3 Robotic Three-Field Esophagectomy

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Introduction

Minimally invasive esophagectomy (MIE) has become a popular option for the treatment of esophageal cancer. MIE reportedly decreases postoperative complications [1–5], and its long-term survival is comparable to open esophagectomy [3–6]. Robot-assisted minimally invasive esophagectomy (RAMIE) has been recently introduced as an alternative option for MIE. The robotic system enables more meticulous dissection of tissues and gentle handling of organs. Several studies reported early and long-term results of RAMIE, and the outcomes were comparable to other surgical modalities [7–9]. However, the techniques of RAMIE are diverse because of the heterogeneous patient population and different levels of experience in RAMIE. In this chapter we will present the three-hole RAMIE technique, which can be applied to esophageal squamous cell carcinoma located mostly in the upper to mid-thoracic esophagus. In our institute, the abdominal procedure in RAMIE has been performed robotically rather than by a laparoscopic technique. The detailed technical features will be discussed.

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Advantages of Robotic Esophageal Surgery

RAMIE has several advantages over conventional thoracoscopic and laparoscopic MIE. Because RAMIE enables well-controlled fine motion during the operation, it facilitates meticulous dissection of tissue with less traumatic manipulation of organs. These advantages can be especially helpful during dissection of lymph nodes along the recurrent laryngeal nerve (RLN). Dissection along the RLN is a critical and important procedure in mid- and upper thoracic esophageal cancers. The RLN lymph node is the site of most frequent lymph node metastasis and is more closely related to survival than any other lymph node station [10, 11]. So, it has been considered that RLN dissection is critical for predicting prognosis and preventing locoregional recurrence. Robotic technology enables the performance of this critical step more easily. Radical and extensive dissection along the RLN can be possible by robotic upper mediastinal dissection [12] and could reduce the rate of vocal cord palsy [13]. These features of RAMIE may

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lead to reduction of locoregional recurrence and improved overall survival in these patients.

The next important advantage with robotic esophagectomy is gentle manipulation of organs. This is an important advantage when operating on the trachea and stomach. Excessive tracheal retraction during esophagectomy or lymphadenectomy may result in insufficient ventilation or tracheal injury. Very close coordination between the operator and assistant surgeon is required during tracheal retraction in thoracoscopic MIE. However, in RAMIE, the force and extent of tracheal retraction can be controlled by the surgeon and better visualization can be easily achieved without the help of assistant surgeons. Therefore, airway injury during esophagectomy or lymphadenectomy can be minimized. The robotic approach also has advantages in stomach mobilization. Careful handling of the stomach, as in open surgery, is possible using robotic surgery. Excessive traction and traumatic manipulation can jeopardize the submucosal vascular network and decrease blood flow in the graft, which is an important cause of poor healing of the anastomosis with subsequent leakage. Using the robotic technique, the gastric graft can be manipulated gently and less traumatically, which helps to reduce graft-related complications.

The final advantage of robotic surgery is its flexibility in technically challenging situations, which can be frequent during MIE. These situations are the main cause for open conversion. Examples include extranodal metastatic LNs, anatomical variation, adhesion to critical organs (trachea or descending aorta), and extreme left-sided esophagus. The robotic technique can overcome these challenging conditions. The approach enables fine dissection and access to difficult areas. In our series of RAMIE, only two cases of thoracic conversion were necessary. In both cases, the cause was secondary to diffuse severe pleural adhesions. We did not experience any thoracotomy conversion after docking the robot or any conversion during robotic abdominal procedures. This low incidence of conversion is indicative of the high performance of the robotic system in difficult surgical situations.

Indications of RAMIE

RAMIE has been performed in our institute since 2008. In the early period of its use, RAMIE was performed sporadically for highly selected patients. However, the indications of RAMIE were expanded gradually from patients with low-risk early esophageal cancer to patients at high risk with advanced esophageal cancer. RAMIE has become the most commonly performed surgical procedure for esophageal cancer in our institute. Currently, there are several contraindications for RAMIE, which depend on the condition of the patients and the progression of esophageal cancer. The contraindications of thoracic robotic esophagectomy are severe pleural adhesions, previous major chest surgery, large-size esophageal cancer that is not reduced after neoadjuvant treatment, suspicion for airway invasion, intolerance to one lung ventilation, and salvage esophagectomy after definitive chemoradiation therapy. Contraindications of abdominal robotic procedures are previous history of peritonitis, previous major abdominal surgery, abdominal lymph node metastasis, and suspicion for invasion to adjacent organs. Hybrid RAMIE that comprises robotic esophagectomy combined with open laparotomy can be performed when the abdominal situation is not favorable for robotic surgery. However, if the thoracic situation is not favorable for robotic surgery, then we usually do not perform robotic surgery at all. We think that avoiding thoracotomy is the most important component of MIE, rather than avoiding laparotomy.

Position of Patient, Port Placement, and Robotic Setup

In the thoracic procedure, patients are in the left lateral decubitus position with a slight tilt in the anterior direction (Fig. 3.1). In the early period of robotic surgery, we used the prone position during the thoracic procedure. However, we changed to the decubitus position because of the difficulties in airway management during anesthesia and pleural adhesiolysis with whole pleural adhesion.

With experience in RAMIE, we now know that the decubitus position is not inferior to the prone position for esophagectomy.

We prefer the four-arm technique during the thoracic and abdominal procedures and usually use four ports during the thoracic procedure (Fig. 3.2). A camera port is made in the seventh intercostal space just below the scapular tip. The level of the camera port is very important because an optimal surgical view cannot be obtained when the location is too high or too low. The vertebral body and lung parenchyma in high- and low-position camera locations, respectively, can hinder visualization of the esophagus and peri-

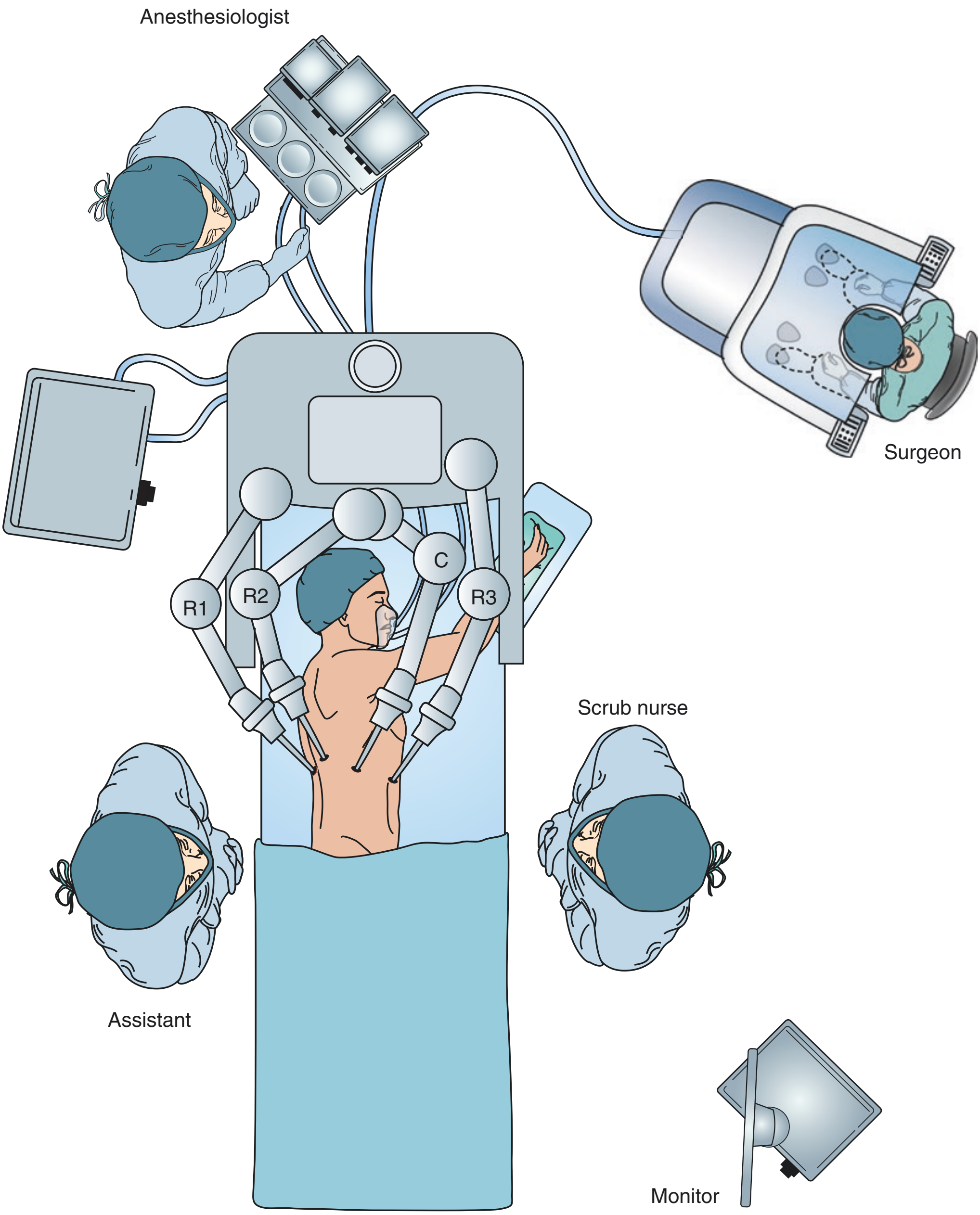

Fig. 3.1 The position of the robot and patient during robotic esophagectomy

esophageal structures. Other ports are usually made to maintain distances >8.5 cm between the arms. Arm 3 port is placed in the third intercostal space of the axillary fossa. The location of this arm should be checked after docking because it can compress the right arm of the patient. Arm 3 is usually used for retraction of structures, so a Cadiere grasper is usually used in this arm. Arm 1 port is made in the fifth intercostal space in the posterior axillary line. This port can be used for the robot but can also be used by an assistant surgeon. Therefore, we make a 4-cm sized port and use a single incision silastic port (Glove port, NELIS Co., South Korea). Arm 2 port is made in the tenth intercostal space on the back of the patient. This arm is exclusively used for the robotic dissecting grasper. Robotic scissors or harmonic scalpel is usually used as the dissection device (Table 3.1). Minimizing clashing of the arms is important and the surgeon should always consider the relative positions of each arm and use the arms properly in each surgical procedure.

In the abdominal robotic procedure, we always place five ports. Four are robotic ports and the remaining port is an assistant port. The camera port is 2 cm in size and made just lateral to the umbilicus. The glove port used for the thoracic procedure can also be inserted in this port. We place a feeding jejunostomy catheter through this port after finishing the robotic procedure. Other ports are placed as depicted in Fig. 3.3. We also use the four-arm technique in the abdominal procedure; most of the robotic arms used in thoracic procedure can be used in the abdominal procedure.

We prefer to use carbon dioxide (CO_2) insufflation in both the thoracic and abdominal procedures. We reduce the CO_2 pressure below 5–8 mm Hg to minimize hemodynamic instability during

Table 3.1 Robotic ports and instruments used in RAMIE

Arms	Instruments
Port for arm 1	Monopolar curved scissors
	Harmonic ACE curved shears
	Large suture cut needle driver
	Medium-large clip applier
	Large clip applier
	Small clip applier
Port for arm 2	Curved bipolar dissector
Port for arm 3	Cadiere forceps

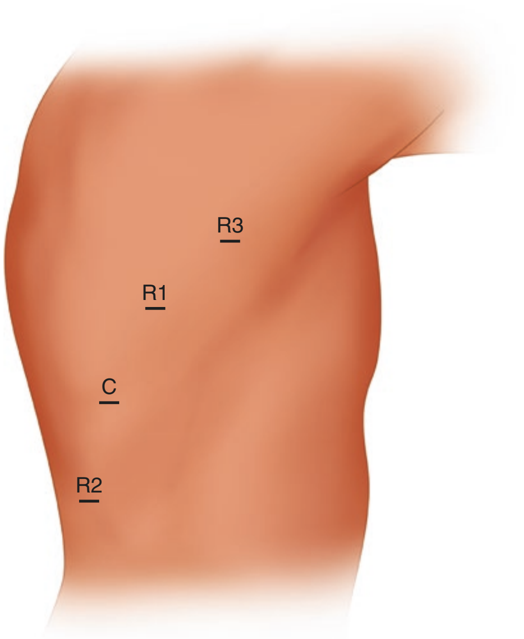

Fig. 3.2 Four ports are made for the robotic thoracic procedure. A silastic port can be applied using a small utility incision. The utility incision can be used by robotic arm #1 or by the assistant surgeon

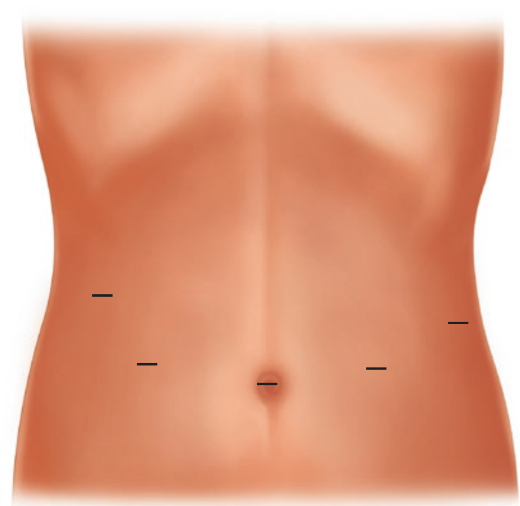

Fig. 3.3 Five ports are made in the robotic abdominal procedure. A silastic port used in the thoracic procedure can be also used in the periumbilical port. However, the assistant surgeon uses a different port

the thoracic procedure. Both bipolar and monopolar electrocoagulation are used during surgery with dissectors in arm 2 connected to bipolar coagulation and scissors in arm 1 to monopolar coagulation.

Surgical Techniques (Video 3.1)

Thoracic Procedure

We start the esophagectomy from the level of the azygous vein. After dividing the azygous vein and the right bronchial artery, we open the mediastinal pleura along the vagus nerve and dissect the lymph nodes in the right upper mediastinum. Then we dissect peri-eosphageal tissue downside along the azygous vein and thoracic duct to the level of the diaphragmatic hiatus. Lastly, we finish by dissecting the subcarinal area and the left paratracheal area. The order of dissection can be dependent on the surgeon's preference.

After dividing the azygos vein, the right bronchial artery can be divided by robotic hemoclips from the origin of aorta. The right main bronchus and vagus nerve can be visualized at this point, and dissection can be performed along the vagus nerve. The distal vagus nerve can be cut just distal to the right pulmonary branch of the vagus nerve. Dissection can proceed to the upper mediastinum along the vagus nerve. The right RLN can be identified at the junctional point between the right subclavian artery and the vagus nerve. Lymph nodes along the right RLN (station 2R in American Joint Committee on Cancer [AJCC] [14], 106recR in Japanese Esophageal Society [JES] mapping [15]) can be dissected from this point. The dissection can be performed up to the level of the inferior thyroidal artery. A portion of cervical paraesophageal lymph nodes can be removed at this area (1R in AJCC, 101R in the JES). Complete removal of lymph nodes and perilymphatic tissue along the right RLN is possible. Figure 3.4 demonstrates lymph node dissection view around right RLN.

Mid- to lower thoracic esophageal dissection is relatively easy compared to upper mediastinal

Fig. 3.4 Robotic view during dissection of lymph nodes in the right upper mediastinum along the right recurrent laryngeal nerve

dissection. Mediastinal pleura can be exposed by sharp dissection with scissors. In other areas, the harmonic scalpel is usually sufficient for dissection. Paraesophageal lymph nodes (8M and 8L in the AJCC map, 108 and 110 in the JES map) are usually dissected in an en bloc fashion with the esophagus. Complete removal of the whole thoracic duct is a routine procedure in our institute, and the thoracic duct is divided just above the diaphragmatic hiatus. The contralateral lung, left pulmonary vein, and left main bronchus should be entirely exposed, and lymph nodes in the left mediastinal side should be completely removed. Anterior para-aortic lymph nodes (112aoA in the JES map) can be removed by converting the camera angle to 30° upside. Dissection can be performed to the level of the hiatus and supradiaphragmatic LNs can be removed (15 in the AJCC map, 111 in the JES map). Along the left main bronchus, the left vagus nerve can be identified and divided just distal to the pulmonary branch, similar to the right side. Subcarinal lymph nodes (7 in AJCC and 107 in JES) can be removed at this point. Esophageal encircling with a traction band is not necessary because the third robotic arm can be used for retraction and lifting the esophagus during the entire procedure.

The most difficult part of the thoracic procedure is the left upper mediastinal dissection. This step requires sufficient experience to finish it completely without damaging the trachea or left RLN. We prefer to detach the esophagus completely from the trachea before lymph node dissection. This is why we perform left upper lymphadenectomy during the last stage of operation. A wide surgical view can be obtained after complete dissection of the entire esophagus. The trachea can be retracted in the anterior direction using Cadiere robotic forceps. Complete control of small vessel branches by monopolar robotic scissors along the left tracheal border before lymph node dissection is helpful for a bloodless surgical field. The left RLN is embedded inside of lymphatic tissue, therefore meticulous and fine dissection of tissue is necessary to find the left RLN. After identifying the RLN, the tracheobronchial lymph nodes can be removed first (10L and 5 in AJCC and 106tbL in JES). The most important aspect at this point is to preserve the left bronchial artery. Because the right bronchial artery has already been divided, cutting both arteries will induce significant ischemia in the airway and increase the possibility of tracheoenteric fistula postoperatively. Then, lymph nodes along the left RLN can be removed up to the inferior thyroidal artery. This step can remove whole lymph nodes in the left paratracheal area (2L and 4L in AJCC and 107recL in JES) and a portion of the left cervical paraesophageal lymph nodes (1L in AJCC and 101L in JES). Figure 3.5 presents a post-dissection view of the left paratracheal area.

As noted previously, RAMIE enables safe and complete lymphadenectomy in precarious anatomic regions. Its ability to do so is better than the thoracoscopic technique; and we feel that it is better than the open technique. The thoracic procedure is the most beneficial part of RAMIE in esophageal cancer surgery. The role of the assistant surgeon is limited in the thoracic procedure, and delivering suture material or retrieving lymph nodes is the major role of the assistant surgeon. Suctioning blood is sometimes necessary, but the amount of bleeding is minor in RAMIE.

Abdominal Procedure

The 4-arm technique can also be used for the abdominal procedure. The Cadiere forceps can be used for retraction of the liver and to hold the stomach during the abdominal procedure. After lifting the left lobe of the liver, the lesser omentum can be divided using the harmonic scalpel. A wide opening of the lesser curvature is necessary to gain a wide view around the celiac axis. The common hepatic artery lymph nodes (18 in AJCC map and 8a in JES), left gastric lymph nodes (17 in AJCC and 7 in JES), and celiac axis lymph nodes (20 in AJCC and 9 in JES) can be dissected at this point. The left gastric artery and coronary vein can be divided at the most proximal part of the celiac axis by robotic polymer clips. Lymph node dissection can be performed along the splenic artery (19 in AJCC and 9 in JES). At the level of the splenic hilum, short gastric vessels can be visualized and divided, and the left side of the cardia can be mobilized from the splenic hilum.

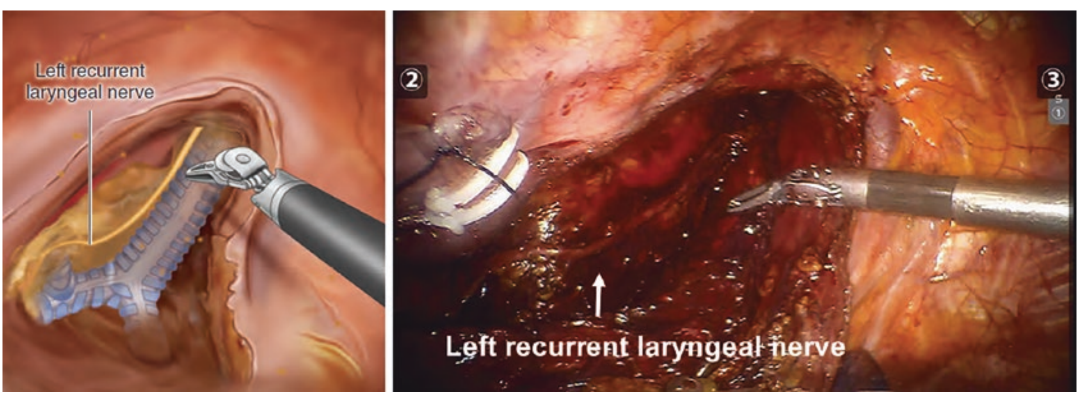

Fig. 3.5 Illustration of the paratracheal area after dissection of lymph nodes in the left upper mediastinum along the left recurrent laryngeal nerve and intraoperative image showing the left recurrent laryngeal nerve following lymph node dissection

After finishing the lesser curvature steps, the stomach can be lifted by the Cardiere forceps. The greater omentum is divided along the left gastroepiploic artery. To preserve collateral blood supply, sufficient omentum should remain with the stomach graft. On the right side, the gastrocolic ligament should be completely divided, and Kocher maneuver can be performed for maximum mobilization of the stomach. Pyloromyotomy is performed by sharp dissection at the pylorus. Grasping the pyloric muscle using the robotic dissecting grasper and severing the muscle with the scissors enable complete division of the pyloric muscle without damaging the gastric mucosa. Ramstedt-type pyloromyotomy is a routine procedure in our institute. The greater omentum is then divided along the right gastroepiploic artery to the level of the left gastroepiploic artery. Sufficient omentum should be preserved on the graft side at this point to preserve collateral blood flow. Attachments to the splenic hilum can be easily divided by gentle traction of the stomach. The hiatus should be opened only at the last stage of the abdominal procedure to prevent CO_2 pressure effects on the intrathoracic organs. The right diaphragmatic crus can be widened using the harmonic scalpel.

After finishing mobilization of stomach and the lymph node dissection, the gastric tube can be created intracorporeally. To maximize the advantages of the minimally invasive approach, we do not make additional laparotomy incisions or perform extracorporeal gastric tube formation. Close coordination with the assistant surgeon is important at this stage. The operator should hold the stomach with the robotic arms and should establish proper position for stapling. The assistant surgeon can divide the lesser curvature of the stomach using an endo-stapler. Stapling starts from 2 cm proximal to the pylorus and up to the level of the cardia. Lesser curvature lymph nodes (17 in AJCC and 3a/3b in JES) and cardiac lymph nodes (16 in AJCC and 1/2 in JES) can be removed during gastric tube formation. Usually five or six 60-mm-sized staplers are necessary for gastric tube formation. We usually make a 4 cm wide graft for the cervical anastomosis. The resected esophagogastic specimen is retrieved thorough the cervical wound and a Foley catheter is introduced into the abdomen. The gastric tube can be pulled up to the neck after suturing the tube to the Foley catheter. We routinely insert a feeding jejunostomy catheter in all patients. The jejunum is pulled out from the periumbilical port site, and a Stamm-type jejunostomy catheter can be inserted at the left port that is used for robotic arm 1.

Cervical Procedures

After pulling up the gastric tube, the esophagogastric anastomosis can be made by side-to-side anastomosis with linear staplers. The technique is a modification of the Orringer technique [16]. In the latter, the posterior walls are stapled and the anterior walls are sutured by interrupted or continuous suturing. Conversely, we close the anterior walls by stapling instead of suturing to maximize the size of anastomosis. Before stapling, the anterior walls are sutured by continuous suture with barbed sutures (V-Loc, Medtronic, MN) to approximate the esophageal and gastric mucosa. Then anterior walls are stretched laterally and stapled using a linear stapler (ECHELON FLEX GST-powered stapler with 60 mm size and 4.1 mm height, Ethicon, OH). This is a simple and fast technique that ensures wide esophagogastric anastomosis. We have performed this technique in 70 cervical anastomoses. The outcomes remain excellent with one occult anastomotic leakage (1.4%) and no anastomotic stricture over the past 2 years. The 2-year rate for our freedom from intervention for anastomotic stricture was 100% in our series.

Cervical lymph node dissection can be performed in indicated patients. Recently, we performed three-field lymph node dissections in advanced stage or upper and mid-thoracic esophageal cancer. Supraclavicular lymph nodes (level 3 and level 4 in the AJCC map, 101 and 104 in the JES map) can be removed during the cervical procedure.

Postoperative Management

Our institute started an enhanced recovery after surgery (ERAS) program 3 years ago. Because most patients were heavy smokers and chronic alcoholics, chronic obstructive pulmonary disease, chronic liver disease, and malnutrition were common in our series. We tried to optimize the ERAS program with modifications over this time period. Table 3.2 presents the ERAS program currently being used in our institute. Modifications to the program continue to be implemented with the goal of further improving postoperative outcomes.

We believe that early enteral nutrition is important for early recovery of patients. This issue has been emphasized in other studies [17–19], and early enteral feeding is related to reduced postoperative complications and early recovery of patients. In our practice, we begin jejunostomy feedings on postoperative day (POD) 1. Calorie intake can be escalated up to 100 kcal/hr by POD 5. Jejunostomy feedings can be maintained until 4 weeks postoperatively when oral calorie intake can be 80% of the feeding requirements.

We routinely use renal dose dopamine for 3 days postoperatively for the following reasons. Our fluid management protocol is to restrict postoperative fluid infusion to prevent pulmonary complications. Therefore, relative hypotension and transient renal insufficiency are expected, and decreased splanchnic blood flow may induce delayed healing of the esophagogastric anastomosis. To improve hemodynamic stability and maintain splanchnic blood flow, we therefore routinely use renal dose dopamine [20, 21].

Vocal cord evaluation is performed on POD 3 in all patients regardless of whether hoarseness is detected. Identifying the status of the vocal cord is important to prevent aspiration after starting oral feedings. Aspiration pneumonia is one of most serious complications after esophagectomy. Because very extensive lymph node dissection is carried out along both RLNs, transient vocal cord palsy is quite common. However, well-controlled management of vocal cord palsy can prevent aspiration pneumonia in most patients.

Table 3.2 ERAS protocol at Seoul National University Hospital

ERAS items	Postoperative periods
ICU stay	POD 0 to POD 1
Pain management	IV PCA until POD 2
Chest tube removal	POD 1
Enteral feeding through jejunostomy	POD 1 to 4 weeks
Nasogastric tube removal	POD 3
Dopamine at renal dose (3 mcg/kg/min)	POD 0 to POD 3
Laryngoscopic evaluation of vocal cords	POD 3
Esophagography	POD 5
Initiation of oral feedings	POD 6
Hospital discharge	POD 8 to 12

PCA patient-controlled analgesia, *POD* postoperative day

Early Postoperative Outcomes

From May 2008 to August 2017, a total of 186 patients underwent RAMIE at Seoul National University Hospital. There was one patient with 30-day mortality (0.5%) and three patients with 90-day mortality (1.6%). Overall in-hospital mortality occurred in five patients, and operation-related mortality rate was 2.7%. Thoracotomy conversion was necessary in two patients (1.1%) because of severe pleural adhesions even before docking the robot. However, in our series, we did not have any conversions after starting the robotic thoracic procedure. Our overall complication rate was 58%. The complications are listed in Table 3.3. The highest Clavien-Dindo grade of complications were grade 1 in 31 patients

Table 3.3 Postoperative complications after RAMIE

Complications	Number	%
Respiratory complication	16	8.6
Gastrointestinal complication	20	10.7
(Anastomotic leakage)	17	9.1
Neurologic complication	54	29.0
(Vocal cord palsy)	50	26.9
Cardiac complication	24	12.9
(Atrial fibrillation)	24	12.9
Chyle leakage	19	10.2

(16.7%), grade 2 in 47 patients (25.2%), grade 3 in 9 patients (4.8%), grade 4 in 5 patients (2.6%), and grade 5 in 5 patients (2.6%). The most common complication was vocal cord palsy at a rate of 26.9%. Because we did extensive lymph node dissection along the bilateral RLNs and evaluated vocal cord palsy in all patients, the incidence was relatively high. However, 24 of 50 patients (48.0%) with vocal cord palsy were asymptomatic by routine evaluation and most vocal cord palsies were transient and had improved at long-term follow-up. Respiratory complications occurred in 16 patients (8.6%) and anastomotic leakage occurred in 17 patients (9.1%). Although the respiratory complication rate did not change during the study period, the leakage rate decreased gradually. The leakage rate of the most recent 100 cases was 4.0%.

Long-Term Outcomes

Complete R0 resection was accomplished in 179 patients (96.2%). The mean number of dissected lymph nodes was 44.3 ± 21.2. A total of 32 patients died during the follow-up period and the overall 5-year survival rate in those who underwent RAMIE was 73.1%. Five-year survival rate of patients who underwent upfront surgery was 75.0% and for patients who underwent neoadjuvant chemoradiation followed by RAMIE was 59.0%. Survival rates according to pathologic stage in patients who underwent upfront surgery were 85.6% for stage 1, 66.0% for stage 2, and 62.2% for stage 3 (Fig. 3.6). We suspect that higher survival rates in patients who underwent upfront surgery were related to patient selection, because most of these patients had clinical stage 1 or 2 and a significant number of patients had stage migration after surgery. The patients who received neoadjuvant treatment had more advanced stage of disease, mostly clinical stage 3. Therefore, direct comparison between the upfront surgery and neoadjuvant treatment groups is not possible with our data. However, long-term survival of the patients who underwent RAMIE was excellent in both upfront surgery and neoadjuvant treatment groups.

Conclusions

RAMIE is based on more advanced technology when compared to thoracoscopic or laparoscopic surgery. It consists of more meticulous dissection of the upper mediastinal lymph nodes and safer

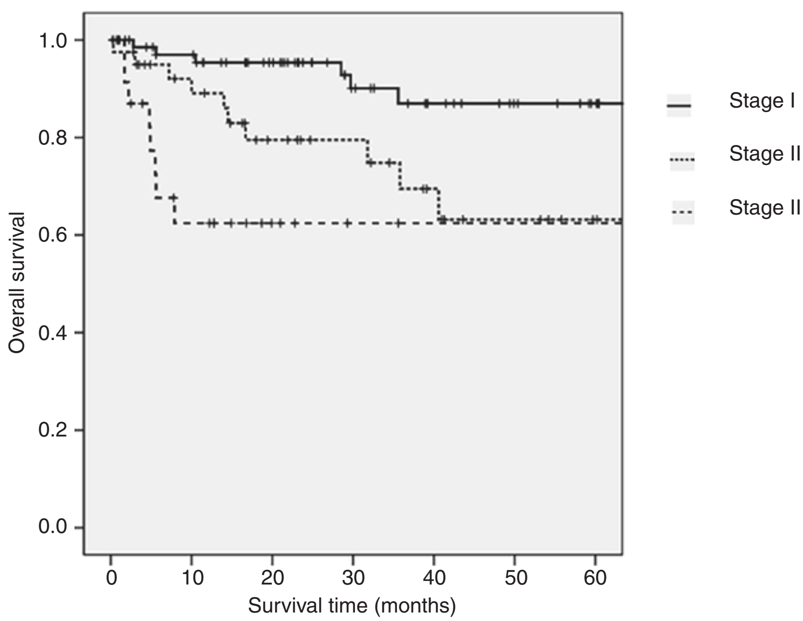

Fig. 3.6 Overall survival of patients who underwent RAMIE as upfront surgery stratified by pathologic stage

preparation of the gastric graft. Major complication rates are acceptable and postoperative mortality rates can be maintained at low levels. The most important advantage of RAMIE was the improved long-term survival when compared to historical reports. We believe that improved survival can be achieved by the combination effect of extensive lymphadenectomy and reduced postoperative mortality. Further studies on the RAMIE should be performed to clarify the oncologic role of RAMIE in the treatment of esophageal cancer.

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