



Robotic assisted minimally invasive esophagectomy: Ivor-Lewis approach

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Abstract: Recent published data indicate robotic assisted minimally invasive esophagectomy (RAMIE) can achieve comparable, if not superior outcomes to minimally invasive esophagectomy (MIE). Several studies have demonstrated improved postoperative pain and decreased cardiopulmonary complications following RAMIE for resectable intrathoracic esophageal cancer compared to MIE. Superior three-dimensional visualization and increased instrument precision result in greater lymph node harvest and ensures R0 resection without an increase in intraoperative complications or anastomotic leaks. Herein the authors describe their recent adoption of RAMIE as the standard of care over MIE for patients with resectable esophageal cancer. The authors present a detailed approach to preoperative considerations, intraoperative technical nuances and technique and postoperative outcomes and follow-up following RAMIE. An up to date review of the literature is presented and congruently acknowledges RAMIE as a feasible and safe alternative to MIE with comparable oncologic outcomes.

Keywords: Robotic; esophagectomy; robotic assisted minimally invasive esophagectomy (RAMIE); Ivor-Lewis

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Introduction

Esophageal cancer is a highly fatal malignancy that is more common in men and is the 6th leading cause of cancer-related mortality worldwide. In 2019, the Surveillance, Epidemiology and End Results (SEER) Program and American Cancer Society predict 17,650 new cases of esophageal cancer with 16,080 deaths and a reported 5-year survival rate of only 19.9% (1). The geographic distribution, contributing risk factors, and disease presentation can vary significantly based on the histologic subtype, predominantly either squamous cell carcinoma or adenocarcinoma. Although squamous cell carcinoma is more common worldwide, in the Western World including North America,

Western Europe, and Australia, adenocarcinoma is the most common histologic subtype correlating with increased rates of obesity and gastroesophageal reflux disease (GERD) (2,3). The strongest risk factor for esophageal adenocarcinoma is obesity, with BMI of 30 having 16 times greater risk compared to a BMI of 22 or less (4). Waist circumference is also associated with proportionally increased risk independent of BMI (4). Additionally, GERD increases the odds of developing adenocarcinoma, with reported risk to be 5 times greater in patients with weekly symptoms, 7 times with daily symptoms, and 9 times in patients with endoscopically confirmed esophagitis (5,6). Barrett's esophagus was associated with 30 to 60 fold increase in incidence of adenocarcinoma (7).

Esophagectomy for the treatment esophageal cancer was described well over a century ago (8). It continues to be an integral part of the multimodality treatment of esophageal cancer though esophagectomy alone had disappointing survival outcomes, leading to the incorporation of chemotherapy and radiotherapy as part of the multimodality treatment. The MAGIC and FLOT4 trials have shown increase disease free and overall survival with addition of chemotherapy as neo-adjuvant therapy followed by esophagectomy (9-11). Similarly, the CROSS trial showed significant improvement in long term survival with addition of chemo-radiation as neo-adjuvant therapy (12). Historically, esophagectomy has been associated with high rates of cardiac and pulmonary morbidity and a reported mortality of 8% to 23% in the United States, higher for centers with lower case volume (13). Minimally invasive esophagectomy (MIE) was first described in the 1990s and studies have demonstrated equivalence in safety and outcomes of total laparoscopic/thoracoscopic esophagectomy compared to open technique (14-16). Several studies have demonstrated a decrease in surgical blood loss, chest tube duration, pulmonary complications, and hospital length of stay with MIE when compared to open esophagectomy (OE) (17,18). Luketich *et al.* compared their minimally invasive McKeown (laparoscopy, VATS, and neck anastomosis) to their modified Ivor Lewis approach (laparoscopy, VATS, and chest anastomosis) with similar outcomes (15).

The last two decades have seen adoption of robotic approach for variety of thoracic procedures including esophagectomy. The robotic approach has the potential advantages of better visualization with three-dimensional optics, increased precision from articulating instruments providing seven degrees of motion, enhanced dexterity, tremor filtration, and telesurgical capabilities that are offered using the DaVinci system (Intuitive, Sunnyvale CA) (19). This is particularly useful for the difficult dissection of the hiatus and mediastinum, where rigid laparoscopic instruments may be restrictive. Robotic assisted minimally invasive esophagectomy (RAMIE) was first described in the early 2000s and there is limited data on the advantages as compared to MIE or traditional open esophagectomy (OE). Several institutions including University of Alabama, Memorial Sloan Kettering, and University of Pittsburgh have established relative safety of the procedure by publishing their single institutional experiences (16,20-24).

Operative technique

RAMIE Ivor-Lewis approach using four-arm robotic techniques with intrathoracic anastomosis using the Orvil 25 mm EEA stapler is the preferred approach for esophagectomy at our institution. The techniques described here utilize the Xi platform (Intuitive, Sunnyvale CA). Here we describe the pre, intra and post-operative details of our approach.

Perioperative planning

All patients with biopsy proven esophageal cancer undergo computed tomography (CT), fluorodeoxyglucose-18 positron emission tomography (PET) and in selected cases, endoscopic ultrasound (EUS). Patients with superficial esophageal cancer (T1a) are considered for endoscopic mucosal resection. If there is submucosal invasion (T1b) then a robotic esophagectomy is offered. Any patient with lymph node involvement or T2 and more advanced lesions are referred for induction treatment. Patients with gastric cardia lesions usually undergo chemotherapy using the FLOT regimen with triplet chemotherapy. The remaining are usually referred for chemotherapy and radiation using Carbo Taxol and 50.4 Gy radiation (modified CROSS trial regime). A repeat CT scan of chest, abdomen and pelvis is performed three weeks after the completion of induction treatment to rule out progression of disease. Patients are placed on full liquid diet for 3 days prior to RAMIE and participate in the institutional ERAS program.

Patients are placed on the operating table in a supine position with both arms out. A foot board is placed to prevent patients from sliding during reverse Trendelenburg position. A double lumen endotracheal tube is used. An endoscopy is performed to evaluate for proximal and distal margins.

Abdominal part of Ivor-Lewis RAMIE

Access to the peritoneal cavity is achieved using a 5 mm access port (Applied Medical, CA, USA) 15 cm from the tip of xyphoid process in mid-clavicular line. This port is later replaced with an 8 mm robotic port and used for the energy device. We use the harmonic scalpel (Johnson & Johnson). Next an 8 mm robotic port is placed 2 cm above and to the left of the umbilicus for the camera. A 12 mm robotic port is placed in the right paramedian region in mid-clavicular line through which a cadiere forceps is used and

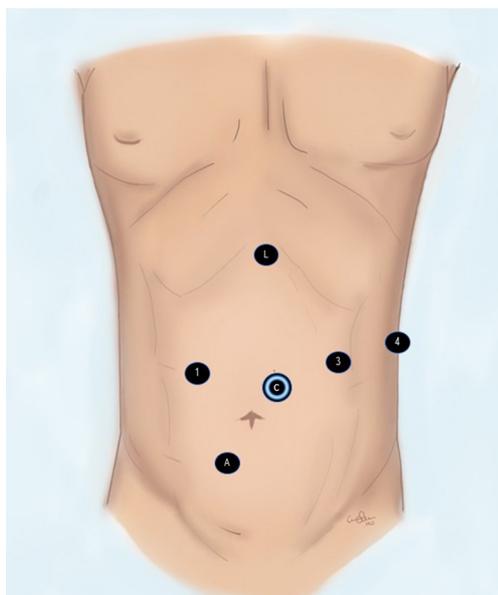


Figure 1 Robotic port placement for abdominal portion of RAMIE Ivor-Lewis approach. 1: 8 mm robotic port inferior angle of the scapula 8th IS. C: 5 mm port in 8th IS in posterior axillary line, CO₂ inflation to 8–10 mmHg, changed to 8 mm robotic port for camera. 3: 12 mm robotic port in 6th IS between mid and anterior axillary line. 4: 8 mm robotic port in 3rd IS, lung retraction. A: 12 mm port above the diaphragm between camera and anterior ports.

later robotic stapler is introduced for creation of the gastric conduit. The fourth 8 mm robotic port is placed in the left subcostal area for the double fenestrated tip up grasper. An assistant 12 mm port is created in the right lower quadrant. A Nathanson liver retractor is introduced through a stab wound in the epigastrium and placed under the left lobe of the liver (*Figure 1*).

The Xi robot is docked. A thorough inspection of the liver and peritoneal cavity is performed to rule out metastasis. The gastro-hepatic ligament is incised and the right crus of the diaphragm is dissected. The phrenoesophageal membrane is incised. The retroesophageal dissection at the level of hiatus is carried out. If possible, authors usually perform circumferential dissection of the esophagus to the level of inferior pulmonary vein to confirm resectability. Next the most proximal short gastric vessels are incised. At this time the dissection is performed at the base of left gastric artery to include all the lymph nodes around celiac axis. Subsequently, the left gastric artery is transected using a vascular Xi robotic stapler introduced through the right paramedian 12 mm port.

Dissection is continued toward the left almost skeletonizing the splenic artery to include all the lymphatic tissue in the specimen. The fourth arm is invaluable during this part of the operation and is used to elevate the gastroesophageal junction enabling the surgeon to have an excellent view of retrogastric area all the way to the spleen. At this point the greater curvature is retracted toward the hiatus exposing the gastro-colic ligament. The right gastroepiploic artery is identified and the gastrocolic ligament is incised parallel to that toward the previously incised short gastric. A tongue of omentum along the greater curvature is taken to wrap the anastomosis in the chest. At this point the dissection is carried toward the duodenum, cutting the gastrocolic ligament parallel to the right gastroepiploic artery. Then the avascular plane between the lesser curvature and pancreas is incised which completes the mobilization of the stomach. The authors do not perform a routine pyloric drainage procedure.

The next step is to create the gastric conduit. We use the robotic Xi Stapler. The fourth arm of the robot is used to retract the fundus along the greater curvature. The assistant retracts the greater curvature at the level of the antrum. The first load is always a vascular load transecting the fatty tissue with the right gastric artery up to the lesser curvature. This stapler is placed just left of the first 2–3 branches of the right gastric artery. Next, we use a green load to start fashioning the conduit, aiming the stapler toward the greater curvature and then parallel to it. Subsequently green and blue loads are used to complete the creation of the conduit. We recommend a 4–5 cm gastric conduit. Attention should be paid to prevent spiraling of the conduit as the staplers are fired toward the fundus. The conduit is sutured to the specimen by suturing the tip of the greater curvature of the conduit to the edge of the lesser curvature of the specimen to prevent torsion during the process of pulling the conduit in the chest.

A standard laparoscopic feeding jejunostomy is then performed. The instruments and cords are kept sterile and used during the thoracic part of the procedure.

Thoracic part of Ivor Lewis RAMIE

The patient is placed in the left lateral decubitus position, tilted toward the front. A 5 mm access port (Applied Medical, CA, USA) is placed in the 8th intercostal space in the posterior axillary line. CO₂ insufflation is started at a pressure of 8–10 mmHg. The port is upsized to a robotic 8 mm port for the camera. A 12 mm robotic port is placed in

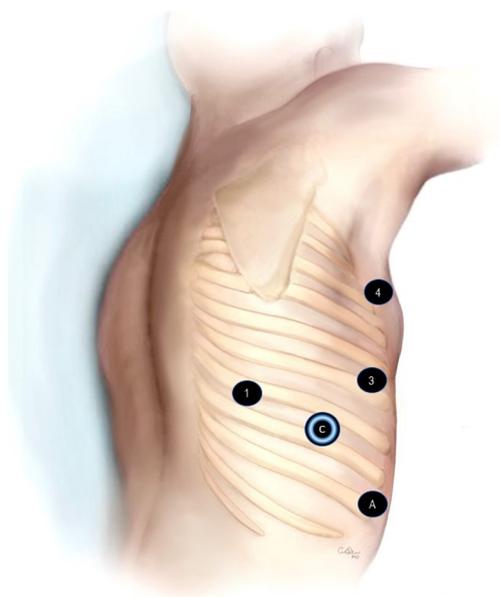


Figure 2 Robotic port placement for thoracic portion of RAMIE Ivor-Lewis approach. 1: 12 mm robotic port right paramedian mid-clavicular line. C: 8 mm robotic port 2 cm above and to the left of umbilicus for camera. 3: 8 mm robotic port 15 cm from tip of xyphoid process mid-clavicular line. 4: 8 mm robotic port left subcostal area. L: Nathanson liver retractor through stab wound in epigastrium. A: assistant 12mm port in the right lower quadrant.

the 6th intercostal space in between mid and anterior axillary line. An 8 mm robotic port is placed in the 3rd intercostal space in the anterior axillary line for the lung retraction. The fourth robotic port is placed in the line of the inferior angle of scapula in the 7th intercostal space. The assistant 12 mm port is placed just above the diaphragm under direct vision between the camera port and the anterior port (*Figure 2*).

The Xi robot is docked. The dissection is started by incising the inferior pulmonary ligament. The pleura over the posterior surface of the lung is opened and the dissection is continued over the pericardium toward the azygous vein. The subcarinal lymph node pocket is included in the specimen. The use of the harmonic scalpel in the peribronchial area increases the risk of airway injury and future fistula formation. It may be better to either use a bipolar dissector or hook cautery, especially during the initial experience. The azygous vein is transected using a white load introduced through the 15 mm anterior robotic port. Dissection is continued on the posterior side of esophagus. The lymphatics and aorto-esophageal vessels are either cut using the harmonic scalpel or clipped.

The dissection is carried down all the way to the hiatus and esophagus is completely mobilized. At this point the gastric conduit is pulled up in the chest using the cadere forceps and the tip-up double fenestrated grasper on arm 4. Attention is paid to ensure the staple line of the conduit faces the camera to prevent twisting of the conduit. The stitch between the conduit and the specimen is cut and conduit is placed over the diaphragm and secure with a stitch over the diaphragm to prevent it from falling back into the abdomen. Remaining adhesion of the esophagus are lysed and dissection is performed above the level of esophagus. At this point a blue stapler load is introduced and the esophagus is transected just above the azygous vein. The anvil of the 25 mm Orvil (Medtronic, MN USA) mounted on an orogastric tube is passed through the patient's mouth. A small hole is created in the esophageal stump below the staple line using the hook cautery and the tube is pulled till the metal part of the anvil comes out of that hole. The thread holding the tube and the anvil is cut and the tube is discarded. A purse-string suture is placed around the exit site of the anvil tip.

Next the posterior port site is extended and a small wound protractor is placed. The specimen is removed and sent for frozen section. The tip of gastric conduit is opened and the contents are sucked out. The handle of the 25 mm EEA stapler is passed through the intercostal space and introduced into the gastric conduit through the opening. The handle is introduced deep into the conduit while pushing against the greater curvature to the desired point where the anastomosis is going to be fashioned. At this point the pin of the EEA stapler is brought out along the greater curvature and engaged with the anvil. The stapler is closed and the anastomosis is fashioned (*Figure 3*). The donuts are checked for completeness and submitted as final proximal margin. A nasogastric tube is placed. The redundant gastric conduit is cut using blue loads 2 cm away from the anastomosis. The fat pad is put between the anastomosis and the trachea. A stitch is placed to narrow the hiatus to prevent future para conduit hernias. The pleural space is irrigated with antibiotic solution. The intercostal are injected with local anesthetic. A Jackson-Pratt (JP) drain is placed between the esophagus and the spine. A chest tube is placed.

Post-operative course

Patients are extubated in the operating room. They are monitored in the intensive care unit for 24 hours. The

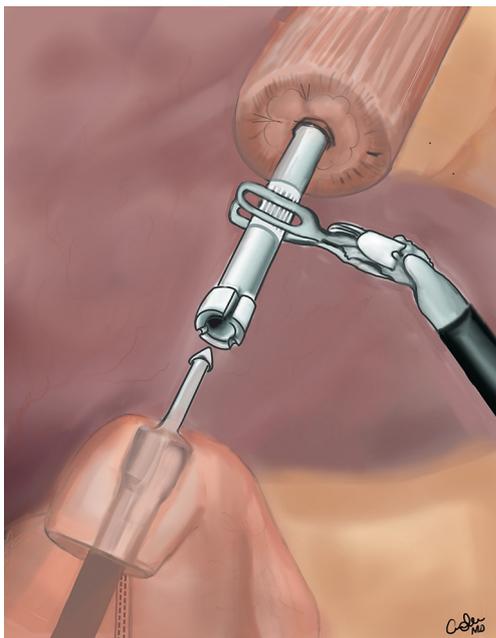


Figure 3 Anastomosis using Orvil EEA stapler for RAMIE Ivor-Lewis approach.

tube feeds are started on the first post-operative day. The nasogastric tube is removed and then Barium swallow performed on post-operative day 4 or 5. The chest tube is removed after the swallow and patients are started on a limited liquid diet. They are discharged the next day on nocturnal tube feeds and an advancing diet. The patients are seen a week later and the JP drain is removed. The jejunostomy tube is removed 4 weeks after surgery.

Discussion

The first reported RAMIE was in 2002 by Melvin and colleagues, with intra-thoracic anastomosis (25). In 2007, Kernstine *et al.* reported a series of 14 patients who underwent completely robotic esophagectomy with three-field lymphadenectomy. The total operating time in this group was reported to be 660 minutes, which was markedly increased compared to laparoscopic technique. However, all patients underwent R0 resection with an average of 18 lymph nodes, indicating the robotic approach may facilitate an extended lymphadenectomy (22). In contrast, Weksler and colleagues published their experience with RAMIE compared to MIE for esophageal cancer (26). This study found no significant differences in operative time, number of resected lymph nodes, postoperative complications, or

length of stay between the two groups.

Different robotic techniques have been described. Dunn *et al.* adopted the transhiatal esophagectomy approach. Their outcomes from 40 patients in 2013 included an average operative time of 313 minutes and hospital stay of 9 days. R0 resection was achieved in 94.7% of patients and mean number of lymph nodes dissected was 18, as found in previous studies (27). The technique described by Puntambekar and colleagues in 2015 used the robotic platform for transthoracic mobilization of the thoracic esophagus and lymphadenectomy, with an open cervical anastomosis. In 83 patients who underwent this operation, mean operative time was 205 mins, mean length of stay 10 days, and mean lymph node yield of 18 (28).

Robotic assisted Ivor Lewis (RAIL) combines VATS, laparoscopy, and an intrathoracic anastomosis and is the most frequently reported technique. In the de la Fuente series, 50 patients underwent a robotic assisted Ivor Lewis (RAIL) esophagogastrostomy with a stapled intrathoracic anastomosis. Outcomes included a mean operative time of 445 minutes, length of stay of 9 days, 20 lymph nodes harvested, and 100% R0 resection (29). Cerfolio *et al.* also reported excellent outcomes in 100 patients undergoing RAIL with an anastomotic leak rate of 6%, zero 30-day mortalities, and a 90-day mortality rate of 1%. They compared a stapled intrathoracic anastomosis with a 2-layered hand sewn technique made feasible by the robot. In this series, R0 resection was achieved in all patients, 18 lymph nodes were removed on average, and median operative time was 367 minutes (21). In 2016, Sarkaria *et al.* reported excellent outcomes in 100 patients undergoing RAMIE with an anastomotic leak rate of 6%, 0% 30-day mortality, and a 90-day mortality rate of 1% (24). In 2017, Okusanya *et al.* described their Ivor Lewis approach to RAMIE which is their preferred approach to removal of lower esophageal tumors (30). They had initial favorable outcomes with no 30- or 90-day mortality and similar perioperative outcomes including blood loss, anastomotic leak rates, and morbidity compared to MIE.

Retrospective database studies have also been performed comparing MIE and RAMIE. Harbison and colleagues used the American College of Surgeons NSQIP database to compare the two approaches (31). In an analysis of 725 cases (100 RAMIE *vs.* 625 MIE), there were no differences in short term postoperative adverse outcomes. Similarly, Espinoza-Mercado compared MIE, RAMIE, and OE, using the national cancer database (32). In this study, mortality and readmission rates were similar amongst groups, while

the median length of stay was significantly shorter in the MIE and RAMIE groups, compared to the OE group. The authors also found that there was no difference in median overall survival (32).

The ROBOT trial was the first randomized control trial performed by van der Sluis *et al.* Between January 2012 and 2016, 112 patients with resectable intrathoracic esophageal cancer were randomized to the standard curative treatment of perioperative or preoperative chemoradiation followed by open transthoracic esophagectomy or RAMIE. Post-operative complications including cardiopulmonary occurred less frequently after RAMIE (59% compared to 80%). There was decreased mean post-operative pain using the visual analog scale and improved quality of life score at discharge and at 6 weeks follow up. Both short and long term oncological outcomes were similar with average follow up of 40 months (33,34).

MIE Ivor-Lewis esophagectomy used to be our preferred approach. Recently we transitioned to robotic approach. The authors compared their experience of MIE *vs.* RAMIE and found the outcomes to be comparable with robotic approach being associated with increased number of lymph node harvested and fewer re-admissions. There were no mortalities or anastomotic leaks. The operative time was around 310 minutes with a median length of stay 7 days in both groups. Overall, RAMIE is a safe, feasible, and potentially advantageous approach to esophagectomy.

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of interest to declare.

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