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Lymph node dissection around left recurrent laryngeal nerve: robot-assisted vs. video-assisted McKeown esophagectomy for esophageal squamous cell carcinoma

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Abstract

Objective This study investigated the advantages of robot-assisted McKeown esophagectomy (RAME) for extensive superior mediastinal lymph node dissection (LND) versus video-assisted McKeown esophagectomy (VAME).

Methods The cases of 184 consecutive esophageal squamous cell carcinoma (ESCC) patients who underwent minimally invasive McKeown esophagectomy (109 with RAME, 75 with VAME) performed by a single surgical group between June 2017 and December 2019 were retrospectively reviewed.

Results Overall, 59.8% (110/181) patients (70 treated with RAME, 40 treated with VAME; 64.2% vs. 53.3%, respectively, $p=0.139$) underwent complete LND around the left recurrent laryngeal nerve (RLN) by pathological assessment. Cumulative sum plots showed increased numbers of LND around the left RLN (3.6 ± 2.0 vs. 5.4 ± 2.7, $p=0.008$) and a decreased incidence of recurrent nerve injury (27.9% vs. 7.4%, $p=0.037$) after RAME learning curve. Despite similar overall LND results (30.6 ± 10.2 vs. 28.1 ± 10.2, $p>0.05$), RAME yielded more LND (5.4 ± 2.7 vs. 4.4 ± 2.2, $p=0.016$) and a greater proportion of lymph node metastases (37.0% vs. 7.5%) around the left RLN but induced a lower proportion of recurrent nerve injuries (7.4% vs. 22.5%, $p=0.178$) compared with VAME. Further analysis revealed that the complete LND around the left RLN was associated with recurrent nerve injury in the RAME (20.0% vs. 5.1%, $p=0.035$) and VAME (22.5% vs. 5.7%, $p=0.041$) groups but did not affect other clinical outcomes including surgical duration, intraoperative blood loss, postoperative intensive care unit stay, hospital stay, and other complications.

Conclusions For patients with ESCC, RAME has great advantages in LND around the left RLN and recurrent nerve protection after learning curve of robotic esophagectomy.

Keywords Esophageal squamous cell carcinoma · Lymph node dissection · Minimally invasive esophagectomy · Recurrent laryngeal nerve · Robot surgery

Despite high postoperative complication and mortality rates after esophagectomy, radical surgical resection remains the mainstream treatment method for early esophageal cancer and those after induction therapy. Minimally invasive esophagectomy (MIE) reportedly has better short-term clinical effects than open procedures, including a decreased incidence of postoperative complications, rapid postoperative recovery, and a shortened hospital stay [1–3]. Long-term follow-up results also confirm that MIE can achieve similar or better long-term survival than open surgery [4–7].

In recent years, robotic surgical systems have gradually been used to perform minimally invasive surgical treatment of esophageal cancer; similar to open surgical procedures, they can be divided into Ivor Lewis surgery and McKeown surgery. Kernstine et al. [8] first reported the use of robot-assisted McKeown esophagectomy (RAME) in esophageal cancer. Park et al. [9] reported the experience of 114 patients

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with esophageal cancer treated with RAME and confirmed its safety and feasibility. Suda [10] and Park [11] confirmed that the robotic surgical system better visualizes the anatomy, enables lymph node dissection (LND) of the recurrent laryngeal nerve (RLN), and significantly reduces the incidence of recurrent nerve paralysis. Precise dissection and radical dissection of the bilateral recurrent laryngeal paralymphatic lymph nodes are particularly important for patients with esophageal squamous cell carcinoma (ESCC) [12].

At our center, a robotic surgical system installed in 2016 has been used for esophagectomy and radical LND for ESCC. In recent years, some studies have compared robot- and video-assisted MIE [13, 14] with open surgery [15, 16]. The results confirmed that robot-assisted MIE can obtain better mediastinal LND and RLN protection [17, 18]. However, controversy persists without consensus. Here we reviewed our experience with robotic surgical procedures in patients with ESCC and investigated the advantages of RAME versus video-assisted McKeown esophagectomy (VAME) with a specific focus on the LND around the left RLN.

Patients and methods

Patients

To minimize selection bias, we retrospectively reviewed the data of ESCC patients who underwent MIE (RAME and VAME) performed by a single surgical group at our department between June 2017 and December 2019. During the study period, a total of 184 minimally invasive McKeown esophagectomies for ESCC were performed. We had no intended selection bias toward robotic or video surgical procedures; rather, we enrolled patients based on their consecutive admission. The present study was approved by our cancer center's institutional review board (no. E2019053). Written informed consent was obtained from each of the enrolled patients.

The preoperative evaluation of the study patients included medical history, physical examination, laboratory analysis, anesthesia evaluation, imaging examination, and endoscopy. Esophageal cancer diagnosis and staging were performed by endoscopic multi-point biopsy and endosonography. Ultrasonography and computed tomography combined with enhanced scanning determined the local growth, lymph node status, and distant metastasis. In some cases, positron emission tomography was used to exclude metastatic diseases and evaluate resectability. Patients who received induction chemo/chemoradiotherapy were also included. Chemotherapy consisted of platinum combined with paclitaxel, docetaxel, or fluorouracil. Radiotherapy with 46 Gy in 23 fractions for 5 days per week with weekly chemotherapy was used.

Surgical procedures

All patients underwent RAME or VAME with two-field lymphadenectomy performed by the surgical team of Dr. H.J.J. RAME were performed using a Da Vinci surgical system (Da Vinci Si/Xi, Intuitive Inc., USA). VAME was completed using a laparoscopic–thoracoscopic system. The surgical procedures included the following steps: transthoracic esophagectomy, LND, stomach mobilization, gastric tube construction, and left cervical esophagogastric anastomosis. The details for RAME are described below, and we used similar surgical procedures for VAME.

In the thoracic part, the patient was placed in the left lateral position and was ventilated by a single lumen endotracheal intubation. A 3-arm robotic surgical system (Da Vinci Si) was used. The robotic port placed on the chest is shown in Fig. 1A. Insufflation with carbon dioxide to a pressure of 6–8 mmHg was used to provide sufficient visualization. The patient's cart was docked onto the ports from behind the patient. After inspection, the esophagus was mobilized between the thoracic inlet and the diaphragmatic crura. The azygos vein was routinely transected, and lymph nodes were removed at the paratracheal, subcarinal, and paraesophageal areas, including both sides of the RLN (Fig. 1B). The patient was then placed in the supine position. First, the cervical esophagus was removed through a 5-cm incision in the left side of the neck. Figure 1C shows the placements of ports for the abdomen. A pressure of 12–15 mmHg was used. The robot was docked from the side of patient's head. We opened the gastrohepatic ligament, and separated and clipped the left gastric vessels. The lymph nodes surrounding the celiac trunk and the left gastric, common hepatic, and splenic arteries were dissected. The gastrocolic ligament and the short gastric vessels were transected after mobilizing of the stomach. We pulled out the stomach and specimen through a 5-cm midline incision and created a 3-cm-wide gastric tube. The gastrotomy line was closed with a linear stapler. A cervical anastomosis was constructed at the high point of the stomach using a circular stapler end to side (Fig. 1D). The distal end of the gastric tube was closed using a linear stapler approximately 1–2 cm away from the circular anastomosis. Nasogastric tubes, chest tubes, neck drains, and jejunostomy tubes were routinely inserted in all patients.

Collection outcomes and analysis

The baseline data, pathological outcomes, and lymph node yields were collected and analyzed. The number of dissected lymph nodes and positive lymph nodes were recorded according to the pathological reports. To examine further

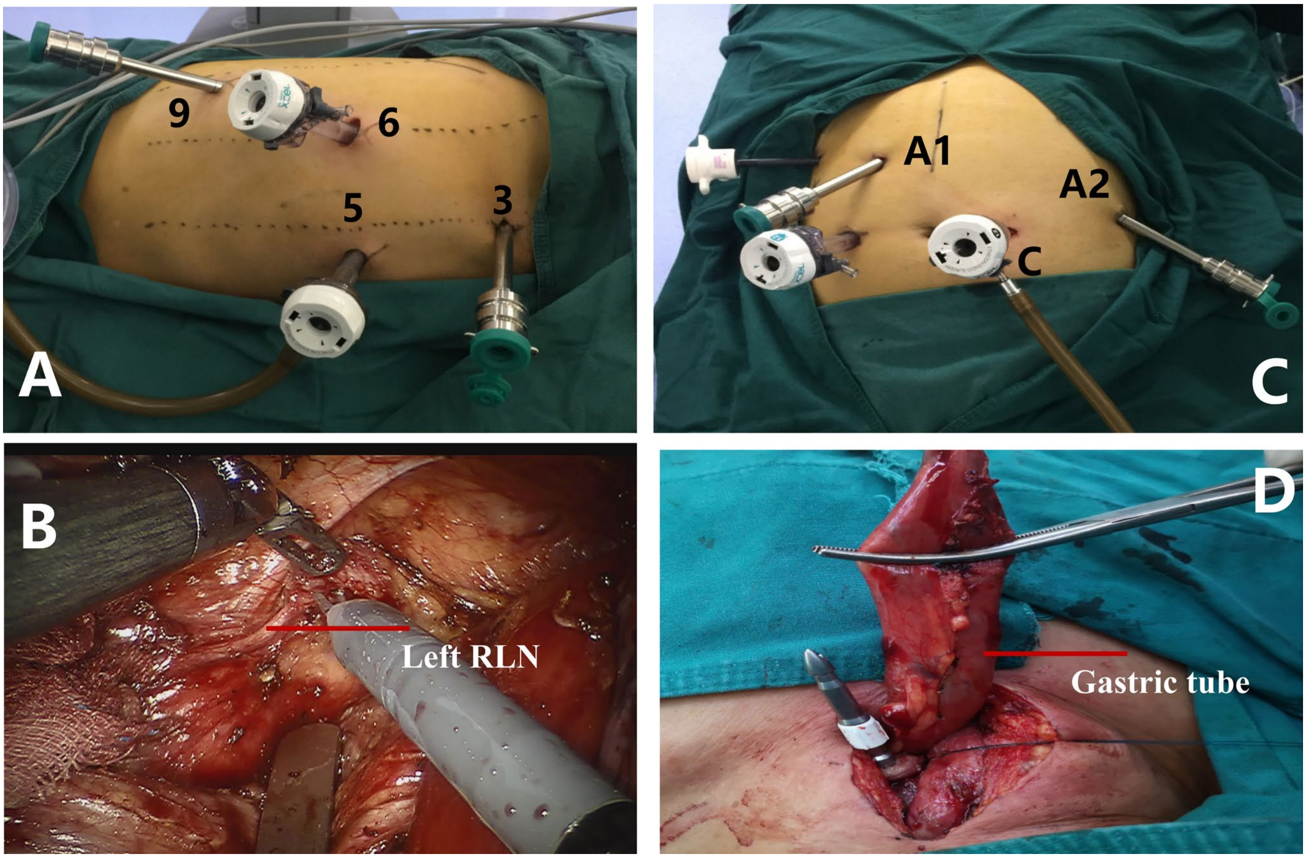

Fig. 1 **A** A 12-mm trocar for assistant was placed at the 5th–7th intercostal space (ICS) in the midaxillary line. A 12-mm trocar for camera at the 6th ICS in the posterior axillary line. Two 8-mm trocars for instruments were inserted as below: third ICS in the midaxillary line for arm 1, 9th ICS in the scapula angle line for arm. **B** The intraoperative imagines of robot-assisted esophagectomy in dissecting lymph nodes along left recurrent laryngeal nerve. **C** A 12-mm observational port was created just on the left side of umbilicus. A 12-mm and a 5-mm trocar for assistant was placed at the right anterior axillary line below the costal arch and on the right side of umbilicus. Two 8-mm trocars for the instruments were inserted as below: robotic arm 1 was placed at the left anterior axillary line below the costal arch, robotic arm 2 was placed at the right midclavicular line, respectively. **D** The gastric tube of 3 cm wide was pulled up to the neck and a cervical anastomosis was constructed at the high point of the stomach using a circular stapler end to side

details, the dissected lymph nodes were classified into total categories as well as those along the right and left RLN. The complete LND around the left RLN meant that at least one lymph node was found by pathological examinations, but not the soft tissue. We also analyzed perioperative data including blood loss, surgical duration, postoperative hospital stay, major complications, and hospital mortality. The operation time is defined as time from incision until final closure. All major complications were evaluated based on the Esophagectomy Complications Consensus Group [19]. All patients were staged using the American Joint Committee on Cancer 8th edition Tumor Node Metastasis staging system [20].

Statistical analysis

Cumulative sum (CUSUM) plots were used to analyze the RAME learning curve. We calculated the CUSUM for each patient in chronologic order and visually inspected the plots for the LND number around left RLN. All data are shown as mean ± SD or median (range) for continuous variables and as frequency (%) for categorical variables. The unpaired Student's *t*-test or Wilcoxon rank sum test was used for continuous variables. The Chi-squared test or Fisher's exact test was used for categorical variables. Two-tailed p values < 0.05 were considered significant. The statistical analysis was performed using SPSS 24 (IBM SPSS Statistics for Windows version 24.0, USA).

Results

Patient demographics

The data of 184 ESCC patients (109 RAME, 75 VAME) underwent minimally invasive McKeown esophagectomy and two-field lymphadenectomy between June 2017 and December 2019 were collected and reviewed. Among them, the cases of RAME and VAME during the same study period are presented in Table 1. The demographic characteristics did not differ significantly between the two groups.

To reduce the impact of the surgical procedures in each group, 70 treated with RAME and 40 treated with VAME who underwent complete LND around the left RLN were included in the further analysis after postoperative pathological lymph node examination. To reduce the impact of the learning curve of robotic surgery, CUSUM plots showed that increased LND around the left RLN was seen after patient 43 (3.6 ± 2.0 to 5.4 ± 2.7, $p = 0.008$), and the patients in the RAME group were separated into the early stage group (the first 43 patients) and late stage group (the last 27 patients), Fig. 2. The demographic characteristics did not differ significantly among the VAME, first RAME, and last RAME groups (Table 1).

Perioperative outcomes

Before matching, the total number of LND (24.8 ± 8.0 vs. 22.2 ± 8.6, $p = 0.114$) and number around the left RLNs (2.8 ± 2.6 vs. 2.3 ± 2.2, $p = 0.325$) were similar in the RAME and VAME groups, respectively. The other perioperative outcomes were also similar between the two groups (Table 2). Matching by surgical procedures and learning curve revealed that RAME yielded more LND (5.4 ± 2.7 vs. 4.4 ± 2.2, $p = 0.016$) and higher lymph node metastasis rates (37.0% vs. 7.5%, $p = 0.003$) around the left RLN

Table 1 Demographics characteristics

Variables	All patients ($n = 184$, %)		*p*-value	LRLN lymph node dissection ($n = 110$, %)			*p*-value
	VAME ($n = 75$)	RAME ($n = 109$)		VAME ($n = 40$)	Early RAME ($n = 43$)	Last RAME ($n = 27$)	
Age, years, mean ± SD	61.1 ± 6.6	60.0 ± 6.1	0.329	60 ± 6.1	59.6 ± 6.8	59.5 ± 5	0.845
Sex ratio (M:F)	65:10	90:19	0.453	35:5	36:7	23:4	0.941
Smoking (*n*, %)	48 (64.0)	72 (66.1)	0.774	27 (67.5)	28 (65.1)	20 (74.1)	0.758
Drinking (*n*, %)	46 (61.3)	77 (70.6)	0.187	22 (55.0)	29 (67.4)	21 (77.8)	0.148
Comorbidity							
Hypertension	18 (24.0)	42 (38.5)	0.039	9 (22.5)	15 (34.1)	11 (40.7)	0.259
Diabetes	6 (8.0)	10 (9.2)	0.781	4 (10.0)	5 (11.6)	3 (10.9)	1.000
Heart disease	5 (6.7)	13 (11.9)	0.238	1 (2.5)	5 (11.6)	3 (11.1)	0.266
Weight loss			0.958				0.290
Yes	20 (23.5)	26 (23.9)		10 (25.0)	15 (34.9)	5 (18.5)	
No	65 (76.5)	83 (76.1)		30 (75.0)	28 (65.1)	22 (81.5)	
Tumor location			0.481				0.817
20–25 cm	7 (9.3)	8 (7.3)		3 (7.5)	2 (4.7)	2 (7.4)	
> 25 & ≤ 30 cm	29 (38.7)	35 (32.1)		12 (30.0)	14 (32.6)	10 (37.0)	
> 30 cm	36 (48.0)	64 (58.7)		23 (57.5)	27 (62.8)	14 (51.9)	
Mutitumor	3 (4.0)	2 (1.8)		2 (5.0)	0 (0)	1 (3.7)	
Neoadjuvant chemoradiotherapy/chemotherapy	10/10	12/16	0.877	2/9	6/8	2/4	0.653
pCR	4 (20)	7 (25)	–	2 (18.2)	5 (35.7)	0 (0)	–
Pathological T stage			0.213				0.514
0	4 (5.3)	8 (7.3)		2 (5.1)	5 (11.6)	1 (3.7)	
1	23 (30.7)	18 (16.5)		8 (20.5)	10 (23.3)	4 (14.8)	
2	14 (18.7)	26 (23.9)		11 (28.2)	9 (20.9)	4 (14.8)	
3	23 (30.7)	34 (31.2)		12 (30.8)	9 (20.9)	8 (29.6)	
4	11 (14.7)	23 (21.1)		6 (15.4)	10 (23.3)	10 (37.0)	
Pathological N stage			0.327				0.113
0	45 (60.0)	52 (47.7)		20 (50.0)	25 (58.1)	8 (29.6)	
1	15 (20.0)	29 (26.6)		10 (25.0)	12 (27.9)	8 (29.6)	
2	13 (17.3)	21 (19.3)		9 (22.5)	5 (11.6)	7 (25.9)	
3	2 (2.7)	7 (6.4)		1 (2.5)	1 (2.3)	4 (14.8)	

LRLN left recurrent laryngeal nerve

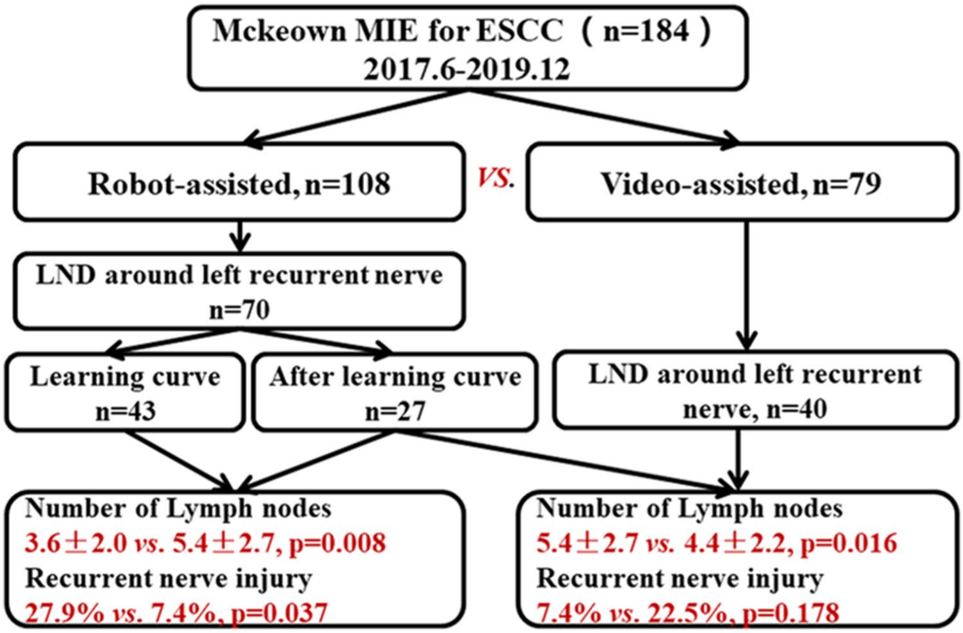

Fig. 2 Study flow chart and central findings

Table 2 Perioperative outcomes

Variables	All patients ($n=184$, %)		p-value	LRLN lymph node dissection ($n=110$, %)			p-value*
	VAME ($n=75$)	RAME ($n=109$)		VAME ($n=40$)	Early RAME ($n=43$)	Last RAME ($n=27$)	
Operation time	321.8 ± 29.1	321.2 ± 45.0	0.336	321.9 ± 35.1	327.4 ± 37.5	324.5 ± 50.5	0.827
Blood loss	187.7 ± 27.8	198.1 ± 35.2	0.379	188.1 ± 29.2	200.0 ± 4.6	171.2 ± 47.6	0.003
Re-surgery	0	0		0	0	0	
R0 resection	74 (98.7)	109 (100)	0.408	40 (100)	43 (100)	27 (100)	1.000
Number of DLN	22.2 ± 8.6	24.8 ± 8.0	0.114	28.1 ± 10.2	23.2 ± 5.9	30.6 ± 10.2	0.003
RRLN lymph node	2.2 ± 1.5	2.7 ± 1.7	0.242	2.5 ± 1.7	2.7 ± 1.4	2.8 ± 1.6	0.785
Metastasis rate	7 (9.3)	16 (14.7)	0.281	5 (12.5)	5 (11.6)	11 (40.7)	0.004
LRLN lymph node	2.3 ± 2.2	2.8 ± 2.6	0.325	4.4 ± 2.2	3.6 ± 2.0	5.4 ± 2.7	0.008
Metastasis rate	3 (4.0)	15 (13.8)	0.029	3 (7.5)	5 (11.6)	10 (37.0)	0.006
90-day mortality	0	0	–	0	0	0	–
ICU stay, *n*	8 (10.7)	8 (7.3)	0.431	6 (15.0)	3 (7.0)	2 (7.4)	0.476
Length of ICU stay	7 (3–20)	5.5 (1–21)	0.495	7 (3–20)	4, 5, 21	6, 10	0.895
Postoperative stay	18.9 ± 7.8	18.0 ± 5.9	0.596	17.8 ± 6.5	16.3 ± 3.5	20.1 ± 8.3	0.056

RRLN right recurrent laryngeal nerve, *DLN* dissected lymph node, *LRLN* left recurrent laryngeal nerve

*p value of difference between early and late RAME group

than VAME. In addition, the last RAME group included more total LND number than the early RAME group over the learning curve (30.6 ± 10.2 vs. 23.2 ± 5.9, $p=0.003$) despite being similar with the VAME group (30.6 ± 10.2 vs. 28.1 ± 10.2, $p=0.105$). Similar to the entire study population, the mean number of LND around the right RLN in the RAME group was the same as that in the VAME group (2.8 ± 1.6 vs. 2.5 ± 1.7, $p=0.785$).

Postoperative complications

The overall rates of postoperative complications were similar in the two matched cohorts (40.7% vs. 35.0%, $p=0.862$; Table 3). Specifically, the rate of pneumonia and incidence of anastomotic leakage were not significantly different between groups. Focusing on recurrent nerve injury, the incidence decreased significantly from 27.9% in the early RAME group to 7.4% in the last RAME group ($p=0.037$).

Table 3 Postoperative complications

Variables	All patients ($n=184$, %)		*p*-value	LRLN lymph node dissection ($n=110$, %)			*p*-value
	VAME ($n=75$)	RAME ($n=109$)		VAME ($n=40$)	Early RAME ($n=43$)	Last RAME ($n=27$)	
Overall complications	20 (26.7)	36 (33.0)	0.357	14 (35.0)	15 (34.9)	11 (40.7)	0.862
RLN paralysis	11 (14.7)	16 (14.7)	0.998	9 (22.5)	12 (27.9)	2 (7.4)	0.106*
Pulmonary infection	9 (12.0)	7 (6.4)	0.187	7 (17.5)	4 (9.3)	1 (3.7)	0.225
Ventilator-assisted ventilation	8 (10.7)	8 (7.3)	0.431	6 (15.0)	3 (7.0)	2 (7.0)	0.476
Anastomotic leakages	4 (5.3)	6 (5.5)	1.000	1 (2.5)	1 (2.3)	3 (11.1)	0.295
Tracheoesophageal fistula	0 (0)	3 (2.8)	0.272	0 (0)	0 (0)	1 (3.7)	0.245
Pleural effusion	0 (0)	3 (2.8)	0.272	0 (0)	0 (0)	1 (3.7)	0.245
Atelectasis	2 (2.7)	1 (0.9)	0.568	2 (5.0)	0 (0)	1 (3.7)	0.349
Surgical site infections	0 (0)	2 (1.8)	0.514	0 (0)	0 (0)	1 (3.7)	0.245
Chylothorax	1 (1.3)	1 (0.9)	1.000	1 (2.5)	0 (0)	1 (3.7)	0.519
Arrhythmia	0 (0)	2 (1.8)	0.514	0 (0)	1 (2.3)	0 (0)	1.000
Stroke	0 (0)	1 (0.9)	1.000	0	0	0	–
ARF	0 (0)	1 (0.9)	1.000	0 (0)	0 (0)	1 (3.7)	0.245
Chest infection	0 (0)	1 (0.9)	1.000	0 (0)	0 (0)	1 (3.7)	0.245

LRLN left recurrent laryngeal nerve, *ARF* acute renal failure

*$p=0.037$ between early and last RAME group

The incidence of recurrent nerve injury was still lower in the last RAME group than in the VAME group, although the difference was significant different (7.4% vs. 22.5%, $p=0.106$).

Effect of LND around left RLN on clinical outcomes

We further investigated whether complete LND of left RLN would have an adverse effect on perioperative outcomes. The cases of complete LND around left RLN had greater numbers of total LND for both RAME (26.1 ± 7.8 vs. 22.0 ± 7.9, $p=0.070$) and VAME (28.1 ± 10.2 vs. 15.5 ± 5.0, $p<0.001$) and more advanced pN stage (50% vs. 28.6%, $p=0.059$) for VAME but not RAME. The complete LND around left RLN was associated with recurrent nerve injury in the RAME (20.0% vs. 5.1%, $p=0.035$) and VAME (22.5% vs. 5.7%, $p=0.041$) groups but had no effect on other clinical outcomes including surgical duration, interoperative blood loss, postoperative intensive care unit or hospital stay, and other complications (Table 4).

Discussion

Theoretically, RAME achieves better short-term and oncological results than traditional MIE [21]. Using a magnified three-dimensional image, articulating forceps, and tremor filtering, RAME can overcome some limitations of traditional MIE. In addition, through enhanced visualization of tissue structures, robotic surgical systems can facilitate intraoperative steps, reduce injury to neighboring structures, and improve LND precision [22]. Third, the robotic system can accelerate the learning curve by compensating for the drawbacks of video-assisted esophagectomy when performed in the confined mediastinal space, retroperitoneal space, and splenic hilum [23]. More recently, robotic-assisted surgery has been used in minimally invasive McKeown esophagectomy and demonstrated good short-term outcomes [16, 17, 24, 25].

In the present study, we compared the short-term outcomes of RAME versus VAME for the surgical treatment of patients with ESCC in a single surgical group and mainly focused on LND around the left RLN. By matching and performing CUSUM analysis, we found that RAME yielded a higher number of lymph nodes around the left RLN than VAME and provided better recurrent nerve protection after the learning curve of robotic esophagectomy in late stage group than early stage group. These data suggest that RAME is a safe and feasible technique with advantages over VAME.

Robotic esophageal surgery is among the most challenging procedures in thoracic surgery. With its popularity and widespread applicability, its learning curve requires evaluation. According to Hernandez [26], the surgical proficiency of robotic esophagectomy with Ivor Lewis can be obtained after approximately 20 cases are treated by surgeons skilled in non-robotic MIE. Sarkaria et al. [27] conducted a learning curve analysis of 100 robot-assisted MIE and noted that the median operative time decreased to approximately 370 min between the 30th and 45th cases. Zhang et al. [28]

Table 4 Perioperative effect of lymph node dissection around left recurrent laryngeal nerve

Variables	VAME (n = 75, %)		p-value	RAME (n = 109, %)		p-value
	Yes (n = 40)	No (n = 35)		Yes (n = 70)	No (n = 39)	
Operation time	321.9 ± 35.1	303.1 ± 39.6	0.114	326.3 ± 42.5	311.9 ± 47.4	0.211
Blood loss	188.2 ± 29.2	212.5 ± 26.3	0.917	189.2 ± 24.7	214.8 ± 76.3	0.258
Number of DLN	28.1 ± 10.2	15.5 ± 5.0	< 0.001	26.1 ± 7.8	22.0 ± 7.9	0.070
ICU stay, n	6 (15.0)	2 (5.7)	0.271	5 (7.1)	3 (7.7)	1.000
Length of ICU stay	7 (3–20)	7, 16	–	6 (4–21)	1, 3, 8	–
Postoperative stay	17.8 ± 6.5	20.2 ± 9.2	0.462	17.8 ± 5.6	18.5 ± 6.4	0.688
pT			1.000			0.875
T0–2	22 (55.0)	19 (54.3)		33 (47.1)	19 (48.7)	
T3–4	18 (45.0)	16 (45.7)		37 (52.9)	20 (51.3)	
pN			0.059			0.875
N0	20 (50.0)	25 (71.4)		33 (47.1)	19 (48.7)	
N1–3	20 (50.0)	10 (28.6)		37 (52.9)	20 (51.3)	
Overall complications	14 (35.0)	6 (17.1)	0.081	26 (37.1)	10 (25.6)	0.289
Recurrent nerve injury	9 (22.5)	2 (5.7)	0.041	14 (20.0)	2 (5.1)	0.035
Pulmonary infection	7 (17.5)	2 (5.7)	0.162	5 (7.1)	2 (5.1)	1.000
Ventilator-assisted ventilation	6 (15.0)	2 (5.7)	0.271	5 (7.1)	3 (7.7)	1.000
Anastomotic leakages	1 (2.5)	3 (8.6)	0.334	4 (5.7)	2 (2.6)	0.653
Tracheoesophageal fistula	0	0	–	1 (1.4)	2 (5.1)	0.291
Pleural effusion	0	0	–	1 (1.4)	2 (5.1)	0.291
Atelectasis	2 (5.0)	0	0.495	1 (1.4)	0	1.000
Surgical site infections	0	0	–	1 (1.4)	1 (2.6)	1.000
Chylothorax	1 (2.5)	0	1.000	1 (1.4)	0	1.000
Arrhythmia	0	0	–	1 (1.4)	1 (2.6)	1.000
Stroke	0	0	–	0	1 (2.6)	0.358
ARF	0	0	–	1 (1.4)	0	1.000
Chest infection	0	0	–	1 (1.4)	0	1.000

ARF acute renal failure, *DLN* dissected lymph node

retrospectively reviewed 72 consecutive patients treated with RAME and found that experience with 26 cases is required to gain early proficiency for a surgeon experienced with open and thoracolaparoscopic esophagectomy.

The LND around the left RLN in ESCC cases is a surgically challenging procedure. In the present study, we evaluated the learning curve of RAME in lymphadenectomy around the left RLN to enable better comparison with VAME. For a surgeon experienced with VAME, experience of 43 cases is required to gain proficiency with robot-assisted lymphadenectomy around the left RLN, which is evidenced by more completed LND and a decreased recurrent nerve injury rate. In this respect, robot-assisted surgery shows great advantages. The feasibility and safety of robot-assisted lymphadenectomy along the bilateral RLN were demonstrated in a previous study. Chao et al. [29] showed that, compared with VAME, RAME resulted in a higher LND around the left RLN without increasing morbidity. In a recent study of 271 patients in each group, the number of dissected lymph nodes along RLN was significantly higher using RAME than VAME [21]. We also found that the LND number of left RLN in present study was larger than those of previous studies [11, 30]. With respect to total LDN, Park et al. [11] and Deng et al. [30] retrospectively found that robot-assisted esophagectomy yielded more dissected lymph nodes than conventional MIE. However, several recent studies together with our study demonstrated that the number of total dissected lymph nodes was comparable between the two surgical approaches [13, 21].

Recurrent nerve injury remains a concern for LND around RLN. Recurrent nerve injury was the most frequently observed complication in RAME and VAME in the present study as seen in previously published data. Park et al. [9] reported a 26.5% incidence of hoarseness after robotic esophageal surgery. Park et al. [12] again reported that recurrent nerve paralysis after robot-assisted MIE was significantly reduced from 36 to 17% after 60 cases. After the learning curve of 43 cases, the incidence of recurrent nerve injury decreased from 27.9 to 7.4% in the present study. This might be attributed to the better skeletonization of the RLN, the use of a lower-energy platform, and the use of more cold instruments in recent RAME.

This study has some limitations including its retrospective nature with potential selection bias. Although the sample size of this study was relatively large, the number of patients that remained after matching was relatively small. In addition, we are still following our patients to determine their long-term outcomes. One recent study found that RAME was associated with a lower rate of mediastinal lymph nodes recurrence after median follow-up of 20.2 months [21]. More thorough LND, especially in the lymph nodes along RLNs, and more precise esophageal en-bloc resection with the periesophageal tissue may enable a better oncological outcome. Furthermore, we focused on only LND around the left RLN to determine the learning curve of robotic surgery for better comparison; thus, other parameters should be used for determining the learning curve in future studies. Neoadjuvant therapy has been recommended as the standard treatment approach for patients with esophageal cancer to improve long-term survival rates. The other limitation of the present study is that only a small number of patients received neoadjuvant therapy; however, the concept of neoadjuvant therapy is gradually gaining popularity.

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Compliance with ethical standards

Disclosures Drs. Xiaofeng Duan, Jie Yue, Chuangui Chen, Lei Gong, Zhao Ma, Xiaobin Shang, Zhentao Yu and Hongjing Jiang have no conflicts of interest or financial ties to disclose.

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