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# Optimizing the technical results of robotic esophagectomy: conduit creation and esophagogastric anastomoses

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## Abstract

The esophagectomy, first done over a century ago, has evolved from open procedures to minimally invasive techniques. As minimally invasive surgery has progressed in both safety and efficiency since its inception, it is becoming increasingly favored and continues to demonstrate advantageous outcomes over open techniques. In terms of operative decisions, conduit diameter choice is crucial in esophagectomy. Narrower conduits (≤ 3 cm) seem to be more efficacious, and less prone to stricture than their wider counterparts (> 5 cm). Perfusion assessment, notably with indocyanine green (ICG), is still a topic of debate among surgeons with conflicting opinions on ICG's impact. There are varying results in leak rates; however, the use of ICG in determining anastomotic site seems to exert some influence on surgical decision-making. Anastomotic techniques, such as circular stapling and linear stapling, have shown to be preferred over more traditional hand-sewn methods. At our institution, a completely robotic approach is used with creation of a 3-4 cm wide conduit and hybrid-type anastomosis. ICG is used to guide conduit transection and gastrotomy for anastomosis. Our experience shows that this approach offers an excellent combination of safety and reproducibility.

**Keywords:** Robotic assisted, minimally invasive, esophagectomy, conduit diameter, indocyanine green, stapled anastomosis

## INTRODUCTION

The esophagectomy has been a fundamental treatment for esophageal neoplastic disease since the early 20th century. As medicine evolved, so did the technique. In 1996, Dr. Jim Luketich reported the first fully minimally invasive esophagectomy (MIE). The efficacy of the minimally invasive approach in esophagectomy surgery was scrutinized in a 2012 multicenter randomized controlled trial conducted by Biere *et al*.[1]. According to their findings, patients subjected to MIE exhibited notably reduced rates of in-hospital pulmonary infections (34% *vs.* 12%, $P = 0.005$), shorter average hospitalization stays (14 *vs.* 11 days, $P = 0.04$), and comparable rates of anastomotic leakages[1]. Subsequent to this, a systematic review and meta-analysis, published in 2019 that encompassed 55 studies with over 14,000 patients, described that the minimally invasive approach yielded a five-year mortality rate of 18%, lower than that associated with the open approach[2]. These studies collectively provide evidence supporting that minimally invasive surgery stands as not only a secure option for esophagectomies but conceivably the preferred and safest approach.

The introduction and Food and Drug Administration (FDA) approval of the Da Vinci surgical system in 2000 saw robotics becoming a cornerstone of minimally invasive surgery. In 2002, the first reported robotic esophagectomy was completed by Melvin *et al.*[3]. Since then, the advantages of robotic assisted MIE (RAMIE) have been demonstrated in studies such as the famous "ROBOT trial", published by Van der Sluis *et al.* in 2012 and updated by a long-term follow-up study in 2020[4,5]. In a meta-analysis published in 2022, patients who underwent RAMIE showed significantly lower rates of pulmonary complications, wound infections, blood loss, and shorter hospital stays when compared to open esophagectomies[6]. This gives us evidence that a robotic approach is a safe and effective means for minimally invasive esophagectomies.

To further expand on the validity of the robotic approach, in 2019, Jin *et al*. published a systemic review and meta-analysis on comparing RAMIE to conventional MIE[7]. In this review of eight case-control studies that looked at over 1,800 esophagectomy patients, it was found that patients undergoing the RAMIE approach had significantly less estimated blood loss and lower rates of recurrent laryngeal nerve injury[7].

While robotic esophagectomy has proven effective, the optimization of the technical details of such an operation has elicited greater debate. In this article, we will discuss conduit creation during robotic Ivor Lewis (transthoracic) esophagogastrostomy, specifically optimal conduit diameter size, the use of indocyanine green (ICG) fluorescence to evaluate perfusion, and ideal anastomotic techniques to reduce rates of anastomotic leaks and strictures.

## DIAMETER OF CONDUIT

A critical factor to consider in conduit creation is the diameter of the conduit. Selecting the correct diameter is crucial to prevent post-operative reflux, anastomotic stricture, and anastomotic leakage. In standard practice, most gastric conduits range from three to five centimeters in diameter, with < 3 cm considered narrow and > 5 cm considered wide. A 2020 study by Zhu *et al*. indicated that gastric conduits > 5 cm in diameter were independently associated with benign anastomotic stricture, particularly in circularly stapled anastomoses[8]. As summarized in Table 1, the findings of the first three studies [Zhu *et al.* (2020), Shen *et al.* (2014), and Zhen *et al.* (2016)] indicate that gastric conduits 3 cm in width had lower rates of anastomotic leaks compared to their wider (> 5 cm width) comparison group (8.7% *vs.* 17.3%, $P = 0.041$). Additionally, conduits < 3 cm in width were associated with lower rates of delayed gastric emptying compared to both a medium width group (3-5 cm) and a wide width group (> 5 cm)[8-10]. This topic is still an area of active research, and more information is needed to arrive at a conclusive determination regarding the consequences of different conduit diameter choices.

**Table 1. Summary of gastric conduit diameter and ICG fluorescence studies**

| Author(s), year | Aim of study | Study design | Comparison groups | Results |
|---|---|---|---|---|
| Zhu *et al.*[8], 2020 | Comparison of wide and narrow gastric conduit width and association with BAS | Retrospective single-center study (*n* = 201) | Wide conduit creation (> 5 cm width, *n* = 116) compared to narrow conduit creation (3-5 cm width, *n* = 85) | Wide conduit width was an independent risk factor for BAS development (OR = 2.84, *P* = 0.02) |
| Shen *et al.*[9], 2014 | The effect of conduit diameter on anastomotic leakage following MIE | Retrospective single-center study (*n* = 259) | Wide conduits (5 cm width, *n* = 133) compared to narrow conduit (3 cm width, *n* = 126) | Incidence of anastomotic leakage was significantly lower in the narrow group (3 cm) than in wide group (5 cm) (8.7% *vs.* 17.3%, *P* = 0.041) |
| Zhen *et al.*[10], 2016 | The effect of gastric conduit width on gastric emptying following Ivor-Lewis's procedure | Retrospective single-center study (*n* = 282) | Wide conduit (> 5 cm width, *n* = 93) *vs.* medium conduit width (3-5 cm, *n* = 70) *vs.* narrow conduit width (< 3 cm, *n* = 119) | The incidence of delayed gastric emptying between wide, medium, and narrow groups was 17.2%, 14.3%, and 3.4% respectively Wide and moderate groups had higher incidence of delayed gastric emptying compared to narrow groups (*P* = 0.001 and *P* = 0.006) |
| Pather *et al.*[13], 2021 | The efficacy of intraoperative use of ICG to assist with visualizing profusion in robotic assisted MIE | Retrospective single-center study (*n* = 100) | "Good" perfusion of conduit (brisk ICG visualization) *vs.* non-perfusion (any demarcation present on conduit) | Anastomotic leaks occurred more frequently in the non-perfusion (67%) versus the good perfusion category (33%, *P* = 0.03)<br>On multivariable analysis, non-perfusion (OR 6.60; *P* = 0.04) independently associated with leak |
| Slooter *et al.*[14], 2019 | A systemic review to provide an overview of current practice of ICG use during esophagectomy | Systemic review and meta-analysis | A total inclusion of 22 articles that assessed the use of ICG to judge conduit profusion during esophagectomy | The final meta-analysis concluded that less anastomotic leakages and graft necrosis occur in the ICG prefusion assessment group (OR 0.30, 95%CI: 0.14-0.63) |
| Casas *et al.*[15], 2021 | To determine usefulness of ICG fluorescence imaging to assist in preventing anastomotic leak in totally MIE | Systemic review and meta-analysis | Comparison of anastomotic leak, mortality rates, and length of stay in ICG group (*n* = 381) *vs.* non-ICG group (*n* = 2,790) in esophagectomy | The risk of leak was similar between groups (OR 0.85, 95%CI: 0.53-1.28, *P* = 0.45) Mortality was 3% (95%CI: 1%-9%) in patients with ICG and 2% (95%CI: 2%-3%) in those without ICG. Median length of hospital stay was similar |
| Banks *et al.*[16], 2023 | To assess how anastomotic evaluation using ICG during MIE affects outcomes | Retrospective, single-institution study | Comparison of ICG (*n* = 59) *vs.* non-ICG groups (*n* = 122) in MIE | ICG patients experienced higher anastomotic leak rate (10.2% *vs.* 1.6%, *P* = 0.015) and higher 90-day mortality (8.5% *vs.* 1.6%, *P* = 0.038) compared with non-ICG patients |

ICG: Indocyanine green; BAS: benign anastomotic stricture; OR: odds ratio; MIE: minimally invasive esophagectomy.

## ICG USE IN PERFUSION ASSESSMENT

Ensuring adequate perfusion at both the conduit and anastomotic site is imperative to mitigate the risk of post-operative graft necrosis and the associated escalation in morbidity and mortality. One method employed for intraoperative perfusion assessment involves the utilization of ICG fluorescence. Specifically, ICG is an anionic water-soluble dye that is non-toxic and relatively safe in high doses[11]. ICG rapidly circulates which allows for quick intraoperative visualization. The liver serves as the main metabolic site and up to 90% of ICG is metabolized and excreted via the gallbladder within 24 h[12].

Anatomically speaking, it is believed that the right gastroepiploic vasculature predominantly perfuses most of the conduit, with the more proximal segments relying on smaller vessels, rendering them more susceptible to ischemia. The utilization of ICG remains a subject of ongoing debate.

A study encompassing 100 patients undergoing minimally invasive Ivor Lewis esophagectomy (MI-ILE) evaluated this. In this cohort, ICG proved useful in identifying well-perfused areas conducive to optimal conduit creation. Patients exhibiting incomplete perfusion of the gastric conduit were over six times more likely to experience an anastomotic leak compared to those with complete perfusion [odds ratio (OR): 6.6; 95%CI: 1.6-40.92; *P* = 0.04][13].

Continuing, the role of ICG in esophagectomies can be further explored by analyzing published systematic reviews. The systemic review and meta-analysis by Slooter *et al.*, published in 2019, indicated that ICG angiography significantly diminishes post-operative anastomotic leaks and graft necrosis[14]. However, a separate systematic review and meta-analysis of ICG use in MI-ILEs, conducted in 2021, opposed this. This review found no discernible differences in anastomotic leak rates, mortality, or length of stay between the ICG and non-ICG cohorts[15].

Interestingly, a 2023 single-institution study evaluating the efficacy of ICG in a sample of 181 (ICG $n$ = 59, non-ICG $n$ = 122) patients undergoing MI-ILE found individuals in the ICG group exhibited significantly higher rates of both anastomotic leakage (10.2% *vs.* 1.6%, $P$ = 0.015) and 90-day mortality (8.5% *vs.* 1.6%, $P$ = 0.038) in comparison to the non-ICG group. Notably, a subset of patients within the ICG group identified with "abnormal perfusion" of the conduit experienced significantly elevated rates of anastomotic leak, repeat interventions, and 30-day mortality compared to both the broader ICG group and the non-ICG group[16].

There is also the question of how the use of ICG intraoperatively affects a surgeon's decision-making. A 2022 study by De Groot *et al.* investigated this in the setting of RAMIE and found that the use of ICG (7.5 mg) after anastomotic site selection led to a change in anastomotic location in 14% of cases[17]. This provides some evidence that the ability to visualize perfusion intraoperatively does exert an influence on surgical decision-making. Of note, the cohort of 63 patients included in this study had an anastomotic leak rate of 22%.

Furthermore, LeBlanc *et al.* published a similar article in 2023 that investigated this same question, comparing two groups of RAMIE patients, 251 non-ICG patients to 61 ICG patients[18]. In this study, time to initial perfusion, time to maximum perfusion, and the surgeon's initial line of demarcation (prior to ICG injection) were used to assess ICG efficacy. They found no significant difference in anastomotic leak rates between the groups (non-ICG, 5.2% *vs.* ICG, 5.6%). Additionally, there were no significant differences in 30- and 90-day mortality between the groups. Intriguingly, of the patients within the ICG group who did develop an anastomotic leak, all had extended time to initial perfusion, time to total perfusion, and time to maximum perfusion. In terms of decision-making, a 15-patient cohort showed that a surgeon's observed line of demarcation of perfusion and the ICG-observed line of demarcation differed in 80% of cases by an average of 0.77 cm[18].

ICG also has use in detecting regional lymph nodes separate from the esophagus during MIE. A study published by Hachey *et al.* in 2016 showed that a mixture of ICG and human serum albumin was effective in detecting and identifying regional lymph nodes intraoperatively[19]. While this was done in a small cohort of ten patients, it still provides evidence for the potentially multifaceted use of ICG within the scope of neoplastic resection[19].

Due to the heterogeneity across the aforementioned studies, the use of ICG angiography and its efficacy remain debated among surgeons. At worst, it serves as a low-risk tool to help assess perfusion during conduit creation and locate an optimal anastomotic site on the conduit; thus, its use should be at the discretion of the surgeon.

## ANASTOMOSIS

One of the most critical aspects of esophagectomy is the esophagogastric anastomosis, which, according to the most recent meta-analysis, has a 9% incidence of anastomotic leak. This analysis also revealed that high-volume centers (> 37 esophagectomies per year) had lower esophageal leak rates compared to centers of lower volume [8.34% (95%CI = 7.54; 9.22) *vs.* 9.58% (95%CI = 8.76; 10.46), $P = 0.043$]. Furthermore, thoracic anastomosis was associated with a lower anastomotic leak rate compared to cervical anastomosis (5.55% *vs.* 10.06%, $P < 0.001$)[20].

With this in mind, there are numerous approaches to this anastomosis, and understanding common methods, their advantages, and disadvantages is imperative. The first method to consider is circular stapling; this technique uses an anvil (either trans-oral or intra-thoracic approach is possible) and a circular stapler. In the intra-thoracic approach, the anvil is inserted into the distal portion of the transected esophagus and secured in place using a combination of a so-called "baseball" stitch with an overlying purse-string for added security[21]. The trans-oral approach differs in the fact that instead of advancing the anvil portion of the mechanism into the distal esophagectomy directly, the anvil is guided through the oral cavity with the use of a plastic guide tube into the distal esophagus. A small linear incision is made on the esophageal staple line through which the plastic guide tube can be advanced by allowing for proper positioning of the anvil within the esophagus. Once the anvil is positioned properly for anastomosis, the plastic guide tube can be removed[22]. In both approaches, the staple spike is then advanced through a proximal gastrotomy, pushed through the gastric wall along the greater curvature, and connected to the anvil. After joining the anvil to the handle, the stapler is fired, the handle is removed, and the open end of the conduit is closed. If an omental flap was created, it can be wrapped around the staple line to provide an additional layer of security[21]. A propensity-matched study comparing trans-oral anvil placement to intrathoracic anvil placement in patients undergoing MI-ILE found that the trans-oral anvil approach resulted in significantly lower anastomotic leak rates (1.5% *vs.* 12.3%, $P = 0.033$), significantly lowered operating time (259 *vs.* 288 min, $P = 0.031$), and significantly lowered intraoperative hemorrhage (150 *vs.* 250 mL, $P \leq 0.001$) compared to patients that underwent intrathoracic anvil placement[23].

Another commonly used anastomotic technique is the linear staple method. This approach allows for the creation of a wider conduit but necessitates a longer gastric conduit to complete the anastomosis successfully. In this technique, a gastrotomy is created near the greater curvature of the posterior aspect of the gastric conduit. The transected end of the esophagus and the gastric conduit are then stapled together with a linear stapler, whether handheld by the assistant or robotically. The remaining opening can be either stapled or hand-sewn. Hand-sewn techniques are more time-consuming but may offer advantages by allowing more precise protection of the vascular supply to the conduit[24]. Anchoring sutures can be placed between the conduit and the right parietal pleura, particularly when performing an intrathoracic anastomosis. These sutures help relieve tension from the anastomosis and have been associated with reduced rates of anastomotic leakage[21].

With the multitude of approaches available for esophagogastric anastomosis, several studies have sought to discern the most effective techniques in terms of efficiency and outcomes. A randomized controlled trial conducted in 2007 compared circularly stapled intrathoracic anastomosis to cervical hand-sewn anastomosis and revealed no significant differences in anastomotic leak, stricture rates, or long-term post-operative outcomes[25]. Similarly, a 2012 randomized controlled trial comparing hand-sewn anastomosis to the linear staple technique for cervical esophagogastric anastomosis found no disparities in anastomotic leak rates between the groups. However, the linear staple method exhibited a faster average anastomosis time and a lower rate of anastomotic stricture at follow-up (20.7% *vs.* 8.6%, $P = 0.045$)[26].

In a non-randomized single-center study from 2015, which specifically assessed intrathoracic hand-sewn and linear staple techniques in 415 patients undergoing open Ivor Lewis esophagectomies, the hand-sewn technique demonstrated a higher rate of anastomotic leakage (20.9% *vs.* 10%, $P = 0.002$) and anastomotic stricture (20.3% *vs.* 6.3%, $P = 0.002$). However, overall morbidity, in-hospital mortality, and length of hospital stay did not significantly differ between the two groups[27].

A systemic review and meta-analysis of anastomotic techniques, published in 2020, reviewed 37 studies and included over 8,000 patients. The findings indicated that stapling techniques, especially the aforementioned linear staple method, had lower rates of anastomotic leaks compared to hand-sewn techniques. Additionally, the meta-analysis revealed that the linear staple technique exhibited lower rates of anastomotic stricture compared to both circular stapling and hand-sewn anastomotic techniques[28].

Other studies examine the results of various anastomotic techniques performed specifically in a minimally invasive setting. A retrospective study in 2019 by Zhang *et al.* evaluated 79 patients undergoing robotic Ivor Lewis esophagectomy and compared linear-stapled anastomosis to circularly stapled anastomosis[29]. The findings indicated that the linear staple method exhibited a longer mean anastomosis time (63.0 *vs.* 44.2 min, $P \leq 0.001$), with no significant differences observed in anastomotic leakage and post-operative dysphagia when compared to the circularly stapled group[29]. Additionally, a separate study, also published in 2019, evaluated different anastomotic techniques in the setting of totally minimally invasive transthoracic esophagectomy. In this study of 996 patients, it was found that the intrathoracic linear staple, circular staple with purse-string, and cervical linear staple approaches had significantly lower anastomotic leakage rates when compared to cervical hand-sewn techniques and intrathoracic circular staple using the double staple technique[30]. This is still a very active area of research within thoracic surgery, and the lack of published randomized control trials, specifically in the robotic setting, makes it difficult to declare one specific technique the best. However, the currently published studies support the notion that the stapled anastomosis is faster and does not contribute to increased rates of strictures, leakage, or mortality in the post-operative setting.

Researchers have studied whether the diameter of the circular stapler used affects esophagogastric anastomosis outcomes. A 2021 study published by Tagkalos *et al.* evaluated this question, comparing 25 and 28 mm circular staple diameters[31]. In their population of 349 Ivor-lewis patients, they found no differences between the groups in rates of anastomotic insufficiency or strictures[31]. A single-institution retrospective study by Feingold *et al.* of 391 patients showed that using the 28 mm diameter circular stapler was associated with a decreased need for additional dilations; however, this was not statistically significant[32]. While the issue of diameter in the context of circular staple technique is still being explored, the current evidence supports little impact.

Regardless of the chosen technique, the primary objective is to create an anastomotic junction that is free of tension and adequately perfused. Failing to achieve this goal can lead to conduit necrosis or anastomotic stricture, with potentially devastating consequences.

## PROCEDURE: HOW WE DO IT

### Preparation

We use a completely portal technique for the thoracic and abdominal phases of esophagectomy. We generally prefer an Ivor Lewis approach to resection, unless the tumor extends to 25 cm from the incisors or above, in which case a McKeown approach is taken. Standard preoperative testing for medical fitness for esophagectomy includes pulmonary function testing and a myocardial perfusion scan (stress test). Smoking cessation is strongly encouraged. Generally speaking, arterial lines and central venous lines are NOT part of our intraoperative preparation of the patient, unless there exist specific reasons for this (e.g., valvular heart disease, coronary artery disease, poor intravenous access). A Foley catheter is placed due to the extended length of the operation, which is typically between 4.5 to 6 h (including repositioning).

For an Ivor Lewis esophagectomy, the operation is started in the abdomen, and then finished in the thorax. For a Mckeown esophagectomy, the operation is started in the thorax, and then finished with the patient supine with an abdominal approach followed by anastomosis via a cervical incision.

### Abdominal phase

For the abdominal phase of the operation, a total of six ports are used: three 8 mm robotic ports, one 12 mm robotic port in the patient's right upper quadrant for stapling of the left gastric vessels and conduit creation, a 12 mm assistant port in the right lower quadrant, and a 5 mm liver retractor port were placed [Figure 1]. After port placement and robot docking, the peritoneum and liver are inspected for metastases. The lesser sac is entered by penetrating the greater omentum between the stomach and transverse colon, typically at the midpoint of the stomach. The greater omentum is divided from the transverse colon with a Vessel Sealer instrument (Intuitive Surgical; Sunnyvale, CA), moving from screen right to screen left, taking care to preserve the gastroepiploic vessels. A Kocher maneuver is performed to mobilize the duodenum, and the ability of the pylorus to easily reach the esophageal hiatus is confirmed. Then, the surgeon works from the initial point of entry into the lesser sac, dividing the tissue between the greater curvature of the stomach and the colon and/or spleen, working towards the proximal stomach. Attention to the location of the colon and avoiding thermal injury to the organ is paramount during this process. Extra omentum is left on the stomach in order to act as an omental flap used to buttress the anastomosis later in the case. The esophageal hiatus is dissected circumferentially, and the esophagus, along with periesophageal fat and lymphatic tissue, is dissected several centimeters up into the mediastinum. The posterior location of the aorta is noted and the structure is avoided during this phase of the operation. The right and left pleural spaces are often entered during mediastinal dissection; the anesthesia team should be informed of any entry into either pleural space as higher airway ventilator pressures may be needed to maintain tidal volume once the pleural space is opened. Hemodynamic instability can be caused by tension capnothorax (even if both pleural spaces are opened) due to a "one-way valve" effect resulting in continued insufflation of carbon dioxide into a hemithorax rather than equilibration of pressure across the diaphragm. This is treated by stopping insufflation and opening up the window to the pleural space, to allow the pressure to equilibrate. Any adhesions of the stomach to the retroperitoneum that could prevent easy repositioning of the conduit into the thorax need to be lysed. The left gastric artery and vein are skeletonized (the vein is typically located anteriorly) and divided with a robotic stapler (white load, 2.5 mm staple height). The pylorus was injected with 100 units of botulinum toxin diluted into 4 mL of normal saline, 1 mL in each quadrant of the pylorus anteriorly. A gastric conduit is then fashioned using the robotic stapler (green load, 4.8 mm staple height). We aim for a 4 cm or so diameter of the conduit, using the 2 cm size of the fenestrated bipolar forceps (Intuitive Surgical; Sunnyvale, CA) measured from tip to hinge as a guide. The proximal stomach is typically rotated posteriorly, which can lead to underestimating the width of the conduit at that level. After the second robotic staple fire on the stomach, a Penrose drain encircled around the distal stomach and grasped by the assistant with a firm retraction toward the patient's right lower quadrant, with counter-traction exerted by the grasper in the accessory arm of the robot, permits maximizing the length of the created conduit. The end of the staple line for the gastric conduit is located well away from the esophagogastric junction, typically at least 6 cm in distance from the angle of His along the pathway following the greater curvature of the stomach. We do not transect the conduit from the specimen in the abdomen to avoid needing to take extra time to suture the two together and experiencing a risk of suture breakage. If a Mckeown esophagectomy is being performed, we resect the lesser curvature of the stomach at

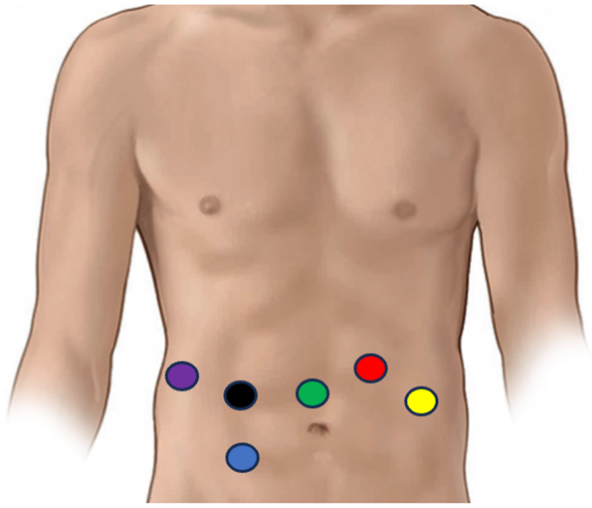

**Figure 1.** Robotic port placement for the abdominal phase of the RAMIE. Red: right arm; Green: camera; Black: left arm; Blue: assistant port; Yellow: accessory arm; Purple: liver retractor. Images provided by: Ron Slagter, license: Creative Commons Attribution-noncommercial-ShareAlike[34]. RAMIE: Robotic assisted minimally invasive esophagectomy.

the esophagogastric junction, in order to decrease the bulk of the specimen traveling through the thoracic inlet when the conduit is pulled up for the anastomosis. If an Ivor Lewis esophagectomy is being performed, the Penrose drain used earlier is stapled to itself and pushed up into the mediastinum, to be used for retraction during the thoracic phase of the operation. A jejunostomy tube is placed laparoscopically by inserting three 2-0 absorbable sutures into the proximal jejunum and exteriorizing the ends via a Carter Thomason needle. A 16 French jejunostomy tube is then placed via a modified Seldinger technique and secured with two #5 Ethibond sutures opposite from each other at the level of the skin to prevent inadvertent migration of the tube.

### Thoracic phase

After switching the single lumen to a double lumen endotracheal tube, the patient is placed in left lateral decubitus, with the patient rolled towards a prone position to allow the lung to drop away from the esophagus. Markings for the right, camera, and left robotic ports are placed in a line from the anterior axillary line to the right anterior superior iliac spine [Figure 2], ideally with 9 cm of spacing between the ports. The camera port is placed first and an intercostal nerve block is performed before placing the remaining ports. An accessory port is placed in the 10th or 11th intercostal space or so posteriorly, at least 9 cm away from the left robotic port. The camera is then placed in the accessory port to visualize placement of the remaining ports. The left robotic port is a 12 mm port to permit stapling of the azygos vein and "posterior" wall of the anastomosis. A long trocar can be used for the right robotic port to minimize collisions between the port and the patient's right arm and shoulder. A 12 mm assistant port is placed in a position triangulated behind the left arm and camera ports. Early on, the azygos vein is divided as close to the spine as possible with a vascular load staple fire to facilitate periesophageal dissection. The intrathoracic esophagus is then dissected from surrounding structures. Particular attention needs to be paid to: (1) removing as much of the periesophageal tissue as possible (entry into the left pleural space is not avoided, and even considered desirable); (2) protecting the airway, which is often located easily just above the carina and then followed distally towards the left (the right-sided airways are fairly obvious); and (3) avoiding injury to the thoracic duct as it crosses from the right to the left side of the chest in the high mediastinum. The Penrose drain can be retracted towards the ceiling and then anteriorly in the chest to help avoid structures such as the airway and the aorta, respectively, during dissection. A "diagonal" direction of

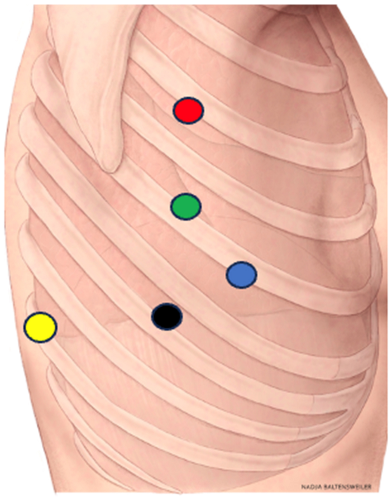

**Figure 2.** Robotic port placement for the thoracic phase of the RAMIE. Red: right arm; Green: camera; Black: left arm; Blue: assistant port; Yellow: accessory arm. Images provided by: © Nadja Baltensweiler and Ned. Anatomen Vereniging, license: Creative Commons Attribution-Noncommercial- ShareAlike[35]. RAMIE: Robotic assisted minimally invasive esophagectomy.

retraction towards the right upper corner of the screen can be helpful to discern both structures simultaneously. It is prudent to avoid excessive cautery in the thoracic inlet, to avoid recurrent laryngeal nerve injury. Ideally, the carina is NOT skeletonized completely of lymphatic tissue, as this can lead to ischemia of the airway. The esophagus should be mobilized well into the thoracic inlet, to make encircling the esophagus in the neck easier (for Mckeown esophagectomy) or to maximize the length of esophagus, which tends to retract after transection (for Ivor Lewis esophagectomy).

For an Ivor Lewis esophagectomy, the esophagus is transected at or above the azygos vein: factors affecting exact location of transection can include the perceived length of the gastric conduit, the presence of Barrett's esophagus that would ideally be extirpated, and the present location/extent of tumor (and past location/ extent, if neoadjuvant treatment was given). The gastric conduit is cautiously pulled up and 10 mg of ICG is injected intravenously to visualize perfusion of the conduit. The conduit is divided from the esophagogastrectomy specimen at the level where the gastric staple line ended in the abdomen, but if perfusion is suboptimal the conduit can be divided more proximally in a well-perfused area. The specimen is placed in a gore-tex bag, and the conduit is tacked to the thoracic inlet with two 3-0 silk sutures. A posterior gastrotomy is performed near the greater curvature of the stomach and at least 4-5 cm proximal to the end of the conduit. The "posterior" wall of the anastomosis is performed using 2.5-3 cm of the robotic stapler (green) for the back wall, with the small "jaw" in the conduit and the large jaw in the esophagus. Mucosa-to-mucosa alignment of the edges of the esophagus and conduit in the stapler jaw should be ensured. The "anterior" wall is performed with two 3-0 absorbable V-Loc sutures running from each end of the opening (Medtronic; Minneapolis, MN). The omental flap is used to buttress the anastomosis; rotation of the conduit should be avoided when mobilizing the flap. The gastric conduit is secured to the diaphragm with another suture. An excessively large hiatus should be closed if necessary, to minimize the chance of a paraconduit hernia. A 24-French Blake drain was placed adjacent to the conduit/anastomosis in the right pleural space; an additional Blake drain is placed in the left pleural space if opened during the operation.

For a Mckeown esophagectomy, after mobilization of the esophagus, a Penrose drain is used to encircle the esophagus, stapled to itself, and pushed up into the thoracic inlet for later retrieval during the cervical phase of the operation.

### Cervical phase

An incision parallel and anterior to the left sternocleidomastoid is made in the lower third of the neck. The omohyoid muscle is divided. Excessive retraction and the use of electrocautery are avoided as the esophagus is approached, to avoid injury to the recurrent laryngeal nerve. The location of the carotid sheath should be noted. The dissection is carried towards the tracheoesophageal groove and inferiorly towards the thoracic inlet. The clear space from the intrathoracic dissection is encountered, and the Penrose drain is located and used to pull the cervical esophagus into the surgical field. The esophagus is divided sharply. Attention should be given to avoiding unexpected retraction of either end of the esophagus after division. The esophagogastrectomy specimen is gently pulled up through the cervical incision. Care needs to be ensured to avoid tearing of the gastric conduit during this step. The conduit is divided from the specimen with a stapler. A posterior gastrostomy is performed in the conduit, and a side-to-side anastomosis is performed using the full length of a 45 mm stapler to create the common channel. The opening is then approximated with interrupted sutures, and a stapler is fired transversely to close it. The anastomosis is pushed back towards the thoracic inlet, and the incision is closed in layers. No drain is placed.

## CONCLUSIONS

The technical methods to minimize the rate of complications such as pneumonia, respiratory failure, leak, stricture, and conduit necrosis following esophagectomy are widely debated. To mitigate these risks, the approach supported by the current literature appears to be a minimally invasive surgical approach using a gastric conduit between 3-5 cm in diameter with ICG assessment of conduit perfusion and a stapled transthoracic anastomosis. However, there are many ways to perform esophagectomy with excellent results. At our institution, we use a completely robotic approach with creation of a 3-4 cm wide conduit and hybrid-type anastomosis, with ICG fluorescence used to guide conduit transection and localization of the gastrotomy for anastomosis; this approach demonstrates an excellent combination of safety and reproducibility. We published our results for 85 patients undergoing robotic esophagectomy in 2016 which demonstrated perioperative morbidity in 36%, mean operating time of 6 h, R0 resection in 99%, a single patient requiring conversion to thoracotomy, median hospital stay of 8 days, 7.1% rate of anastomotic or conduit complication, and a 3.5% 30-day mortality rate[33]. Continued study is necessary to determine the optimum strategy with regard to conduit diameter, conduit perfusion, and anastomotic technique during esophagectomy.

## DECLARATIONS

### Authors' contributions

Authored the introduction, conduit diameter, ICG fluorescence, and anastomotic technique portion: Hambright B

Wrote the "How we do it" section, including abdominal, thoracic, and cervical phases; provided edits to all portions of the paper and oversaw the project: Wei B

Contributed to the conclusion: Hambright B, Wei B

### Availability of data and materials

All reference material can be found cited in the references section. Due to the nature of this manuscript, there is no data to be provided.

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## Conflicts of interest
Both authors declared that there are no conflicts of interest.

## Ethical approval and consent to participate
Not applicable.

## Consent for publication
Not applicable.

## Copyright


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