Robotic esophagectomy with chest anastomosis: technical aspects and clinical outcomes

Travis C. Geraci, Robert J. Cerfolio

Department of Cardiothoracic Surgery, New York University, Langone Health, New York, NY, USA

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Correspondence to: Robert J. Cerfolio, MD, MBA, FACS, FCCP. Senior Vice President, Vice Dean and Chief Operating Officer, Chief of Clinical Thoracic Surgery, Perlmutter Cancer Institute, Director of Lung Cancer; Department of Cardiothoracic Surgery, New York University, Langone Medical Center, 550 First Ave, 9V, New York, 10016, USA. Email: robert.cerfolio@nyumc.org.

Abstract: The use of robotic platforms for thoracic surgery, including esophagectomy, is increasing. A robotic-assisted Ivor Lewis esophagectomy with an anastomosis in the chest is a safe and feasible method of minimally-invasive esophagectomy. Further, this approach offers technical advantages over previous minimally-invasive techniques. In this review, we describe our technical approach to a robotic-assisted Ivor Lewis esophagectomy describing the abdominal and thoracic phases of the operation. We also review the most recent clinical outcomes of this approach and make comparisons with other techniques. Advantages and disadvantages to robotic esophagectomy are discussed.

Keywords: Robotic surgery; esophageal cancer; esophagectomy; Ivor Lewis; thoracic anastomosis

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Introduction

Interest in minimally-invasive esophagectomy continues to expand. The use of robotic systems in thoracic surgery has accelerated over the last decade. For patients with esophageal carcinoma, the overall 5-year survival remains modest, with significant perioperative morbidity after esophagectomy (1). When compared to an open operation, minimally-invasive esophagectomy has been shown to achieve comparable oncologic outcomes with decreased complications and reduced length of hospitalization (2). Surgeons using a robot-assisted platform aim to utilize robotic technology, such as precision control, instrument angulation, and advanced optics, to further decrease the morbidity associated with esophagectomy and to increase survival in patients with esophageal carcinoma.

We prefer a chest anastomosis as we believe it allows a more complete lymph node dissection with a low complication rate: fewer recurrent laryngeal nerve injuries, fewer aspiration events, and lower leak rate than a cervical anastomosis (3). In a retrospective review of 22 consecutive patients, we have shown that robotic esophagectomy with a chest anastomosis is safe and affords an R0 resection with a thorough thoracic lymph node dissection (4). In this review, we detail our technique for a completely portal, robotic Ivor Lewis esophagectomy (CPR-ILE) and review recent clinical outcomes with this approach.

Preoperative evaluation and patient selection

The work-up of a patient with suspected esophageal carcinoma is standardized (5). Esophagoscopy often confirms the diagnosis by endoscopic biopsy. Clinical staging is established with esophageal ultrasound (EUS), chest and abdominal computed tomography (CT), and integrated positron emission tomography/computed tomography (PET-CT). Adjunctive studies are reserved for patients with system-specific symptoms to evaluate for distant metastasis (M1 disease).

Patient selection for robotic Ivor Lewis esophagectomy is similar to those for an open or thoracoscopic approach. Patients typically undergo pulmonary function testing, nutritional evaluation, and if indicated, cardiac stress testing and frailty assessment. Since the most common cause of 90-day mortality in our most recent series was from liver failure, surgery is aborted in patients with cirrhosis (6). Patients with proximal lesions (less than 23 cm from the incisors) are not eligible for a chest anastomosis. We recommend that these patients undergo a robotic mobilization of the esophagus followed by a transhiatal dissection and neck anastomosis.

Robotic equipment and operating team

A robotic thoracic operation is defined as a minimally-invasive procedure that does not remove, spread, or lift any part of the chest or abdominal wall (7). The da Vinci system (Intuitive Surgical Inc., Sunnyvale, CA, USA) is the only US FDA (United States Food and Drug Administration) approved robotic system eligible for advanced thoracic surgery. The surgeon is positioned at a console separate from the sterile field. A three-dimensional operating view, generated by a high-definition endoscopic camera, is observed through the console binoculars. The patient is positioned on a standard operating table adjacent the robotic unit that has four operating arms that rotate from an over-head beam.

The robotic instruments are inserted via trocars inserted through small intercostal incisions, similar to other minimally-invasive techniques. The arms incorporate remote center technology that anchors the fulcrum of the robotic arms in space, thereby reducing stress to the chest wall. EndoWrist instruments are attached to the arms allowing a wide range of high-precision motions. Hand tremor is filtered out by a 6-Hz motion filter. The "robotic" instruments do not function autonomously, but are controlled by the surgeon's hand movements via master controls. A second optional console allows tandem surgery, permitting a clear field of view and fluid instrument exchange for a second surgeon or trainee.

Robotic esophagectomy: Ivor Lewis approach

Abdominal phase

The abdominal phase of the operation can be performed with laparoscopic or robotic assistance. Esophagoscopy is performed prior to the operation to confirm the tumor location and to assess for local invasion. The patient is then positioned supine, with arms tucked, in moderate reverse Trendelenburg. A Veress needle is placed in the abdomen, 2 cm below the left costal margin to establish pneumoperitoneum. The camera port is made two-thirds the distance between the xiphoid and umbilicus, 2 cm left of the midline. The "right-hand," port is inserted at the same level as the camera, 2 cm to the right of the midline. Two additional 5 mm ports are inserted in the right (liver retractor) and left ("left-hand,") subcostal abdomen.

Our standard robotic instruments for the abdominal phase are as follows:

- ❖ Arm 1: Cadiere forceps;
- ❖ Arm 2: robotic camera;
- ❖ Arm 3: long bipolar grasper/vessel sealer;
- ❖ Arm 4: tip-up fenestrated grasper.

After initial laparoscopy, a liver retractor is inserted to retract the left lobe of the liver superiorly and laterally, exposing the hiatus. In patients at risk of liver disease, a liver biopsy is performed to ensure than unsuspected cirrhosis is not present. The gastrohepatic ligament is divided with attention to identify a replaced left hepatic artery, if present. The phrenoesophageal ligament is incised and the esophagus is circumferentially dissected at the hiatus starting at the right crus of the diaphragm. The lower esophagus is mobilized into the mediastinum and encircled with a penrose for retraction. Care is taken to avoid violation of the pleural space in order to prevent capnothorax.

The gastrocolic ligament is divided and a plane is established between the greater curvature of the stomach and the greater omentum. We preserve a flap of omental fat tissue along the lateral aspect of the stomach, which is later used in the thoracic phase to encircle the anastomosis and protect the carina and right main-stem bronchus. Effort is employed to minimize retraction and tissue manipulation. When retracting the stomach, the portion along the lesser curve is grasped, as this tissue will be discarded. Lymph node tissue is swept inward to be included with the pathologic specimen.

The short gastrics along the greater curvature are divided with a vessel sealer to the level of the left crus. Robotic arm #4 is used for lateral traction avoiding undue tension on the spleen, which may cause capsular tears. The stomach is divided posteriorly and the left gastric artery and vein are divided with an endoscopic or robotic vascular stapler. The gastric dissection is completed inferiorly to the pylorus preserving the right gastroepiploic artery. For a pyloric drainage procedure, we inject Botulinum toxin into the submucosa of the pylorus at two locations (100 units in 4 mL of saline). At approximately three vessel groups from the pylorus, the lesser curve is dissected towards the gastroesophageal junction (GEJ), resecting the lesser omentum, which often contains lymph nodes and is sent as a specimen. We do not routinely perform a Kocher maneuver, as we believe this does not add length to the conduit.

The stomach is then tubularized with sequential firing of a 45-mm endoscopic GIA (gastrointestinal anastomosis) stapler. The gastric conduit is created on slight tension to assure maximal length. Assure that any enteric devices, such as the nasogastric tube or temperature probe, are removed from the esophagus and stomach prior to stapling. Our preferred conduit diameter is between 3–4 cm. The GEJ is then transected distal to the tumor and the margin is sent to pathology to assure a negative margin. The conduit is then sutured to the future esophageal specimen. A soft wide drain is sutured around the esophagus in the abdomen. The hiatus is opened slightly toward the right side of the chest and the conduit and drain are placed into the lower aspect of the right side of the chest. An interrupted prolene suture is placed at distal staple line, which is observed at the diaphragmatic hiatus to assure the entire staple line is in the chest. The robotic instruments are then removed and the port sites are sutured closed.

We do not routinely place a feeding jejunostomy. Rather, we utilize them selectively for patients at risk of postoperative malnutrition. The left abdominal port is used for peritoneal access and a 12-Fr feeding tube is placed using a modified Seldinger technique. The jejunum is sutured to the abdominal wall and an anti-mesenteric serosal Witzel tunnel is performed to prevent twisting and torsion of the small bowel.

Thoracic phase

After completion of the abdominal phase, the patient is placed in the left lateral decubitus position with the right chest up and titled forward to allow the lung and blood to fall away from the posterior mediastinum. The port for robotic arm #1 is marked at the inferior aspect of the right axilla, just below the hairline, and just medial to the anterior edge of the scapula. The robotic camera port is then inserted 9 cm inferiorly to the robotic arm #1. Initial thoracoscopy ensures that the pleural space is free of adhesions. Humidified warm carbon dioxide is delivered via an Insuflow device (Lexicon Medical, St Paul, Minn) at a pressure of 8 to 10 mmHg. The airflow depresses the diaphragm, thereby creating a larger working space in the chest. A paravertebral block is achieved using a 21-gauge needle filled with 0.25% bupivacaine with epinephrine, injected posteriorly along the intercostal nerves.

The working ports are placed under direct visualization. The first port inserted is robotic arm #1, which serves as the surgeon's right hand. The second port is placed 9 cm inferior to the camera port, at the anterior axillary line, and is used for robotic arm #2. The port should be positioned slightly posterior to robotic arm #1 and the camera, to allow room for the port used by the bedside assistant. This port is inserted between robotic arm #1 and the camera, anterior in the chest, but avoiding the rectus muscles. The assistant port is used to evacuate blood from the field, exchange instruments, and is later enlarged to remove the specimen. The last port placed for robotic arm #3 and is placed 10 cm from robotic arm #2 and more posterior.

Our standard robotic instruments for the abdominal phase are as follows:

- ❖ Arm 1: tip-up fenestrated grasper;
- ❖ Arm 2: Cadiere forceps;
- ❖ Arm 3: robotic camera;
- ❖ Arm 4: long bipolar grasper/vessel sealer.

The robot is driven over the patient's back on a slight 30-degree angle allowing visualization of the thoracic esophagus and posterior mediastinum from the diaphragm to the apex of the chest. The resection is started with division of the inferior pulmonary ligament with resection of regional lymph nodes. The anterior mediastinal pleural adjacent the esophagus is dissected circumferentially, mobilizing the esophagus from the aorta. The dissection proceeds to the GEJ, where the esophageal penrose drain is identified and lifted into the chest. The penrose aids in esophageal retraction, helping expose the aortic arterial branches, which are ligated sequentially with the bipolar cautery or clipped.

The azygos vein is divided with a vascular stapler. The esophagus is divided well above the divided azygos vein stump, and the tumor, esophagus, and proximal stomach are extracted in an Anchor bag (Progressive Medical, Addison, Ill). After bagging, the specimen it is removed via the non-robotic assistant port and the enlarged port-site is covered with an occlusive dressing to maintain carbon dioxide insufflation. The proximal esophageal margin is sent to pathology for frozen section to ensure that it is free of cancer and Barrett cells.

Hand-Sewn 2-layered robotic chest anastomosis

The tubularized stomach is then carefully brought into the apex of the chest with a Scanlan clamp (Scanlan International, St Paul, Minn) that is introduced from the non-robotic assistant port. The conduit is positioned above the divided azygos vein and under the divided esophagus. A location on the tubularized gastric conduit, at least 3 to 4 cm below the most superior aspect of the gastric staple line and as far away as possible from the lesser curve staple-line, is selected for the anastomosis. The anticipated anastomosis should be tension-free. Visualizing the tissues of the planned anastomosis in Firefly fluorescence after the injection of intravenous indocyanine green contrast, helps assure adequate perfusion. Two to three 3-0 silk sutures (Ethicon, Inc., Somerville, NJ, USA) are placed to align the distal esophageal margin and the gastric conduit for anastomosis. The harvested omental fat pad is placed between the carina and around the esophagus.

A gastrotomy is made in the conduit using a monopolar-curved scissor. The posterior aspect of the conduit is then stapled to the esophagus using a 20-mm enteric stapler. The anterior anastomosis is then completed using a two-layer hand-sewn technique. To perform the anterior anastomosis, a robotic fine-tipped needle-driver is inserted in robotic arm #1 (right hand) and a robotic long-tip needle forceps is inserted in robotic arm #2 (left hand). An interior running 3-0 V-Loc suture (Medtronic, Minneapolis, Minn) is placed joining the mucosal margins and a second V-Loc suture is placed anteriorly in a Lembert fashion. The anastomosis is then buttressed with the remaining omental fat pad. Lastly, the diaphragmatic hiatus is sutured closed posteriorly to prevent herniation. A single chest tube is placed through the most inferior port site, assuring placement to the apex of the chest. The ports are subsequently removed and the incisions are closed.

Conversion to thoracotomy

The reasons to convert from a completely portal robotic operation to an open thoracotomy are as follows: bleeding that cannot be controlled robotically, the inability to enter the pleural space and insufflate carbon dioxide secondary to pleural symphysis from adhesions, or the inability to completely remove the tumor and achieve an R0 resection.

Postoperative management

Patients are recovered in the post-anesthesia care unit (PACU) and transitioned to the floor. Serial pleural amylase levels are collected to survey for evidence of an esophageal leak (8). Pain control is achieved with a combination of opioid and non-opioid analgesics. Patients are kept *nil per os* (NPO) and tube feeding (if jejunostomy placed) is started on the first post-operative day. Patients undergo a fiberoptic swallow study on post-operative day four and if normal an esophagram with water-soluble contrast is performed. If no evidence of an esophageal leak is observed, the patient is started on a clear liquid diet with aspiration precautions and advancement of dietary consistency as tolerated. Chest tubes are removed once diet and/or tube-feedings are at goal and without evidence of a chylothorax. We counsel our patients to anticipate a hospital length of stay between 6 and 8 days.

Discussion

Review of clinical outcomes

As the 8th most common malignancy, esophageal carcinoma is a global disease. Esophageal carcinoma is the 6th most common cause of cancer-related death, with a mortality rate nearly congruent with its incidence (mortality-to-incidence rate ratio, 0.84) (9). For early-stage disease, esophagectomy offers curative treatment, but carries substantial perioperative morbidity and mortality (10). Compared to open techniques, minimally invasive esophagectomy reduces operative risk (2,11). Robotic esophagectomy has shown equally promising reductions in perioperative morbidity and mortality versus open or "hybrid," partially-open, esophagectomy (see *Table 1*) (6,12-16).

In 2004, Kernstine and colleagues were the first to describe a robotic esophagectomy (17). The feasibility and safety of robotic esophagectomy was subsequently established by a series of authors describing their techniques: Bodner in 2005 in a series of 4 patients, Boone in 2009 in 47 patients, Puntambekar in 2011 in 32 patients, and Weksler in 2011 in 11 patients (18-21). Weksler's institutional series, for example, directly compared thoracoscopic esophagectomy with a robotic approach in a cohort of non-randomized patients. The study showed no significant differences between the groups in terms of an ability to achieve an R0 resection, and postoperative outcomes, including morbidity and mortality.

All of these institutional series, however, featured a

Table 1 Comparison of studies of robot-assisted Ivor Lewis esophagectomy

Study	Pts	Operative approach	Select technical aspects	Operative time (min)	Estimated blood loss (mL)	LNs	Leak rate (%)	Major morbidity (%)	Mortality
Okusanya, 2017 (12)	25	Robotic abdominal and chest (2 McKeown)	Pyloroplasty; divided L gastric and short gastric vessels; anastomosis stapled with end-to end anastomosis stapler; +/– omental flap	361	250	26	4	24	0%, 30-day; 0%, 90-day
Cerfolio, 2016 (6)	85	Lap or robotic abdominal and chest	Botox injection pylorus; stretch stomach during stapling phase of conduit; no thoracic duct ligation; anastomosis stapled posteriorly, 2 rows hand sewn anterior; omental flap wrapped around anastomosis and placed between carina and conduit	361	35	22	4.3	36.4	3.5%, 30-day; 11%, 90-day
Sarkaria, 2016 (13)	100	Robotic abdominal and chest	Pyloroplasty; anastomosis stapled with end-to end anastomosis stapler; +/– omental flap	379	250	24	6	23	0%, 30-day; 1%, 90-day
Hodari, 2015 (14)	54	Lap abdominal, robotic chest	Pyloroplasty; indocyanine green perfusion; robot-sewn 2 row suture anastomosis	362	74	16.2	5.5	NR	2%, 30-day
de la Fuente, 2013 (15)	50	Robotic abdominal, robotic or lap chest	Pylorus injected with botox; 25 mm anvil used transorally for creation of anastomosis	445	146	18	4	28	NR
Sarkaria, 2013 (16)	21	Robotic abdominal and chest (4 pt McKeown)	Pyloroplasty; anastomosis stapled with end-to end anastomosis stapler reinforced with running "baseball" suture; chest tube plus J-P drain	556	300	20	14	24	5%, 90-day

pts, patients; min, minutes; LN, lymph nodes; NR, not reported.

neck anastomosis. With some variability in approach, the authors started the operation in the right side of the chest robotically, mobilized the entire thoracic esophagus, and performed a right thoracic lymphadenectomy. They then placed their patients in a supine position and, after creating a gastric tube, performed an anastomosis in the left side of the neck. Few studies have reported outcomes after robotic assisted anastomosis in the chest.

In 2013, we established the feasibility and safety of a robotic-assisted thoracic anastomosis in a series of 22 patients who underwent laparoscopic gastric mobilization with robotic-assisted esophagectomy (4). After adjusting our surgical technique from a stapled posterior and hand-sewn anterior anastomosis to performing a two-layered anastomosis, we were able to achieve an R0 resection with a complete lymph node dissection (median lymph nodes removed, 18), without anastomotic leak (final 16 patients after changing our technique), and no 30- or 90-day mortalities. In both our robotic and open esophagectomy experience, we favor a completely hand-sewn 2-layered chest anastomosis for patients with distal esophageal cancer. This type of anastomosis may decrease conduit ischemia by allowing for a precise gastrotomy and the avoidance of staple lines.

In a subsequent series of 85 patients undergoing robotic esophagectomy with a chest anastomosis, we reported superior perioperative outcomes versus our previous benchmarks for open esophagectomy (6). Mean operating time, from the initial skin incision to close, was 6 hours. Only a single patient required conversion to thoracotomy (1.2%) due to tumor invasion of the right main-stem bronchus. Equally, a single patient was converted to laparotomy during the abdominal phase (1.2%) due to difficulty creating the gastric conduit due to a significantly thickened gastric tissue. An R0 resection was achieved in nearly all patients (99%), with a median lymph node harvest of 22 nodes. Hospital stay averaged eight days and 36% of patients experienced a complication, such as pneumonia (7%), atrial fibrillation (7%), and chylothorax (6%). Four patients had an anastomotic leak (4.3%), three of which were treated with an esophageal stent. Two patients require re-operation for revision of the anastomosis due to leak or conduit necrosis. Three patients died within 30 days (3.5%), which were attributed to pulmonary embolism, anastomotic leak, and embolic mesentery ischemia. The overall 90-day mortality rate was 10.6% (9 of 85 patients). Two of these patients were found to have liver cirrhosis and require readmission for liver-related complications after an initial post-operative recovery.

A number of other surgeons have reported their experience with robotic esophagectomy performing an anastomosis in the chest. In 2013, de la Fuente and colleagues reported an institutional series of 50 patients who underwent a robotic-assisted Ivor Lewis esophagectomy with a thoracic anastomosis, representing approximately a one-third of the total esophagectomy volume for their institution during a one-year period (15). A transoral 25 mm anvil end-to-end anastomotic (EEA) stapler was used for creation of the anastomosis. The authors found that operative time was longer during robotic esophagectomy, but decreased with experience. An R0 resection was achieved in all patients with a median of 20 lymph nodes resected. There were no conversions to thoracotomy. Complicated occurred in 28%, including pneumonia (10%), atrial fibrillation (10%), and anastomotic leak (2%). Mortality rates were not reported.

In a retrospective review of 54 patients, Hodari and colleagues reported their outcomes after robotic-assisted Ivor Lewis esophagectomy (14). Uniquely, their technique employed a real-time perfusion assessment of the gastric conduit esophageal anastomosis using a dilute indocyanine green injection with robotic Fire-fly fluorescence to assess the location of the esophageal anastomosis. A total of three patients experienced anastomotic complications (5.5%) and one patient had a leak at the gastric staple line.

In 2017, Okusanya and colleagues reported a series of 25 consecutive patients who underwent a robotic-assisted esophagectomy, comparing outcomes against a minimally invasive approach, in the context of a high-volume program with extensive experience in minimally invasive esophagectomy (12). The abdominal and thoracic portions of the cases were both accomplished robotically, and the use of near infrared fluorescence was used to guide the creation of the anastomosis. The thoracic anastomosis was created using a transoral 28 mm anvil EEA stapler. The median operating time was 661 minutes, with a median of 26 lymph nodes resected, and a total of 4 conversions from the robotic platform, 2 of which were unplanned (8%). Significant complications occurred in 64% of patients, including atrial fibrillation (24%), pneumonia (12%), and anastomotic leak (4%). There were no 30- or 90-day mortalities. The authors concluded, that in comparison to a large institutional series of over 1,000 patients undergoing minimally invasive esophagectomy, that the robotic-assisted patients had a similar 30-day mortality rate (0% *vs.* 2.8%), clinically significant anastomotic leak rate (4% *vs.* 5%), conversion rates (8% *vs.* 5%) and R0 resection (96% *vs.* 98%). A higher rate of lymph node harvest was achieved robotically (27 *vs.* 21).

Advantages of robotic esophagectomy

The robotic platform for esophagectomy offers surgical advantages over previous minimally invasive techniques, including enhanced visualization, greater instrument precision, increased range of motion, and camera stability and control. The ease of technical execution permits facile surgery, which may allow more surgeons to perform minimally invasive operations. The robot equally allows for a complete lymph nodes dissection. With improved visualization of the mediastinum, the robot enables meticulous dissection of the periesophageal lymph nodes from the hiatus of the diaphragm to the thoracic inlet. Multiple studies have reported an improved lymph node retrieval rate during a robotic esophagectomy, which may translate to an improved survival (12,22). The increased initial costs of the robot, therefore, may be offset by greater long-term survival, generating a net value to the patient and health care system.

Additionally, patients undergoing robotic esophagectomy have an enhanced recovery when compared to an open operation, including a shorter length of stay, improved quality of life, decreased rates of pulmonary and infectious complications (6).

Challenges of robotic esophagectomy

Robotic esophagectomy has a number of challenges. The cost associated with robotic surgery is significant, including the robot system, maintenance costs, limited-use instruments, costs of depreciation, and costs of training the surgical team. In order to justify these costs, surgeons must show value for the patient and/or surgery. Research that continues to show long-term oncologic effectiveness is needed to justify the initial investment.

The delivery of the gastric conduit into the chest via robotic instruments alone can traumatize the tissue and staple line. The robotic instruments are currently not suitable for this maneuver independently. Additionally, the use of energy devices must be selected and utilized carefully, as there is a risk of airway injury with the use of thermal dissection during esophageal mobilization (13).

Ultimately, randomized data is needed to compare robotic esophagectomy with established minimally invasive techniques. As market competition increases and as robotic and adjunctive technologies continue to develop, however, we believe that the technical advantages of a robotic-assisted Ivor Lewis esophagectomy will translate to early, enhanced patient recovery and long-term oncologic benefit.

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