34 Robotic Esophagectomy

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Anatomy

The esophagus is a tubular structure that connects the pharynx to the stomach. On its way it traverses three body areas and cavities – the neck, the chest, and the abdomen. It has a multilayered architecture, consisting of the mucosa with squamous epithelium, the submucosa (a strong layer of connective tissue and vasculature), and the muscularis propria, consisting of internal circular, and outer longitudinal layers. The esophagus has no serosal lining, except in the very distal intraabdominal portion, proximal to the gastroesophageal junction (GEJ) and is otherwise surrounded by an adventitia and mediastinal fat.

History

Esophagectomy is most commonly performed for malignancy and, occasionally, for end-stage benign diseases. The first successful esophagectomy for cancer was performed by Dr. Franz Torek in 1913 in New York. The author removed the thoracic esophagus, closed the distal end, and connected a cervical esophagostomy to a gastrostomy with an extracorporeal rubber tube. The patient, a 67-year-old female, survived for more than 11 years on a pureed diet [1]. Since then, more sophisticated approaches have been introduced with immediate reconstruction of alimentary tract continuity.

Definition and Classification

Esophagectomy is a complex surgical procedure, involving the removal of part of the esophagus and replacing it with a suitable conduit, most commonly, a gastric tube.

Esophagectomy can be classified by several parameters, such as:

- Surgical approach to the esophagus for resection (i.e., transthoracic vs. transhiatal)
- Location of the anastomosis (neck, chest, abdomen)
- Type of the conduit – the stomach (whole or tubularized), colon, small bowel, or skin tubes
- Route of the conduit placement (native – posterior mediastinal bed, left or right chest, substernal or subcutaneous)
- Timing of the reconstruction (immediate vs. delayed)

Classic Esophagectomy Procedures

Several classical esophagectomy procedures have been described. We will discuss the history of esophageal resection, with immediate or delayed reconstruction using a tubularized gastric conduit. We will also review the current state of robotic-assisted esophagectomy.

Transhiatal Esophagectomy (THE)

Transhiatal esophagectomy performed via laparotomy and a left cervical incision were reported as early as 1933 by Dr. Turner, who used an ante-thoracic skin tube to connect the esophageal stump and stomach in a second-stage procedure [2]. This approach was popularized by Dr. Orringer in 1978 in his initial report on 26 patients [3]. Until the development of minimally invasive port-based techniques, this procedure was regarded as "minimally invasive," due to decreased pulmonary morbidity by avoiding thoracotomy. It was, however, challenged by a decrease in the lymph node (LN) yield, as well as increased risk of airway and cardiac injury from the blunt dissection, neck morbidity (specifically recurrent laryngeal nerve (RLN) paralysis), and higher incidence of anastomotic leaks. On the other hand, it was praised for the ease of management of leaks by simply opening of the wound and external drainage [4, 5].

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Ivor Lewis Esophagectomy (ILE)

This procedure combines a laparotomy for the preparation of the gastric conduit, followed by right thoracotomy for esophageal resection and esophagogastrostomy, first described by Dr. Ivor Lewis in 1946 [6]. Its benefits include visual-guided dissection with a higher lymph node yield, lower incidence of anastomotic leaks due to shorter conduit, and avoidance of the neck morbidity. However, traditionally, intrathoracic leaks are harder to manage, and there is increased pulmonary morbidity. Proponents of this approach argue that although the proximal margin is shorter, it is usually sufficient, especially for GEJ adenocarcinomas. Another disadvantage is the full commitment to resection with division of the stomach prior to chest exploration, where surgeon can stumble upon unresectable malignancy, despite a thorough preoperative workup. Incomplete resection or esophageal bypass might be performed as a bailout plan in these circumstances [5, 7].

McKeown Esophagectomy (MKE)

Described by K. C. McKeown [8], this approach combines right thoracotomy, laparotomy, and a left cervicotomy. This allows visual control of intrathoracic dissection, minimizes sequelae of intrathoracic leaks, and allows better proximal margin, especially for more proximal squamous cell cancers. It also allows a three-field lymphadenectomy, with a potential for a higher LN yield [7, 8]. However, it combines the morbidity of both the transthoracic and cervical approaches [9, 10].

Left Thoracoabdominal Esophagectomy (TAE) (Sweet Esophagectomy)

Described by Richard Sweet in 1947 [11], this procedure is infrequently performed nowadays. It is performed via a left thoracoabdominal incision in the 9th interspace across the costal margin toward the umbilicus and usually requires division of the diaphragm. Due to limitation of the exposure by the aortic arch in the left chest, resection is limited to the middle and lower esophagus, potentially compromising proximal oncologic margin [12].

Left Thoracoabdominal Esophagectomy with Neck Anastomosis (Hugo Matthews Esophagectomy)

This modification combines a left cervicotomy for the proximal margin and left thoracoabdominal approach for visual control and mediastinal dissection. It combines the benefits and complications of both procedures. It was introduced into clinical practice by H.R. Matthews in 1976 and was reported in 1987 [13]. It has declined in clinical applications since the development of minimally invasive techniques.

Minimally Invasive and Robotic Approaches

Since the introduction of minimally invasive techniques towards the end of the last century, it was natural to expect expansion of these approaches in an attempt to decrease the morbidity and mortality of this complex procedure [9, 14, 15]. A multitude of the approaches have been described with different combinations of laparoscopy, thoracoscopy and open approaches (hybrid techniques), or purely minimally invasive techniques to replicate the classical procedures [9, 16–18]. The robotic technology further advanced the field of minimally invasive surgery by offering superior dexterity and visualization, tremor filtration, improved ergonomics, and additional technologies with potential impact on outcomes, such as the near-infra red autoflourescence [18–23]. This, in turn, produced yet another multitude of different combinations of robotics, traditional thoracoscopy, and laparoscopy and sometimes opens approaches, sometimes complicating analysis of outcomes, and meaningful comparison.

Anesthesia Consideration

Esophagectomy is a major procedure and is performed under general anesthesia with endotracheal intubation. Single lung ventilation is necessary for the thoracic portion and usually is achieved with double-lumen endotracheal tube [16, 19].

Fig. 34.1 Lung isolation with single-lumen endotracheal tube with bronchial blocker

In order to maximize working space and exposure positive pressure by capnothorax is usually employed in port-based techniques. Maintaining the intrathoracic pressure at 8–10 mmHg displaces the mediastinum and diaphragm, maximizing the working space without negative hemodynamic effects. That also facilitates lung atelectasis, and our group prefers to use single-lumen tube with bronchial blocker in that setting (Fig. 34.1).

Preoperative Evaluation

Before undergoing an esophagectomy for cancer, patients require an extensive workup that is beyond the scope of this chapter. However, before committing to resection, an intraoperative endoscopy should be performed for clear anatomic definition of the tumor extent with potential implication on the surgical approach, location of the anastomosis, and choice of the conduit. For example, a high proximal tumor extension might require a neck anastomosis even for surgeons who prefer a transthoracic (TTE) approach. Extension of the tumor onto the cardia and further onto the lesser curvature might render the stomach unusable and require the use of alternative conduit [16, 24]. Bronchoscopy is also performed on the table to clear tracheobronchial secretions and confirm absence of airway invasion by the esophageal tumor.

Surgical Technique

Robotic McKeown Esophagectomy

Thoracic Part of the Procedure: Right Robotic-Assisted Thoracoscopic Surgery (RATS)

The patient is positioned in the left lateral decubitus position with slight flexion and 45° anterior tilting in a "semi-prone" position. A total of four 8 mm ports are placed (Fig. 34.2).

The first is the "assistant port" placed at the seventh intercostal space (ICS), just anterior to the anterior axillary line. Capnothorax to a pressure of 8–10 mmHg is created. A 5 mm thoracoscope is placed and utilized for visual control of the placement of the remaining three ports. The camera port is placed at the sixth ICS, midaxillary line to be at the midpoint of the thoracic esophagus, about 2 inches below the azygos vein arch. Following this, another port is placed in the third ICS, midaxillary line for the right arm, and the final port is placed in the 9th ICS at the posterior axillary line for the left arm. Port placement can be verified with injection needle for fine-tuning of the precise location. To avoid robotic arm collision, the port should be spaced at least 10 cm for the Si platform and 8 cm for the Xi.

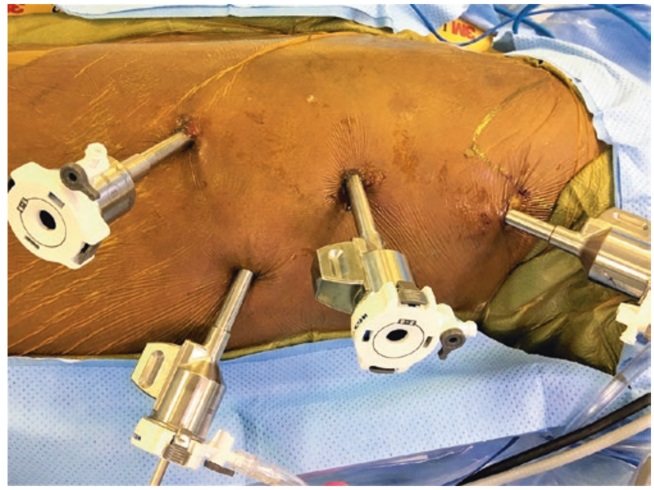


Fig. 34.2 Thoracic port placement for the robotic McKeown esophagectomy

For the dissection in the thoracic cavity, Vessel Sealer is placed in the right arm, while the left arm will use a bipolar fenestrated or Cadiere forceps. Bedside assistant will utilize initial assistant port to apply suction and in passing sutures, drains and controlling staplers if necessary.

Steps of the Thoracic Part of the Procedure

The lung is retracted anteriorly, and the inferior pulmonary ligament is divided. The mediastinal pleura is divided longitudinally anterior and posterior to the esophagus up to the level of the azygos vein arch. At this point, the esophagus is encircled with Penrose drain, which facilitates the retraction. The vein is then dissected free and usually left intact unless the tumor is large (Fig. 34.3). Above the azygos vein, parietal pleura is kept intact to remain as a "tent," covering the eventual conduit. This may help to "wall off" any cervical anastomotic leak from the chest. Both vagus nerves are divided bilaterally below the recurrent laryngeal nerve takeoff. The esophagus with all the lymph nodes and fatty tissue in between the azygous vein, aorta, and pericardium is then dissected circumferentially. The Vessel Sealer is especially useful in controlling bleeding from the aorto-esophageal blood vessels. All lymph nodes in subcarinal, periesophageal, and inferior pulmonary ligament stations are dissected with the esophagus. Superior and inferior paratracheal lymph nodes are dissected and removed separately. After completing esophageal dissection, Penrose drains are used to encircle the esophagus at both the thoracic inlet and the diaphragm (Fig. 34.4) and are tucked under the tissue to help in identifying the esophagus in the neck and in the hiatus. A flexible 24 French drain is placed next along the posterior esophageal gutter. The instruments are then removed, the robot is undocked, and the incisions are closed. The bronchial blocker is removed as the remainder of the procedure does not require lung isolation.

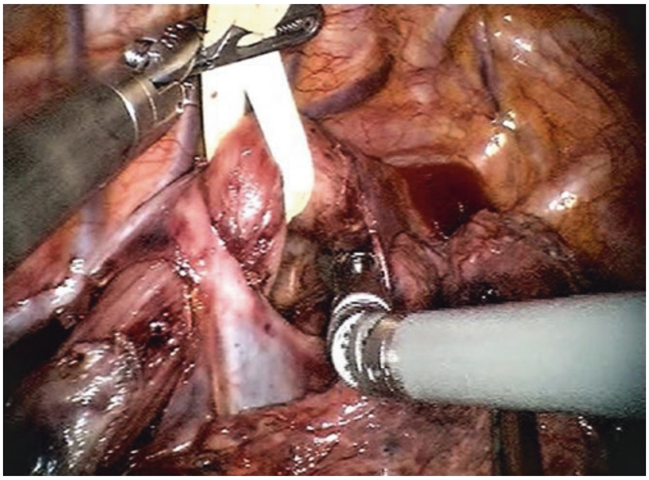


Fig. 34.3 The esophagus is encircled with the Penrose drain to aid with the retraction and exposure

Fig. 34.4 Positioning of the patient for the abdominal and cervical part of the procedure

Left Cervicotomy

The patient is repositioned into the supine position and a long soft medium size gel roll is placed under the left flank and left shoulder (Fig. 34.4). This facilitates both the placement of the most lateral port in the abdomen and the cervical esophageal exposure. The head is turned to the right, and the skin is prepped from the abdomen to the neck in one field.

Cervicotomy is performed simultaneously with abdominal part through a 4 centimeter incision along the inferior anterior border of the left sternomastoid muscle. Carotid sheath and internal jugular vein are dissected laterally, and the prevertebral plain is developed. The Penrose drain around the esophagus from thoracic dissection is identified and delivered into the wound (Fig. 34.5). This facilitates the circumferential dissection of the cervical esophagus keeping the left recurrent laryngeal nerves away from the harm ways.

Abdominal Part of the Procedure: Robotic-Assisted Laparoscopic Surgery (RALS)

Pneumoperitoneum is created either with a Veress needle through the umbilicus or after the placement of the optical 5 mm trocar. Next, a 12 mm port is placed in the linea alba

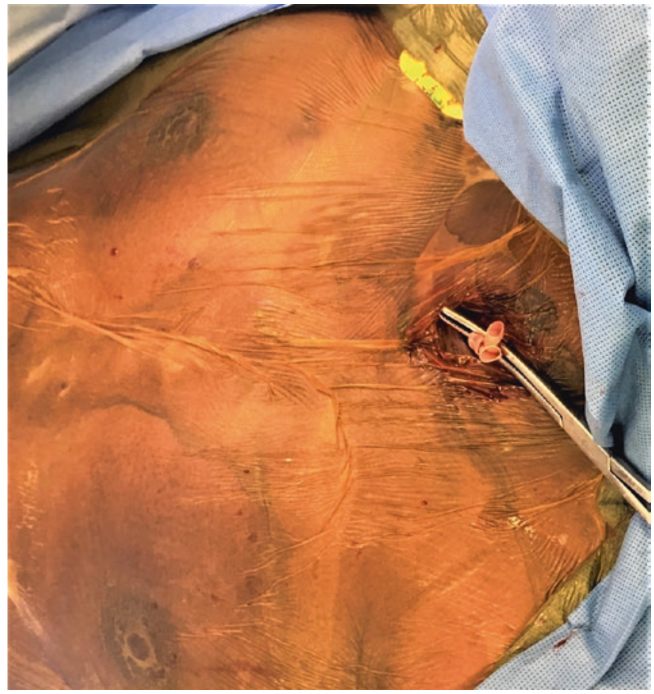


Fig. 34.5 Identification and delivery of the upper Penrose drain into the cervicotomy wound

just below the umbilicus and used for visual control via a regular laparoscope for correct placement of the robotic ports. The left-hand port is placed at the right midclavicular line, a hand width below the costal margin, few centimeters above the umbilicus. The camera port is positioned at the left paramedian line, an inch above the level of the umbilicus and below the lowest point of the greater curve of the stomach. Two remaining ports are placed on the same level – an inch above umbilicus. Right-hand port is located in the left midclavicular line and hand width below the costal margin. Retraction port is placed maximally laterally in the flank, few centimeters below costal margin. For liver retraction we use a flexible retractor through a 5 mm port in the right flank which is secured in place with table mount (Fig. 34.6). Before robot docking, the patient is transitioned into steep reverse Trendelenburg position to use gravity in retraction of the omentum and the loops of bowel and facilitate the exposure.

During the dissection, the right flank arm is used mainly for retraction utilizing a non-traumatic double fenestrated or tip-up fenestrated grasper. The right-hand port is used for majority of the dissection and will mainly use the Vessel Sealer, which, with some practice, can be also used as a needle driver and suture cutter. During pyloromyotomy, this arm is switched for the bipolar Maryland forceps for fine dissection of the layers of the gastric wall. The left arm will mainly use the Fenestrated Bipolar or Cadiere Forceps to assist in dissection and retraction.

Fig. 34.6 Placement of the abdominal robotic ports, the assistant port, and the liver retractor

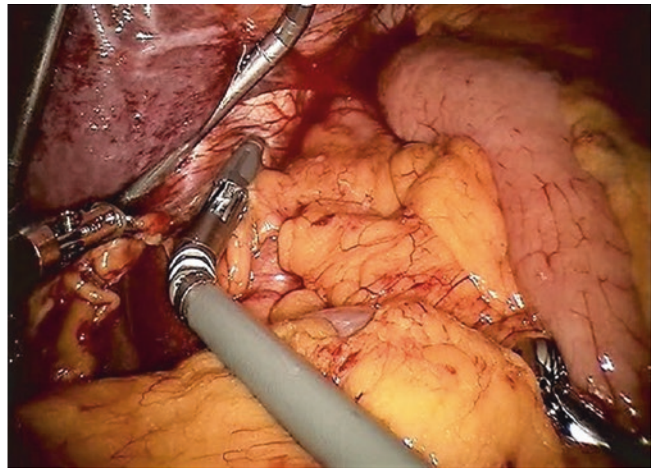


Fig. 34.7 Dissection of the gastrohepatic ligament on exposure of the hiatus

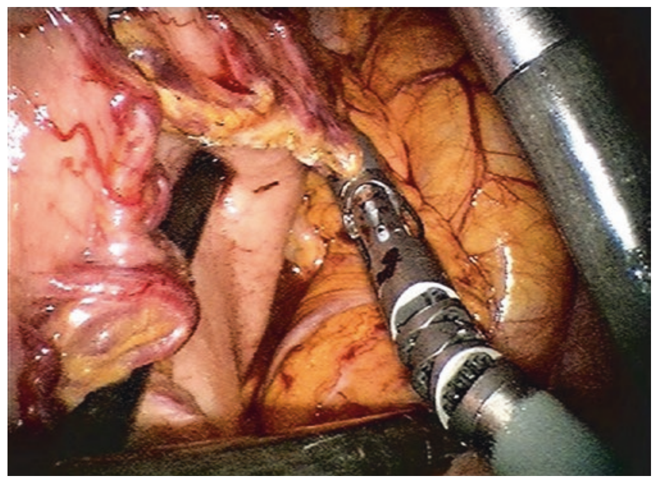


Fig. 34.8 Mobilization of the greater curvature of the stomach with division of the short gastric vessels

Steps of the Abdominal Part of the Procedure

Gastric dissection and conduit preparation begun by dividing the gastrohepatic ligament and dissection of the diaphragmatic hiatus (Fig. 34.7). At this stage to avoid entrance to the chest with loss intraperitoneal pressure and complicated exposure, the phrenoesophageal ligament was left intact until the end of the gastric mobilization. The gastrocolic ligament is then opened at the level of the mid-body, dividing the short gastric vessels toward the fundus for complete mobilization (Fig. 34.8). An omental flap, based on the shot gastric vessels, can be harvested at this stage for the later use in anastomotic coverage. After clearly identifying the location of the gastroepiploic pedicle, the greater omentum is divided, while keeping the pedicle intact, in a caudal direction toward the pylorus to the takeoff of the gastroepiploic artery from the gastroduodenal artery (Fig. 34.9). Extreme diligence is required during this stage, especially in obese individuals with excessive omental fat deposits, as injury to the vascular pedicle will render the stomach unusable as the conduit.

The attachments of the hepatic flexure are divided to allow exposure of the duodenum. Gentle "kocherization" is completed next by dividing lateral retroperitoneal attachments of the duodenum. The goal is to achieve tension-free transposition of the pylorus to the level of the hiatus. This promotes a tension-free conduit placement. The pylorus is identified and can be dealt with according to the surgeon's preference. We perform classical pyloromyotomy that is facilitated by a magnification and depth perception of the robotic platform. Stitch is applied to the pyloric muscle, and with the use of bipolar Maryland grasper, pyloric fibers are divided to the submucosal plane, which is developed without mucosotomy (Fig. 34.10).

The stomach is then retracted superiorly to expose retrogastric adhesions which are divided until the left gastric pedicle is identified. A complete nodal dissection is accomplished by mobilizing the lymphatic nodal tissue along the celiac artery toward the specimen. The left gastric artery is then divided with the linear stapler at its takeoff from the celiac artery (Fig. 34.11).

At this point, division of the phrenoesophageal ligament allows delivery of the Penrose drain into the abdomen, traction on which facilitated complete circumferential dissection of the gastroesophageal junction (Fig. 34.12). Attention at this point is turned to the formation of the gastric conduit. Nasogastric tube is pulled until into the thoracic esophagus. The stomach

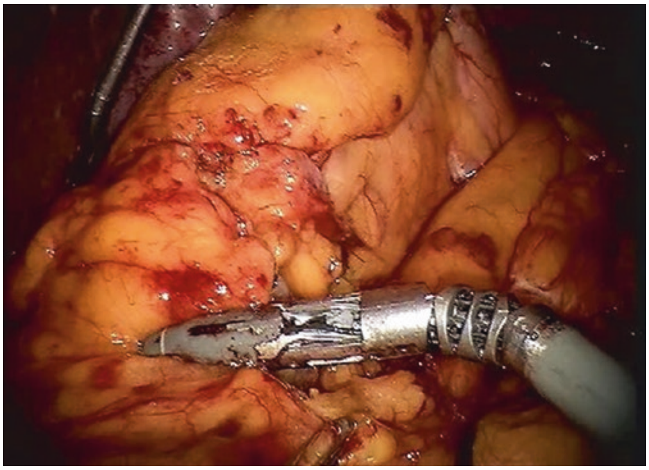


Fig. 34.9 Division of the gastrocolic ligament caudally for complete mobilization of the greater curvature up to the takeoff of the gastroepiploic artery

is divided with a linear stapler, starting at the incisura and running along the greater curvature to the fundus to form a narrow, 5 cm gastric tube (Fig. 34.13). Attention is paid to avoid the common mistake of stapling too close to the esophagogastric junction (EGJ) as this might compromise lateral margin at the GEJ and might also have negative impact on the final conduit length. Perfect aligning of the tissue is required at this stage by stretching the stomach with all robotic arms to avoid spiraling of the staple line and folding of the posterior wall. After completing the conduit, its proximal end is secured to the distal end of the specimen with a silk stitch.

Under vigilant visual control from the surgeon on the console to assure appropriate conduit placement without axial torsion, the assistant delivers the esophagogastric specimen along with the attached conduit into the cervicotomy wound by constant gentle traction (Fig. 34.14). After surgeon is satisfied with conduit placement, diaphragmatic hiatus is closed

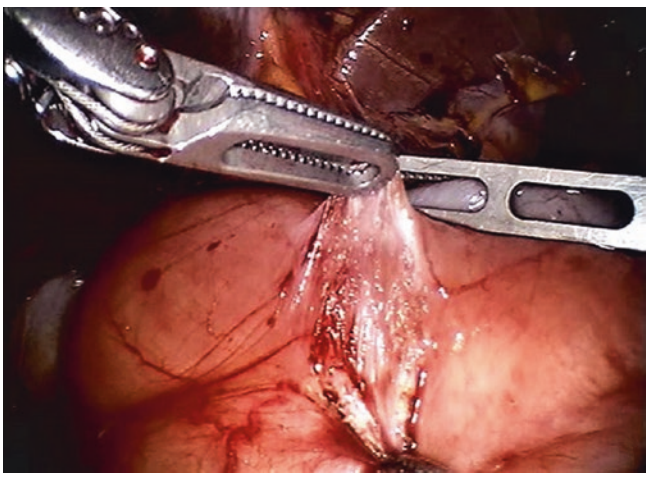


Fig. 34.10 Robotic pyloromyotomy

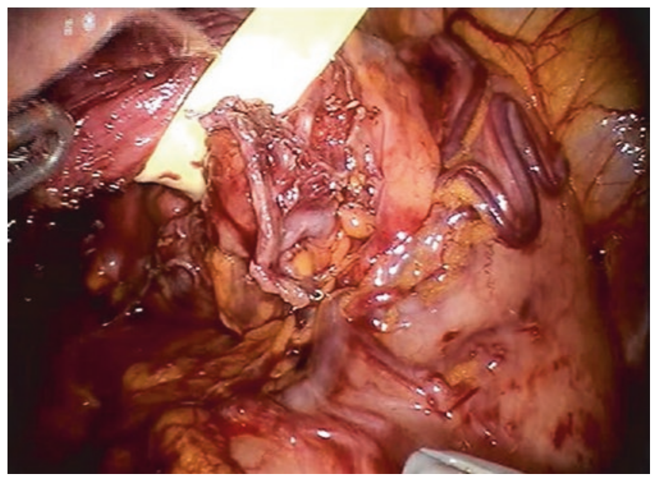


Fig. 34.12 Circumferential esophageal dissection after delivery of lower thoracic Penrose drain into the abdomen

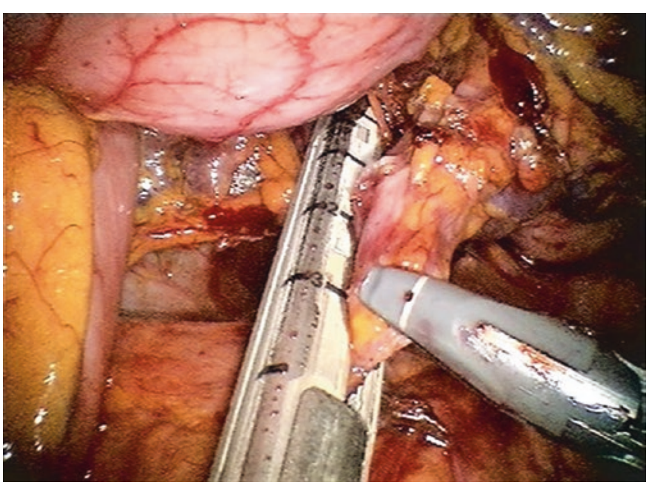


Fig. 34.11 Division of the left gastric pedicle

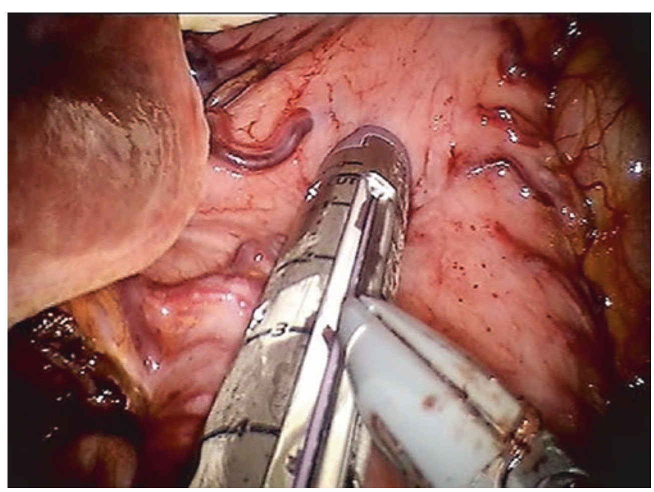


Fig. 34.13 Formation of the narrow gastric tube

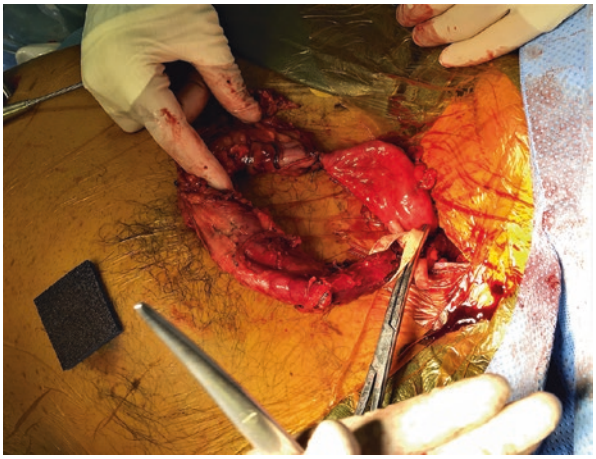


Fig. 34.14 Delivery of the specimen and the conduit into the cervicotomy wound

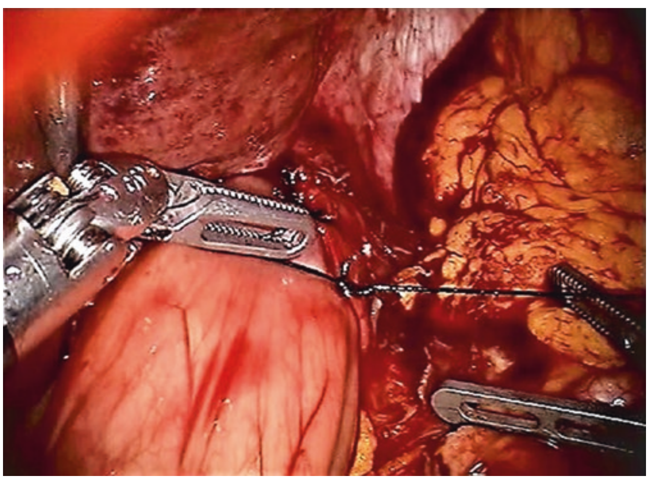


Fig. 34.15 Closure of the hiatus around the conduit

around the conduit to avoid visceral herniation (Fig. 34.15). The robot is then undocked, and the surgeon returns to the operating table to complete the procedure.

The cervical anastomosis is completed according to surgeon's preference. We prefer linear completely stapled side-to-side technique, which is illustrated in the following images (Figs. 34.16, 34.17, and 34.18).

A laparoscopic feeding jejunostomy with 14 Fr jejunostomy tube with the balloon is performed using a percutaneous Seldinger technique after undocking the robot (Figs. 34.19 and 34.20).

Robotic Ivor Lewis Esophagectomy

The initial steps, including anesthesia, intubation, endoscopy, and positioning for abdominal part of the procedure are identical to previously described steps.

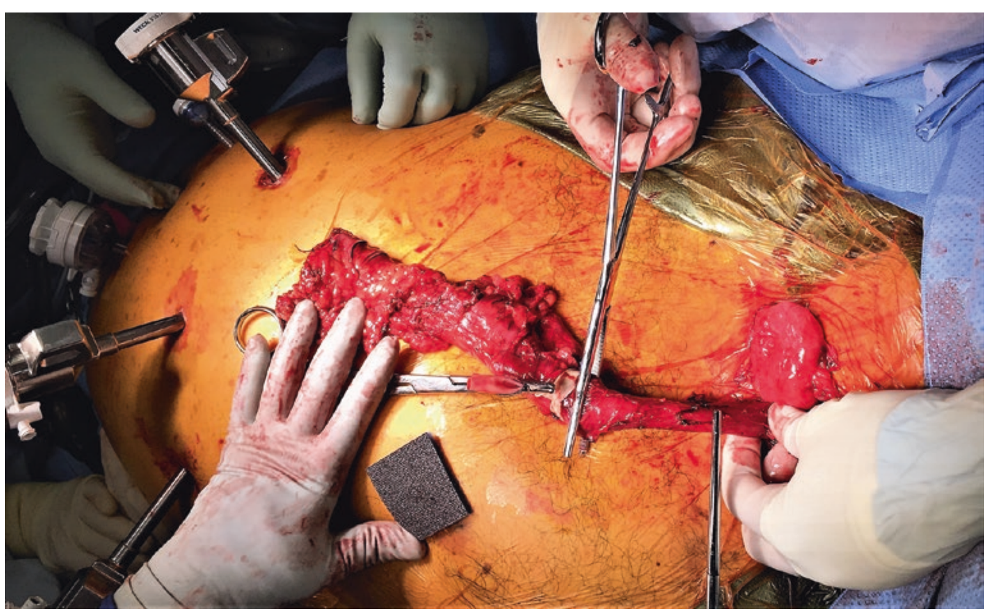
Abdominal Part of the Procedure: Robotic-Assisted Laparoscopic Surgery (RALS)

The robotic gastric dissection and preparation of the gastric conduit is also identical to that described above. The exception is that since the conduit remains in the abdomen, it is not possible to close the hiatus, and thus it has to be accomplished later on from the chest. At the conclusion of the abdominal part, jejunostomy is placed if indicated.

Thoracic Part of the Procedure: Right Robotic-Assisted Thoracic Surgery (RATS)

After completion of the abdominal dissection, the patient is transitioned into left lateral decubitus position for thoracic part. However, due to higher complexity of the thoracic part,

Fig. 34.16 Extraction of the specimen and proximal division of the esophagus



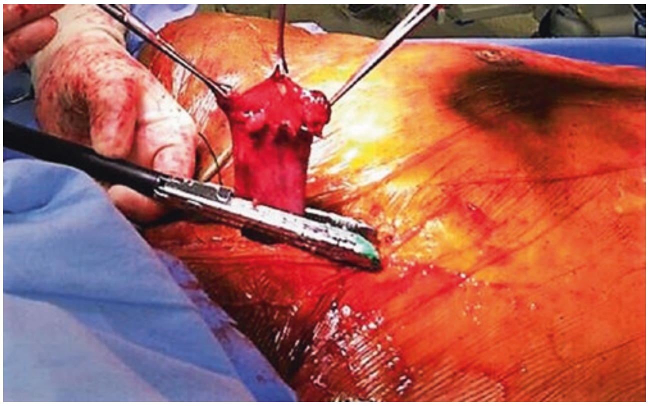


Fig. 34.17 Advancement of the NGT after creation of the linear anastomosis

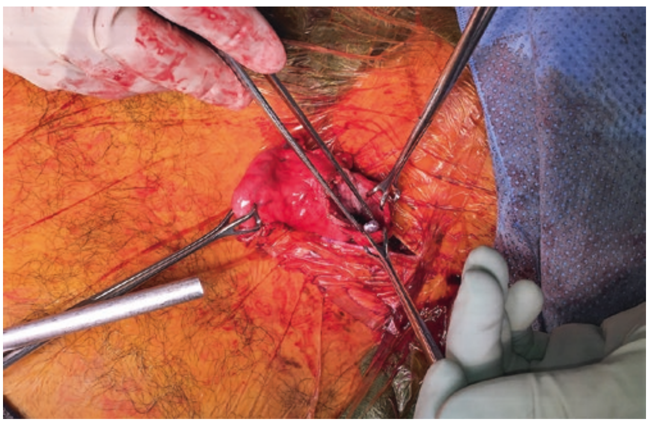


Fig. 34.18 Closure of the enterotomy with creation of the triangular anastomosis and resection of the excessive gastric conduit

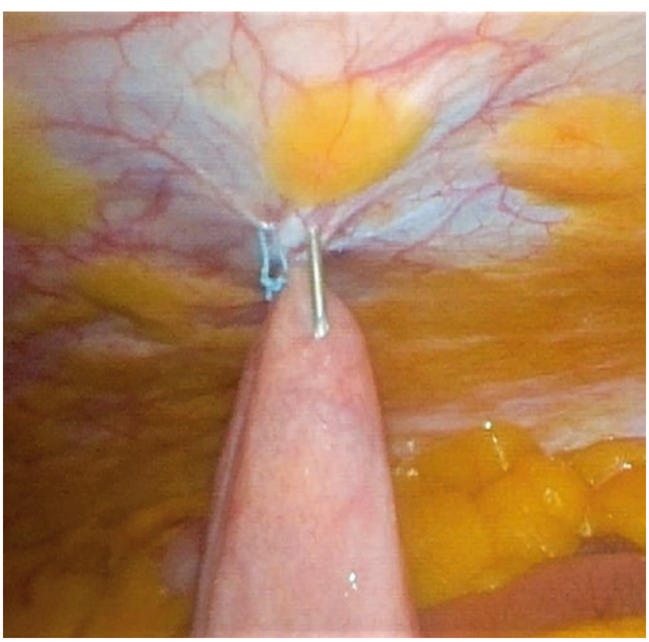


Fig. 34.19 Jejunostomy. Placement of access needle

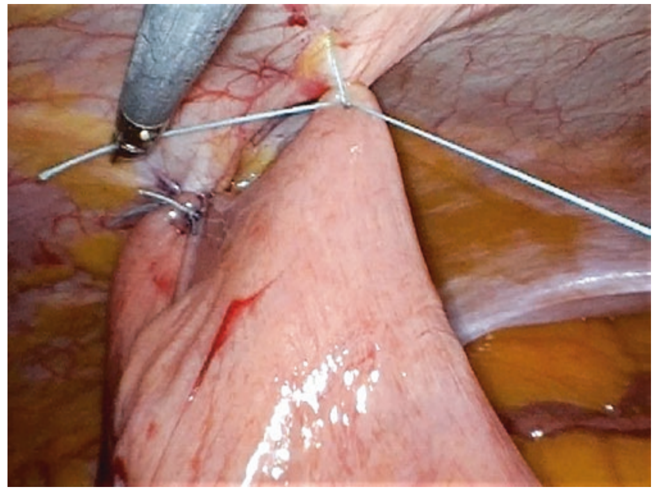


Fig. 34.20 Final view of the feeding jejunostomy with antitorsion stitch

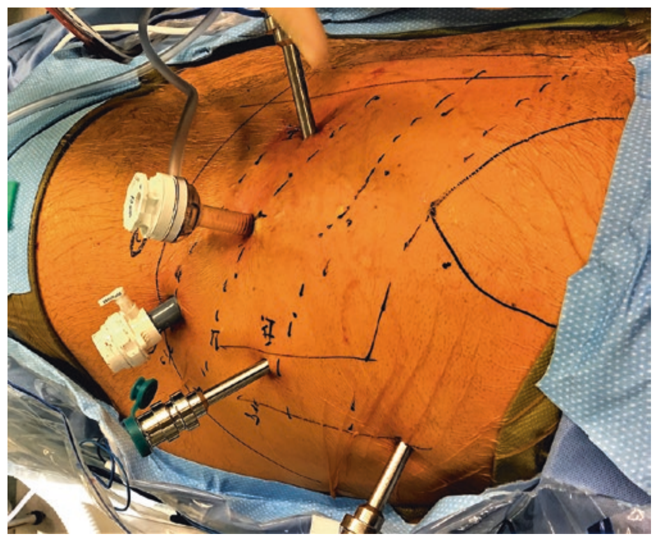


Fig. 34.21 Placement of the robotic ports for the thoracic part of Ivor Lewis esophagectomy

because of creation of the anastomosis, as opposed to the simple dissection, the location and number of ports differs from McKeown modification (Fig. 34.21). If robotic stapler is available, a 12 mm robotic stapling port is placed in the 8th ICS anterior axillary line. Two other robotic 8 mm ports are then placed also in the 8th ICS at the posterior axillary line and lateral to the paraspinal muscles. A third robotic 8 mm port is placed in the fifth ICS midaxillary line for retraction. If the plan is for robotic linear stapled anastomosis, we only place an 8 mm assistant port at the 9th ICS at the midclavicular line. However, if bedside stapling is planned, a 15 mm port is placed in the anterior axillary line through the diaphragm attachments below the costal margin.

The superior robotic arm is used mainly for retraction, utilizing an atraumatic double fenestrated or tip-up fenestrated forceps. The right hand will use mainly the bipolar Vessel Sealer, alternating with the robotic stapler. The left arm will mainly use the bipolar fenestrated or Cadiere forceps to assist in dissection, exposure, and hemostasis.

Steps of the Thoracic Procedure

The lung is retracted anteriorly and the inferior pulmonary ligament is divided. The mediastinal pleura is opened longitudinally both anterior and posterior to the esophagus up to the level of the azygos vein arch. The vein is then circumferentially dissected free and divided with the robotic or handheld linear vascular stapler. The thoracic esophagus is then mobilized circumferentially with all the surrounding lymphatics and fatty tissue in between the azygos vein, aorta, and pericardium including a complete mediastinal nodal dissection. The vagus nerve is divided bilaterally below the recurrent laryngeal nerve takeoff.

After completing the circumferential dissection of the esophagus, the specimen and attached to it conduit are delivered into the chest, until the caudal end of conduit staple line is visible above the diaphragm (Fig. 34.22). Attention is paid to maintain proper orientation of the conduit to avoid axial torsion during the conduit delivery. The NGT is pulled back to 20 cm, and the esophagus is divided with a linear stapler just above the azygos vein arch (Fig. 34.23). The specimen is placed anteriorly to the lung until completion of the anastomosis.

There are different techniques for the formation of the anastomosis. We prefer a robotic side-to-side linear stapler technique. The conduit is placed in the native esophageal bed and medial to the esophageal stump. The conduit is secured to the medial aspect of the esophagus with two 2-0 silk sutures. The stapled end of the esophagus is opened at the medial end of the staple line. Likewise, a gastrotomy is created in the lateral aspect of the conduit. A 45 mm robotic linear stapler is advanced into the lumen of the esophageal stump and gastric conduit and fired, creating the anastomosis (Fig. 34.24). Under direct vision the NGT is advanced into the caudal portion of the conduit. The enterotomy of the esophagogastrostomy is approximated with 2-0 silk stitches and then reinforced by firing another linear stapler (Fig. 34.25).

Another technique of the esophagogastrostomy is utilizing a circular stapler for the creation of the end-to-side anastomosis. The entire esophageal staple line is resected using the Vessel Sealer. The assistant port is removed and enlarged to accommodate EEA anvil which is then passed inside the esophageal lumen. A purse-string running suture is applied

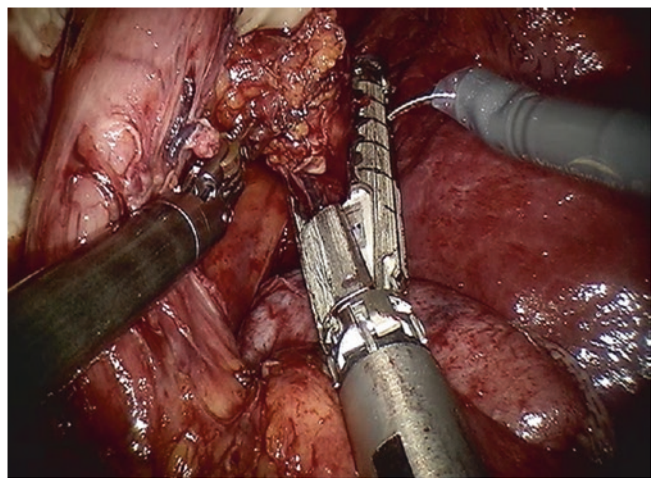


Fig. 34.23 Proximal division of the esophagus with the linear stapler

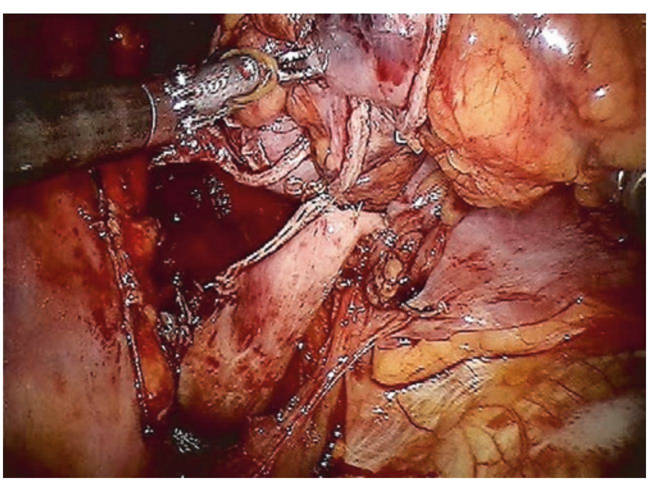


Fig. 34.22 Delivery of the specimen and attached to it conduit into the chest

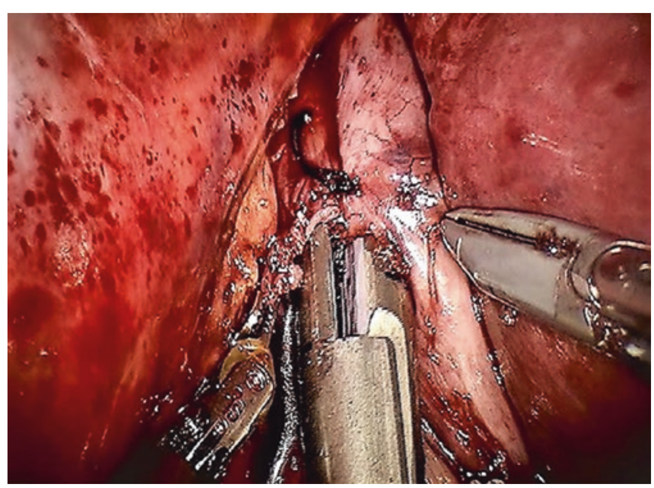


Fig. 34.24 Placement of the linear stapler for the esophagogastric anastomosis

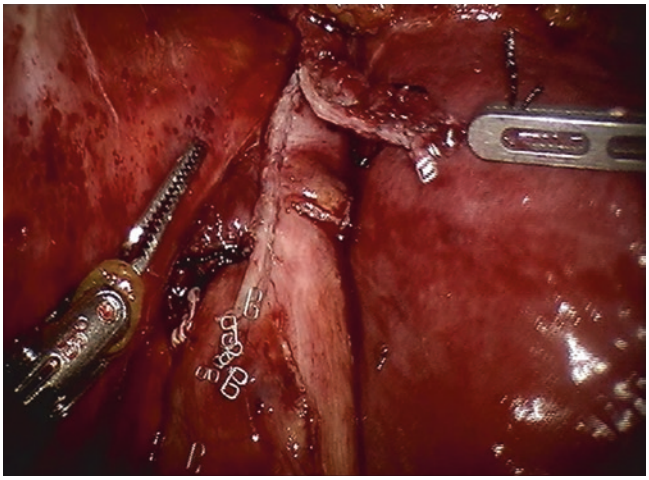


Fig. 34.25 Closure of the esophagogastrostomy with linear stapler

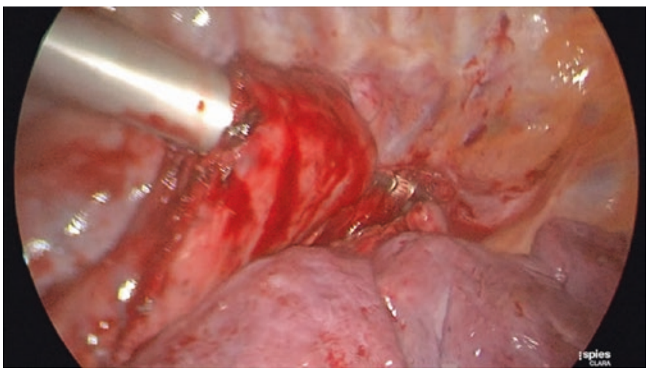


Fig. 34.26 Technique of esophagogastrostomy with circular EEA stapler

around it with 3-0 Prolene. A gastrotomy is made at the tip of the conduit, and the EEA stapler is advanced into the lumen. The spike is pushed through the conduit wall, opposite to the staple line, engaged to the anvil, tightened, and then fired, creating a circular anastomosis (Fig. 34.26). The tip of the conduit, containing the opening, is then transected with a linear stapler, providing closure. Specimen is retrieved in the plastic bag.

Alternatively, OrVil can be used for the placement of the EEA anvil. It represents an anvil, attached to the long plastic tube, which can be advanced transorally. Whereas it facilitated the placement by avoiding the need of the purse-string stitch, it comes in smaller sizes (not large than 25 mm) that potentially can contribute to stricture formation and in author's experience can fail to deploy appropriately for firing.

The diaphragmatic hiatus is closed with interrupted silk stitches around the conduit which is sutured to the right crus with 2-0 silk.

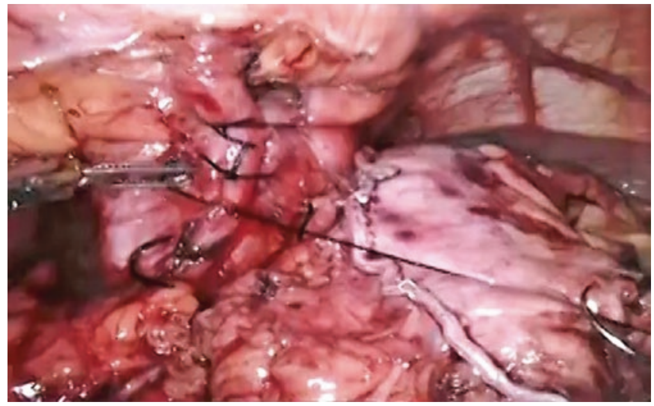


Fig. 34.27 Closure of the hiatus with nonabsorbable sutures

Finally, a flexible 24 French flexible drain is placed along the posterior esophageal gutter. The robotic instruments are then removed, the robot is undocked, and the incisions are closed.

Extra-anatomic Substernal Reconstruction

Immediate reconstruction after esophagectomy almost always positions conduit in the native, posterior mediastinal bed. In cases of delayed reconstruction, when native bed is scarred and obliterated, palliative resection and esophageal bypass alternative routes might be employed. Among those, substernal route is most commonly utilized.

Patient is placed in supine position with the neck hyperextended and the head turned to the right. If jejunostomy was previously established, left flank ports need to be placed superior and medial to jejunostomy loop.

Abdominal Part of the Procedure

Initial port placement and conduit dissection is similar to previously described. Hiatus is dissected, and the esophagus is mobilized maximally high into posterior mediastinum if it hasn't been done before. The esophagus is divided with linear stapler as high as in the mediastinum as possible. Hiatus then is completely closed in the interrupted fashion with nonabsorbable stitches (Fig. 34.27).

Sternal part of the diaphragm is dissected off of the posterior table of the sternum for approximately 5 cm. With blunt and sharp dissection with both working arms, pericardium and mediastinal tissue is mobilized off of the sternum, creating retrosternal tunnel.

Left Cervicotomy

Neck dissection is started simultaneously and performed as previously described. In delayed reconstruction cases, esophagostomy is dissected from the skin, and esophagus is

Fig. 34.28 Connection of the cervical and substernal dissection planes with surgeon digit identified in the tunnel

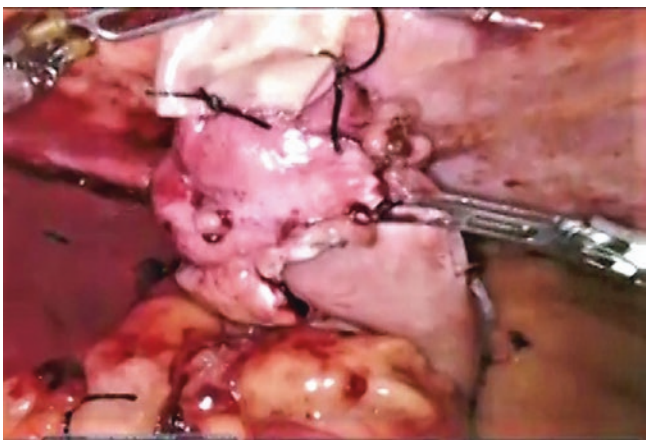


Fig. 34.29 Conduit is secured to the Penrose drain and is delivered to the neck

mobilized for the sufficient distance for the anastomosis. Resection of the left sternoclavicular junction is performed next to prevent conduit compression and obstruction. Digital dissection is carried caudally, over the aortic arch to meet the dissection plane from the abdomen (Fig. 34.28).

Delivery of the Conduit and Anastomosis

Umbilical tape is advanced from the cervicotomy wound into the abdomen through the tunnel and secured to the specimen, which is removed. At this point (Fig. 34.29), cervical anastomosis is performed in one of the previously described fashions.

Postoperative Management

Patients typically remain in the hospital until their thoracic and nasogastric drains are removed. This is usually achieved by postoperative days 4–5. They are discharged on enteral nutrition via the jejunal tube. A water-soluble esophagram is performed as an outpatient procedure on postoperative days 10–14. When an esophageal leak is ruled out, the patient's diet is advanced to oral fluids and later soft food. The diet is progressively advanced until full calorie intake is met via oral route. At this point, enteral nutrition is ceased, and if the patient maintains weight and oral intake, the jejunostomy tube is removed several weeks later. Postoperatively patients require rigorous support and are advised of lifestyle and diet modification with small frequent meals, avoiding eating before bedtime, sleeping with the head of bed elevated, and remaining on proton pump inhibitors (PPI) twice a day for life [25, 26].

Early Postoperative Complications

Cardiac Arrhythmias

Cardiac arrhythmias, especially atrial fibrillation, are common after thoracic surgical interventions. Development of the arrhythmia has been associated with anastomotic leaks. Rate and rhythm control is usually achieved with beta blockers and calcium channel blockers and amiodarone. Anticoagulation can be started when it is safe from surgical standpoint [27–29].

Anastomotic Leaks

Anastomotic leak is defined as disruption of the integrity of the anastomosis, resulting in transposition of luminal content outside of the confines of the esophagus. Anastomotic leaks can be classified as grade 1/subclinical (radiological, biochemical), not requiring change in management; grade II/clinical minor, requiring conservative management without anastomotic intervention; grade III/clinical major, requiring reintervention; and grade IV/conduit necrosis, requiring surgical diversion [30].

Anastomotic leaks usually present after the fifth postoperative day and could be as late as 3–4 weeks postoperatively. Once identified, endoscopy is performed to evaluate the extent of the dehiscence and rule out gastric tip necrosis. The leak is treated according to the extent of the anastomotic dehiscence. In cases of disruption of less than 50% of the circumference, conservative management with simple drainage or exclusion with covered stent is utilized [31, 32]. In cases of cervical anastomosis, the incision is opened to allow drainage of infection. Serial esophageal dilation to prevent structuring and distal obstruction seems to facilitate healing as well [4, 30]. Cases with complete disruption of the anastomosis are treated as gastric tip necrosis [30, 33, 34]. Application of new endoscopic suturing overstitch device has been reported for the closure of fistulas, however, was less successful for management of anastomotic leaks [35].

Gastric Tip (Conduit) Necrosis

This is a rare but potentially lethal complication related to ischemia of the gastric conduit. This usually requires takedown of the anastomosis with resection of the ischemic portion and diversion of the esophagus with a cervical esophagostomy [30]. The remaining healthy portion of the stomach is repositioned into the abdomen, and the hiatus is closed. Delayed reconstruction with either preserved remnant of gastric conduit or alternative conduit can be performed. It is recommended to perform gastrostomy to the tip of the conduit with bolus feeds postoperatively to avoid gastric conduit contraction. It is necessary to identify these cases early to avoid the onset of sepsis [16, 19, 33, 34]. Firefly technology helps in assessment of the conduit perfusion and has a potential of decreasing incidence of the anastomotic leaks [20, 21].

Airway Injury

It is a devastating complication, regardless of the approach. Intraoperative occurrence usually immediately detected. Presentation in early postoperative period is believed due to thermal injury to the posterior membranous portions of the airway during mediastinal dissection. Once identified, it requires swift and radical intervention as delay leads to the development of the conduit airway fistula and results in severe lung soilage, sepsis, and unsalvageable situation. Repair requires thoracotomy with muscle flap buttressing of the airway and usually a takedown of the conduit with diversion esophagectomy and delayed reconstruction via extra-anatomic routes [36–38]. Attempts of palliating with stents usually only delay the inevitable [39].

Chylothorax

Prevention is the best management of thoracic duct injury. Preoperative administration of either heavy cream or vegetable oil has been shown to improve identification of the duct and decreased incidence of injury [40]. Some authors advocate routine thoracic duct ligation to prevent this occurrence [41]. Although low-volume chylothorax, presumably due to small side branch injury, can be successfully treated with conservative measures such as fasting, octreotide, and TPN, most will require definitive intervention. Delayed repair may predispose to malnutrition, immunodeficiency, and dehydration. Ligation of the thoracic duct can be performed surgically via right chest approach. Administration of cream or olive via jejunostomy tube helps in identifying the source of chyle leak [42]. Alternatively, cisterna chyli embolization can be attempted, but this requires robust IR support and has various degree of success [43].

Vocal Cord Paralysis

Although this complication is secondary to retraction and is usually self-limited, it may impact on the patient's ability to clear pulmonary secretions and predispose patient to aspirations. Thorough speech pathologist evaluation is required postoperatively. If patient is aspirating, oral intake can be safely postponed with enteral nutrition until patient can undergo medialization or thyroplasty [5, 44, 45].

Conduit Obstruction

Early conduit obstruction is due to technical errors during conduit positioning and creation of the anastomosis. Axial torsion or kinking of the conduit can occur. As such, the best management is prevention of this occurrence with meticulous attention to details during this part of the procedure. If identified early, especially intraoperatively, the best course of action is takedown and redo of the anastomosis. Many surgeons believe that conduit obstruction and subsequent leak can be due to pylorospasm as a consequence of denervation and routinely perform either full pyloroplasty or medical pyloromyotomy. Others avoid pyloric draining procedures in consideration of later complications such as dumping and bile reflux [32, 46, 47].

Late Complications

Anastomotic Stricture

Typically, patients present with late-onset dysphagia up to a year postoperatively. It is more common in patients who experienced anastomotic leak postoperatively. Usually, this can be managed endoscopically by serial endoscopic dilations. Repeat and maintenance procedures might be required. Refractory strictures may be ameliorated with temporary self-expanding covered stents, placed for 4–6 weeks. In severe cases, endoscopic incision or surgical structureless can be considered [48, 49]. Endoscopic injection of the steroids has been shown to decrease rate of restricturing and number of the repeat interventions [50, 51].

Hiatal Hernia (Paraconduit Hernia)

This occurrence seems to be unique after minimally invasive esophagectomies believed to be related to inadequate hiatal closure and diminished adhesions formation postoperatively. These hernias do not have a sack, and significant portions of small and large bowel can translocate into the chest, compromising respiratory mechanics and increasing the risk of strangulation. Surgical repair may be approached by means of a thoracotomy on the side of the herniation or laparotomy. Minimally invasive approaches have been reported successful as well [52–54].

Delayed Conduit Emptying

This can lead to stasis in the conduit, chronic aspiration, and malnutrition. Thorough investigation is required to determine the cause of the problem. If pyloric drainage procedure has not been performed, pyloric obstruction can be the cause. Initially, endoluminal interventions (balloon dilation, botulinum toxin injection) can be trialed. Definitive drainage can be achieved with surgical pyloroplasty. Promising results have been reported with gastric peroral endoscopic myotomy (GPOEM) procedure [55].

Conduit Redundancy

This is a consequence of a long-standing vagotomized conduit in the negative pressure environment of the chest, leading to conduit elongation and dilation with tortuosity and kinking. Patients present with dysphagia, chronic aspiration, and malnutrition, usually many years after the procedure. Distal obstruction from pylorospasm might play a role and needs to be addressed. Reoperation might be the only option in severe cases. Careful dissection with preservation of vascular pedicle of the conduit is necessary. After complete intrathoracic conduit mobilization, abdominal part commences with careful dissection of the hiatus. Subsequently, conduit is straightened by pulling down to eliminate redundancy. The hiatus is closed and pexy of the conduit to the hiatus is performed. Re-resection of the conduit with anastomosis at proximal end is rarely required. Retubularization of dilated conduit along previous stapling line might be performed [53, 56].

Tracheoesophageal Fistula (TEF)

This is a serious complication, and when it occurs, careful evaluation for malignancy recurrence is required. Endoscopic palliation with covered stents or endoscopic fistula closure is possible. In severe cases conduit takedown and extra-anatomic reconstruction might be undertaken [35–37, 57].

Reflux and Barrett's Esophagus

After esophagectomy with gastric conduit reconstruction, patient requires regular surveillance endoscopy to monitor for recurrence and development of Barrett's esophagus due to acid reflux. Lifelong diet and lifestyle modification and chronic maximal dose PPI use are required. If patient develops Barrett's esophagus, aggressive endoscopic treatment is required to prevent progression to metachronous malignancy [58, 59]. In cases of uncontrolled debilitating reflux, conversion to Roux-en-Y or colon interposition has been described [60]. The use of pyloric drainage procedure was associated with increased prevalence of reflux esophagitis [46, 47].

Recurrent or Metachronous Malignancy

Esophageal cancer usually recurs systemically with distant metastasis. However, even local recurrence carries poor prognosis. Recurrent malignancy usually develops within the first 3 years and occurs from regrowth of tumor deposits in the surrounding tissues and lymph nodes. It is rarely salvageable; however, long-term survival has been reported in select group of patients [61, 62]. Usually, palliative interventions for lumen restoration and enteral access are undertaken with savage chemoradiation.

Metachronous malignancy usually develops many years later and, due to mucosal origin, sometimes might be re-resected. In cases of previously low anastomosis with enough length of esophageal stump, repeat resection and potential diversion or even extra-anatomic reconstruction may be feasible. For early-stage malignancies, endoscopic resection can be undertaken [63].

Outcomes of Robotic Esophagectomy

Published Robotic Esophagectomy Series (Table 34.1)

The application of laparoscopic and thoracoscopic techniques in esophageal cancer surgery has been well established [16]. The robotic technology with its included digital processing offers additional advantages, particularly depth perception due to tridimensional view, wristed motion, magnification, Firefly, and surgeons' total control of all arms including camera and the stapler. The first robotic thoracoscopic mobilization of the esophagus was reported by Bodner and coauthors in 2004 in four patients along with the other procedures [64].

In 2007 Kernstine et al. reported one of the early series of totally robotic McKeown esophagectomy. Of 14 patients, 8 had completely robotic procedures. Total average operating

Table 34.1 Outcomes of published robotic esophagectomy series

Author and year	Number of patients	Surgical approach	Procedure type	LOS	OR time total/consol	LN yield	Morbidity	Mortality (30 days/90 days)	Leak rate/conduit necrosis
Kernstine, 2007	14	RT, RL – (8)	MKE	8–72	11.1 (9.5–13.2)/5.0 (4.2–5.9), hrs	18 (10–32)	93% (minor), 29% (major)	0/7.1%	14.3%/–
Sarkaria, 2013	21	RT, RL	ILE – 17, MKE – 4	10 (7–70)	556 (395–807)	20 (10–49)	24%	/4.9%	14%/0
Abbas, 2013	33	RT, RL	MKE	7 (4–31)	310 (270–340)	16 (7–44)	39	3/3	6%/
Dylewski, 2013	20	RT, RL	–	9	303	–	–	/10%	15%/
Carrera, 2015	32	RT, RL	MKE – 11, ILE – 21	12	Console time 218 (190–285)	16	28.1	3.1%/	21.875% /3.125%
Cerfolio, 2015	85	RT (85), CL (79), RL (5), OL (1), (conversion)	ILE	8	361 (283–489)	22	36.4%	3.5/10.6	4.3%/2.3
Hodari, 2015	54	RT, CL	ILE	12.9 (7–37)	362 (260–516)	16 (3–35)	–	0/1.8%	5.5% + 1.8% (staple line)
Park, 2016	114	RT, CL/OL	MKE	16	419.6 ± 7.9 (consol time 206.6 ± 5.2)	49 ± 1.9	–	3.5%/2.5%	14.9%
Chiu, 2017	20	RT, OL (2), CL (18). Exteriorized conduit	MKE	13 ± 6	499 ± 70	18 ± 13	–	–	15%/
Okusanya, 2017	25	RT, RL. Conversion (CT 3, OL 1)	ILE	8 (6–20)	661 (503–902)	26 (11–78)	–	4%	0/0
Amaral, 2017	237	RT, RL/CL	ILE	9	–	–	–	–	15% (4% clinical)
Luketich, 2012	1011	CT, CL,	MKE 481, ILE 530	8 IQR (6-14)		21	–	1.7% total, 2.5% MKE, 0.9% ILE /2.8% total,3.95% MKE, 1.7% ILE	

NB. Last study is presented for comparison as the largest minimally invasive esophagectomy series
MKE McKeown esophagectomy, *ILE* Ivor Lewis esophagectomy, *RT* Robotic thoracoscopy, *RL* Robotic laparoscopy, *CT* conventional thoracoscopy, *CL* conventional laparoscopy, *OT* open thoracotomy, *OL* open laparotomy

room time was 11.1 h with console time of 5.0 h. Major complications occurred in four (29%) of the patients – thoracic duct leak (one), severe pneumonia (one), anastomotic leak (two), and bilateral vocal cord paresis (one). There was one intraoperative right main stem bronchus injury. One patient died on POD 72 [65].

In another series by Sarkaria and colleagues, 16 (76%) out of 21 patients had received induction therapy. An R0 resection rate was achieved in 17 (81%) patients, and the median operative time was 556 min (range, 395–807 min), which decreased to 414 min (range, 405–543 min) for the last 5 cases in the series. The median number of lymph nodes resected was 20 (range, 10–49). Five patients (24%) had major complications. One (5%) died of complications on postoperative day 70, and three (14%) had clinically significant anastomotic leaks (grade II or greater). Three patients (14%) in this early experience developed airway fistulas [36].

Cerfolio and coauthors reported on his series of 92 patients, undergoing robotic Ivor Lewis Esophagectomy. Seven initial patients were excluded due to open abdominal part of the procedure. Of 85 patients with robotic thoracic part, laparoscopy was used in 79 (92.9%), robotic approach in 5 (5.9%), and conversion to laparotomy was required in 1 (1.2%) patient due to stapling failure. Total procedure time (skin to skin) was 360 min with average blood loss on 35 ml and no intraoperative transfusions. Median lymph node yield was 22 and R0 resection was achieved in 99% (84/85). Median hospital stay was 8 days (5–46 days). Morbidity occurred in 31 (36.4%) patients. Four patients had anastomotic leak and two had conduit necrosis requiring surgical intervention. Leaks occurred on average on POD 8 [4–15]. Thirty day in-hospital mortality was 3 (3.5%), and 90 days mortality was 9 (10.6%) [19].

Carrera and coauthors report on their experience of robotic esophagectomy. Of 51 cases of minimally invasive esophagectomy, 32 patients underwent robotic esophagectomy. There was 11 MKE and 21 ILE. Tumors located below 30 cm from incisors were treated with TTE and above that with MKE. Twenty-nine patients received induction therapy. The thoracic part was performed in the prone position, and hand-sewn anastomosis was performed. Average console time was 218 min (190–285). Blood loss was 170 min. One (3%) patient died from cardiac causes. Major complications (Dindo-Clavien grade II and up) occurred in nine (28%) patients. Mean LOS was 12 [8–50] days. All patients had R0 resection, and median LN yield was 16 [2–23]. In 21 patients with ILE, 4 (19%) patients developed grade I leak, all treated with covered stent placement. One (5%) patient developed grade IV leak, failing stenting and requiring surgical diversion. There were four (19%) cases of chylothorax, two of which required surgical reintervention. In the 11 patients of MKE group, 2 (18%) patients developed grade II leak, treated conservatively, and 1 (9%) grade IV leak, requiring diversion [66].

Hodari et al. reported on their experience with hybrid ILE in 54 patients. Authors performed laparoscopic abdominal part of the procedure with robotic thoracic part. Authors estimated that with the need of robot docking and undocking, robotic abdominal part will extend the total timing of the procedure for up to an hour. Forty-six (85%) had adenocarcinoma and 3 (6%) had squamous cell carcinoma histology. Thirty-eight (70%) patients underwent induction therapy. Authors utilized Firefly technology for real-time perfusion assessment of the conduit. Of the total 3 (20%) leaks, all happened in first 15 patients, prior to the use of perfusion assessment. One leak was traumatic due to reintubation and perforation by nasogastric tube, requiring surgical closure with muscle flap. One more leak from conduit staple line was due to technical error of stapling the NGT, requiring hand-sewn closure. Mean ICU stay was 4.6 days and hospital stay of 12.9 days. All patients had R0 resection. Average LN yield was 16.2 (range 3–35) [21].

Park with coauthors summarized his experience in robotic-assisted thoracoscopic esophagectomy (RATE) vs standard thoracoscopic esophagectomy. Authors utilized robotic thoracoscopic mobilization with lymphadenectomy and laparoscopic (84 (73.7%) or open (30 (26.3%) abdominal part in McKeown esophagectomy. In the group of 114 patients, 110 patients had squamous cell carcinoma. Fifteen (13%) received induction therapy. All but one patient underwent RATE. Five patients had salvage esophagectomy. Total operation time was 419.6 ± 7.9 min with robot console time of 206.6 ± 5.2 min. Pulmonary complications developed in 11 patients (9.6%). Seven patients (6%) needed reintubation or prolonged ventilator therapy in the ICU. RLN palsy was observed in 30 patients (26.3%): unilateral in 27 patients (23.7%) and bilateral in 3 patients (2.6%). Anastomotic leak developed in 17 patients (14.9%), and most of these were treated by drainage only. Reoperation was required in five patients (4.4%). Ninety-day mortality was 2.6% due to pneumonia [18].

In 2017 Park et al. in a follow-up analysis reported on the oncologic feasibility of his technique. Three years overall survival for the group was 85% and recurrence-free survival 79.4%. Subgroup analysis demonstrated 3-year OS was 94.4% in patients with stage I disease, 86.2% in patients with stage II disease, 77.8% in patients with stage IIIA disease, and 37.5% in patients with stage IIIB/C disease. The 3-year RFS was 96.2% in patients with stage I disease, 80.1% in patients with stage II disease, and 79.5% in patients with stage IIIA disease. Tumor recurrence within 2 years after operation developed in more than 80% of patients with stage IIIB/C disease. Authors believe these excellent outcomes related to high rate of R0 resection (97.4%) and high lymph nodes yield [49, 67].

Reporting on the Moffitt Cancer Center experience, Amaral and coauthors analyzed results of the 237 patients, undergoing robotic-assisted esophagectomy [68]. Fifteen percent of the patients developed anastomotic leak; however, only 4% required an intervention.

Senior author of this chapter has published his experience of 33 robotic esophagectomies in 2013 [24]. All patients underwent robotic-assisted MKE. Postoperative complications developed in 39% of patients, with anastomotic leaks and chylothorax in 6% each. Mortality occurred in one (3%) patient on POD 12 due to mesenteric ischemia. Since that time the group experience has expanded, and presently an analysis of outcomes is underway.

Currently there is a monocenter randomized controlled trial underway, comparing result of robotic assisted vs open esophagectomy [69]. Publication of the results is anxiously awaited.

In summary, robotic surgery appears to offer advantages in surgical management of patient with esophageal cancer and benign conditions, requiring esophagectomy. Thorough staging workup is still obviously required. Meticulous surgical technique, diligent postoperative care, and timely intervention for management of complications are required for the best outcomes. In the foreseeable future, with rising adoption and increased affordability of the robotic technology, we fully expect near universal adoption of the robotics in the area of esophagectomy.

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