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DYNAMIC MANUSCRIPT

Robotic esophagectomy with outermost layer-oriented dissection for esophageal cancer: technical aspects and a retrospective review of a single-institution database

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Abstract

Background Systematic lymph node dissection in patients with gastric cancer could be sufficiently and reproducibly achieved along the outermost layer of the autonomic nerves and similar concept has been extensively used for robotic esophagectomy (RE) since 2018. This study aimed to determine the surgical and oncological safety of RE using the outermost layer-oriented approach for esophageal cancer (EC).

Methods Sixty-six patients who underwent RE with total mediastinal lymphadenectomy for primary EC between April 2018 and December 2021 were retrospectively reviewed. All underwent the outermost layer-oriented approach with intraoperative nerve monitoring (IONM). Postoperative complications within 30 days were analyzed.

Results Among the patients, 51 (77.3%) were male. The median age was 64 years, and the body mass index was 21.8 kg/m^2. Furthermore, 58 (87.9%) patients had squamous cell carcinoma and eight (12.1%) patients had adenocarcinoma. Clinical stages I, II, and III were seen in 23 (34.8%), 23 (34.8%), and 16 (24.2%) patients, respectively. Thirty-four (51.5%) patients received preoperative treatment. No patient shifted to conventional thoracoscopic or open procedure intraoperatively. The median operative time was 716 min with 119 mL of blood loss. Additionally, 64 (97%) patients underwent R0 resection. The morbidity rates based on Clavien–Dindo grades ≥ II and ≥ IIIa were 30.3% and 10.6%, respectively, within 30 postoperative days. None died within 90 days postoperatively. Three (4.5%) patients exhibited recurrent laryngeal nerve (RLN) palsy (CD grade ≥ II). The sensitivity and specificity of IONM for RLN palsy were 50% and 98.3% at the right RLN and 33.3% and 98.0% at the left RLN, respectively.

Conclusion RE with the outermost layer-oriented approach can provide safe short-term outcomes.

Keywords Robotic surgical procedures · Minimally invasive surgical procedures · Morbidity · Esophageal neoplasms

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Abbreviations

EC	Esophageal cancer
RCTs	Randomized controlled trials
DVSS	Da Vinci Surgical System
RE	Robotic esophagectomy
OL	Outermost layer
RLN	Recurrent laryngeal nerve
CD	Clavien–Dindo
IONM	Intraoperative nerve monitoring
ICS	Intercostal space
PPV	Positive predictive value
NPV	Negative predictive value

Esophagectomy with total mediastinal lymphadenectomy with or without cervical lymphadenectomy is used to treat esophageal cancer (EC) [1]. However, it has high postoperative morbidity and mortality because of the complex anatomy in the mediastinal area [2]. Randomized controlled trials (RCTs) showed that the minimally invasive approach led to improved pulmonary [3] and major postoperative complications [4] compared with the conventional thoracoscopic approach and open approach. The da Vinci™ Surgical System (DVSS; Intuitive Surgical, Sunnyvale, USA) was developed to overcome the limitations of thoracoscopic/laparoscopic surgery, including the limited range of motion resulting from straight forceps use and hand tremors. Moreover, it facilitates safer, more precise, and more reproducible procedures by surgeons in a confined surgical field with impressive dexterity [5]. In 2009, we introduced robotic esophagectomy (RE) using the DVSS and found that it led to reduced recurrent laryngeal nerve (RLN) palsy [6]. However, the benefits of RE remain unknown.

We established the outermost layer (OL)-oriented nodal dissection in a minimally invasive gastrectomy for gastric cancer, which could achieve favorable surgical and oncological outcomes, especially in robotic gastrectomy [5, 7–9]. In this approach, the thin loose connective tissue layer (termed as the OL of the autonomic nerve) between the autonomic nerve sheaths of the major arteries and the adipose tissue bearing lymphatic tissue is dissected. Based on our experience in using this technique and our understanding that this OL can be identified along the autonomic nerves (including the vagus nerve and RLNs present around the major mediastinal anatomical structures containing trachea, bronchi, pericardium, aortic arch, and subclavian arteries), we hypothesized that this OL-oriented approach can help surgeons determine ventrolateral border of mediastinal lymphadenectomy and perform RE for EC safely and reproducibly in the same manner as gastrectomy.

Since the Japanese government approved the national medical insurance coverage in April 2018, RE has been the first surgical treatment option for EC in our institution. The development of DVSS-Xi™ and approval of the national medical insurance coverage facilitated the standardization of the RE procedure [10]. Accordingly, we hypothesized that the robotic system with the OL-oriented approach has clinical advantages for technically demanding procedures such as RE. Thus, this study aimed to evaluate the short-term clinical outcomes including postoperative morbidity of RE using the OL-oriented approach for EC.

Materials and methods

Patients

After obtaining approval from the Fujita Health University Review Board, patients from a prospectively maintained institutional database were identified. Ninety-six consecutive patients who underwent esophagectomy for primary EC in our institute between April 2018 and December 2021 were included. Patients with clinical T4 tumor, severe intrathoracic adhesion, and one-lung ventilation failure are considered contraindications for the robotic transthoracic approach. Patients with clinical T4 are considered an indication for two-stage resection if downstaging to clinical $T \leq 3$ is obtained after induction chemo- or chemoradiotherapy. After excluding 30 patients, 66 patients who underwent RE with total mediastinal lymphadenectomy were analyzed (Fig. 1).

The database and medical records were used to collect demographic and clinicopathological characteristics, treatment information, and follow-up information. Cancer was staged according to the 11th edition of the Japanese Classification of Esophageal Cancer [11] and the findings of contrast-enhanced

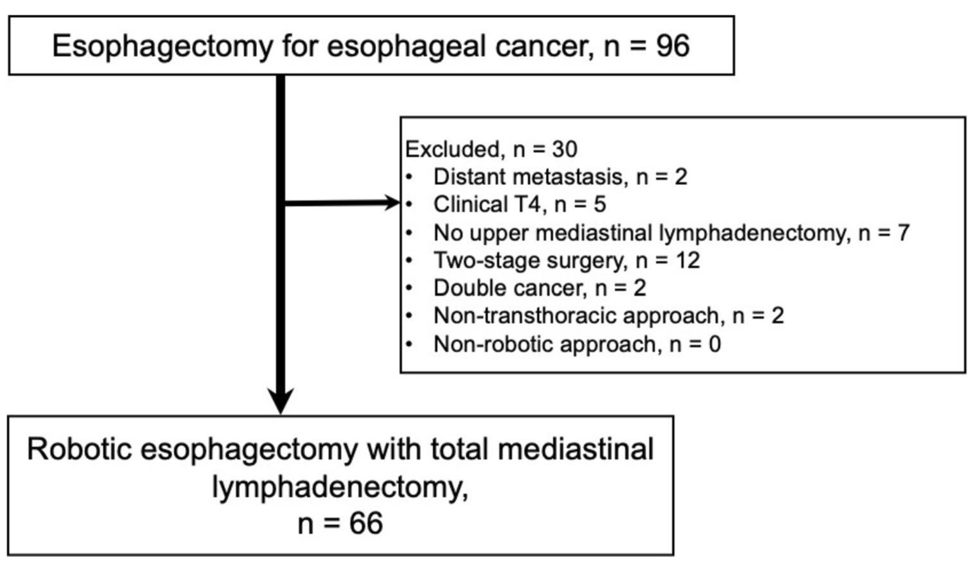

Fig. 1 Patient selection flow

computed tomography, positron emission scanning, esophagogastrography, endoscopic study, and endosonography before any treatment initiation. The indications for endoscopic treatment and radical esophagectomy, including the extent of lymph node dissection, were determined according to the Japanese Esophageal Cancer Treatment Guidelines [12, 13]. The assessment and criteria of physical function for RE were previously described [6]. Patients with clinical T stage ≥ 2 and/or positive clinical N status were generally offered neoadjuvant treatment [11, 14]. The neoadjuvant treatment regimen was selected according to the guideline recommendations. Subtotal esophagectomy (Mckeown procedure) with total mediastinal lymphadenectomy was indicated for all patients with EC. Bilateral supraclavicular lymph node (station 104) dissection was indicated for patients with EC at the upper esophagus or clinical T ≥ 2 tumor at the middle esophagus. Two-stage resection was recommended for patients with poor systemic function and those after undergoing definitive chemoradiotherapy. All operations were supervised by IU and performed by IU, KS, or SS, who had obtained the Japan Society for Endoscopic Surgery's Endoscopic Surgical Skill Qualification [15, 16]. All procedures were also video recorded and reviewed by independent surgeons (MN and TT) to confirm the completion of the OL-oriented approach.

The morbidity rate within 30 days postoperatively was the primary outcome. The Clavien–Dindo (CD) classification was used to classify postoperative complications [17]. An otolaryngologist evaluated patients' vocal cord movement preoperatively and seven days after surgery. The time from the start of chest incision to the completion of trocar site closure on the chest was defined as the thoracic operative time during the thoracic phase.

Intraoperative nerve monitoring (IONM)

RLN function was routinely monitored intraoperatively via IONM (NIM TriVantage™, Medtronic, Jacksonville, FL, USA) to identify the bilateral RLNs and confirm their function before, during and after nodal dissection. Muscle relaxants were not administered to maintain vocal cord activity, which was monitored by IONM during the thoracic phase of the surgery. Neural stimulation was performed with a monopolar stimulator, usually with currents of 1.0 mA. Loss of signal was confirmed when no electromyogram activity or substantially reduced activity (< 100 mV) was produced via RLN and vagus nerve stimulation.

Operative procedure

Setting

The patient was placed in a semi-prone position. After placing five trocars at the right thorax (Fig. 2), the patient cart was docked, targeting the caudal edge of the azygos arch. The surgical procedures are detailed in Supplemental Video 1.

OL in the posterior mediastinum

Figure 3 shows the OL in the posterior mediastinum. Autonomic fibers including vagus nerves and RLNs are distributed around major anatomical structures, including bilateral subclavian arteries, aortic arch, trachea, bronchi, and pericardium. These autonomic fibers are wrapped by a loose connective tissue (OL layer), and the lymph nodes to be dissected are located outside of this tissue. The ventrolateral border can be identified in mediastinal lymphadenectomy, including lymph nodes along RLNs (106recR and 106recL), by dissecting along the OL (Fig. 3).

Mobilization of the middle and lower mesoesophagus and dissection of the lower mediastinal lymph node

The ventral aspect of the lower and middle thoracic esophagus with the adipose tissue bearing posterior mediastinal nodes (station 112) was mobilized on the OL of the pericardium (Fig. 4a). The dorsal aspect was mobilized on the dissectable layer, preserving the thoracic duct (Fig. 4b). Then, the supradiaphragmatic lymph nodes (station 111) were dissected along the diaphragmatic crus.

Middle mediastinal lymph node dissection

The subcarinal nodes (station 107 + 109) was dissected on the OL of the pericardium, while the cranial edge of the pulmonary veins was exposed. By keeping on dissecting the station 109L nodes on this layer, the membranous portion of the left main bronchus became evident (Fig. 5a). The upper thoracic paraesophageal lymph nodes (station 105) were dissected on the OL of the right main bronchus along the pulmonary branches of the right vagus nerve, exposing the main trunk of the right vagus nerve behind the azygos arch. Then, the station 109R nodes were dissected on the OL of the right main bronchus along the pulmonary branches of the right vagus nerve (Fig. 5b). The esophageal branches of the right vagus nerve were transected at each origin. The upper thoracic esophagus was mobilized on the OL of the tracheal carina. Meanwhile, the distal side of the right bronchial artery was divided. Finally, the ventral border of the subcarinal lymph nodes (station 107) was determined.

Mobilization of the upper esophagus along the OL

Three independent dissectable layers were identified as landmarks for mobilization of the dorsal aspect of the upper esophagus (Supplemental Fig. 1). After transecting the

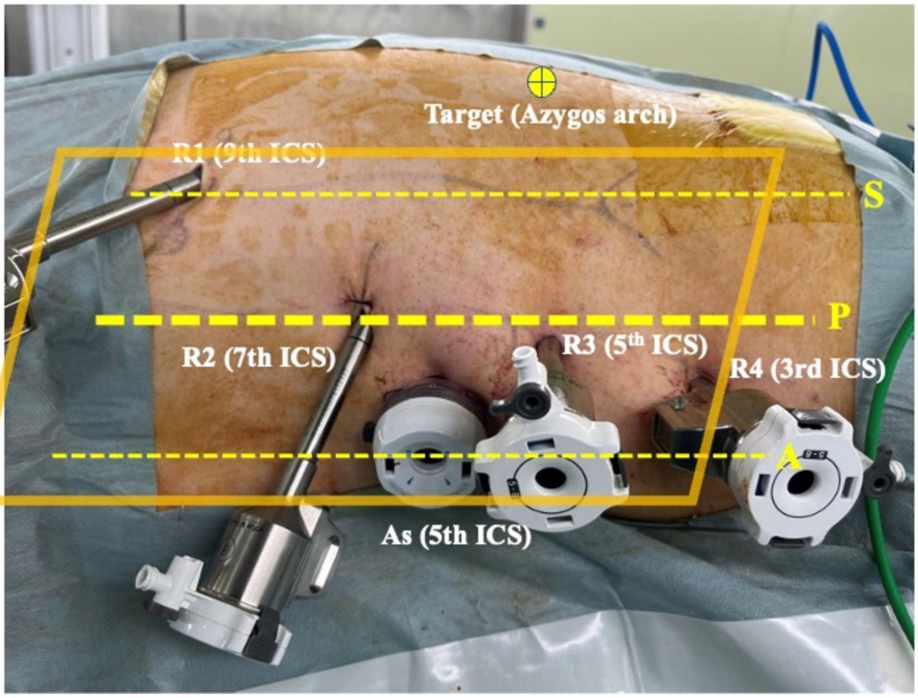

Fig. 2 Trocar position. The center of the parallelogram formed by the subscapular angle line and anterior axillary line (between the 2nd and the 12th ribs) was marked and an 8-mm trocar for the 2nd arm (scope) was inserted. This position is usually located at the 7th intercostal space (ICS) on the posterior axillary line. Then, the three remaining 8-mm trocars were placed under thoracoscopic guidance at the 9th ICS behind the posterior axillary line (1st arm), 5th ICS below the posterior axillary line (3rd arm), and 3rd ICS behind the anterior axillary line (4th arm). One 12-mm trocar for the assistant surgeon was added at the 5th ICS on the anterior axillary line. *S* subscapular angle line, *P* posterior axillary line, *A* anterior axillary line, *ICS* intercostal space, *As* assistant port, *R* robot arm with the number

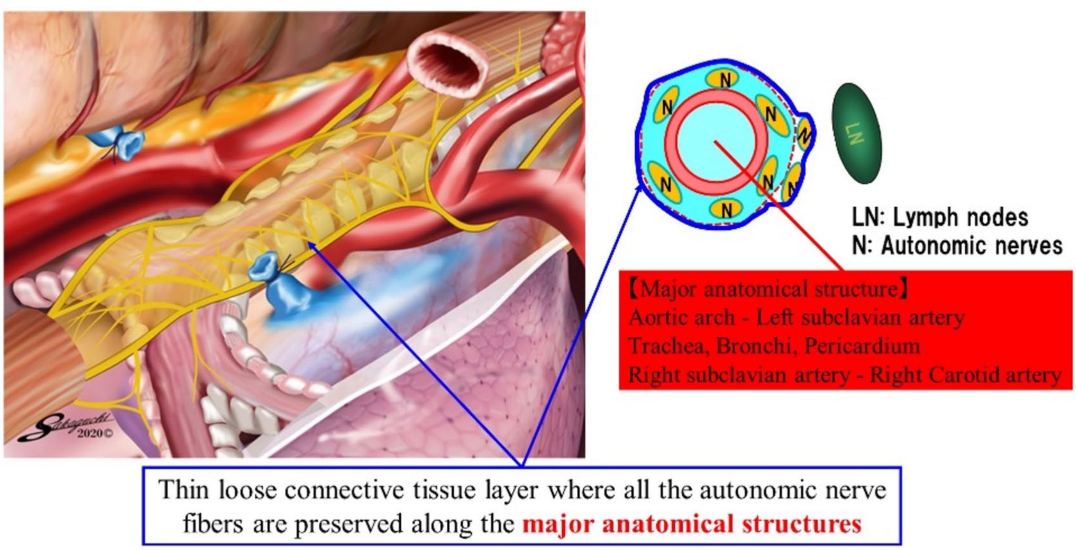

Fig. 3 Outermost layer in the upper and middle mediastinum

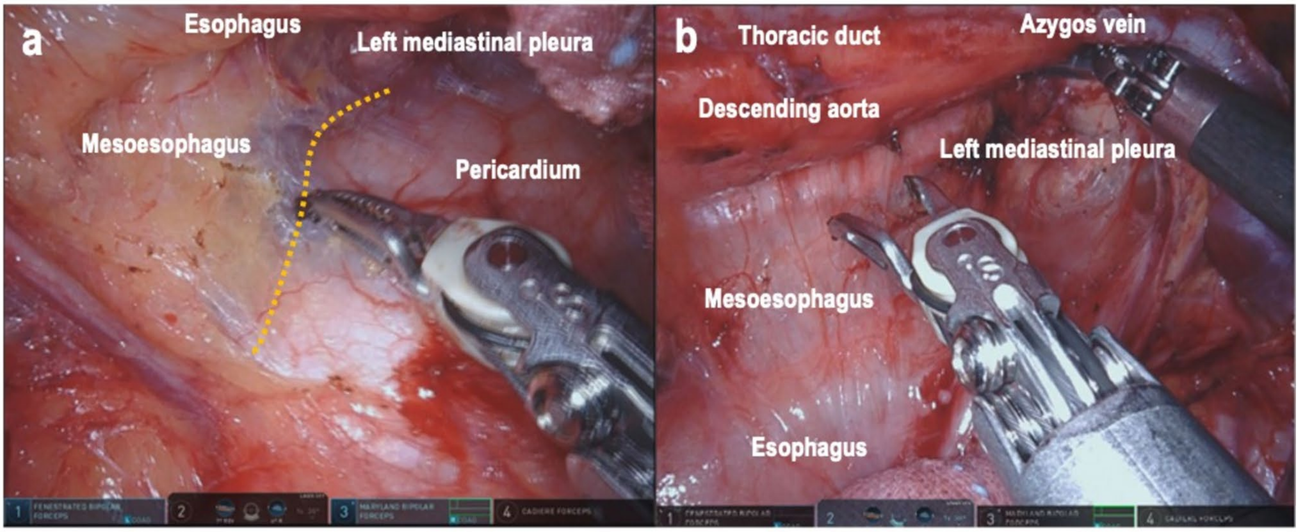

Fig. 4 The ventral aspect of the lower and middle thoracic esophagus with mesoesophagus was mobilized on the outermost layer (yellow line) of the pericardium (**a**). The dorsal aspect of the middle and lower thoracic esophagus was mobilized on the dissectible layer preserving the thoracic duct (**b**) (Color figure online)

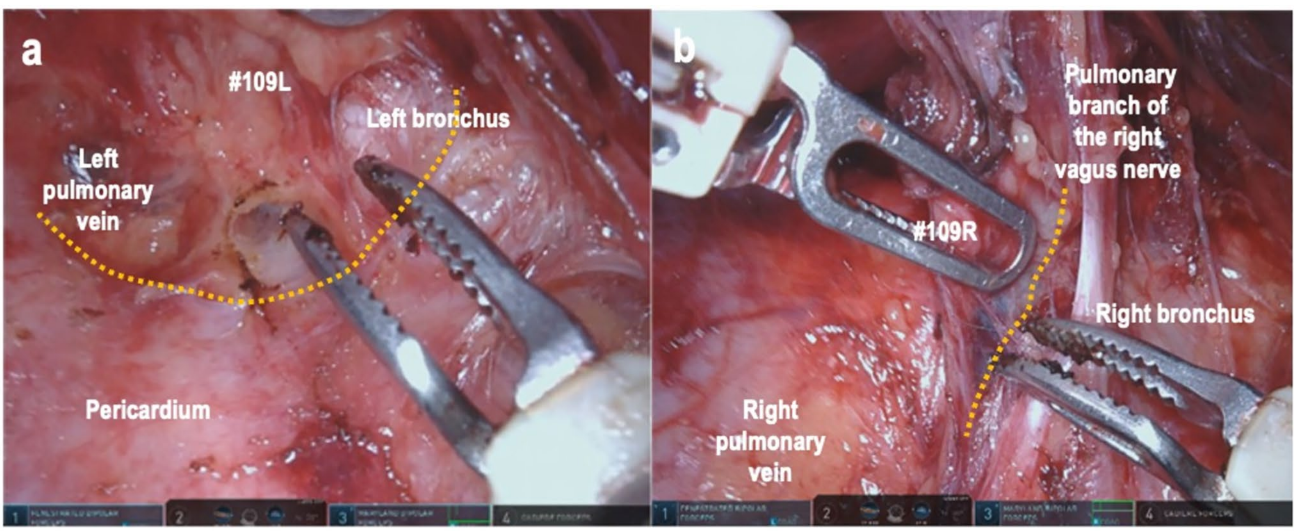

Fig. 5 The subcarinal nodes (station 109L) were mobilized on the outermost layer (yellow line) of the pericardium and the left main bronchus (**a**). The outermost layer preserved the pulmonary branch of the right vagus nerve (yellow line) (**b**) (Color figure online)

azygos arch, the ventral aspect of the upper esophagus was mobilized on the OL of the trachea along the right vagus nerve and the right RLN was identified on the right subclavian artery (Fig. 6). Mobilization of the dorsal aspect of the upper esophagus is performed as shown in supplemental Fig. 2.

Dissection of the recurrent nerve and cervical paraesophageal lymph nodes

The right upper mediastinal periesophageal tissue was mobilized on the OL of the trachea. The lateroventral border of the lymph nodes around the right RLN (station 106recR + 101R) was defined on the OL of the right subclavian artery and carotid artery along the right RLN (Fig. 7). The right RLN was not detached from the right subclavian artery to avoid postoperative right RLN palsy.

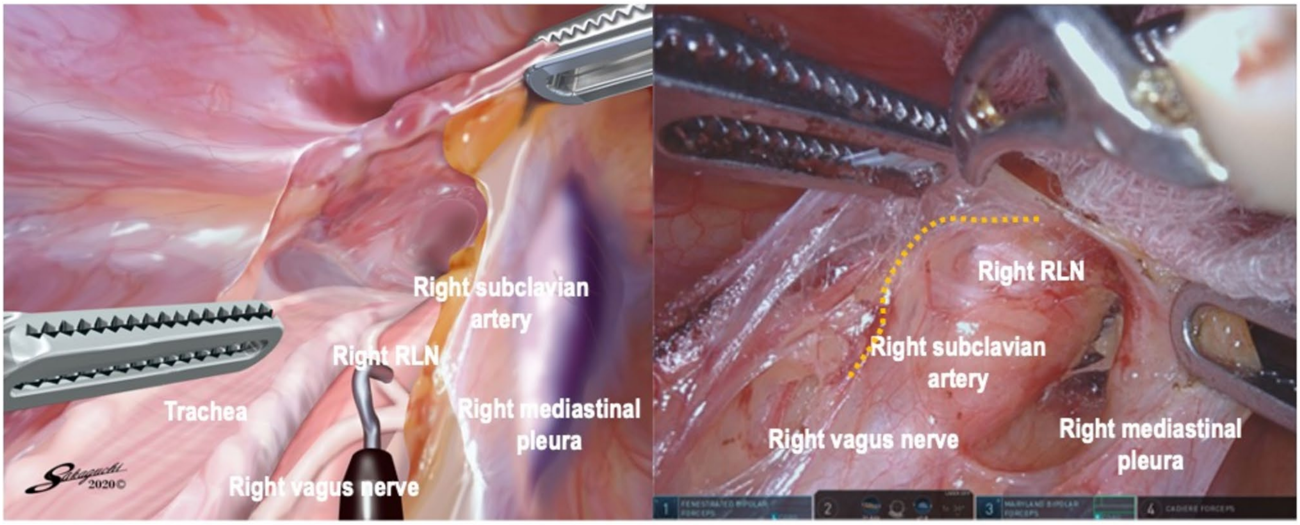

Fig. 6 Location of the right RLN and the outermost layer (yellow line) on the right subclavian artery. *RLN* recurrent laryngeal nerve (Color figure online)

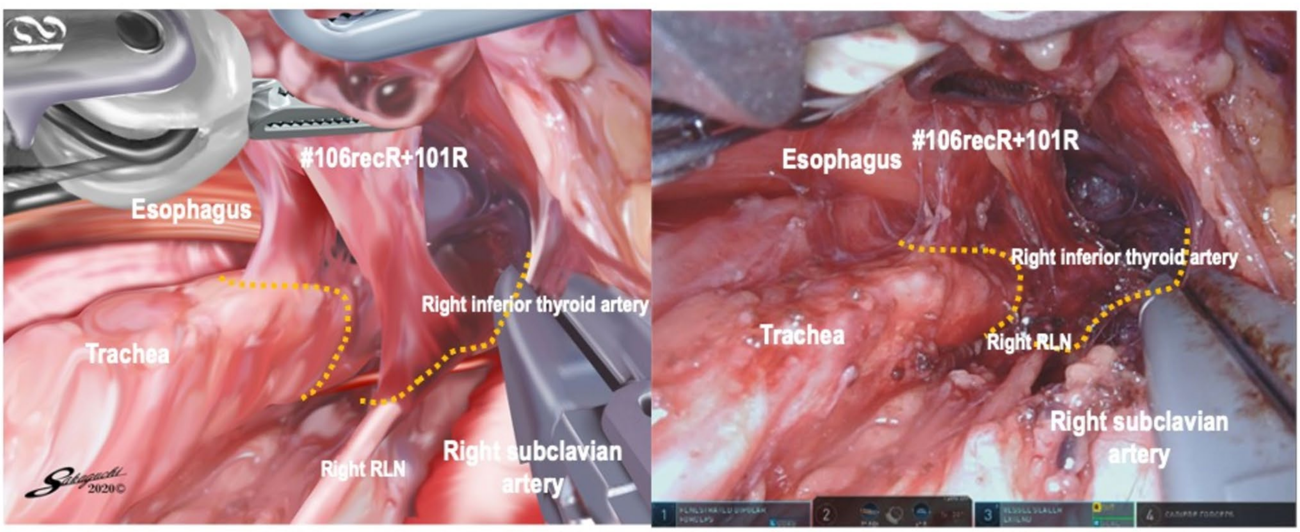

Fig. 7 Dissection around the right RLN. The outermost layer (yellow line). *RLN* recurrent laryngeal nerve (Color figure online)

The bottom of the station 106recR + 101R was determined by dividing the lymphatic connection between station 106recR + 101R and the pretracheal lymph nodes (station 106pre). Next, the ventromedial aspect of the left upper esophagus with the mediastinal periesophageal tissue was mobilized on the outermost layer of the trachea. Then, the upper esophagus was transected using a 45-mm linear stapler at the aortic arch level. Subsequently, the left upper periesophageal tissue was detached from the upper esophagus up to the top of the left cervical paraesophageal lymph nodes (station 101L). The adipose tissue including the left recurrent nerve lymph nodes (station 106recL) + 101L nodes was dissected on the dissectable layer along the left RLN (the OL of the aortic arch and the left subclavian artery) (Fig. 8). Then, the lymphatic connection between station 106recL + 101L and station 106pre was transected. Finally, the lateral aspect of station 106recL + 101L was dissected in the craniocaudal direction.

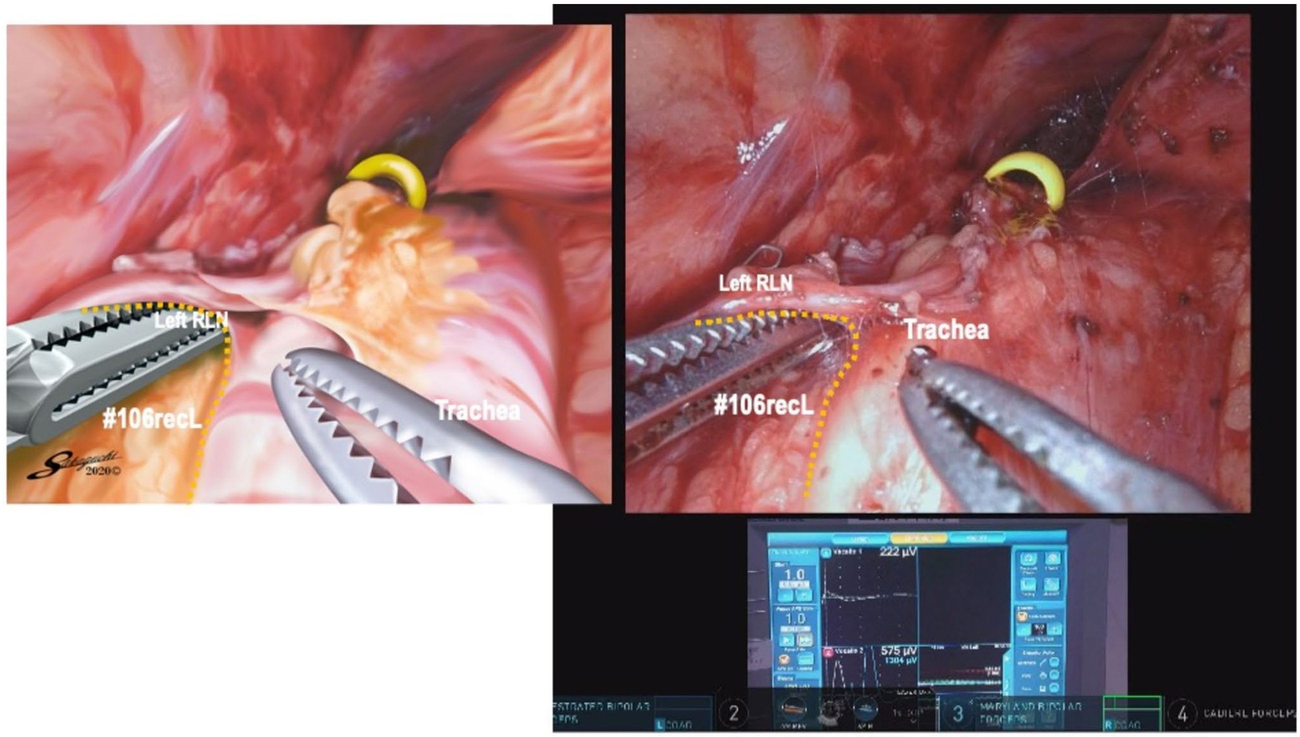

Fig. 8 Dissection of the station 106recL + 101L nodes along the outermost layer of the left RLN (yellow line). The adipose tissue (106recL + 101L nodes) was pulled toward the right ventral direction, and the dorsolateral aspect of the target tissue was gently exfoliated on the dissectable layer along the left RLN (the outermost layer of the aortic arch and the left subclavian artery). The IONM signal was confirmed (right lower). *RLN* recurrent laryngeal nerve, *IONM* intraoperative nerve monitoring (Color figure online)

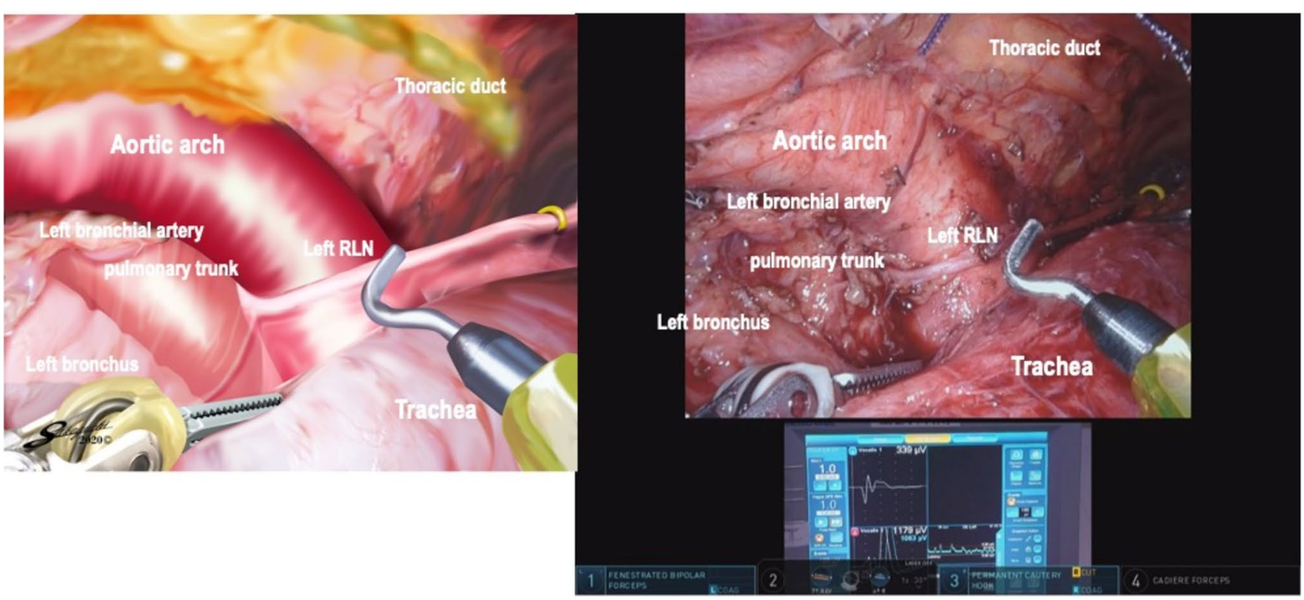

Fig. 9 Dissection of the tracheobronchial nodes (station 106tbL). The IONM signal was confirmed (right lower). *RLN* recurrent laryngeal nerve, *IONM* intraoperative nerve monitoring

Dissection of tracheobronchial and posterior mediastinal lymph nodes

The tracheobronchial nodes (station 106tbL) were dissected on the face of the pulmonary artery trunk, preserving the recurrent portion of the left RLN along the OL of the aortic arch (Fig. 9). Then, the esophageal branches of the left vagus nerve were dissected below the left main bronchus, preserving the left pulmonary branches. Finally, the posterior mediastinal nodes (station 112) were dissected together with the left mediastinal pleura and the left inferior pulmonary ligament, and the thoracic phase of RE was completed.

Stomach mobilization, abdominal lymph node dissection, and reconstruction

In the supine position, the stomach was mobilized robotically in the same manner as robotic proximal gastrectomy as previously described [18, 19]. A 3.5-cm-wide greater curvature gastric conduit was extracorporeally created and pulled up through the retrosternal route. Generally, subtotal esophagectomy is performed and esophagogastrostomy is made through end-to-side anastomosis using a circular stapler at 20 cm from the incisor [20].

Data and statistical analysis

Data are expressed as median (interquartile range) unless otherwise specified. Clinical staging, including T and N status, was determined before initiation of any treatment. The inspection accuracy of IONM was defined as follows: sensitivity, number of IONM-positive cases (loss of signal) among all cases with RLN paralysis; specificity, number of IONM-negative cases among all cases without RLN paralysis; positive predictive value (PPV), percentage of cases with postoperative RLN paralysis among all cases with RLN paralysis estimated by IONM; and negative predictive value (NPV), percentage of cases without postoperative RLN paralysis among all cases without RLN paralysis estimated by IONM. All statistical data were analyzed using IBM SPSS Statistics 28 (IBM Corporation, Armonk, NY, USA).

Results

Demographic and clinicopathological characteristics

The demographic and clinicopathological characteristics of 66 patients included in this study are listed in Table 1. Fifty-eight (87.9%) patients had squamous cell carcinoma. Clinical stages I, II, and III were seen in 23 (34.8%), 23 (34.8%), and 16 (24.2%) patients, respectively. Furthermore, 34 (51.5%) patients received preoperative treatment (Table 1).

Table 1 Patients' demographic and clinicopathological characteristics

	$N=66$
Sex, *n* (%)	
Male	51 (77.3)
Female	15 (22.7)
Age, years (IQR)	64 (56–72)
BMI, kg/m^2 (IQR)	21.8 (19.6–24.2)
ASA status, 1/2/3	24/40/2
History of thoracic/abdominal surgery, *n* (%)	8 (12.1)
Histology, *n* (%)	
Squamous cell carcinoma	58 (87.9)
Adenocarcinoma	8 (12.1)
Tumor location, *n* (%)	
Upper third	5 (7.6)
Middle third	38 (57.6)
Lower third	18 (27.3)
Abdominal esophagus	5 (7.6)
Clinical T stage, *n* (%)	
1a	3 (4.5)
1b	27 (40.9)
2	12 (18.2)
3	24 (36.4)
Clinical N status, *n* (%)	
0	41 (62.1)
1	15 (22.7)
2	7 (10.6)
3	2 (3.0)
4	1 (1.5)
Clinical stage, *n* (%)	
0	3 (4.5)
I	23 (34.8)
II	23 (34.8)
III	16 (24.2)
IVa	1 (1.5)
Preoperative treatment, *n* (%)	
None	32 (48.5)
Chemotherapy alone	33 (50.0)
Chemoradiotherapy	1 (1.5)
Radiation alone	0 (0)
Adjuvant treatment, *n* (%)	
None	59 (89.4)
Chemotherapy alone	6 (9.1)
Chemoradiotherapy	0 (0)
Radiation alone	1 (1.5)

BMI body mass index, *IQR* interquartile range, *ASA status* American Society of Anesthesiologists Physical Status Classification

Table 2 Surgical and pathological findings

	$N=66$
Thoracic duct, preserved	53 (80.3)
#104 LN dissection, yes	23 (34.8)
Esophagogastric tube anastomosis	
Circular	57 (86.4)
Hand-sewn	9 (13.6)
Conversion into thoracotomy/thoracoscopy	0 (0)
Operative time, total (min)	716 (648–770)
Operative time, thoracic (min)	279 (258–310)
Console time, thoracic (min)	243 (220–274)
Estimated blood loss, total (mL)	119 (72–175)
Estimated blood loss, thoracic (mL)	23 (16–31)
R0 resection	64 (97.0)
Tumor grade	
1	15 (22.7)
2	41 (62.1)
3	4 (6.1)
Unknown	6 (9.1)
Tumor size (mm)	35 (22–58)
Dissected nodes, total	47 (38–56)
Dissected nodes, mediastinum	20 (16–25)
Metastatic nodes, total	0 (0–1)
Pathological T stage	
0	0 (0)
1a	14 (21.2)
1b	25 (37.9)
2	11 (16.7)
3	16 (24.2)
4a	0 (0)
4b	0 (0)
Pathological N status	
0	49 (74.2)
1	11 (16.7)
2	4 (6.1)
3	1 (1.5)
4	1 (1.5)
Pathological stage	
0	13 (19.7)
I	21 (31.8)
II	20 (30.3)
III	11 (16.7)
IVa	1 (1.5)
IVb	0 (0)
Tumor regression grade, $n=34$	
0	1 (2.9)
1a	19 (55.9)
1b	5 (14.7)
2	7 (20.6)
3	0 (0)
Unknown	2 (5.9)

LN lymph node

Table 3 Postoperative complications

	$N=66$
Overall complications, CD grade ≥ II	20 (30.3)
Overall severe complications, CD grade ≥ IIIa	7 (10.6)
Systemic complications, CD grade ≥ II	13 (19.7)
Pneumonia, CD grade ≥ II	10 (15.2)
Local complications, CD grade ≥ II	8 (12.1)
Anastomotic leakage, CD grade ≥ II	3 (4.5)
Local severe complications, CD grade ≥ IIIa	5 (7.6)
Anastomotic leakage, CD grade ≥ IIIa	2 (3.0)
Anastomotic stenosis, CD grade ≥ IIIa	1 (1.5)
Chylothorax, CD grade ≥ IIIa	1 (1.5)
Mediastinitis, CD grade ≥ IIIa	1 (1.5)
RLNP, CD grade ≥ II	3 (4.5)
Right	1 (1.5)
Left	3 (4.5)
Bilateral	1 (1.5)
RLNP, by CD grade	
0	55 (83.3)
I	8 (12.1)
II	2 (3.0)
IIIa	1 (1.5)
IIIb	0 (0)
IVa	0 (0)
IVb	0 (0)
V	0 (0)
90-day mortality	0 (0)
ICU stay, hours	39 (35–41)
Postoperative stay, days	24 (18–39)

CD grade Clavien–Dindo classification grade, *RLNP* recurrent laryngeal nerve palsy, *ICU* intensive care unit

Surgical and pathological outcomes

The surgical and pathological outcomes are shown in Table 2. None of the patients converted to conventional thoracoscopic or open procedure intraoperatively. The median operative time was 716 min, with 119 mL of blood loss. Moreover, R0 resection was performed in 64 (97%) patients (Table 2). The median number of dissected nodes was 47 overall and 20 in the thoracic field. In addition, 27 (40.9%) patients had pathological $T \geq 2$ and 17 (25.8%) patients had positive nodes. The video record confirmed that the OL-oriented dissection in the thoracic procedure was completed in all patients.

Postoperative short-term outcomes

Postoperative short-term outcomes are shown in Table 3. The morbidity rates of CD grade ≥ II and severe morbidity rates of CD grade ≥ IIIa were 30.3% and 10.6%,

Table 4 Relation of IONM signal and RLNP

	RLNP (+)	RLNP (−)
Right		
Signal lost	1	1
Signal retained	1	57
Left		
Signal lost	3	1
Signal retained	6	50

IONM intraoperative nerve monitoring, *RLNP* recurrent laryngeal nerve palsy

respectively, within 30 days postoperatively. The incidence of pneumonia (CD grade ≥ II) was 15.2%. Additionally, anastomotic leakage (CD grade ≥ II) occurred in three (4.5%) patients. No one died within 90 days postoperatively. RLN palsy (CD grade ≥ II) occurred in three (4.5%) patients. CD grades I, II, and IIIa were seen in 8 (12.1%), 2 (3.0%), and 1 (1.5%) patient, respectively. The sensitivity, specificity, PPV, and NPV of IONM for RLN palsy were 50%, 98.3%, 50%, and 98.3% in the right RLN and 33.3%, 98.0%, 75%, and 89.3% in the left RLN, respectively (Table 4).

Discussion

The OL-oriented approach for RE was found to be safe and feasible for EC, with 10.6% of CD grade ≥ IIIa morbidity rates, 4.5% of RLN palsy (CD grade ≥ II) incidence, 47 dissected lymph nodes, and no mortality. The video review confirmed that the procedure was completed in all cases, indicating that this approach is highly reproducible.

Considering the complex anatomy involved in esophagectomy combined with mediastinal lymphadenectomy, several studies have reported surgical approaches of esophagectomy according to anatomical landmarks [21–25]. Cuesta et al. retrospectively reviewed 35 patients undergoing thoracoscopic esophagectomy and reported a new concept of surgical anatomy called "mesoesophagus." They found a thin connective tissue along the dissected aspect in the upper, middle, and lower mediastinal area, and the esophagus with esophageal vessels and lymph nodes that should be dissected was mobilized as the "mesoesophagus" similarly in rectal cancer surgery [21]. In addition, Fujiwara et al. introduced a concentric three-layer model, consisting of the visceral, vascular, and parietal layers, with a loose connective tissue between them, based on human embryonic development. They reported that this method improved the operative time and postoperative RLN palsy [23]. Thus, resection based on the theory of the detachable layer has become popular in EC surgery. Collectively, these anatomical studies have made it possible to mesenterize the dorsal aspect of the esophagus. In the present study, the OL of the autonomic nerves surrounding the major anatomical structures in the mediastinum might be the definite dissectable layer, which divides the esophagus with regional lymph nodes from the organs and tissues that should be preserved in the visceral layer of the concentric three-layer model (Supplemental Fig. 3). Our OL-oriented approach is more comprehensive and practical based on the following points: (1) The nerve fibers, including the bilateral vagus nerves, RLNs, and their branches surrounding the trachea, bronchi, pericardium, and major vessels, are easily detected and traced. (2) The dissection along the nerve network divides the visceral layer of the concentric three-layer method and leads to easy, safe, and reproducible mobilization of the esophagus with adipose tissue bearing reginal lymph nodes, preserving the surrounding anatomical structures. (3) This method enables to preserve the bilateral RLNs together with the thin membranous tissue covering the nerves, which may help prevent intraoperative physical injuries to the RLNs.

In addition, 30.3% and 10.6% of our patients had CD grade ≥ II and ≥ IIIa complications, respectively. In previous studies, the postoperative morbidity (CD grade ≥ II) ranged from 19.2 to 66% [25–29]. Complications such as anastomotic leakage and pneumonia have an incidence of 3.6–33% and 4.8–33%, respectively [25–29]. In the ROBOT trial, Van der Sluis et al. compared the short-term outcomes between RE and the open approach for patients with intrathoracic EC; the RE group showed fewer postoperative complications (CD grade ≥ II, 59% vs. 80%) and pneumonia (28% vs. 55%) [30]. The recent RAMIE trial showed comparable incidence of postoperative major complications (CD grade ≥ III, 12.2% vs. 10.2%) and pulmonary complications (13.8% vs. 14.7%) in the robotic and laparoscopic approach [29]. The postoperative morbidity rates in the present study including anastomotic leakage and pneumonia were comparable or even better than those in the aforementioned retrospective studies and RCTs, indicating that our methodology is feasible and safe.

The incidence of RLN palsy (CD grade ≥ II) associated with our method was 4.5%. Upper mediastinal lymphadenectomy including the lymph nodes along the bilateral RLNs is essential in radical surgery for esophageal squamous carcinoma [1]. Akiyama et al. reported that the RLN palsy rate was 38.1% in patients who underwent open esophagectomy for EC [31]. A minimally invasive approach improves the incidence of RLN palsy, ranging from 2.4 to 29.2% in previous studies for RE with upper mediastinal lymphadenectomy [25–27, 30, 32]. Although the aforementioned RCT reported a similar incidence between the robotic and thoracoscopic approaches (27.1% vs. 32.6%, $p = 0.258$), Fujita et al. reported better outcomes in RE (8.0% vs. 34.0%, $p < 0.01$) [33]. Several studies reported that IONM helped identify

RLNs intraoperatively and reduce RLN palsy in esophagectomy with upper mediastinal lymphadenectomy [34–37], although no study has reported the effect of IONM on RE. The present study indicated that the combined application of our OL-oriented approach using the DVSS, which may reduce physical traction and heat given to RLNs and IONM in RE could help reduce RLN palsy. In addition, IONM could well predict RLN palsy. The specificity and NPV were reported to be 54.8–100% and 68–96.6%, respectively [37], consistent with those in our study. The lower NPV at the left side (89.3% vs. 98.3%) might be due to injury of the left RLN during the creation of left neck anastomosis, as supported by an RCT comparing intrathoracic and cervical anastomoses for Ivor Lewis esophagectomy without upper mediastinal lymphadenectomy; in this RCT, the RLN palsy rate was 7.3% in the cervical anastomosis group [38].

However, this study has several limitations. This study has a single-center, retrospective, and noncomparable design. Although we applied the robotic approach to all surgery-eligible patients with EC during the study period, selection bias was inherent considering the retrospective nature of the study. This study also focused on the short-term outcomes with a relatively small sample size, which may influence the outcomes. To validate the advantages of our OL-oriented approach, oncological long-term evaluation with more cases are needed, although the number of dissected lymph nodes in this study was at least comparable with those of previous reports [26].

In conclusion, RE with the OL-oriented approach can provide safe short-term outcomes.

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Declarations

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