linear regression adjusted model was not statistically significant ($P > 0.05$) (Supplementary Table 1).

A Simple scatter plot of procedure number versus procedure time was plotted with Microsoft Excel (Microsoft Excel 2019, Microsoft, Redmond, WA, USA) and its trend line was plotted using polynomial regression analysis. The CUSUM curves were segmented using joinpoint linear regression analysis (Joinpoint Regression Program 4.9.0.0, March 2021, Bethesda, MD; Statistical Research and Applications Branch, National Cancer Institute, Bethesda, MD, USA). Data are shown as mean (standard deviation) or median (interquartile range) for continuous variables and n [%] for categorical variables. Kolmogorov–Smirnov test and Shapiro–Wilk test were used to test the normality of continuous variables. Trend analysis was performed using the one-way analysis of variance test or the Kruskal–Wallis test for comparisons between groups of continuous variables and the χ^2 test for comparisons between groups of categorical variables or hierarchical information. Significance values were adjusted for multiple testing using the Bonferroni test, and a two-tailed P-value < 0.05 was considered to be statistically significant. All data were analyzed using SPSS software (version 25.0, IBM-SPSS, Armonk, NY, USA).

Results

Patient demographics

During the study period, there were a total of 182 consecutive patients with esophageal cancer underwent LASPME (Table 1):146 males and 36 females with a mean age of 62.4 (8.9) years. Preoperative comorbidities were assessed using the aCCI score, with a median score of 2. All patients had a preoperative ECOG performance status score of 0–1, including 76 [41.8%] with a score of 0 and 106 [58.2%] with a score of 1. The tumors were

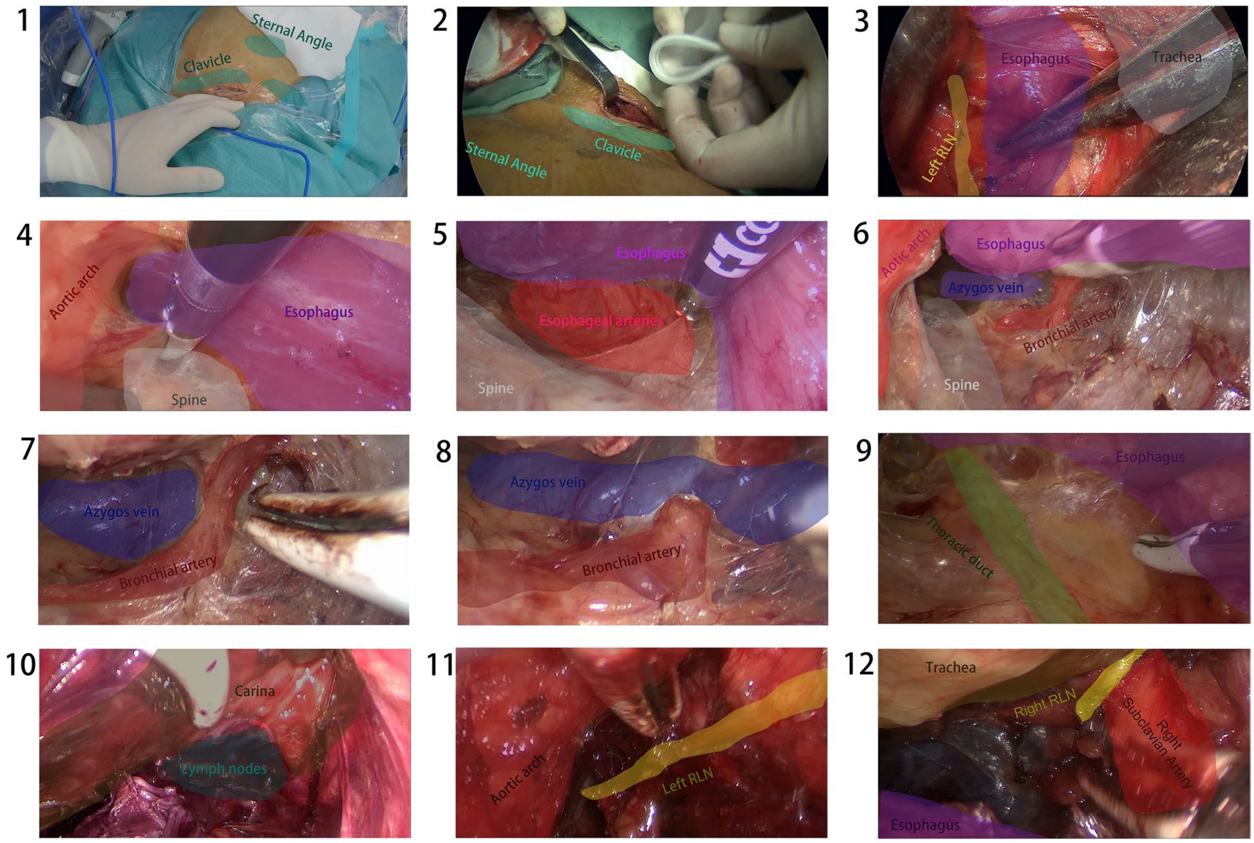

Fig. 2 Pictures of intraoperative anatomical landmarks in the mediastinal group portion of laparoscopic-assisted single-port mediastinoscopic esophagectomy

located in the upper, middle, and lower thoracic esophagus in 25 [13.7%], 68 [37.4%], and 89 [48.9%] patients, respectively. The majority of histological types were squamous carcinoma [175 patients, 96.2%]. Clinical T-stage were T1, 32 [17.6%] patients; T2, 38 [20.9%] patients; and T3, 112 [61.5%] patients. Clinical N-stage were N0, 73 [40.1%] patients and N1-3, 109 [59.9%] patients. In addition, 78 [42.9%] patients didn't receive neoadjuvant therapy, 78 [42.9%] patients received neoadjuvant chemotherapy and only 26 [14.3%] patients received neoadjuvant radiotherapy or neoadjuvant immunotherapy combined with chemotherapy. Except for gender, clinical N classification, and neoadjuvant treatment ($P<0.05$), there were few significant differences in the remaining indicators ($P>0.05$), indicating that the cohort analyzed in this study remained highly consistent.

Learning curve

We examined the relationship between procedure number and procedure time using polynomial regression analysis (Fig. 3A). A complex relationship between these two numerical variables could be found, with procedure time decreased as procedure number increased and showed different phases of change. In this study, the CUSUM curves of procedure time were divided into three different phases, which represented three different stages of surgical proficiency: preliminary, transitional, and proficient stage (Fig. 3B).

The preliminary phase was the beginning of the learning curve and included procedures 1 to 91, with a maximum overall procedure time: 275 (250 –300) minutes. After completing the first learning phase one entered a transition phase with relatively stable efficiency, and the curve in this phase remained stable for procedures 91 to 125, representing an improvement in the surgeon's ability. Its median procedure time was 230 (195 –270) minutes, significantly faster than the preliminary phase ($P<0.001$). After crossing the transitional phase one entered the proficiency phase of the learning curve, which encompassed procedures 125 to 182 and represented a further improvement in the surgeon's skill level of proficiency. The median operative time for surgeons entering this phase was only 178.5 (161.5 –205.0) minutes, which was significantly faster than the other two learning phases ($P<0.001$) (Table 2).

Table 1 Population demographics according to learning curve phases

Demographics	Total ($n=182$)	Preliminary phase (1–91)	Transition phase (91–125)	Proficient phase (125–182)	*P*-value
Sex, n [%]					0.011
Male	146 [80.2]	69 [75.8]	25 [71.4]	54 [93.1]	
Female	36 [19.8]	22 [24.2]	10 [28.6]	4 [6.9]	
Age, y	62.4 (8.9)	62.3 (8.4)	61.8 (9.7)	61.5 (9.1)	0.593
BMI	21.9 (2.9)	22.1 (2.9)	22.1 (2.4)	21.5 (5.2)	0.482
Smoking status, n [%]					0.103
Never	81 [44.5]	43 [47.3]	20 [57.1]	19 [32.8]	
Previous	26 [14.3]	10 [11.0]	3 [8.6]	13 [22.4]	
Current	75 [41.2]	38 [41.8]	12 [34.3]	26 [44.8]	
aCCI Median [IQR]	2 (1–3)	2 (1–3)	2 (1–3)	2 (1–3)	0.729
ECOG, n [%]					0.485
0	76 [41.8]	40 [44.0]	17 [48.6]	20 [34.5]	
1	106 [58.2]	51 [56.0]	18 [51.4]	38 [65.5]	
Histology, n [%]					0.679
Squamous	175 [96.2]	86 [94.5]	34 [97.1]	57 [98.3]	
Others	7 [3.8]	5 [5.5]	1 [2.9]	1 [1.7]	
Clinical T, n [%]					0.110
cT1	32 [17.6]	20 [22.0]	7 [20.0]	5 [8.6]	
cT2	38 [20.9]	21 [23.1]	8 [22.9]	9 [15.5]	
cT3	112 [61.5]	50 [54.9]	20 [57.1]	44 [75.9]	
Clinical N, n [%]					0.034
cN-	109 [59.9]	49 [53.8]	19 [54.3]	15 [25.9]	
cN +	73 [40.1]	42 [46.2]	16 [45.7]	43 [74.1]	
Neoadjuvant, n [%]					< 0.001
No therapy	78 [42.9]	52 [57.1]	17 [48.6]	11 [19.0]	
Chemotherapy	78 [42.9]	33 [36.3]	12 [34.3]	33 [56.9]	
Combined chemotherapy	26 [14.3]	6 [6.6]	6 [17.1]	14 [24.1]	
Radiotherapy	17 [9.3]	6 [6.6]	4 [11.4]	7 [12.1]	
Immunotherapy	9 [5.0]	0 [0.0]	2 [5.7]	7 [12.1]	
Tumour location, n [%]					0.199
Upper	25 [13.7]	12 [13.2]	5 [14.3]	8 [13.8]	
Middle	68 [37.4]	28 [30.8]	12 [34.3]	29 [50.0]	
Lower	89 [48.9]	51 [56.0]	18 [51.4]	21 [36.2]	

BMI Body Mass Index, *IQR* interquartile range, *ECOG* Eastern Cooperative Oncology Group

Intraoperative and perioperative outcomes

Comparing other intraoperative indicators of surgical competence between stages (Table 2): intraoperative bleeding volume decreased significantly from the preliminary to the transitional or proficiency stage [median bleeding 100 (100 −200) mL vs 60 (50 −100) mL or 50 (50 −80) mL, $P<0.001$]. The number of total intraoperative dissected lymph nodes, mediastinal lymph nodes and RLN lymph nodes increased from the preliminary stage to the proficiency stage [17 (12–23) vs 22 (16–29), 7 (5 −11) vs 13 (9 −18), 5 (4 −7) vs 6 (5 −8), respectively, $P<0.05$], and the increase in the rate of RLN lymph node harvest was more pronounced (71.4% vs 96.6%, $P<0.001$). In addition, a total of 4 [2.2%] patients were converted to right-sided open-chest surgery intraoperatively, including 3 [3.3%] during the preliminary phase, 1 [2.9%] during the transitional phase, and 0 during the proficiency phase, with the most common cause being an injury to the tracheal membrane (Table 4).

Comparing postoperative outcomes between stages (Table 3): the median postoperative hospital stays decreased from the preliminary to the proficiency stage [15 (13 −31) d vs 13 (11 −17) d, $P=0.006$], and the incidence of anastomotic fistula also decreased significantly (19.8% vs 5.2%, $P=0.017$). In addition, the most common complication was vocal cord paralysis [22.0%], but

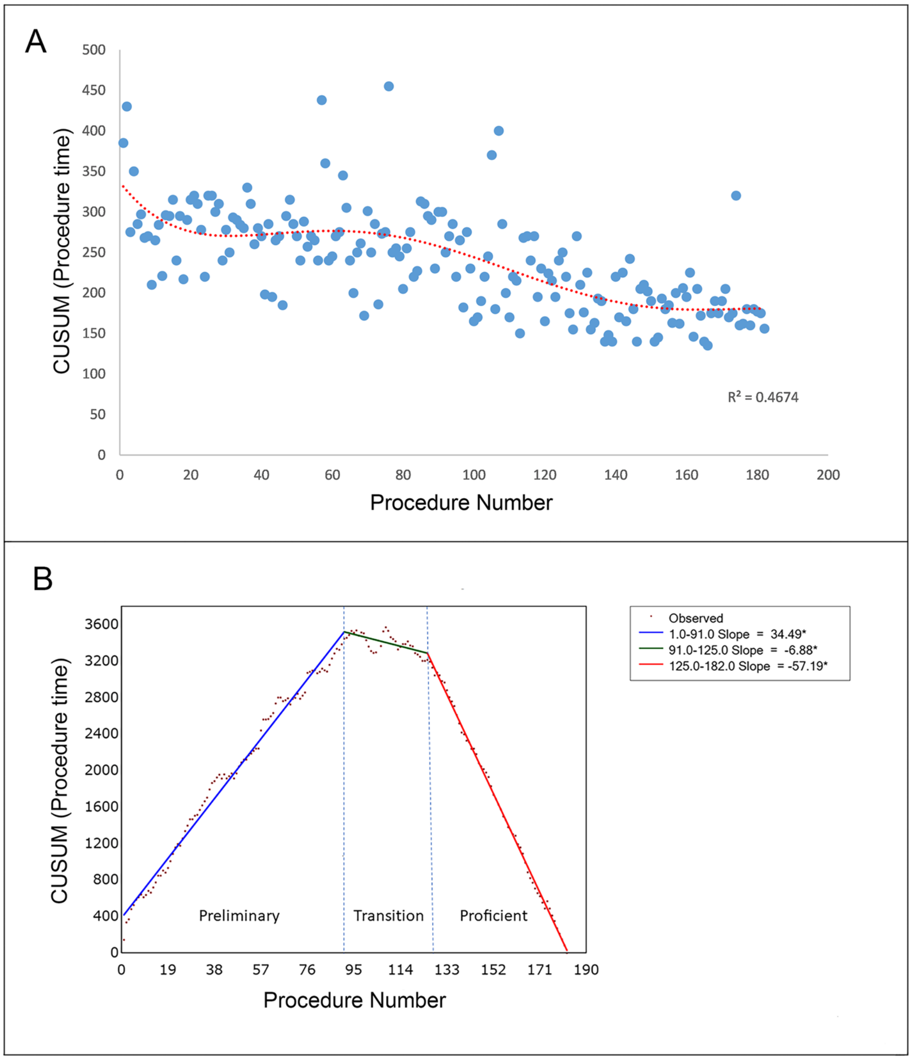

Fig. 3 **A** Simple scatter plot and its trend line of procedure time for laparoscopic-assisted single-port mediastinoscopic esophagectomy. **B** Jointpoint linear regression analysis of CUSUM values for procedure time: The 1st-91st, 91st-125th, and 125th-182nd procedures comprised the preliminary, transitional, and proficiency phases, respectively. The indicates that the slope is significantly different from zero at the alpha = 0.05 level

they were all type 1, which was a temporary injury and none of them appeared at 3 months after postoperation. Throughout the study, only one patient died in the hospital due to an acute cerebrovascular accident. The overall incidence of secondary surgery during hospitalization was 3.8%, with common causes being tracheoesophageal fistula and wound dehiscence, and only one patient developed a severe chyle leak requiring thoracic duct ligation (Table 4).

Discussion

In 2017, Samina Park et al. [21] reported the learning curve of robot-assisted combined thoracolaparoscopic MIE for esophageal cancer, which showed a significant improvement in perioperative outcomes after the robot gained surgical experience. Taking operative time as an indicator of efficiency, although their mean operative time was reduced from 496 to 431 min, our median operative time decreased from 275 min in the preliminary stage to only 178.5 min in the proficiency stage (Table 2). However, the surgical approach required about 91 consecutive cases to overcome the initial learning phase due to the technical difficulties, whereas their robot-assisted approach required only 80 cases.

In 2018, van der Sluis et al. [22] presented the learning curve for robot-assisted MIE, showing that the learning curve could be visualized in three phases using CUSUM analysis: phase 1 included the first 70 cases and

Table 2 Intraoperative outcomes according to the learning curve phases

Outcomes	Total (*n* = 182)	Preliminary phase (1–91)	Transition phase (91–125)	Proficient phase (125–182)	Preliminary VS Transition (*P*-value)	Preliminary VS Proficient (*P*-value)	Transition VS Proficient (*P*-value)
Procedure time, min Median [IQR]	240 (190–284)	275 (250–300)	230 (195–270)	178.5 (161.5–205)	< 0.001	< 0.001	< 0.001
Bleeding volume, mL Median [IQR]	100 (50–100)	100 (100–200)	60 (50–100)	50 (50–80)	< 0.001	< 0.001	> 0.99
Total lymph nodes Median [IQR]	18.5 (14–25)	17 (12–23)	18 (14–24)	22 (16–29)	> 0.99	0.002	0.123
Total mediastinal lymph nodes Median [IQR]	10 (6–14)	7 (5–11)	12 (10–16)	13 (9–18)	< 0.001	< 0.001	0.551
RLN-LN							
Harvest, n [%]	151 [83]	65 [71.4]	32 [91.4]	56 [96.6]	0.051	< 0.001	> 0.99
Quantity Median [IQR]	5 (4–7)	5 (4–7)	7 (4–8)	6 (5–8)	0.081	0.028	> 0.99
Conversions, n [%]	4 [2.2]	3 [3.3]	1 [2.9]	0 [0]	> 0.05	> 0.05	> 0.05
Pathological T, n [%]					> 0.05	> 0.05	> 0.05
CR	6 [3.3]	1 [1.1]	1 [2.9]	4 [6.9]			
pT1	55 [30.2]	31 [34.1]	10 [28.6]	14 [24.1]			
pT2	36 [19.8]	22 [24.2]	7 [20.0]	9 [15.5]			
pT3	85 [46.7]	37 [40.7]	17 [48.6]	31 [53.4]			
Pathological N, n [%]					> 0.05	> 0.05	> 0.05
pN0	97 [53.2]	52 [57.1]	21 [60.0]	26 [44.8]			
pN1	50 [27.5]	26 [28.6]	9 [25.7]	15 [25.9]			
pN2	24 [13.2]	9 [9.9]	3 [8.6]	12 [20.7]			
pN3	11 [6.0]	4 [4.4]	2 [5.7]	5 [8.6]			
Pathological M, n [%]	3 [1.6]	0 [0]	1 [2.9]]	2 [3.4]	> 0.05	> 0.05	> 0.05

RLN-LN recurrent laryngeal nerve lymph node, *IQR* interquartile range, *CR* Complete remission

represented the initial learning curve; In phase 2 (70 to 175 cases), a plateau was reached and the surgeon's competence was improved; In stage 3 (175 to 232 cases), the indications for robot-assisted MIE were expanded. This study used joint point regression analysis to similarly divide the learning curve of LASPME into three distinct stages of proficiency (Fig. 3B): approximately 91 consecutive procedures were required to cross the initial learning stage and approximately 125 consecutive procedures to become proficient in the technique.

Dissection of the bilateral lymph nodes of the RLN was crucial for the success of this procedure, but vocal cord paralysis was also its most common complication [21]. Although maryland forceps used intraoperatively to separate and cut the tissue could reduce thermal damage to the surrounding tissues, it was still difficult to completely avoid damaging the RLN. Therefore, we recommend avoiding the use of energy instruments whenever possible when performing the lymph node dissection of RLN. In addition, it was difficult to completely avoid hyperextension of the RLN for the complete dissection of its lymph nodes. These might be the main reasons why the incidence of vocal cord palsy in patients at the skilled stage remained at a high level of 19.0% (Table 3).

Compared with traditional transthoracic esophagectomy [23, 24], this surgical approach completed the dissection of the thoracic segment of the esophagus and lymph nodes by the mediastinal route, overcoming the defects of traditional transthoracic esophagectomy, which was not only significantly reduced the operative time, intraoperative blood loss, and postoperative hospital stay but also effectively reduced the occurrence of cardiopulmonary complications (Table 3). This expands the indications for esophagectomy, such as severe pleural adhesions, thoracic deformities, poor cardiopulmonary function, etc. However, esophagectomy with this technique has its unique anatomical features, the most important of which is the alteration of the anatomical perspective of the tissue structure during the operation, requiring reconstruction of its structure in the spatial thinking of the operator. In addition, the surgical field of view is still smaller than that of thoracoscopy. The

Table 3 Perioperative outcomes according to the learning curve phases

Outcomes	Total (n = 182)	Preliminary phase (1–91)	Transition phase (91–125)	Proficient phase (125–182)	Preliminary VS Transition (*P*-value)	Preliminary VS Proficient (*P*-value)	Transition VS Proficient (*P*-value)
Postoperative hospital stays, days Median [IQR]	15 (12–22)	15 (13–31)	15 (13–25)	13 (11–17)	> 0.99	0.006	0.043
ICU, n [%]	22 [12.1]	13 [14.3]	5 [14.3]	4 [6.9]	> 0.05	> 0.05	> 0.05
Complications, n [%]							
Vocal cord palsy					> 0.05	> 0.05	> 0.05
Type I	40 [22]	24 [26.4]	5 [14.3]	12 [19]			
Type II	0 [0]	0 [0]	0 [0]	0 [0]			
Type III	0 [0]	0 [0]	0 [0]	0 [0]			
Anastomotic leak	26 [14.3]	18 [19.8]	5 [14.3]	3 [5.2]	> 0.99	0.017	0.660
Type I	4 [2.2]	3 [3.3]	1 [2.9]	0 [0]			
Type II	22 [12.1]	15 [16.5]	4 [11.4]	3 [5.2]			
Type III	0 [0]	0 [0]	0 [0]	0 [0]			
Pneumonia	20 [10.9]	8 [8.8]	6 [17.1]	6 [10.3]	> 0.05	> 0.05	> 0.05
Cardiac	10 [5.5]	5 [5.5]	1 [2.9]	4 [6.9]	> 0.05	> 0.05	> 0.05
Urologic	2 [1.1]	1 [1.1]	1 [2.9]	0 [0]	> 0.05	> 0.05	> 0.05
Thromboembolic	2 [1.1]	0 [0]	1 [2.9]	1 [1.7]	> 0.05	> 0.05	> 0.05
Chyle Leak					> 0.05	> 0.05	> 0.05
Type I	2 [1.1]	1 [1.1]	0 [0]	1 [1.7]			
Type II	2 [1.1]	1 [1.1]	1 [2.9]	0 [0]			
Type III	1 [0.5]	1 [1.1]	0 [0]	0 [0]			
Wound Infection	6 [3.3]	3 [3.3]	1 [2.9]	2 [3.4]	> 0.05	> 0.05	> 0.05
RDH	7 [3.8]	5 [5.5]	0 [0]	2 [3.4]	> 0.05	> 0.05	> 0.05
In-hospital death	1 [0.5]	0 [0]	1 [2.9]	0 [0]	> 0.05	> 0.05	> 0.05

RDH Reoperation during hospitalization, *ICU* Intensive care unit, *IQR* interquartile range

Table 4 Reasons for conversion to right-sided thoracotomy and secondary surgery during hospitalization

Learning curve phase	Reasons for conversion to right-sided thoracotomy	Reasons for secondary surgery during hospitalization
Preliminary phase	① Tracheal accident (Injury to the tracheal membrane) ② Technical difficulty (Dense adhesions at the left main bronchus) ③ Technical difficulty (Dense adhesions at the right main bronchial membrane)	① Tracheoesophageal fistula ② Acute abdominal wall dehiscence ③ Tracheoesophageal fistula ④ Tracheoesophageal fistula ⑤ Need for thoracic duct ligation
Transition phase	④ Tracheal accident (Injury to the tracheal membrane)	
Proficient phase		⑥ Gastrostomy opening does not heal ⑦ Lateral neck wound dehiscence

success of the operation is therefore highly dependent on the experience and skill of the surgeon. Therefore, a total of four patients were converted to right-sided open esophagectomy due to intraoperative difficulties and tracheal membrane injury during the initial and transitional periods (Table 4).

In September 2024, both Edin Hadzijusufovic and Takeo Fujita et al. [25, 26] reported Single-Port da Vinci Robot-Assisted Cervical Esophagectomy, which provides a new minimally invasive transcervical esophagectomy option for patients. The report by Takeo Fujita et al. [26] further suggested the use of a neurologic integrity monitoring system for simultaneous cervical and abdominal surgery without the use of muscle relaxants, which is consistent with the surgical model of this study. Its operative time [168.9 ± 24.1 min vs. 178.5 (161.5–205) min] and incidence of anastomotic leak [6.6% vs. 5.2%] did not differ significantly from that of the proficient stage of the present study, however, its laryngeal reentrant nerve paralysis [13.3% vs. 19%] and total number of surgically removed mediastinal lymph nodes [31.4 ± 8.6 vs. 13 (9–18) are clearly superior to the data in this study, which may be where the advantages of robotic assistance for this surgical approach lie. Of course, robot-assisted cervical esophagectomy combined with abdominal transhiatal surgery for thoracic esophageal cancer is also a project that our center is currently working on, and we are looking forward to the better development of this technology.

The question is whether these results can be generalized to other hospitals. The introduction of new techniques needs to be supervised with measurement and control of all outcomes, it is necessary to maintain good oncological principles according to international guidelines and to meet the highest safety parameters to achieve high efficiency [15]. According to our experience, it is recommended that surgeons learning this procedure should have experience in esophageal surgery, starting with at least 3 cases or video observations in an experienced center, followed by a basic anatomy course in a cadaveric laboratory, and finally performing the procedure under the supervision of an experienced specialist. The surgical videos and results should be reviewed periodically to see where improvements can be made. In addition, the construction of a standardized and modular system for this procedure to shorten the learning curve is one of the research directions of our center, and the experience of its clinical application will be reported in the future.

This study was a single-center retrospective study, and the main limitations were his retrospective design and the inability to accurately assess the surgeon's previous surgical experience. In addition, it was difficult to determine how new surgical equipment, operating room aids, and teaching may have affected the learning curve.

Conclusions

In this study, a clear learning curve could be observed. Clinical outcomes such as procedure time improved dramatically at approximately the 91st procedure, but proficiency still needs to be achieved by continuing with 34 consecutive LASPME.

Abbreviations

LASPME	Laparoscopic-assisted single-port mediastinoscopic esophagectomy
aCCI	Age-adjusted Charlson Comorbidity Index
MIE	Minimally invasive esophagectomy
RLN	Recurrent laryngeal nerve
BMI	Body mass index
ICU	Intensive care unit
ECOG	Eastern Cooperative Oncology Group
CUSUM	Cumulative sum

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12893-025-02772-5.

Supplementary Material 1.

Supplementary Material 2: Video 1. Partial video of the operation of the mediastinal group during laparoscopic-assisted single-port mediastinoscopic esophagectomy.

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Authors' contributions
QC, WL, XG, and LL performed the operation and postoperative management. WL and XG drafted the manuscript. YW, WH, and YL critically revised the manuscript. QC, WL and YL were responsible for this study. All authors have read and approved the final manuscript.

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Data availability
Data supporting this study's results are available from the corresponding author upon request. However, due to privacy or ethical constraints, these data are not publicly available.

Declarations

Ethics approval and consent to participate
This post hoc analysis was used collected data of ChiCTR-ONC-17011044 that complied with the Declaration of Helsinki requirements, of which the study protocol was approved by the Institutional Review Board and the Ethics Committee of the Fifth Hospital of Sun Yat-sen University [IRB# 2017- Lun Zi No. (K97-1)]. The informed consent about the secondary use of the data was obtained from the enrolled patients at the registration to ChiCTR-ONC-17011044.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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