World J Surg (2018) 42:590–598
DOI 10.1007/s00268-017-4179-0

ORIGINAL SCIENTIFIC REPORT WITH VIDEO

Lymph Node Evaluation in Robot-Assisted Versus Video-Assisted Thoracoscopic Esophagectomy for Esophageal Squamous Cell Carcinoma: A Propensity-Matched Analysis

Yin-Kai Chao[1] · Ming-Ju Hsieh[1] · Yun-Hen Liu[1] · Hui-Ping Liu[1]

Published online: 11 August 2017

Abstract

Objective Radical lymph node dissection (LND) along the bilateral recurrent laryngeal nerve (RLN) is a surgically challenging procedure with a high rate of morbidity. Here, we assessed in a retrospective manner the adequacy of LND along the RLN performed with robot-assisted thoracoscopic esophagectomy (RATE) versus video-assisted thoracoscopic esophagectomy (VATE) in patients with esophageal squamous cell carcinoma (ESCC).

Methods This was a single-center, retrospective, propensity-matched study. ESCC patients who underwent McKeown esophagectomy and bilateral RLN LND with a minimally invasive approach were divided into two groups according to the use of robot-assisted surgery or not (RATE vs VATE, respectively). Using propensity score matching, 34 balanced matched pairs were identified. The number of dissected nodes as well as the rates of RLN palsy and perioperative complications served as the main outcome measures.

Results No conversion to open thoracotomy occurred in either group. Intraoperative blood loss and the need of blood transfusions did not show significant intergroup differences. The mean number of dissected nodes was similar in the two study groups, the only exception being the left RLN area. Specifically, the mean number of nodes removed from this region was 5.32 in the RATE group and 3.38 in patients who received VATE ($p = 0.007$). Notably, the RATE and VATE groups did not differ significantly with regard to rates of both RLN palsy (20.6 vs 29.4%, respectively, $p = 0.401$) and pulmonary complications (5.9 vs 17.6%, respectively, $p = 0.259$).

Conclusions Compared with VATE, RATE resulted in a higher lymph node yield along the left RLN without increasing morbidity.

Introduction

Lymph nodes located in the upper mediastinum—especially along the bilateral recurrent laryngeal nerve (RLN)—are common site of early metastatic spread in patients with upper and middle third esophageal squamous cell carcinoma (ESCC) [1–3].

Although a thorough RLN lymph node dissection (LND) allows a better staging, the routine application of RLN LND in esophageal cancer surgery remains uncommon. This is not only due to its unconfirmed therapeutic value

Electronic supplementary material The online version of this article (doi:10.1007/s00268-017-4179-0) contains supplementary material, which is available to authorized users.

✉ Yin-Kai Chao
chaoyk@cgmh.org.tw

[1] Division of Thoracic Surgery, Chang Gung Memorial Hospital-Linko, Chang Gung University, No 5. Fu-Hsing Street, Taoyuan, Taiwan

but also due to the high morbidity that frequently accompanies RLN LND [4, 5]. Damage to the RLN causes a hoarse voice and swallowing difficulties. Coughing and airway clearance are also impaired by the inability to perform an adequate Valsalva maneuver, which in turn significantly increases the postoperative pulmonary complication rates [6–8].

Over the last two decades, video-assisted thoracoscopic esophagectomy (VATE) has gained increasing popularity owing to its capacity to provide an improved magnification and precise tissue dissection [9]. In experienced hands, VATE may result in a significant reduction of postoperative mortality and morbidity compared with open surgery [9–11]. However, a safe performance of RLN LND through VATE remains challenging. The limitations imposed by two-dimensional vision, instrument rigidity, and limited surgical spaces represent the main obstacles to achieving this goal. In addition, the potential occurrence of direct mechanical or thermal damage to the RLN has led to unchanged RLN palsy rates even when RLN LND is performed through VATE [12].

In recent years, robotic surgical systems incorporating three-dimensional stereoscopic vision and arms with wrist-like joints have allowed a meticulous dissection even in the limited mediastinum space. Despite the growing interest in robot-assisted thoracoscopic esophagectomy (RATE) [13–15], few published studies have directly compared its results with those of VATE [16, 17]. Moreover, the question as to how RATE compares with VATE for RLN LND has received scarce attention. Because our thoracic surgery center is witnessing this technology shift, we designed the current propensity-matched study to directly compare RATE with VATE in ESCC patients, with a special focus on the adequacy of LND along the RLN.

Materials and methods

Patients

This retrospective analysis was performed under the approval of our institutional review board. Consecutive ESCC patients who had undergone McKeown minimally invasive thoracoscopic esophagectomy and bilateral RLN LND between January 2013 and May 2016 were deemed eligible. Robot-assisted surgery was made available to our center as of October 2014, and it was subsequently offered to all patients. Patients who agreed to undergo a partially insured operation with the da Vinci Si HD Surgical System (Intuitive Surgical Inc., Sunnyvale, CA, USA) were included in the RATE group. All of the remaining patients who refused the partially insured use of RATE underwent VATE under complete health insurance coverage (VATE group). Pretreatment staging was based on the results of chest and abdomen CT scans, PET imaging, and endoscopic ultrasound. Patient staging was performed according to the American Joint Committee on Cancer (AJCC) staging criteria, seventh edition (2010). The severity of comorbidities was determined with the Charlson comorbidity index (CCI) [18]. The total score ranges between 0 and 37, with a score of zero indicating that no comorbidities are found.

Indications for neoadjuvant therapy

When clinically staged as T2N0M0 or higher, patients were offered neoadjuvant chemoradiotherapy (nCRT). It consisted of either a combination of cisplatin plus 5-fluorouracil or carboplatin plus paclitaxel given with concurrent radiation therapy (at a dose of 30 Gy before 2014 and 41.4–45 Gy thereafter). At 6–8 weeks after completion of nCRT, patients underwent surgical resection. Our standard surgical approach consisted of transthoracic esophagectomy followed by the creation of a gastric tube (either through laparotomy or laparoscopy) and a cervical esophagogastric anastomosis via left neck incision. All ESCC patients underwent a total two-field LND (which included the lower mediastinal/upper abdominal and bilateral RLN lymph nodes). However, neck LND was selectively performed only in patients who had evidence of lymph node involvement on preoperative CT or PET imaging. Patients were kept in an intensive care unit for at least one night after surgery and transferred thereafter to their appropriate ward. Jejunostomy tube feeding was started 24 h after surgery. A leak test was performed on the seventh postoperative day.

Thoracic procedure in the semiprone position

The patient was placed in the left semiprone position with single-lung ventilation. An artificial pneumothorax using CO_2 at a pressure of 6–8 mmHg was created. As far as RATE was concerned, five trocars were positioned at the following sites: (1) a 12-mm trocar at the sixth intercostal space (ICS) along the posterior axillary line for a 30-degree angled thoracoscope; (2) a 8-mm trocar at the fourth ICS along the mid axillary line medially to the scapula for the right robotic arm (R, Fig. 1a); (3) a 8-mm trocar at the ninth ICS along the posterior axillary line for the first left robotic arm (L1, Fig. 1a); (4) a 8-mm trocar at the ninth ICS along the mid point between the mid-scapular line and the paraspinal line for the second left robotic arm (L2, Fig. 1a); and (5) a 12-mm trocar at the seventh or eighth ICS along the mid axillary line for an accessory port. A da Vinci Si robotic cart (Intuitive Surgical Inc.) was docked at 45-degree in a counterclockwise direction from the patient craniocaudal axis. With regard to VATE, four trocars were

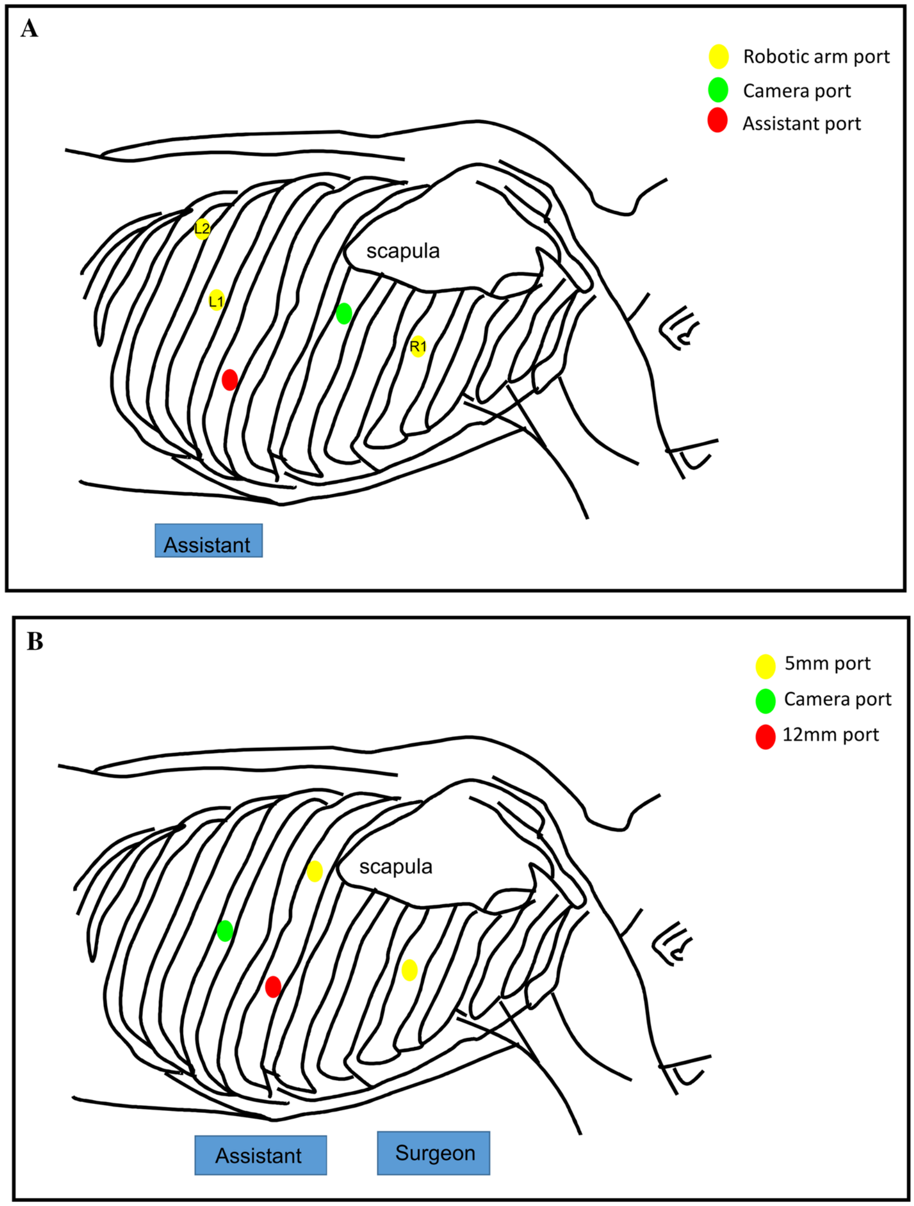

Fig. 1 **a** Trocar arrangement during RATE performed with the patient lying in the semiprone position. *R* right robotic arm; *L1* first left robotic arm; *L2* second left robotic arm. **b** Trocar arrangement during VATE performed with the patient lying in the semiprone position

positioned (Fig. 1b). The observation port lied at the posterior axillary line in the eighth or ninth ICS, whereas the main working port was located at the midaxillary line in the fourth intercostal space. The secondary working ports were positioned at the scapular line and the midaxillary line in the seventh ICS. The surgeon and the assistant stood on the right side of the patient, with a high-resolution screen being located on the opposite side.

Dissection along the bilateral recurrent laryngeal nerve

After incision of the mediastinal pleura, the layer between the esophagus and the thoracic duct was dissected to ensure the maximum mobilization of the posterior part of the esophagus. The mediastinal pleura was then incised along the course of the right vagus nerve until the lower margin of the subclavian artery to identify the right RLN. Left RLN LND was started by exposing the cartilage portion of the trachea. The esophagus was then retracted toward the dorsal side by the third robotic arm (or by surgeon's left hand in the case of VATE), while the trachea was pushed aside by an assistant to improve operative exposure. The soft tissue between the left side trachea and the esophagus (which included the left RLN and lymph nodes) was carefully dissected. Complete lymphadenectomy was subsequently performed by careful skeletonization of the left RLN. Video clips 1 and 2 demonstrate the key steps of lymphadenectomy along the bilateral RLN during RATE and VATE, respectively.

Gastric tube formation and cervical anastomosis

The mobilization of the stomach was performed under laparoscopy. All of the left gastric, paraesophageal, and splenic lymph nodes were removed. Mobilization of the stomach was conducted on the right gastroepiploic and right gastric arteries. A 4-cm gastric tube was prepared extracorporeally by making a 5-cm incision in the midline.

After construction of the gastric tube, a left cervical incision was performed and the cervical esophagus was identified. After completion of a stapled cervical esophagogastric anastomosis, a drain was placed and all of the incisions were closed.

Definitions

Perioperative complications were defined according to the system proposed by the Esophagectomy Complications Consensus Group [19]. Vocal cord function was assessed by an otolaryngologist using a flexible laryngoscope 2 weeks after surgery even when overt hoarseness was not evident. RLN palsy was further classified by site (unilateral vs bilateral) and type of treatment required (type I: no therapy required; type II: injury requiring elective surgical procedure; type III: injury requiring acute surgical intervention) [19]. Thirty- and 90-day mortality were defined as any death within 30 or 90 days, respectively, after the date of surgery. In-hospital mortality was defined as death occurring at any time during the postoperative hospital stay. Thirty-day readmission was defined as any inpatient admission to our institution within 30 days of discharge from a postoperative stay.

Statistical analysis

Patient characteristics, perioperative results, and surgical performances were analyzed with the Chi-square test, Fisher's exact test, Student's t test, and the Mann–Whitney U test, as appropriate. To control for potential confounding factors, patients were matched according to six variables (age, sex, CCI, clinical stage, use of CRT, and RLN nodal findings on preoperative CT imaging). Propensity scores for all patients were estimated by using a multiple logistic regression. Two comparable treatment groups were identified using a 1:1 match ratio based on 8 digits of the estimated propensity score. Data were analyzed using SAS version 9.3 (SAS Institute Inc., Cary, NC, USA) and SPSS version 20.0 (SPSS Inc., Chicago, IL, USA). p values < 0.05 (two tailed) were considered statistically significant.

Results

Patient characteristics

Between January 2013 and May 2016, we identified 141 ESCC patients who underwent McKeown esophagectomy accompanied by bilateral RLN LND with a minimally invasive approach (Fig. 2). Of them, 37 were treated with RATE and 104 received VATE. After propensity matching, a total of 34 patient pairs were included in the study. Table 1 shows the general characteristics of the study patients before and after propensity matching. Notably, patients in the RATE group were older and had a higher CCI before the matching procedure. Moreover, a higher proportion of patients in the VATE group were treated with CRT before surgery.

Propensity-matched analysis

After propensity matching, the general characteristics of the RATE and VATE groups were well balanced. Notably, no significant intergroup differences were evident even for unmatched clinical variables (e.g., tumor location and tumor length). Details on the surgical quality before and after propensity matching are summarized in Table 2. No conversion to open thoracotomy occurred in either group. The thoracic operating time in the RATE group was longer than in the VATE group, albeit not statistically significant. Similarly, intraoperative blood loss and the need of blood transfusions did not show significant intergroup differences. The mean number of dissected nodes was similar in

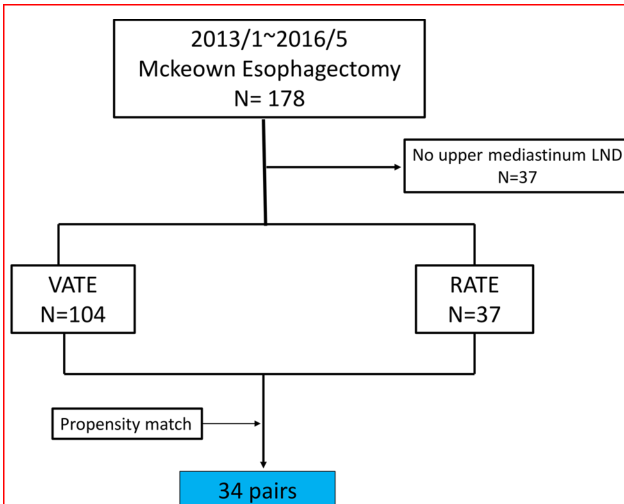

Fig. 2 Flow of the patients through the study

Table 1 Demographic and clinical data of the study patients before and after propensity matching

	Entire study cohort			Propensity-matched cohort		
	VATE ($n = 104$)	RATE ($n = 37$)	p value	VATE ($n = 34$)	RATE ($n = 34$)	p value
Age (years)	54.1 ± 7.71	58.6 ± 10.13	0.006	53.47 ± 8.69	56.76 ± 8.39	0.116
CCI	2.6 ± 1.16	3.03 ± 1.34	0.065	2.88 ± 1.27	2.88 ± 1.27	**
Sex						1
Male	97 (93.3%)	34 (91.9%)	0.779	33 (97.1%)	32 (94.1%)	
Female	7 (6.7%)	3 (8.1%)		1 (2.9%)	2 (5.9%)	
Preop therapy			0.118			**
nCRT	52 (50%)	17 (45.9%)		17 (50%)	17 (50%)	
None	43 (41.3%)	20 (54.1%)		17 (50%)	17 (50%)	
dCRT	9 (8.7%)	0 (0%)				
Clinical stage			0.162			1.0
I/II	37 (35.6%)	18 (48.6%)		16 (47.1%)	16 (47.1%)	
III	67 (64.4%)	19 (51.4%)		18 (52.9%)	18 (52.9%)	
Tumor location			0.718			0.446
Upper third	25 (24%)	10 (27%)		10 (29.4%)	10 (29.4%)	
Middle third	53 (51%)	16 (43.3%)		19 (55.9%)	15 (44.1%)	
Lower third	26 (25%)	11 (29.7%)		5 (14.7%)	9 (26.5%)	
RLN LNM			0.591			**
Yes	37 (35.6%)	15 (40.5%)		14 (41.2%)	14 (41.2%)	
No	67 (64.4%)	22 (59.5%)		20 (58.8%)	20 (58.8%)	

Data are given as means ± SD or counts, as appropriate

VATE video-assisted thoracoscopic esophagectomy; *RATE* robot-assisted thoracoscopic esophagectomy; *CCI* Charlson comorbidity index; *Preop* preoperative; *nCRT* neoadjuvant chemoradiotherapy; *dCRT* definitive chemoradiotherapy; *RLN* recurrent laryngeal nerve; *LNM* lymph node metastases

** Propensity-matched variable

Table 2 Surgical quality in the RATE and VATE groups

	Entire study cohort			Propensity-matched cohort		
	VATE ($n = 104$)	RATE ($n = 37$)	p value	VATE ($n = 34$)	RATE ($n = 34$)	p value
Thoracic phase operating time (min)	198.08 ± 46.6	227.71 ± 44.49	<0.001	200.15 ± 103.48	231.15 ± 42.84	<0.001
EBL (mL)	115.19 ± 139.77	94.05 ± 99.74	0.399	102.65 ± 96.67	92.06 ± 99	0.657
Intraoperative BT, n (%)	11 (10.6%)	4 (10.8%)	1	2 (5.9%)	3 (8.8%)	1
R0 surgery, n (%)	98 (94.2%)	37 (100%)	0.328	33 (97.1%)	34 (100%)	1
Number of dissected lymph nodes						
Total number	34.42 ± 14.54	37.02 ± 17.89	0.381	36.24 ± 12.95	37.18 ± 18.25	0.807
Thoracic nodes	17.55 ± 9.19	19.05 ± 8.49	0.384	18.68 ± 9.32	18.47 ± 7.89	0.922
Total RLN nodes	5.95 ± 4.15	7.60 ± 3.61	0.034	6.18 ± 4.48	7.68 ± 3.51	0.129
Right RLN nodes	2.77 ± 2.23	2.27 ± 1.87	0.226	2.79 ± 2.1	2.32 ± 1.87	0.333
Left RLN nodes	3.18 ± 3.21	5.30 ± 2.95	0.001	3.38 ± 2.94	5.32 ± 2.79	0.007
Abdominal nodes	15.86 ± 9.72	13.78 ± 5.11	0.219	15.91 ± 7.18	14.15 ± 4.97	0.243

Data are given as means ± SD or counts (percentages), as appropriate

VATE video-assisted thoracoscopic esophagectomy; *RATE* robot-assisted thoracoscopic esophagectomy; *EBL* estimated blood loss; *BT* blood transfusions; *RLN* recurrent laryngeal nerve

Table 3 Subgroup analysis of surgical quality in the RATE and VATE groups stratified according to the use of preoperative CRT (yes vs no)

	Primary surgery			Preoperative CRT		
	VATE ($n = 17$)	RATE ($n = 17$)	p value	VATE ($n = 17$)	RATE ($n = 17$)	p value
Thoracic phase operating time (min)	162.15 ± 37.14	225.15 ± 37.19	<0.001	197.38 ± 43.41	232.13 ± 54.95	0.057
EBL (mL)	121.18 ± 122.88	74.41 ± 41.85	0.150	85.53 ± 56.01	109.41 ± 134.98	0.471
Intraoperative BT, *n* (%)	2 (11.8%)	0 (0%)	0.485	0 (0%)	3 (17.6%)	0.227
R0 surgery, *n* (%)	17 (100%)	17 (100%)	NA	16 (94.1%)	17 (100%)	1
Number of dissected lymph nodes						
Total number	40.47 ± 12.62	38.59 ± 20.35	0.748	32 ± 12.19	35.77 ± 16.38	0.453
Thoracic nodes	21.77 ± 10.16	18.35 ± 7.01	0.263	15.58 ± 7.45	18.59 ± 8.91	0.295
Total RLN nodes	7.24 ± 5.52	7.94 ± 3.25	0.653	5.12 ± 2.91	7.41 ± 3.83	0.058
Right RLN nodes	3.35 ± 2.47	2.71 ± 1.90	0.398	2.24 ± 1.52	1.94 ± 1.82	0.613
Left RLN nodes	3.88 ± 3.46	5.24 ± 2.66	0.21	2.88 ± 2.34	5.41 ± 3.01	0.010
Abdominal nodes	17.06 ± 7.55	14.53 ± 6.14	0.292	14.77 ± 6.81	13.77 ± 3.61	0.596

Data are given as means ± SD or counts (percentages), as appropriate

VATE video-assisted thoracoscopic esophagectomy; *RATE* robot-assisted thoracoscopic esophagectomy; *EBL* estimated blood loss; *BT* blood transfusions; *RLN* recurrent laryngeal nerve; *NA* not applicable

Table 4 Short-term perioperative outcomes in the RATE and VATE groups

	Entire study cohort			Propensity-matched cohort		
	VATE ($n = 104$)	RATE ($n = 37$)	p value	VATE ($n = 34$)	RATE ($n = 34$)	p value
MV time (min)	703.04 ± 968.71	502.81 ± 357.24	0.223	409.85 ± 289	524.53 ± 364.93	0.156
ICU stay (h)	43.72 ± 52.2	31.53 ± 17.78	0.167	35.62 ± 47.33	31.85 ± 18.22	0.666
Pneumonia	18 (17.3%)	3 (8.1%)	0.281	6 (17.6%)	2 (5.9%)	0.259
Pleural effusion	25 (24%)	5 (13.5%)	0.179	6 (17.6%)	4 (11.8%)	0.493
MV > 72 h	2 (1.9%)	0 (0%)	1.0	0 (0%)	0 (0%)	NA
RLN palsy	30 (28.8%)	8 (21.6%)	0.395	10 (29.4%)	7 (20.6%)	0.401
Right/Left/Bilateral	3/27/0	0/8/0		2/8/0	0/7/0	
Type: I/II/III	25/5/0	7/1/0		7/3/0	6/1/0	
Anastomotic leak	4 (3.8%)	1 (2.7%)	1.0	2 (5.9%)	0 (0%)	0.493
30-day mortality	0 (0%)	0 (0%)	NA	0 (0%)	0 (0%)	NA
In-hospital mortality	4 (3.8%)	1 (2.7%)	1.0	1 (2.9%)	0 (0%)	1.0
90-day mortality	4 (3.8%)	1 (2.7%)	1.0	1 (2.9%)	0 (0%)	1.0
LOS (days)	20.63 ± 11.66	17.5 ± 8.42	0.141	17.82 ± 5.76	16.36 ± 5.79	0.305
30-day readmission	13 (12.5%)	5 (13.5%)	1.0	4 (11.8%)	5 (14.7%)	1.0

Data are given as means ± SD or counts (percentages), as appropriate

VATE video-assisted thoracoscopic esophagectomy; *RATE* robot-assisted thoracoscopic esophagectomy; *MV* mechanical ventilator; *ICU* intensive care unit; *RLN* recurrent laryngeal nerve; *LOS* length of stay; *NA* not applicable

the two study groups, the only exception being the left RLN area. Specifically, the mean number of nodes removed from this region was 5.32 in the RATE group and 3.38 in patients who received VATE ($p = 0.007$).

Table 3 shows the subgroup analysis of surgical quality in the RATE and VATE groups stratified according to the use of preoperative CRT (yes vs no). Although preoperative CRT significantly reduced the mean number of LND (39.75 vs 31.36, respectively, $p < 0.001$), RATE produced a higher lymph node yield along the left RLN compared with VATE (regardless of CRT use or not).

With regard to morbidity after RLN LND, 17 (25%) patients suffered from RLN palsy; of them, 15 and 2 cases had left-sided and right-sided lesions, respectively. Most patients (13/17, 76.5%) with RLN palsy had self-limiting clinical manifestations that required no therapy (type I).

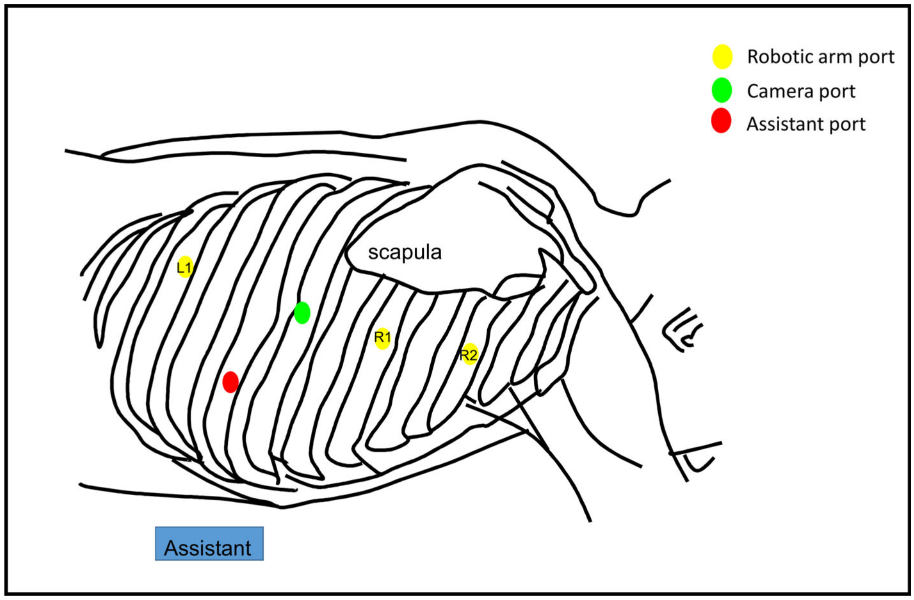

Fig. 3 Trocar arrangement during RATE performed in patients with a deep-seated esophagus (i.e., an esophagus located in the left side of mediastinum). *R1* first right robotic arm; *R2* second right robotic arm; *L* left robotic arm

Four patients with type II RLN palsy required elective office-based intracordal hyaluronate injections after discharge [20]. The short-term perioperative outcomes of the two study groups before and after propensity matching are depicted in Table 4. Besides RLN palsy, no significant differences were also observed in terms of pulmonary complications, anastomotic leaks, 30-day/90-day/in-hospital mortality, and 30-day readmission rates between the two groups.

Discussion

The results of our study demonstrate that RATE allows achieving a higher mean number of dissected nodes along the RLN area (especially in the left side) compared with VATE, without increasing RLN palsy and pulmonary complications rates. Besides the case series reported by Suda et al. [16], this is the second study that directly compared McKeown RATE versus VATE. Notably, our current report includes a larger number of cases and is the first to apply a propensity-matched study design. We specifically performed a careful matching of several potential confounders that could affect both lymph node yields and postoperative outcomes.

Complete left RLN LND required the complete removal of soft tissue and lymph nodes located both ventrally and dorsally to the RLN (from the aortic arch level to the cervical part). Specifically, the dissection of nodes located ventrally to the left RLN is frequently the most challenging part of the surgical procedure. Video clip 2 illustrates the most common difficulties that may be encountered during left RLN LND performed through VATE. The limited flexibility of the instrument tip precludes a tension-free dissection of lymph nodes located between the trachea and the left RLN. Notably, RLN injury can be caused by contusions, excessive stretching, and thermal damage occurring during manipulation. In order to improve the operative exposure and reduce RLN injury, several novel approaches—including esophageal isolation with loops of umbilical tapes (with the goal of suspending the esophagus and ensure the maximum exposure of the left RLN) or the replacement of a double-lumen tube with a single-lumen tube coupled with CO_2 insufflation (with the goal of reducing the trachea rigidity elicited by the double-lumen tube and facilitate a better countertraction)—have been recently proposed during VATE. [21, 22]. Unfortunately, and despite all of these technical improvement, left RLN LND remains difficult to be achieved through VATE. In this scenario, experienced assistants are strictly required to ensure a high-quality dissection. We believe that RATE offers at least three advantages as far as the dissection of the left RLN lymph nodes is concerned. First, the three-dimensional self-controlled magnified view provided by the robotic camera allows a better visualization of the upper mediastinum compared with a traditional two-dimensional monitor. Owing to its ability to offer an adequate depth perception, this feature significantly facilitates left RLN LND. Second, the use of the third robot arm (controlled by the operator) allows achieving an excellent operating exposure through the application of stable and self-controllable tractions and countertractions on the esophagus and trachea. With the help of a third robotic arm, the surgeon can perform left RLN LND while maintaining the full use of the primary "working" arms, ultimately ensuring a safer and easier approach to nodal dissection. All of the "self-controlled" features offered by the robotic system may ultimately abrogate the need for experienced surgical assistants (who are strictly required when VATE is performed). Third, RATE facilitates a meticulous tension-free dissection even in a limited anatomical space; this is achieved both by tremor filtering and the use of instruments with articulating function that allows obtaining seven degrees of freedom. It can be anticipated that all of these features may decrease the rates of RLN injury.

During the RATE procedure, we decided to place the third robotic arm on the surgeon's leftmost side to facilitate the esophageal traction. Under these circumstances, the third robotic arm may come into collision with either the second robotic arm or the patient's spine; a category of patients at special risk of developing this accident during the upper mediastinum dissection are those with a deep-seated esophagus (i.e., an esophagus located in the left side of mediastinum). When these patients are operated, it is advisable to shift the R port and the camera port (as reported in Fig. 1a) downward of one intercostal space; the third robotic arm (L2) should then be shifted to the right-most side at the third intercostal space. Figure 3 illustrates the details of trocar design.

An important observation from our study is that a better operating exposure is not paralleled by a shorter thoracic operating time, with RATE time being 30 min longer than that of VATE (even though the difference was not statistically significant). One potential explanation for the prolonged operating time is the higher surgeon confidence provided by the robotic system, which can ultimately lead to the willingness of achieving a complete RLN LND. Another potential cause underlying this phenomenon is the inclusion of cases operated when RATE was still in its development stage (i.e., with surgeons operating during the early phase of their learning curves). Further studies specifically aimed at analyzing the surgical learning curves are needed to address this issue in an appropriate manner.

Our findings should be interpreted in the context of several caveats. First, our study shares the limitations of small-sized, retrospective investigations. We acknowledge the low number of participants and the reduced statistical power. Second, our results are limited by the short follow-up time. Although a higher number of dissected nodes along the left RLN was achieved in the RATE group, the question as to whether a more extensive RLN LND could result in a significant survival advantage clearly requires a long-term follow-up analysis. Third, the use of RATE was driven by the patient's own willingness to undergo a partially insured robot-assisted operation. Despite the use of propensity matching, we cannot rule out the presence of potential selection biases. Consequently, prospective randomized studies are necessary to confirm and expand our findings.

Conclusions

Compared with VATE, RATE resulted in a higher lymph node yield along the left RLN without increasing morbidity.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

References

1. Tachimori Y, Ozawa S, Numasaki H et al (2016) Efficacy of lymph node dissection for each station based on esophageal tumor location. Esophagus 13:138–145
2. Udagawa H, Ueno M, Shinohara H et al (2012) The importance of grouping of lymph node stations and rationale of three-field lymphoadenectomy for thoracic esophageal cancer. J Surg Oncol 106:742–747
3. Mizutani M, Murakami G, S-I Nawata et al (2006) Anatomy of right recurrent nerve node: why does early metastasis of esophageal cancer occur in it? Surg Radiol Anat 28:333–338
4. Sato Y, Kosugi S-I, Aizawa N et al (2016) Risk factors and clinical outcomes of recurrent laryngeal nerve paralysis after esophagectomy for thoracic esophageal carcinoma. World J Surg 40:129–136. doi:10.1007/s00268-015-3261-8
5. Fujita H, Sueyoshi S, Tanaka T et al (2003) Optimal lymphadenectomy for squamous cell carcinoma in the thoracic esophagus: comparing the short-and long-term outcome among the four types of lymphadenectomy. World J Surg 27:571–579. doi:10.1007/s00268-003-6913-z
6. Gockel I, Kneist W, Keilmann A et al (2005) Recurrent laryngeal nerve paralysis (RLNP) following esophagectomy for carcinoma. Eur J Surg Oncol (EJSO) 31:277–281
7. Berry MF, Atkins BZ, Tong BC et al (2010) A comprehensive evaluation for aspiration after esophagectomy reduces the incidence of postoperative pneumonia. J Thorac Cardiovasc Surg 140:1266–1271
8. Hulscher JB, van Sandick JW, Devriese P et al (1999) Vocal cord paralysis after subtotal oesophagectomy. Br J Surg 86:1583–1587
9. Luketich JD, Pennathur A, Awais O et al (2012) Outcomes after minimally invasive esophagectomy: review of over 1000 patients. Ann Surg 256:95–103
10. Zhou C, Zhang L, Wang H et al (2015) Superiority of minimally invasive oesophagectomy in reducing in-hospital mortality of patients with resectable oesophageal cancer: a meta-analysis. PloS ONE 10:e0132889
11. Biere SS, van Berge Henegouwen MI, Maas KW et al (2012) Minimally invasive versus open oesophagectomy for patients with oesophageal cancer: a multicentre, open-label, randomised controlled trial. Lancet 379:1887–1892
12. Noshiro H, Iwasaki H, Kobayashi K et al (2010) Lymphadenectomy along the left recurrent laryngeal nerve by a minimally invasive esophagectomy in the prone position for thoracic esophageal cancer. Surg Endosc 24:2965–2973

13. Park S, Kim D, Yu W et al (2015) Robot-assisted thoracoscopic esophagectomy with extensive mediastinal lymphadenectomy: experience with 114 consecutive patients with intrathoracic esophageal cancer. Dis Esophagus 29:326–332
14. Van der Sluis P, Ruurda J, Verhage R et al (2015) Oncologic long-term results of robot-assisted minimally invasive thoraco-laparoscopic esophagectomy with two-field lymphadenectomy for esophageal cancer. Ann Surg Oncol 22:1350–1356
15. Cerfolio RJ, Wei B, Hawn MT et al (2015) Robotic esophagectomy for cancer: early results and lessons learned seminars in thoracic and cardiovascular surgery. Elsevier, Amsterdam
16. Suda K, Ishida Y, Kawamura Y et al (2012) Robot-assisted thoracoscopic lymphadenectomy along the left recurrent laryngeal nerve for esophageal squamous cell carcinoma in the prone position: technical report and short-term outcomes. World J Surg 36:1608–1616. doi:10.1007/s00268-012-1538-8
17. Weksler B, Sharma P, Moudgill N et al (2012) Robot-assisted minimally invasive esophagectomy is equivalent to thoracoscopic minimally invasive esophagectomy. Dis Esophagus 25:403–409
18. Charlson ME, Pompei P, Ales KL et al (1987) A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. J Chronic Dis 40:373–383
19. Low DE, Alderson D, Cecconello I et al (2015) International consensus on standardization of data collection for complications associated with esophagectomy: esophagectomy Complications Consensus Group (ECCG). Ann Surg 262:286–294
20. Fang T-J, Hsin L-J, Chung H-F et al (2015) Office-based intracordal hyaluronate injections improve quality of life in thoracic-surgery-related unilateral vocal fold paralysis. Medicine 94:e1787
21. Xi Y, Ma Z, Shen Y et al (2016) A novel method for lymphadenectomy along the left laryngeal recurrent nerve during thoracoscopic esophagectomy for esophageal carcinoma. J Thoracic Dis 8:24
22. Zhang R, Liu S, Sun H et al (2014) The application of single-lumen endotracheal tube anaesthesia with artificial pneumothorax in thoracolaparoscopic oesophagectomy. Interact Cardiovasc Thorac Surg 19:308–331