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Study on the learning curve for thoracoscopic and laparoscopic radical resection of esophageal cancer

Kexin Cao[1†], Kun Li[2†], Geng Zhang[1], Zhijun Chen[1*] and Jian Zhu[3*]

Abstract

Background The procedure for thoracoscopic and laparoscopic radical resection of esophageal cancer is complicated, so the operation time is long, which can easily negatively affect the self-confidence of young thoracic surgeons. This retrospective cohort study aimed to improve young thoracic surgeons' understanding of this type of surgery by analyzing the learning curve.

Methods From October 2017 to August 2018, 64 patients who underwent thoracoscopic and laparoscopic radical resection of esophageal cancer by a single team were reviewed by a retrospective cohort study. These patients were divided into four groups according to the date of operation. The baseline data, operation time, the amount of bleeding during the operation, and the number of lymph nodes sampled were compared. Then, the quality of the different stages of the operation was analyzed and evaluated.

Results There were no significant differences in the general baseline data, chest tube duration, or number of samples collected from the right laryngeal nodes among the four groups ($p > 0.05$). With the accumulation of experience, several key measures of surgical benefit were significantly different among the four groups. Specifically, the operation time became shorter, the amount of bleeding gradually decreased, the number of lymph nodes sampled gradually increased, and the number of left para-recurrent laryngeal nerve lymph nodes sampled gradually increased ($p < 0.05$).

Conclusion According to the learning curve, approximately 16 patients needed to complete this type of operation in 300 min, and 22 patients needed to be independently sampled from more than 20 lymph nodes.

Keywords Esophageal cancer, Thoracoscopy, Laparoscopy, Learning curve, Surgical quality

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Introduction

Thoracoscopic and laparoscopic esophagectomy are the mainstream surgical treatments for esophageal cancer; these procedures involve reducing intraoperative trauma, blood loss, and pain and eliminating large chest and abdominal incisions and rib cuts [1, 2]. There are some studies on minimally invasive surgical treatment for esophageal cancer [3, 4], and the National Comprehensive Cancer Network (NCCN) guidelines also list thoracoscopic and laparoscopic radical resection as one of the most demanding surgical treatments for esophageal cancer [5]. However, thoracoscopic and laparoscopic radical resection of esophageal cancer is a complicated operation for the majority of young doctors, which complicates long operation times and easily frustrates their confidence. Therefore, this study analyzed the data of 64 cases of thoracoscopic and laparoscopic radical resection of esophageal cancer by a single team in the First Affiliated Hospital of Xinxiang Medical College, Xinxiang City, Henan Province, from October 2017 to August 2018, which is a region with a high incidence of esophageal cancer in China, and explored the learning curve for radical resection of esophageal cancer, providing an empirical reference for young surgeons.

Methods

Patient general information

The clinical data of patients who underwent thoracoscopic or laparoscopic radical resection for esophageal cancer between October 2017 and August 2018 were collected by retrospective cohort study. Of these patients, 36 were males and 28 were females, and their median age was 67 year (range 49–81 year). Twelve patients were diagnosed with upper thoracic esophageal cancer, 38 patients were diagnosed with middle thoracic esophageal cancer, and 14 patients were diagnosed with lower thoracic esophageal cancer. According to the T staging of esophageal cancer, 21 patients were diagnosed with stage T1 disease, 16 patients were diagnosed with stage T2 disease, 23 patients were diagnosed with stage T3 disease, and 4 patients were diagnosed with stage T4 disease. According to the N staging system for esophageal cancer, 39 patients were diagnosed with stage N0 disease, 14 patients were diagnosed with stage N1 disease, 7 patients were diagnosed with stage N2 disease, and 4 patients were diagnosed with stage N3 disease. All patients were diagnosed with esophageal squamous cell carcinoma postoperatively. There were no obvious contraindications to surgery for any of the patients, and the tumor did not significantly invade the surrounding tissues or metastasize before surgery. All patients signed a surgical consent form before the operation.

The inclusion criteria for patients were as follows: (a) esophageal squamous cell carcinoma or esophageal high-grade intraepithelial neoplasia confirmed by preoperative gastroscopy; (b) preoperative enhanced CT scan of the chest and upper abdomen confirmed no signs of metastasis; (c) preoperative echocardiography, electrocardiogram, pulmonary function, and blood gas analysis indicated that cardiopulmonary function could tolerate the operation; (d) the possibility of distant organ or tissue metastasis was excluded, and there were no other contraindications related to nutrition, the blood system, the immune system, etc.; (e) all operations were performed by the same surgeon or his team; (f) the enrollment data started from the first thoracoscopic and laparoscopic radical resection of esophageal cancer performed by the surgeon; (g) operation time was from disinfection of the surgical area to closure of all surgical incisions; and (h) excluded patients also included those who were found to have severe adhesion in the pleural cavity/abdominal cavity during chest/abdominal entry and needed to be changed to open thoracotomy/laparotomy.

Surgical team

Professor Zhijun Chen completed all the surgeries. He has independently performed 60 or more radical esophageal cancer surgery with open thoracotomy, and more than 100 independently underwent video-assisted thoracic surgery (VATS). Doctor Kexin Cao was the first assistant. Doctor Geng Zhang was the second assistant.

Surgical procedures

The patients were administered combined general anesthesia and received single-lumen endotracheal intubation, which helped to clear the right recurrent laryngeal nerve lymph nodes. The patient was then fixed in the left decubitus position via the right thoracic approach. The right upper limb was fully abducted, and the patient was routinely disinfected and draped.

The thoracic esophagus was dissociated according to the following procedure. A 1 cm hole was made at the anterior axillary line in the 7th intercostal space, and a 10 mm trocar thoracoscope was inserted to observe possible pleural adhesions. Next, the mixture was filled with CO_2 to a pressure of 8 cm Hg to establish artificial pneumothorax, and the right lung completely collapsed. In addition, a 5 mm trocar was inserted at the posterior axillary line in the 6th intercostal space and served as the first auxiliary operating hole; a 10 mm trocar was inserted at the scapular line in the 9th intercostal space and served as the second auxiliary operating hole; and a 10 mm trocar was inserted at the anterior axillary line in the 4th intercostal space and served as the surgical port. The mediastinal pleura was incised to assess the extent of tumor invasion or adherence to adjacent structures such as blood vessels, trachea, and pericardium. Initially, the lower part of the esophagus near the azygos vein was

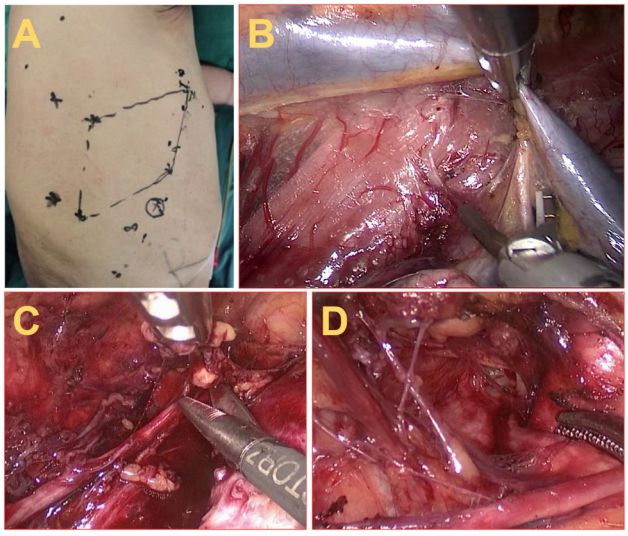

Fig. 1 The main procedure for accessing the thoracic esophagus involved dissociation during thoracoscopic and laparoscopic radical resection of esophageal cancer by Prof. Zhijun Chen. (**A**)Choice of incision for thoracic surgery. (**B**) Bronchial branch arteries appeared under the azygos vein arch while the thoracic esophageal artery was dissociated. (**C**) Root identification was used to find and dissect the right recurrent laryngeal nerve lymph nodes. (**D**) The hollow-out method was used to treat and dissect the left recurrent laryngeal nerve lymph nodes

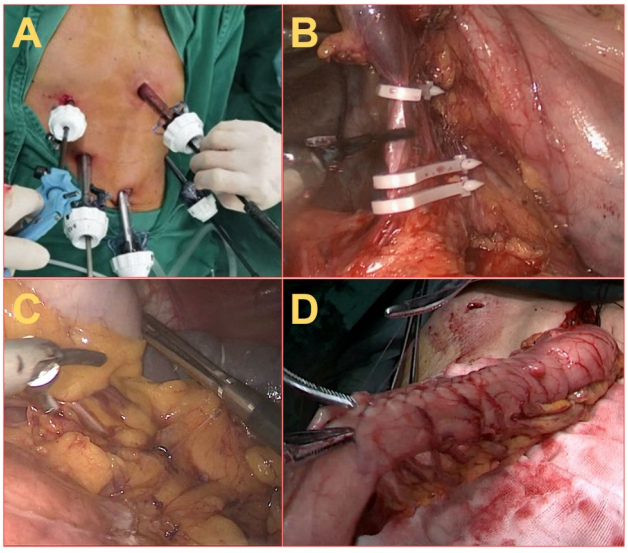

Fig. 2 The main procedure involved dissociating the peritoneal stomach, and the gastric conduit was removed during thoracoscopic and laparoscopic radical resection of esophageal cancer by Prof. Zhijun Chen. (**A**) Choice of incision for abdominal surgery. (**B**) The left gastric artery was released and transected following double ligation employing Hem-o-lock; (**C**) the short gastric artery located on the posterior aspect of the detached stomach was double ligated; (**D**) the gastric conduit was approximately 3.5 cm in diameter

dissected (Fig. 1). Subsequently, the azygos vein was dissected, ligated, and transected using a stapler. The dissection continued superiorly to the apex of the right thorax. In accordance with the general rule of nerve distribution, under the favorable anatomical conditions of a single-lumen endotracheal intubation (the organ is not inflated), dissection of the right recurrent laryngeal nerve lymph nodes, left recurrent laryngeal nerve lymph nodes, subcarinal lymph nodes, middle esophageal lymph nodes, and lower esophageal lymph nodes was performed with due consideration given to safeguarding the thoracic duct. The exact order can be based on the surgeon's habits. An ultrasonically activated scalpel or high-frequency electrocoagulator hook was routinely utilized during this procedure. Hemostasis was diligently ensured to prevent any active bleeding intrathoracic, while also verifying the absence of any leakage on the surface of the expanded lungs, trachea, or bronchus. Subsequently, a chest tube was inserted into the second auxiliary operating hole, which was then connected to a water seal drainage bottle. Finally, the surgical incisions were sutured.

Abdominal and neck procedures were performed as follows, the patient was repositioned in a supine position with a reverse Trendelenburg tilt, while the shoulders were elevated using padding. Additionally, the patient's head was rotated approximately 30 degrees toward the right side. A small incision measuring 10 mm was made below the umbilicus to facilitate the insertion of an insufflation needle. CO_2 was then introduced into the abdominal cavity, achieving a pressure of 14 cm Hg to establish artificial pneumoperitoneum. Subsequently, a 10 mm trocar was inserted at the left beneath 1 cm from the umbilicus serving as the observation hole for the laparoscope. A laparoscope was used to examine the presence of abdominal organ adhesions, ascites, and any metastatic masses in the liver or spleen. A primary surgical port was made by placing a 10 mm trocar at the right 4–5 cm with a horizontal line from the umbilicus. Additionally, a 5 mm trocar was inserted at the intersection of the right midclavicular line and the costal arch serving as the first auxiliary operating hole. A 10 mm trocar was inserted below 1 cm from the xiphoid process, serving as the second auxiliary operating hole. The hepatogastric ligament was then severed beneath the liver, and the lesser curvature of the stomach was dissociated along the right side of the ventral esophagus. The left gastric artery was released and transected following double ligation employing Hem-o-lock (Fig. 2). Subsequently, the gastrocolic ligament was incised at the greater curvature of the detached stomach, the left gastroepiploic artery and vein were severed and ligated, and the short gastric artery located on the posterior aspect of the detached stomach was double ligated and transected using Hem-o-lock. The greater curvature of the stomach to the left of the left side of the abdominal esophagus was completely separated, while the omentum and vascular arch on the greater curvature side were preserved. Throughout these procedures, sequential lymph nodes dissection around

the left gastric artery, the lesser curvature of the stomach, the common hepatic artery, the esophageal hiatus, and abdominal esophagus were meticulously dissected. Subsequently, the laparoscope and trocars were removed.

The esophagus was cut at the quasianastomosis site. A 6 cm oblique incision was made along the front of the sternocleidomastoid muscle, following a stratified approach to respect the cervical lymph nodes. The platysma myocutaneous flap was dissociated, and the sternocleidomastoid muscle was separated and suspended. Next, the omohyoid muscle was exposed and pulled aside, allowing for the removal of the cervical vascular sheath to obtain a clear view of the lymph nodes in regions III, IV, and V. Care was taken to protect the thyroid gland, parathyroid glands, and recurrent laryngeal nerve from injury. Finally, a complete dissection of the neck esophagus was performed.

A 1-Silk suture was used to bind the distal esophagus, followed by two additional 1-Silk sutures for traction. A 5 cm incision was made below the xiphoid process in the center of the abdomen. At this point, the stomach and the esophageal stumps (protected by ligation) were removed through the abdominal incision. The stomach was cut parallel to its greater curvature using staplers, resulting in a shape similar to that of a tube approximately 3.5 cm in diameter. Then, 4 – 0 Silk sutures were added for interrupted suturing of the seromuscular layer to reinforce the incision.

Esophagogastric anastomosis through the cervical incision was performed according to the following procedure. An advanced prepared gastric conduit was pulled up through the posterior mediastinum, and the esophagogastric anastomosis was performed using a circular stapler at the cervical incision (Fig. 3). After confirming the integrity of both cut rings, a 4 – 0 silk suture was used to perform an interrupted suture technique on the seromuscular layer to secure the anastomosis. Subsequently, the gastric tube was positioned at the predetermined site, and a stapler was used to seal the aperture at the fundus of the tubular stomach. Additionally, a 4 – 0 silk suture was employed for an interrupted suture technique to close the opening at the fundus of the stomach within the seromuscular layer. The cervical tissue was then suspended from the gastric fundus.

The neck was rinsed with a diluted iodophor solution, and a negative-pressure drainage tube was inserted while suturing the neck incision site. The abdominal cavity was meticulously inspected, and any bleeding was addressed. Following a thorough inventory check of gauze and instruments, the abdomen was closed in a layered fashion.

Statistical analysis

The data are presented as the mean ± standard deviation for continuous variables and as absolute numbers and percentages for categorical variables. Categorical variables were assessed using $\chi 2$ tests or Fisher's exact tests as appropriate, while *one-way ANOVA* was conducted for continuous variables. The nonnormally distributed data were compared between groups by the U test. A p value ≤ 0.05 indicated statistical significance. All the statistical analyses were performed using SPSS version 26.0 software.

Results

The baseline data comparison

Using SPSS software to construct a line chart of operation time according to the order of operation, we found that after 16 patients underwent surgery, the operation time fluctuated around 300 min (Fig. 4); according to the order of operation, the sample consisted of 64 patients, who were systematically divided into four groups (A, B, C, and D), with each group comprising 16 patients. The data were compared with the baseline data, operation time, amount of bleeding during the operation, one week of drainage, the duration of intrathoracic drainage, rate of conversion to thoracotomy, number of lymph nodes sampled, pulmonary infection, anastomotic leakage, and

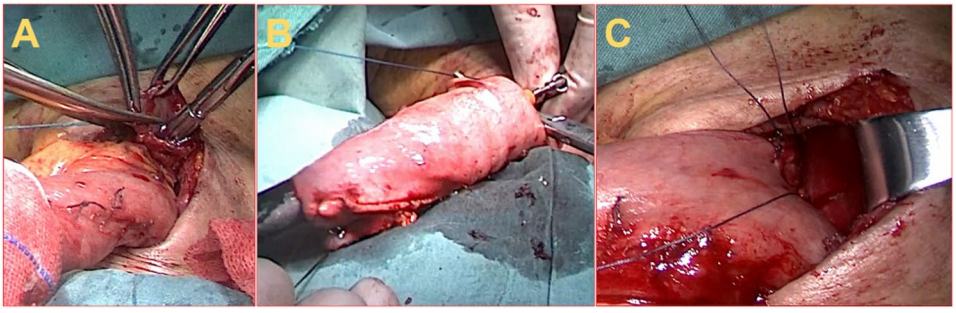

Fig. 3 The main procedure for anastomosis to the esophageal and tubular stomachs in the neck during thoracoscopic and laparoscopic radical resection of esophageal cancer was performed by Prof. Zhijun Chen. (**A**) A disposable needle was inserted to guide the location of the curved anastomosis stapler on the cervical esophagus; (**B**) a disposable curved anastomosis stapler was used to mechanically connect the tubular stomach to the left neck end of the esophagus; (**C**) 4 – 0 Silk sutures were used to perform an interrupted suture technique on the seromuscular layer to secure the anastomosis

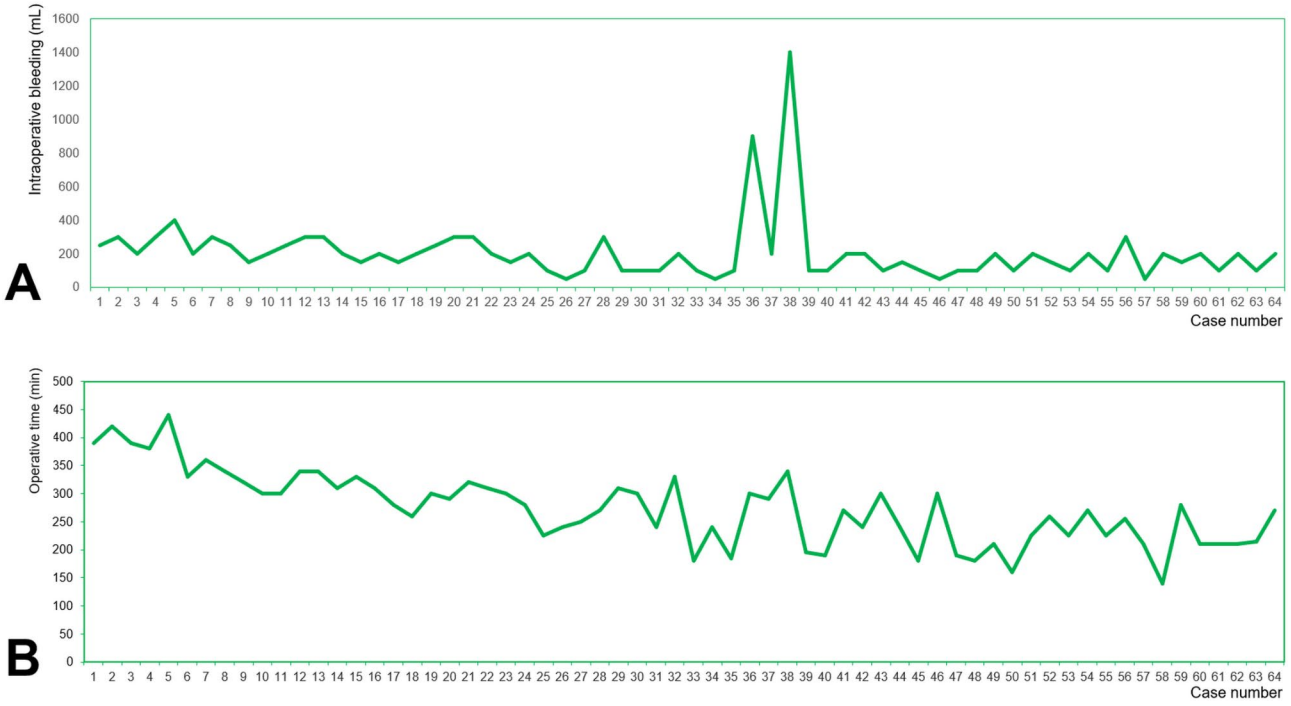

Fig. 4 The intraoperative bleeding and operation time for all patients who underwent thoracoscopic or laparoscopic radical resection of esophageal cancer according to the date sequence

recurrent laryngeal nerve injury. Then, the quality of the different stages of the operation was analyzed and evaluated.

There were no significant differences in sex, tumor location, T stage or N stage among the four groups ($p > 0.05$). The difference in patient age among the four groups was statistically significant ($p < 0.05$); the details are shown in Table 1.

The surgical quality and incidence of surgery-related complications were compared among the four groups

There were no significant differences in postoperative mediastinal drainage tube indwelling time, postoperative fasting time, or the number of lymph nodes along the right recurrent laryngeal nerve dissected among the four groups ($p > 0.05$). The operation time of group A was significantly longer than that of group B, group C, and group D ($p < 0.05$). The intraoperative blood loss in the four groups decreased gradually and tended to stabilize, and the difference was statistically significant ($p < 0.05$). The drainage volume in group A was significantly greater than that in group B, group C, and group D after the operation ($p < 0.05$). The postoperative hospital stays of the four groups decreased gradually and tended to stabilize, and the difference was statistically significant ($p < 0.05$). The duration of analgesic use after the operation in group A was significantly greater than that in group B, group C and group D ($p < 0.05$). There were significantly fewer dissected lymph nodes in group A than in group B, group C and group D ($p < 0.05$). The number of dissected left recurrent laryngeal lymph nodes in group A was significantly less than that in group B, group C and group D ($p < 0.05$). There was no statistically significant difference in the rate of conversion to thoracotomy or the incidence of postoperative complications (both $p > 0.05$). Anastomotic leakage occurred in 6 patients. Chylothorax occurred in 2 patients, of which 1 patient was performed reoperation to repair chylothorax in group C. Postoperative hoarseness occurred in 14 patients, including one patient with hoarseness combined with dysphagia in both group C and group D. The details are shown in Table 1. When 16 patients underwent surgery, the operation time stabilized at 300 min. When the number of operations reached 22, the number of dissected lymph nodes exceeded 20 (Fig. 5).

Discussion

Thoracoscopic surgery has become the mainstream technique in thoracic surgery [6–8]. The National Comprehensive Cancer Network (NCCN) guidelines clearly indicate that the application of thoracoscopic and laparoscopic radical resection for esophageal cancer is highly safe and feasible and has been applied in the clinical treatment of esophageal cancer [5]. However, the operation time of combined thoracoscopic and laparoscopic radical resection is longer for esophageal cancer patients than conventional thoracotomy and laparotomy surgery patients, and the operation procedure is more

Table 1 The baseline characteristics and comparison of surgical outcomes among the four groups of patients who underwent thoracoscopic and laparoscopic radical resection for esophageal cancer

Variable	Group A n = 16	Group B n = 16	Group C n = 16	Group D n = 16	F/χ^2	*p*
Sex (M/F)	10/6	9/7	9/7	8/8	0.45*	0.502
Age (year)	69.81 ± 5.77	67.56 ± 7.61	62.56 ± 7.16	65.43 ± 7.32	3.177#	0.033
Position						
UTEC	2	4	2	4		
MTEC	8	9	13	8	2.63*	0.452
LTEC	6	3	1	4		
T stage						
T1	2	5	4	10		
T2	7	4	5	0	3.84*	0.279
T3	7	6	4	6		
T4	0	1	3	0		
N stage						
N0	13	12	7	7		
N1	3	1	3	7	7.374*	0.061
N2	0	0	6	1		
N3	0	3	0	1		
Operative time (min)	350 ± 42.74	281.56 ± 31.39	238.75 ± 54.78	223.43 ± 38.15	38.433##	0.001
Intrathoracic operative time (min)	210.38 ± 27.91	164.56 ± 21.83	135.81 ± 37.51	118.94 ± 20.05	40.19##	0.001
abdominal operative time (min)	102.63 ± 15.02	80.13 ± 9.63	67.19 ± 17.44	58.94 ± 10.91	39.78##	0.001
Conversion to thoracotomy (n)	0	0	1	0	-	-
Intraoperative bleeding (mL)	246.87 ± 67.00	175 ± 81.64	246.87 ± 367.18	159.37 ± 63.81	14.211#	0.003
One week's drainage (mL)	1162 ± 975.79	753.12 ± 299.15	893.75 ± 792.64	662.50 ± 93.99	12.2#	0.007
MDT indwelling time(day)	14.19 ± 14.19	14.43 ± 15.47	11.43 ± 11.58	9.18 ± 9.30	7.689#	0.053
Postoperative complication†						
Anastomotic leakage	2	2	1	1		
Hoarseness	2	3	5	4	0.5079*	0.9171
Chylothorax	1	0	1	0		
Pulmonary infections	1	1	1	2		
Postoperative fasting time (day)	12.88 ± 13.53	13.18 ± 15.34	10.81 ± 12.62	8.62 ± 9.97	3.458#	0.326
Postoperative hospital stays (day)	19.81 ± 13.78	19.87 ± 14.35	17.31 ± 12.61	14.75 ± 10.25	8.096#	0.044
Time of using analgesics (day)	7.19 ± 1.91	5.88 ± 1.36	5.88 ± 1.50	5.56 ± 0.73	15.608##	0.001
The total number of dissected lymph nodes	11.44 ± 2.61	20.06 ± 5.49	23.88 ± 9.63	26.37 ± 10.64	11.245#	0.001
The number of dissected lymph nodes 106R	1.56 ± 0.29	2.62 ± 0.33	3.12 ± 0.55	2.06 ± 0.62	2.058#	0.115
The number of dissected lymph nodes 106 L	1.06 ± 0.31	2.00 ± 0.26	4.68 ± 0.94	3.50 ± 0.82	5.898#	0.001

UTEC, upper thoracic esophageal cancer; MTEC, middle thoracic esophageal cancer; MTEC, lower thoracic esophageal cancer; MDT, mediastinal drainage tube; 106R, right recurrent laryngeal lymph nodes; 106 L, left recurrent laryngeal lymph nodes

† were analyzed by Clavien–Dindo Classification using χ2 tests, $p = 0.369$; * were assessed using χ2 tests or Fisher's exact tests as appropriate; # were assessed using one-way ANOVA; ## were assessed using U test

complicated [9, 10]. Only through correct understanding and standardized learning can the learning process obtain the model program. Therefore, studying the learning curve of combined thoracoscopic and laparoscopic radical resection of esophageal cancer has positive significance for clinical practice.

At present, there are many ways to learn about radical resection of esophageal cancer via combined thoracoscopy and laparoscopy. The most common way to learn is through video, and proficiency can be achieved through repeated practice [11, 12]. After a certain number of surgical procedures, the operation time can be shortened, the amount of bleeding can be reduced, the postoperative complications can be reduced, and the number of dissected lymph nodes can be increased. Endoscopic surgery must involve a minimally invasive operation and mastery of minimally invasive operation skills. The operation process should include a model operation. Moreover, personalized design for different patients can be used to understand the nature of the operation more systematically. There are few reports on the learning curve for thoracoscopic and laparoscopic radical resection of esophageal cancer in the previous literature in China, but this study is representative of a single-center study in Henan Province, a typical region at high risk for esophageal cancer in China [13–19].

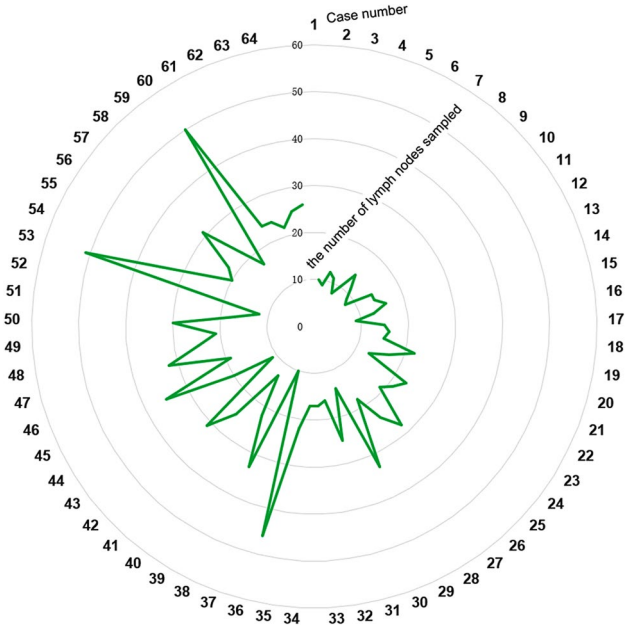

Fig. 5 The number of lymph nodes sampled by all patients who underwent thoracoscopic and laparoscopic radical resection of esophageal cancer according to the date sequence

In this study, some surgical outcomes tended to improve with experience. For example, the duration of analgesic use after the operation in group A was significantly greater than that in group B, group C and group D, the possible reason were shorter operation time, less operative bleeding, and less accidental injury. At the same time, the above details become better, the possibility of potential infection in the chest and abdominal cavity will be reduced, and the patient would feel less pain. In addition, less drainage tube indwelling time was also the reason for the reduction of pain. However, there may have been changes over time in the postoperative care package, including instructions for analgesic use.

The assessment of the number of dissected lymph nodes was also included in this study for the following reasons. First, the number of dissected lymph nodes is an important indicator for evaluating the effectiveness of esophageal cancer surgery [20, 21]. Based on a comprehensive analysis of the literature involving a cohort of 2,303 patients diagnosed with esophageal cancer from 9 international centers who underwent R0 esophagectomy, it was determined that the quantity of dissected lymph nodes serves as an autonomous prognostic factor for postesophagectomy survival. Notably, a minimum of 23 regional dissected lymph nodes was associated with improved survival outcomes [22]. The number of dissected lymph nodes in this study was consistent with that in previous studies, the number of dissected lymph nodes gradually increased from group A to group D, and up to 51 lymph nodes in group D could be dissected. Second, the recurrent laryngeal nerve lymph node metastasis rate is high in patients with esophageal cancer [23, 24]. A previous study showed that the percentage of patients with lymph node metastasis in esophageal cancer with the laryngeal recurrent nerve immediately adjacent to the lymph node is as high as 16.3% [25]. Another study showed that the percentage of patients with either the right or left recurrent nerve lymph node metastasis was 34.2%, the percentage of patients with right-sided laryngeal recurrent nerve lymph node metastasis was 20.8%, and the percentage of patients with left-sided laryngeal recurrent nerve lymph node metastasis was 15.85% [26].

In this study, the right recurrent laryngeal nerve was treated via the root finding method, and the left recurrent laryngeal nerve was treated via the hollow-out method. The left and right recurrent laryngeal nerves were cast off by the combination of separating forceps, scissors and an ultrasonically activated scalpel. This greatly increases the number of lymph nodes along the recurrent laryngeal nerve, but it also leads to complications, such as reversible hoarseness, which occurred in 21.86% of the patients in this study.

Moreover, in the study of this curve, the learning process also accumulated the following experience. (a) Learners should learn in centers where they are very skilled in this operation and have the qualifications for performing and teaching the procedure. (b) Trainees should start with the endoscope holder and the first assistant. After a certain accumulation of their knowledges and surgical experiences, they can try to start the main operation. (c) In the selection of patients, learners can start with patients with early-stage esophageal cancer and do not pursue lymph node dissection in the early stage. (d) During the intrathoracic manipulation step, up to five branches of bronchial arteries may appear under the azygos vein arch; these branches should be carefully dissected with an ultrasonically activated scalpel and clipped with a hem-o-lock clip. (e) On the upper part of the esophagus, the surgeon dissociated the posterior part first, and then, the surgeon dissociated the frontal part to better protect the recurrent laryngeal nerve. (f) The right recurrent laryngeal nerve was found along the vagus nerve and the right subclavian artery (root finding method, see Fig. 1), after which the right recurrent laryngeal nerve was removed, and the near-lymph nodes were fully dissected. (g) During lymph node dissection along the left recurrent laryngeal nerve, the esophagus can be pulled forward, and the tracheal membrane can be pulled and pressed with the help of tools for exposing the tracheoesophageal bed to facilitate access to the left recurrent laryngeal nerve (hollow-out method; see Fig. 1) and lymph node dissection. (h) Thorough lymph node dissection around recurrent laryngeal nerves needs discriminating and understanding among the endoscope

holder and first assistant and operator himself. (i) For lymph node dissection above the left main bronchus and under the aortic arch, attention should be given to the prevention of left pulmonary artery injury. (j) Surgical team members need to work together to formulate a detailed operation process that is as stable as possible before surgery. k) The selection of minimally invasive surgical instruments and equipment should meet the needs of the operation and reduce unnecessary waste of operation time during the operation.

Limitations

The study was not designed as a prospective randomized controlled study because of the need to review the details of the surgical video replay. In order to avoid sampling errors and treatment factors that may affect the outcome of surgery among groups, we did not include non-surgical preoperative treatment patients such as preoperative chemotherapy/radiotherapy/immunotherapy. Now it seems that this may have some shortcomings under the idea of integrative therapy. The details of amount of bleeding during intrathoracic and cervical/abdominal procedures were not required to be recorded separately due to local regulations. However, this study does not affect the application of minimal invasive surgery (MIS) on esophageal cancer, and understand the potential of MIS in clinical practice and resident education on esophageal cancer. The surgeries were performed in this study by a professor. It is both expected that the surgical time is longer and the amount of bleeding is greater if the surgery is performed by a trainee.

Conclusion

The current investigation revealed that a thoracic surgeon must perform surgery on approximately 16 patients to achieve proficiency in thoracoscopic and laparoscopic radical resection of esophageal cancer in 300 min. A total of 22 patients were independently sampled from more than 20 lymph nodes. Nevertheless, it is important to acknowledge that this study solely examines the learning curve associated with this specific technique based on the experiences of the participating surgeons. It is crucial to recognize that individual physicians may have varying experience, thus potentially resulting in divergent learning curves. Consequently, the primary objective of this study was to improve young thoracic surgeons' understanding and facilitating the advancement of this surgical procedure by analyzing the learning curve and obtaining learning confidence.

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Author contributions
(I) Conception and design: ZC and JZ; (II) Administrative support: ZC; (III) Provision of study materials or patients: KC, GZ and ZC; (IV) Collection and assembly of data, data analysis, and interpretation: KC and ZC; (V) Manuscript writing, figures and tables making: KL and JZ; (VI) Manuscript review and final approval of manuscript: All authors.

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Data availability
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical approval
The authors are accountable for all aspects of the work, ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. This study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). This study was approved by the Ethics Committee of the First Affiliated Hospital of Xinxiang Medical University.

Informed consent
Written informed consent was obtained from all patients before surgery.

Consent of publication
Informed consent to publish the study was obtained from all patients before surgery.

Competing interests
The authors declare no competing interests.

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