Ivor Lewis robotic assisted minimally invasive esophagectomy: different approaches

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Abstract: The best surgical approach for esophageal cancer remains controversial. Minimally invasive esophagectomy has gained popularity over the last two decades, and has shown some advantages over open esophagectomy (OE) without compromising oncologic outcomes. Surgical robotics has expanded on that approach with the development of the robotic assisted minimally invasive esophagectomy (RAMIE). A growing experience has been described from highly specialized centers, however, long-term data remains sparse. We describe our operative approach in detail herein, and provide a summarization of different technical considerations published in the literature to date.

Keywords: Robotic esophagectomy; surgical approaches

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Introduction and history

In the United States, esophageal cancer represents 1% of all cancer diagnoses but remains a more prevalent problem worldwide. Estimates for 2019, include 17,650 newly diagnosed cases while 16,080 people will die of the disease next year. Despite these intimidating statistics, outcomes with multimodal therapy have improved survival. Estimated 5-year survival is now 19.2%. This has doubled from the 1980s when it was 9% (1).

The best surgical approach to esophageal cancer remains controversial and is somewhat dependent on surgeon preference and anatomic location of the tumor. The transthoracic esophagectomy was first reported in 1946 by its namesake, Ivor Lewis. Described initially as a two-staged operation, it consisted of a laparotomy followed 10–15 days later by a right thoracotomy after optimizing nutrition. The first stage is performed through a left upper paramedian laparotomy incision. The upper portion of the greater curvature of the stomach is mobilized, dividing the short gastric arteries, the left gastroepiploic artery and the left gastric artery, leaving a vascular arch to the greater curvature of the stomach. This is followed by placement of a feeding jejunostomy tube (2).

The second stage consists of a right thoracotomy with resection of the entire sixth rib. The lung is packed anteriorly, the azygos vein is divided and the mediastinal pleura is opened. The esophagus is encircled with tape superiorly and inferiorly to the mass. The lower end is freed at the diaphragm and hiatal dissection is carried out, allowing the cardia to be pulled into the chest and the peritoneal attachments are divided. With previous abdominal mobilization, the fundus reaches well above the mass. The stomach is secured in place between the vertebral bodies and the mediastinum with the esophagus overlying. The anastomosis is performed, using a two-layer interrupted closure, ensuring adequate bites of mucosa on the inner layer. The posterior layer is completed first prior to dividing the specimen. The specimen is transected above the tumor with adequate margin along with a rim of stomach distally. The mucosal and anterior layer is then completed, followed by tacking the stomach at the level of the hiatus. The anastomotic area is well drained and the omentum is used to cover the anastomosis (2). Despite this description being published nearly 75 years ago, many of the operative concepts are still employed in today's surgical techniques and having been adapted into the minimally invasive esophagectomy, and more recently in robotic assisted minimally invasive esophagectomy (RAMIE) (3-6).

Surgical robotics enhances some of the advantages that were developed with standard minimally invasive surgery. Robotics provides a stereoscopic camera that enhances visual depth perception. Articulated instrument arms allow superior motion with an extra degree of freedom, utilizing a wristed mechanism to enhance standard straight-line laparoscopic instruments. The primary surgeon console has the ability control the camera while also being able to toggle between multiple instruments/fourth arm, controlling all operative components without the need to rely on assistants (7). As important as the enhanced surgical techniques are oncologic outcomes and safety. Similar to the minimally invasive esophagectomy and open approaches, RAMIE series have reported similar oncologic outcomes without compromising patient safety when performed at high volume centers (7).

In 2003, Horgan *et al.* described the utilization of surgical robotics for esophagectomy from a transhiatal approach combined with an open incision cervical anastomosis (8). The evolution continued as Kernstine *et al.* performed the transthoracic portion robotically. Using a McKeown or three-hole technique, the early portion of the series was a hybrid (robotic chest with laparoscopic abdomen) approach. The last eight operations were completely robotic transthoracic and abdominal. This report provided initial feasibility for the robotic platform to grow, demonstrating that the dissection in the abdomen and chest could be accomplished, however, the anastomosis in both series was still being done through an open cervical incision (9). Sarkaria *et al.* described a cohort of 21 patients in 2013, with the first description of seventeen patients undergoing an Ivor Lewis technique using a total robotic thoracoscopic and laparoscopic approach (10).

Operative setup

Typically, a four-arm robotic platform (Da Vinci Xi, Intuitive Surgical Inc., Sunnyvale, CA, USA) is utilized, with dual consoles for an operating surgeon and a trainee. A surgical assistant is bedside for instrument exchange and suctioning. The Da Vinci Xi platform provides better versatility in positioning of the patient and improved instrumentation including robotic stapling devices over the previous Da Vinci Si. The surgical techniques are essentially the same, regardless of the platform.

Abdominal phase

The patient is positioned to the right side of the operating room table to facilitate placement of the liver retractor (DiamondFlex, Snowden Pencer, USA) and stabilization system (Mediflex, USA). The left arm is tucked at the patient's side and the right arm is abducted to 45°. A footboard is placed to support reverse Trendelenburg positioning. The robotic cart approaches the patient from the right side for the abdominal portion.

Thoracic phase

A standard left lateral decubitus position is utilized with a flexed operating room table and a beanbag for support and padding. The left arm is positioned along an armboard with slight cranial extension, while the right arm is neutrally placed at 90° in a neutral position. Slight cranial rotation of the upper arm may facilitate range of motion of the robotic assistant arm. The robotic cart approaches the patient from the right side.

Port placement/docking/instrumentation

Abdominal port placement

Either an open cutdown midline technique is utilized or a 5 mm optical trocar insertion is performed in the left upper quadrant for initial entry. The peritoneal cavity is insufflated to 15 mmHg carbon dioxide at a high flow rate. The remaining ports are placed under direct vision, including 8 mm midline, right midclavicular and a 5 mm right subcostal port for liver retraction. The optical trocar port is upsized to an 8 mm port. A 12 mm paraumbilical assistant port is placed. The table is placed in steep reverse Trendelenburg position. The robotic cart is advanced from the right and centered over the patient's midline with arms optimized for clearance. Positioning in this manner facilitates movement of intestinal contents into the pelvis and improved hiatal visualization. A grasping retractor is placed in the left subcostal port, a ultrasonic shear in the left midclavicular port and a fenestrated bipolar is placed within the right midclavicular port. If a robotic stapler is to be utilized, a 12 mm robotic stapler port may be placed in the right paraumbilical site that can serve as the bedside assist.

Thoracic port placement

After initiating of single lung ventilation, the chest is entered using a Veress needle just off the scapular tip with confirmation of entry made by a saline drop test. The chest is insufflated with carbon dioxide to 8 mmHg at high flow rate. The robotic 8 mm ports are inserted with the initial camera port placed blindly at the eighth intercostal space in the posterior axillary line. The remaining ports are placed under direct visualization. These consist of ports placed in the third intercostal space in the mid to posterior axillary line, fifth intercostal place into the mid axillary line, and at the ninth intercostal space approximately in line with the tip of the scapula under direct vision. A 12 mm stapler/assistant port can be placed at the diaphragmatic reflection. When utilizing the Da Vinci Xi, the bed position remains unchanged and the robot is docked from the patient's right. The fenestrated bipolar is placed in the ninth interspace, ultrasonic shears in the fifth interspace and a grasping retractor in the third interspace.

Phase 1: abdomen

Hiatal dissection

After inspecting the abdomen (likely done prior to docking the robot) for liver metastasis, peritoneal studding, or omental implants, hiatal dissection is undertaken. The gastrohepatic ligament is opened overlying the caudate lobe. Care should be taken to avoid a replaced left hepatic artery. The left and right crural hiatal pillars and dissected free evaluating for bulkiness of the hiatus, which may necessitate en bloc resection of crural muscle with the esophagus. Posteriorly, the aorta is evaluated. Although, extensive mediastinal dissection can be accomplished at this time, avoiding a pneumothorax prevents hemodynamic changes, loss of insufflation and difficulties with visualization.

Left gastric artery ligation/retrogastric lymphadenectomy

With the gastrohepatic ligament opened and the right crural dissection completed, the stomach is retracted anteriorly by the left-most grasping retractor. The assistant sweeps the antrum caudally and toward the left, allowing dissection of the left gastric vessels. Instituting a systematic approach, retrogastric lymph node tissue is mobilized toward the specimen for en bloc removal. Dissection landmarks include the posterior esophageal hiatus superiorly; the splenic artery, superior border of the pancreas and common hepatic artery inferiorly; laterally on the left to the short gastrics and the aortic plane of the right crural pillar laterally on the right. Once the origin of the left gastric vessels is adequately exposed it can be divided with a stapler. From this exposure, some of the superior short gastric vessels can be divided from a retrogastric approach, facilitating division of these vessels along the greater curvature and avoiding traction on the spleen.

Gastric mobilization

The lesser curvature of the stomach is retracted toward the caudate lobe of the liver by the assistant. A no-touch technique is strictly enforced along the greater curvature of the stomach. The right gastroepiploic arcade is identified, including the termination point and all perforating vessels toward the greater curvature of the stomach are preserved. Near infrared imaging (Firefly, Intuitive Surgical, USA) can assist in this determination (11-13). The remaining short gastric vessels are divided up to the left crural pillar. The fundic tip can be manipulated and any remaining retrogastric attachments are divided. Posting of the fourth arm grasper can provide excellent exposure. The antrum is then grasped to determine the adequacy of mobilization if the pylorus can reach the caudate lobe. This maneuver also exposes residual areas of attachment or tension. Partial of full kocherization of the duodenum can be achieved if needed. Of note, in patients that received neoadjuvant radiation therapy, an omental flap is harvested to buttress the anastomosis. Two robust omental perforating arteries are identified and a rectangular tongue of omentum is preserved and mobilized along its length.

Pyloroplasty

The robotic assist grasps and retracts the pylorus laterally to the left. The muscle bands are identified by gentle palpation with the fenestrated bipolar grasper. Braided permanent sutures are placed across the pylorus superiorly and inferiorly and using the ultrasonic shears the pylorus is divided. The pyloromyotomy is closed using interrupted braided permanent 2-0 sutures in a Heineke-Mikulicz fashion. Approximately 5–6 sutures are utilized and a small piece of omentum is tacked over this repair.

Creation of gastric conduit

The small grasping retractor from the left port grasps the fundic tip and stretches it toward the left hemidiaphragm. This exposure generally provides full view of the stomach and facilitates a straight staple line and enhances the length of the conduit by following the greater curve. The no-touch technique is continued with retraction areas limited to areas that will be resected including the fundic tip or the lesser curve or the thick gastric antrum that will be below the level of tubularization. A vascular staple load firing divides the fat and lesser curvature arcade. Multiple successive firings of a 45 mm endo-gastrointestinal stapler are utilized to form a 4 cm wide tube. A marking stitch is placed and the level of the antral reservoir so an appropriate amount of conduit is brought into the chest. It is imperative to maintain orientation of the stomach to avoid spiraling and changes in caliber and this is achieved by gentle retraction at the fundic tip and the antrum. Once the fundic tip is divided, a horizontal mattress suture attaches the conduit to the specimen, which will ultimately be manipulated through the hiatus into the thoracic cavity. Proper orientation of the conduit to specimen will also limit the chances of spiraling and compromise of the blood supply. If an omental flap was performed, it is also tacked in place. The final step of the abdominal portion is placement of a feeding jejunostomy tube in the left lower quadrant performed laparoscopically after the robot is undocked.

Phase 2: thorax

Esophageal mobilization

The inferior pulmonary ligament is mobilized to the level of the inferior pulmonary vein, starting the posterior dissection plane onto the pericardium. This superficial plane is carried cephalad over the posterior hilar structures, allowing identification of the bronchus intermedius and right mainstem bronchus. Care should be taken to avoid thermal injury to these structures specifically along the posterior membranous wall. The subcarinal lymph node packet is mobilized and removed or left en bloc with the specimen, paying close attention to the carina and left mainstem bronchus, which provide the boundaries of this dissection. Identifying these structures early helps to mitigate the risk of unintended injury. The pleural is opened to the azygos vein, which is dissected circumferentially and divided with a vascular stapler. The vagus nerve is identified at this location and divided to lessen the risk of traction injury to the recurrent laryngeal nerve. Above this point, dissection is performed for another 3–4 cm directly on the esophagus to also avoid injury.

Posteriorly, the mediastinal pleura is opened and mobilized down to the level of the diaphragm, paying special attention to the fat plans that may contain the thoracic duct. Tubular structures in this location are clipped and ligated including all perforating arteries and lymphatic vessels. The anterior and right lateral aspects of the hiatus and crura are dissected free. The robotic assist arm can provide traction on the inferiorly mobilized esophagus to enhance exposure of the aorta. This dissection plane is carried superiorly to the level of the ligated azygos vein.

The surgical specimen is then gently elevated into the chest, keeping the gastric conduit in proper orientation. The gastric staple line of the neo-lesser curve provides a guide as this should be facing the patient's right side. The suture attaching the conduit to the specimen is cut and the conduit is tacked to the diaphragm to prevent retraction into the abdomen. The specimen can now be elevated, allowing the deep dissection along the contralateral pleura to be completed.

Specimen removal

Once complete mobilization is achieved 3–4 cm above the azygos vein, the nasogastric tube is retracted in the esophagus and the posterior 8 mm port site is enlarged to a 4 cm access incision. A wound protector is inserted and the esophagus is sharply transected 3 cm above the azygos vein depending on tumor location and if any concerns regarding the proximal conduit exist. The specimen is removed via the access incision and sent for pathologic evaluation.

Anastomosis: The open end of the esophagus is retracted open with the robotic assist arm and a running "baseball" purse-string stitch is completed circumferentially using the robotic needle driver. The orifice is gentle dilated using the fenestrated bipolar "left" arm and the robotic assist arm at 180° opposition within the lumen. This facilitates placement of the end-to-end anastomosis (EEA) stapler anvil, which is typically inserted with the Cardierre forceps in the "right" robotic position due to the stronger grip strength over the fenestrated bipolar. This suture is secured around the anvil and a second reinforcement purse-string is placed superficially.

The esophagus is left in place and the gastric conduit is elevated further into the chest, taking care to visualize the orientation of the staple line as well as evaluating for the marking stitch just above the antral reservoir. Visual cues allow the operating surgeon to judge the amount of tension being exerted on the conduit. The conduit is then opened with the ultrasonic shears to the right of the staple line at the gastric tip and gently dilated to accommodate the EEA stapler, which is placed through the previously created access incision. The conduit is irrigated prior to insertion. Once the stapler is through the gastrostomy, it is slowly advanced into the conduit and the spike is deployed along the greater curvature, near the terminus of the right gastroepiploic arcade. The spike is engaged with the anvil and deployed, completing the anastomosis. The anastomotic rings are inspected for completeness suggesting mucosal/submucosal apposition if intact. The nasogastric tube is advanced under direct visualization and residual gastric conduit is then resected, discarding the ischemic fundic tip. Several centimeters of conduit may be discarded, however, care should be taken not to encroach on the circular staple line of the EEA, leaving a 2 cm buffer. An omental flap, if harvested, or at least greater curvature fat is rotated between the conduit and the airway for additional protection against fistula formation. The chest is drained by a flat drain positioned posterior to the anastomosis and a chest tube is placed posteriorly and toward the apex.

Differences in technique

Given the complexity of the Ivor Lewis transthoracic esophagectomy, differences in philosophies and technical steps are bound to exist by institution and even surgeon to surgeon. These may be as simple as port placement location or choices for energy devices (5,14). Other differences may exist in philosophy, including whether or not to use a feeding tube post operatively or how to manage emptying of the conduit. Certainly, creating the anastomosis has certain nuances and can vary by center. Even differences in patient positioning exist.

Puntambekar *et al.* initially advocated for a prone approach to the robotic esophagectomy so that the esophagus falls anteriorly out of its normal position. This technique was felt to create natural tension on the esophagus and facilitated the dissection (15). While the transthoracic approach was described as part of a McKeown operation, this positioning has been utilized by others for the thoracic dissection. Jin *et al.* reported on a case utilizing a semi lateral technique, in which the patient was rotated 45° toward the prone position. The most anterior robotic port in this technique was placed in the posterior axillary line with auxiliary/assistant ports more anteriorly (16).

While most authors performing RAMIE advocate for a 4 cm conduit, pyloric emptying procedures vary. Some centers prefer to perform a pyloroplasty, utilizing the sophisticated technical abilities of the robot to sew intracorporeally (6,17). Others advocate for injection of botulinum toxin (18,19). Presently, no good randomized data exists regarding the necessity of a gastric emptying procedure in the setting of a narrow gastric tube. Previous meta-analysis, which compiled studies of varying techniques for conduit creation, have advocated that gastric outlet obstruction and emptying is improved, but there was no significant improvements in mortality, anastomotic leaks or pulmonary morbidity (20).

Even regarding one of the most important steps of the operation, the anastomosis, significant variability in technique exists. Some advocate for performing the anastomosis in an end to side fashion using an EEA stapler, similar to that described by Luketich *et al.* for the minimally invasive esophagectomy (3,5,6). Variations have been made on this, including techniques for inserting the anvil into the esophagus. Wang *et al.* describe making a lateral esophagectomy below the level of the anastomosis that will later be transected. Once inserted a small hole is cut in the end of the esophagus to avoid the need for performing a purse string suture (21). This technique is similar to those employed by de la Fuente *et al.*, who utilize a 25 mm anvil passed transorally (Orvil, Autosuture, Norwalk, CT, USA).

Hybrid anastomoses have also been employed as was originally described by Orringer *et al.* with modifications to allow for minimally invasive/robotic techniques (22). Hodari *et al.* describes this modification, placing the gastric conduit behind the esophageal remnant and securing them in place. A esophagectomy and gastrostomy are made and the back wall is created using a 45 mm stapler. The anterior wall is completed using a two layer closure (23). Cerfolio *et al.* has also described this technique, however, if stapling the back wall does not seem feasible, then a completely hand-sewn anastomosis can be performed. The posterior layer is created using a 10 cm 3-0 silk suture. Typically five interrupted sutures are used approximating the serosa of the stomach to the posterior muscle layer of the esophagus. The inner layer is created using two running polydioxanone suture (PDS), one for the posterior layer and another anteriorly. Several interrupted 3-0 silk sutures complete the buttress of the anterior layer (24). Some authors advocate for covering the anastomosis with omentum, with or without formal creation of a pedicled omental flap, particularly in cases after induction radiation (4-6,23,24).

Early data suggest RAMIE has performed similarly to minimally invasive esophagectomy in terms of safety and ability to perform an adequate resection. In a follow up study from Memorial Sloan-Kettering in 100 sequential patients undergoing total laparoscopic and thoracoscopic RAMIE with an EEA stapled anastomosis, median operative time decreased from 447 to 357 minutes over the two halves of the experience, and 30-day mortality was 0% and 90-day mortality was 1%. Complications and estimated blood loss likewise decreased significantly in parallel, along with a statistically non-significant increase in lymph node harvest.

In a prospective comparison from Sarkaria *et al.* of 64 patients undergoing RAMIE and 106 patients undergoing open esophagectomy (OE) at Memorial Sloan Kettering Cancer Center, patient quality of life was significantly improved with RAMIE as represented by improved post-operative pain (*Figure 1*). Significant improvements favoring RAMIE were also seen in rates of pulmonary and infectious complications, length of ICU and hospital stay, median lymph node harvest, and blood loss. 90-day mortality in both arms was low, 2% for RAMIE and 4% for OE. Okusanya *et al.* evaluated a cohort of 25 patients who underwent RAMIE at a high volume center and outcomes were similar, including 30-day mortality (0% *vs.* 1.7%), ability to perform a R0 resection (96% *vs.* 98%), anastomotic leak rate (4% *vs.* 5%) and number of lymph nodes obtained (26 *vs.* 19) (7). These outcomes have been reproduced at other institutions. Hodari *et al.* reported a 2%, 30-day mortality rate in 54 patients. The anastomotic leak rate using the modified Orringer anastomosis was 6.8%. R0 resection was achieved in all patients and the average lymph node count was 16.2 (23). Cerfolio *et al.* reported on 85 consecutive patients undergoing robotic assisted minimally invasive Ivor Lewis esophagectomy. His results were similar to the previous described data, including a R0 resection in all patients but one (99%). Median lymph node count was 22 and the conversion rate to open was 1.2%. 30-day mortality rate was 3.5%. Four patients had anastomotic leaks (4.3%) and two patients had conduit ischemia (2.2%) (18). All of these series reported similar outcomes despite subtle technical alterations in Ivor Lewis RAMIE, mainly surrounding the creation of the anastomosis (6,18,23,26). RAMIE has demonstrates equipoise compared to standard minimally invasive resection techniques, although long-term oncologic data has yet to be reported. The advantages of surgical robotics may be seen in an abbreviated learning curve to

Video 1. Operative techniques of robotic assisted minimally invasive esophagectomy

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Figure 1 Operative techniques of robotic assisted minimally invasive esophagectomy (RAMIE) (25).
Available online: http://www.asvide.com/watch/32950

Table 1 Summarizes data from a number of series of robotic assisted Ivor Lewis

Author	# cases	Robotic utilization	Anastomosis type	Conversion rate, n (%)	Number of lymph nodes, n [range]	ICU LOS, days [range]	Hospital LOS, days [range]	30-day mortality, n (%)	90-day mortality, n (%)
Okusanya (7)	25	A, T	stapled	2 (8.0)	26 [11–78]	2 [1–10[	8 [6–20]	0 (0)	0 (0)
Sarkaria (14)	100	A, T	EEA	15 (15.0)	24 [10–56]	NR	9 [5–70]	0 (0)	1 (1.0)
Hodari (23)	54	T	stapled	NR	NR	4.6 [1–29]	13 [7–37]	1 (2.0)	1 (2.0)
Hernandez (28)	52	A, T	stapled	0 (0)	20 [8–63]	NR	NR	0 (0)	0 (0)
Zhang (29)	66	A, T	EEA	1	19 (+/– 9.2)	NR	10	0 (0)	NR
Cerfolio (18)	85	T, A (5/85)	Hand-sewn, stapled	2 (2.4)	22 (NR)	NR	8 [5–46]	3 (3.5)	9 (11.0)
Wee (30)	20	T	EEA	0 (0)	23 (+/– 2.3)	NR	8 [7–25]	NR	0 (0)
Wang (31)	24	A, T	EEA	0 (0)	19 [11–30]	1 [0–8]	11 [8–30]	NR	NR
Tagkalos (32)	50	A, T	EEA	NR	27 [13–84]	1 [1–43]	12 [7–59]	0 (0)	2 (4.0)

A, abdomen; T, thoracic; EEA, end-to-end anastomosis.

achieve proficiency for such a complex operation that spans two body cavities (7,27,28). *Table 1* summarizes data from a number of series of robotic assisted Ivor Lewis.

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