Minimally invasive esophagectomy: anastomotic techniques

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Abstract: Esophagectomy is one of the most technically challenging and potentially morbid procedures in thoracic surgery. Goals of esophagectomy include resection of the diseased esophagus with negative margins, an adequate lymphadenectomy, and restoration of gastrointestinal continuity. Traditionally, this required both a thoracotomy and laparotomy incision, which contributed significantly to the high rates of morbidity and mortality associated with this procedure. Esophageal surgery has since evolved considerably. Advances in minimally invasive techniques have improved surgical morbidity to the patient, while providing oncologic benefit that is equal or superior to open approaches. Despite these improvements, technical complications and their consequences persist. Anastomotic complications remain a significant cause of postoperative morbidity and mortality. Clinically, these complications are often devastating and can result in substantial reductions in postoperative quality of life and survival. For this reason, construction of the anastomosis is often considered the most critical step during an esophagectomy. Additionally, with the rise of minimally invasive esophagectomy, techniques for anastomotic construction have had to evolve in concert. As a result, the optimal technique and location for anastomotic creation is frequently debated. Despite extensive research debating the superior esophageal reconstruction method, there is no agreed upon operative standard. This review aims to highlight current methods and provide a critical review of current research.

Keywords: Esophageal cancer; esophagectomy; minimally invasive; operative technique; anastomosis

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Introduction

Most patients with esophageal cancer present with locally advanced disease, for which esophagectomy remains the gold standard treatment. The goals of esophagectomy include resection of the diseased esophagus with negative margins, lymphadenectomy, and restoration of gastrointestinal continuity.

Historically, open esophagectomy was performed with different techniques, most often including a right thoracotomy and laparotomy. This approach was associated with very high rates of postoperative morbidity and mortality (1). The most common complications following open esophagectomy are respiratory, which occur in up to 40% of patients and may significantly increase the risk of mortality (2,3). Pneumonia has repeatedly been reported as an independent risk factor for morbidity and mortality following esophagectomy and is associated with a 20% mortality (2-7).

Minimally invasive techniques were first applied to the surgical treatment of esophageal cancer in the early 1990s as an attempt to mitigate the morbidity associated

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with open resection (8,9). The first approach to minimally invasive esophagectomy (MIE) was developed as a hybrid operation utilizing thoracoscopic techniques for esophageal resection as a method to avoid thoracotomy, followed by open laparotomy and preparation of the gastric conduit (8,10-12). A few years later in 2005, laparoscopic transhiatal esophagectomy emerged as the first totally minimally invasive approach to esophagectomy that avoided a thoracotomy and laparotomy (11-14). Further development of minimally invasive techniques expanded rapidly, giving rise to transthoracic esophagectomy techniques, of which the thoracoscopic and laparoscopic 3-stage McKeown esophagectomy and the thoracoscopic-laparoscopic Ivor Lewis esophagectomy are the most common.

MIE is preferred to the traditional open techniques because it provides an equivalent oncological resection with no difference in disease-free or overall survival but with significantly lower rates of postoperative transfusion, wound infection, ileus, pneumonia, and vocal cord palsy as well as a shorter length of hospital stay (1,15-20). Despite these advantages, several large scale systematic reviews of more than 40 studies failed to show any significant difference in the incidence of anastomotic leak between patients undergoing open resection when compared to those treated with MIE (21-23). Robot-assisted minimally invasive esophagectomy (RAMIE) is an additional approach to MIE that provides a similar oncological resection to traditional MIE approaches with no difference in perioperative morbidity and mortality (20,24).

Restoration of gastrointestinal continuity is most commonly accomplished using the stomach with an esophagogastric anastomosis for esophageal reconstruction. The stomach has an abundant intramural vascular network that allows mobilization of the whole organ and permits it to be brought up as a conduit to the chest or neck so that only a single anastomosis is required. While constructing the gastric conduit, the left gastric, left gastroepiploic, and short gastric vessels are divided, thus it is crucial to preserve the right gastroepiploic artery throughout gastric mobilization to avoid ischemia of the gastric conduit (25). Reconstruction can also be achieved with colon and jejunum, which may be useful in patients with previous foregut surgery.

Creation of the anastomosis is arguably the most critical step regardless of the conduit or surgical approach chosen. The esophagus does not hold sutures or staples well due to the lack of serosa and friability of the muscularis propria that occurs as a result of the longitudinal orientation of the muscle fibers. Anastomotic complications are the most feared complications following esophagectomy, as they contribute to a significant morbidity and mortality in these patients (26-29). These complications may be immediately life-threatening and can also result in substantial reductions in patient quality of life due to stricture formation and severe gastric reflux (28,30,31). Additionally, anastomotic leak decreases the oncologic value of the operation in patients with esophageal cancer and is an independent risk factor for mortality in this population (32-34). Anastomotic leak and gastric conduit necrosis increase the risk for post-esophagectomy trachea-bronchial-esophageal fistula, which is a rare but devastating complication associated with high rates of morbidity and mortality. Therefore, meticulous technique is essential to prevent postoperative anastomotic complications and the optimal anastomotic technique is frequently debated.

Anastomosis location

The location of the esophagogastric anastomosis divides surgical approach into two broad categories. The transhiatal and transthoracic McKeown approaches create a cervical anastomosis, whereas the Ivor Lewis and left thoracoabdominal approaches create an intrathoracic anastomosis (35).

Cervical anastomosis is most commonly performed in the left neck due to the slight curve to the of the cervical esophagus and the longer course of the left recurrent laryngeal nerve as it travels near or in the tracheoesophageal groove, where it is at risk for injury during the thoracic phase of the operation, to avoid inadvertent bilateral injury to the recurrent laryngeal nerves (36,37).

Intrathoracic anastomosis is created after laparoscopic creation of the gastric conduit, thoracoscopic esophageal mobilization, and mediastinal lymph node resection. The proximal esophagus is divided at the level of the azygous vein and the tubularized gastric conduit is carefully positioned in the chest above the divided azygos and under the divided esophagus, taking care to ensure correct orientation without tension (38-41). The intrathoracic gastroesophageal anastomosis is created between the proximal esophagus and a chosen portion of the gastric conduit with a rich vascular supply, enabling adequate healing while reducing the risk of anastomotic leak (42,43). The anastomosis is performed high in the chest at the thoracic inlet to prevent conduit redundancy and reflux (42,44).

With the introduction of minimally invasive techniques, a cervical anastomosis was typically utilized as it could still be performed without significant technical changes. Conversely, creation of an intrathoracic anastomosis using minimally invasive techniques required new techniques or variations of existing techniques to be devised and as a result, it is technically more challenging and time consuming compared to creation of a cervical anastomosis. While more challenging, intrathoracic anastomosis creation offers significant advantages including reduced incidence of anastomotic leak, benign anastomotic stricture, and of recurrent laryngeal nerve palsy, decreased blood loss, improved R0 resection, higher lymph node yield (21,35, 45-48). Increased stretch of the gastric conduit and inability to discard areas of ischemia at the conduit tip are thought to explain the higher rate of anastomotic leak reported with cervical anastomosis.

Although the overall incidence of anastomotic leak is lower, cases of intrathoracic anastomotic leak are difficult to manage and are associated with high rates of morbidity and mortality, whereas cervical anastomotic leaks are often easy to clinically manage and rarely are life threatening (45). While cervical anastomotic leaks may be managed with a conservative approach consisting of nil by mouth, antibiotics, gastric drainage, and enteral or parenteral feeding, intrathoracic anastomoses may lead to devastating consequences requiring more aggressive interventions, such as operative exploration, thoracotomy, thoracoscopic drainage, and even complete gastrointestinal diversion (46,49).

There have been significant advances in interventional treatments of anastomotic leak, including endoscopic treatment techniques with stents or endoscopic vacuum-assisted closure devices, which have led to a more confident attitude towards intrathoracic anastomosis creation by surgeons. As a result, Ivor Lewis MIE now ranks first as the most common approach to MIE used clinically (50). Listed on *Table 1* are the most relevant studies which have compared outcomes in relationship to location of the anastomosis. While some studies are limited by small study numbers, overall the following reports suggest that neck anastomoses are associated with higher rates of anastomotic leak with similar rates of cardiopulmonary complication, perioperative mortality, and benign stricture formation.

Techniques for anastomosis creation

There are three broad methods used to construct the esophagogastric anastomosis (see *Figure 1*), including manual (hand-sewn), mechanical (stapled), and hybrid (semi-mechanical) techniques (59-62). Regardless of technique chosen, it is imperative to ensure adequate apposition of the submucosal layer as collagen within the esophageal submucosa is crucial to maintain the integrity and strength of anastomosis (21,63). Three different configurations can be implemented when fashioning the esophagogastric anastomosis, including end-to-end, end-to-side and side-to-side anastomosis. An end-to-end anastomosis describes when the end of the esophageal stump is connected to end of the gastric conduit at the site of the anastomosis whereas an end-to-side anastomosis is constructed by connecting the end of the esophageal stump to the side of the gastric conduit at the site of the anastomosis. A side-to-side anastomosis is constructed by connecting a transverse gastrotomy made on the anterior wall of the gastric conduit with the adjacent posterior wall of the proximal esophageal stump (64). All three techniques can be used to create either a cervical or intrathoracic esophagogastrostomy, which will be further discussed in detail.

Handsewn anastomosis techniques

Generally, handsewn techniques are often preferred when creating a cervical anastomosis as the length of the conduit may prohibit use of a mechanical stapler. Conversely, creation of an intrathoracic handsewn anastomosis requires considerable technical skill and is often time-consuming, thus a stapled technique is most often utilized (35,65-67).

Hand-sewn anastomoses may be constructed using absorbable or nonabsorbable sutures in a continuous or interrupted fashion. Most commonly the continuous technique is typically considered to be superior as it is generally easier technically, cheaper, and can be performed faster when compared to the interrupted technique (63,68), however, ultimately choice is based on surgeon preference.

A single- or double-layer is used to create an esophagogastric anastomosis. The single layer technique uses absorbable or nonabsorbable sutures with full-thickness bites of the mucosa and muscularis propria in a circumferential fashion to ensure adequate mucosal apposition (63). The double-layer technique also uses an outer row of absorbable or nonabsorbable sutures on the seromuscular layer, either in a running or interrupted fashion, but has an additional inner layer of absorbable suture to invert the mucosa (69). One retrospective study reported reduced incidence of anastomotic leak and

Table 1 Studies comparing intrathoracic versus cervical anastomosis

First author	Year	Study design	Location	Patients	Leak rate	Stricture rate	Main results
Chasseray (51)	1989	Prospective randomized	Neck	43	26%	23%	Cervical anastomosis is associated with increased incidence of anastomotic leak, no difference in stricture
			Chest	49	4%	14%	
Ribet (52)	1992	Prospective randomized	Neck	30	23%	–	Increased rates of anastomotic leak, respiratory complications, and recurrent laryngeal trauma in neck anastomoses
			Chest	30	3%	–	
Blewett (53)	2001	Retrospective cohort	Neck	19	5%	–	No difference in rate of anastomotic leak
			Chest	55	16%	–	
Walther (35)	2003	Prospective randomized	Neck	41	2.4%	20%	No difference in anastomotic leak, stricture formation, cardiopulmonary complications, or hospital mortality
			Chest	42	0%	29%	
Okuyama (54)	2007	Prospective randomized	Neck	18	16.7%	0%	Due to small study numbers, no statistically significant difference in rate of anastomotic leak and stricture
			Chest	14	7.1%	14.2%	
Price (55)	2013	Retrospective cohort	Neck	164	20.1%	24.4%	Anastomotic leak and stricture formation increased in neck anastomoses
			Chest	268	6.0%	13.8%	
Gooszen (49)	2018	Retrospective cohort	Neck	654	21.9%	–	Lower incidence of anastomotic leak and recurrent nerve injury and shorter length of hospital stay in chest anastomoses
			Chest	654	17.0%	–	
Liu (56)	2018	Retrospective cohort	Neck	126	16.6%	19.8%	No difference in anastomotic leak; lower incidence of recurrent laryngeal nerve injury, dysphagia, regurgitation, and stricture requiring dilatation in chest anastomoses
			Chest	332	10.2%	13.5%	
Schroder (57)	2019	Retrospective cohort	Neck	430	17.2%	–	No difference in anastomotic leak; overall morbidity lower after intrathoracic compared with cervical reconstructions
			Chest	536	15.9%	–	
van Workum (58)	2020	Retrospective cohort	Neck	210	28.1%	–	Higher incidence of anastomotic leak, recurrent nerve injury, cardiopulmonary complication, and 90-day mortality and longer length of stay in neck anastomoses
			Chest	210	13.8%	–	

stricture with the double layer technique (70), however, this was not supported in subsequent randomized controlled trials (71,72). Often, the single-layer technique is preferred as it is commonly associated with a shorter operative time and lower cost than the double-layer technique. Listed on *Table 2* are some relevant studies comparing single layer and double layer techniques for cervical anastomosis.

Cervical handsewn anastomosis techniques

Handsewn cervical anastomoses are most often performed using either an end-to-end or end-to-side configuration. Choice is guided by length of the gastric conduit and surgeon preference. An end-to-side approach requires more length of gastric conduit as compared to an end-to-end technique, which is thought to increase the risk of conduit tip ischemia and subsequently lead to a higher chance of dehiscence of the suture and staple line (73). This mechanism is also thought to explain why end-to-side anastomoses are associated with increased incidence of anastomotic leak and longer in-hospital stay (73). Conversely, the incidence of anastomotic stricture has been reported to be higher with an end-to-end technique due to the decreased diameter of anastomosis itself (73,74). Listed on *Table 3* are some relevant studies comparing different configurations techniques for cervical anastomosis.

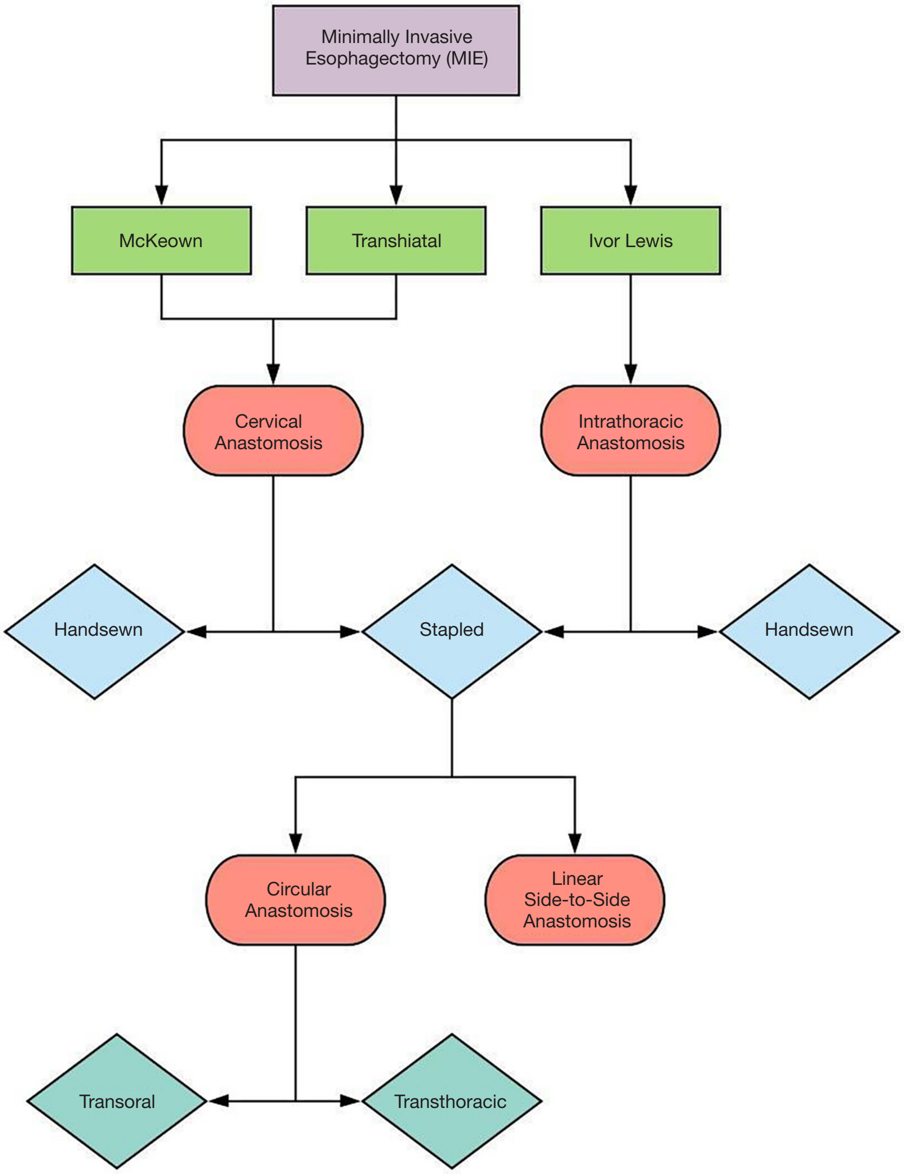

Figure 1 Overview of open and minimally invasive esophagectomy anastomosis techniques.

Thoracic handsewn anastomosis techniques

The technique used to create a handsewn intrathoracic anastomosis is similar to the methods used to create a cervical handsewn anastomosis. Typically, a single- or double-layered, end-to-end or end-to-side anastomosis is created between the distal esophagus and the gastric conduit along the greater curvature (76). Beginning with the outer posterior layer, interrupted seromuscular sutures are placed starting in the center of the posterior wall of the proximal esophagus and working toward both ends in the middle anteriorly, and subsequently a gastrotomy is made on the greater curvature prior to completion of the anterior wall (13,44,77,78). However, unlike the neck, creation of a thoracoscopic handsewn anastomosis can be very challenging so that as a result, it is rarely performed with conventional thoracoscopic techniques (50,79,80).

A handsewn thoracoscopic anastomosis is much more commonly accomplished using a robotic approach due to the improved view of the surgical field and range of motion of the instruments (41) (*Figure 2*). As utilization of robotic-assisted

Table 2 Studies comparing single-layer versus double-layer techniques for cervical anastomosis

First author	Year	Study design	Technique	Patients	Leak rate	Stricture rate	Main results
Zieren (71)	1993	Prospective randomized	Single	54	19%	22%	Anastomotic stricture decreased with single layered technique; no difference in anastomotic leak
			Double	53	19%	48%	
Zhu (70)	2008	Retrospective cohort	Single	69	5.8%	7.8%	Anastomotic leak and stricture rate decreased with double layered technique
			Double	1024	0%	0.6%	
Aslam (72)	2008	Prospective randomized	Single	24	4.2%	–	No difference in anastomotic leak, but single layer technique can be performed faster and at a lower cost
			Double	26	7.7%	–	

Table 3 Studies comparing different anastomotic configurations for handsewn cervical anastomosis

First author	Year	Study design	Configuration	Patients	Leak rate	Stricture rate	Main results
Pierie (75)	1995	Retrospective cohort	End-to-end	28	14%	32%	No difference in rate of anastomotic leak or stricture between techniques
			End-to-side	90	14%	29%	
Nederlof (73)	2011	Prospective randomized	End-to-end	64	22%	44%	End-to-side technique had higher rates of anastomotic leak and lower rates of stricture
			End-to-side	64	41%	21%	
Haverkamp (74)	2013	Retrospective cohort	End-to-end	112	18%	43%	No difference in anastomotic leak; increased anastomotic stricture in end-to-end
			End-to-side	278	21%	32%	

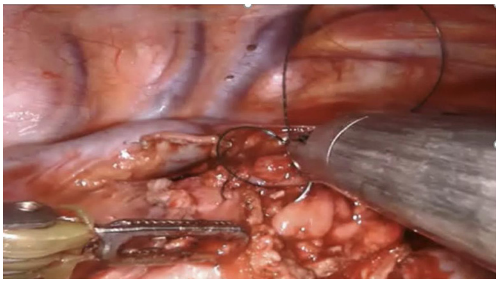

Figure 2 Robotic intrathoracic handsewn anastomosis creation.

techniques continues to increase, postoperative outcomes continue to improve, and recent reports suggest that when compared to traditional MIE, RAMIE is associated with higher total lymph node yield, reduced intraoperative blood loss, reduced incidence of vocal cord palsy, with comparable oncological outcomes and rate of R0 resection (41,48,81-84). However, it is associated with a steep learning curve and more randomized controlled studies with larger sample sizes are needed to confirm observed benefits.

Mechanical anastomosis techniques

Mechanical techniques emerged following introduction of circular staplers in the 1970s (85). There are numerous variations of mechanical staplers used, which are divided into two subgroups based on the specific anastomotic configuration (end-to-end, side-to-side, or end-to-side) and suturing mechanism of the device (59-62). Clinically, the circular end-to-end anastomosis stapler (EEA stapler) and the linear cutting gastrointestinal stapler (GIA stapler) are the most commonly used. Many surgeons prefer mechanical staplers to hand-sewn anastomosis as they reduce intraoperative time significantly, are less operator-dependent, and require less surgical skill to use (63).

Linear side-to-side stapled anastomosis

A linear stapled anastomosis is most commonly performed using a 30- or 45-mm gastrointestinal anastomosis (GIA) stapler, which places a triple staggered row of titanium staples to create a side-to-side anastomosis (86,87).

Depending on the approach, the linear stapler can be used to create a totally mechanical or a hybrid anastomosis.

Hybrid side-to-side cervical anastomosis techniques

Inspired by the high risk of technical complications with manual techniques of cervical esophagogastrostomy creation, a terminalized semi-mechanical side-to-side suture technique was developed for cervical anastomosis (88). If the length of the conduit is sufficient (>5 cm gastric conduit and esophageal stump overlap), an Orringer or modified Collard side-to-side anastomosis using a linear cutting stapler is typically preferred (63,82,88,89).

After delivery of the gastric conduit into the neck, a gastrotomy is made on the anterior wall of the gastric conduit, which is then opposed to the posterior wall of the proximal esophageal stump (65). The large end of an Endo GIA stapler is inserted into the gastrotomy and the thin blade is inserted into the open esophagotomy. After ensuring adequate alignment, the stapler is fired, creating a V-shaped opening between the stomach and esophagus that forms the posterior wall of the anastomosis (88,90). This triangular or V-shaped anastomosis provides a wide anastomosis with a low stricture rate. After completion of the posterolateral aspect of the anastomosis, a nasogastric tube is inserted and guided toward the hiatus for gastric decompression. To create a total mechanical anastomosis, the anterior defect is closed with a 30-mm or 45-mm stapler, whereas a semi-mechanical anastomosis involves using handsewn technique with interrupted 3-0 silk Lembert sutures (9,82). *Table 4* describes various studies comparing handsewn and modified Collard approaches to cervical esophagogastric anastomosis for reconstruction during esophagectomy in patients with esophageal cancer.

Hybrid side-to-side thoracic anastomosis techniques

Similarly, to create an intrathoracic anastomosis, following mobilization of the esophagus, the gastric conduit is placed posterior to the divided esophagus to allow the esophagus to overlap 4 to 5 cm onto the stomach. The anterior wall of the gastric conduit is aligned with the posterior wall of the esophageal stump, and an enterotomy is made approximately 4 cm inferior from the tip of the conduit. The jaws of a 30- or 45-mm endoscopic linear cutting stapler are then inserted into the esophagus and gastric conduit to create a side-to-side, functional end-to-end, anastomosis (9,90). The anterior defect is then closed either with another firing of the linear stapler or with a hand-sewn technique. The are some advantages of this technique: the linear stapler is easy to insert through the ribs and easy to use, and the size of the anastomosis is large. However, the main limitation is the length of the esophageal stump needed to align the esophagus with the stomach and the difficulty of creating an anastomosis high in the thoracic cavity.

Circular stapled anastomosis

Circular stapled methods are commonly utilized to create both cervical and intrathoracic anastomoses. An intraluminal EAA stapler with a built-in cylindrical knife creates an end-to-side esophagogastrostomy by placing a detachable anvil into the proximal esophagus, producing a double row of staplers in a circular fashion. There are various anvil sizes available, and choice is guided by the size of the esophagus. Notably, the size of the anvil has been shown to an important risk factor for anastomotic stricture formation in patients without anastomotic leakage, and recent data suggests that the use of a large-sized circular stapler does not lead to an increased rate of anastomotic leakage but may decrease the incidence of stricture (98,99).

The circular stapler can be introduced into the esophagus either using the transthoracic or transoral method. Technically, cervical and intrathoracic anastomoses can be constructed using either of these two methods, however, in clinical practice, the transoral route is rarely used to construct cervical esophagogastrostomies (35).

Transthoracic route

Regardless of location, the anvil of an end-to-end anastomosis (EEA) stapler is inserted into the cut end of the proximal esophagus, and two purse string sutures are placed to secure the esophagus around the stem of the anvil (35). A 2–2.5 cm gastrotomy is created on the anterior gastric wall 5 cm distal to the tip of the fundus along the staple line. The base of the EEA stapler is then inserted into the conduit through the gastrotomy, which is then docked to the anvil (65,69). The anvil and the stapler are subsequently engaged, and the stapler is fired to complete the end-to-side (esophagus to

Table 4 Studies comparing the handsewn (HS) and modified Collard (MC) approaches to cervical esophagogastric anastomosis for reconstruction during esophagectomy in patients with esophageal cancer

First author	Year	Study design	Type	Patients	Leak rate	Stricture rate	Main results
Collard (88)	1998	Retrospective cohort	HS	24	0%	46%	No difference in anastomotic leak but decreased stricture rate with stapled technique
			MC	16	0%	6%	
Orringer (89)	2000	Retrospective cohort	HS	112	14%	48%	Stapled anastomosis reduces incidence of anastomotic leak and stricture
			MC	111	3%	35%	
Casson (91)	2002	Retrospective cohort	HS	53	23%	17%	Reduced rate of anastomotic leak with stapled technique, resulting in a shorter postoperative stay
			MC	38	8%	8%	
Behzadi (66)	2005	Retrospective cohort	HS	205	13%	34%	Reduced rate of anastomotic leak and stricture with linear stapled approach
			MC	75	5%	15%	
Ercan (82)	2005	Retrospective cohort	HS	188	11%	–	Decreased incidence of anastomotic leak and perioperative morbidity with stapled technique
			MC	86	4%	–	
Kondra (92)	2008	Retrospective cohort	HS	89	27%	55%	Reduced rates of anastomotic leak and stricture, earlier initiation of oral feeds, and decreased hospital length of stay with stapled technique
			MC	79	13%	31%	
Cooke (93)	2009	Retrospective cohort	HS	159	21%	–	Reduced rate of anastomotic leak with stapled technique
			MC	974	12%	–	
Deng (94)	2009	Retrospective cohort	HS	8	–	50%	Increased incidence of stricture in hand-sewn technique, larger anastomotic diameter with stapled technique
			MC	9	–	11%	
Worrell (95)	2010	Retrospective cohort	HS	18	22%	38%	No difference in anastomotic leak or stricture formation
			MC	63	7%	26%	
Saluja (90)	2012	Prospective randomized	HS	87	16%	20%	No difference in anastomotic leak but decreased stricture and operative time with stapled technique
			MC	87	18%	8%	
Mishra (65)	2016	Retrospective cohort	HS	66	18%	16%	No difference in anastomotic leak but decreased stricture and operative time with stapled technique
			MC	74	16%	4%	
Kumar (96)	2018	Retrospective cohort	HS	48	27%	6%	Decreased incidence of anastomotic leak with stapled technique; no difference in stricture formation
			MC	29	7%	7%	
Sugimura (97)	2018	Retrospective cohort	HS	173	8%	59%	No difference in anastomotic leak but decreased stricture formation with modified Collard technique
			MC	225	3%	10%	

stomach) circular anastomosis (63,100). A nasogastric tube is passed by the anesthetist and advanced downward using manual guidance of the surgeon through the intrathoracic stomach to the antrum for postoperative gastric decompression. The gastrotomy opening is closed by stapling off the excess gastric tissue proximal to the anastomosis (including the anterior gastrotomy site) with an Endo-GIA stapler.

Transoral route

Launched in 2008, the transoral circular stapling device permits transoral passage of a 25-mm anvil, which is mounted on nasogastric tubing (101). This pre-packaged commercially available device contains an anvil head secured in the tilted position that is mounted and secured on a 90cm long PVC delivery tube with a suture (102). This device is given to the anesthesiologist only after the

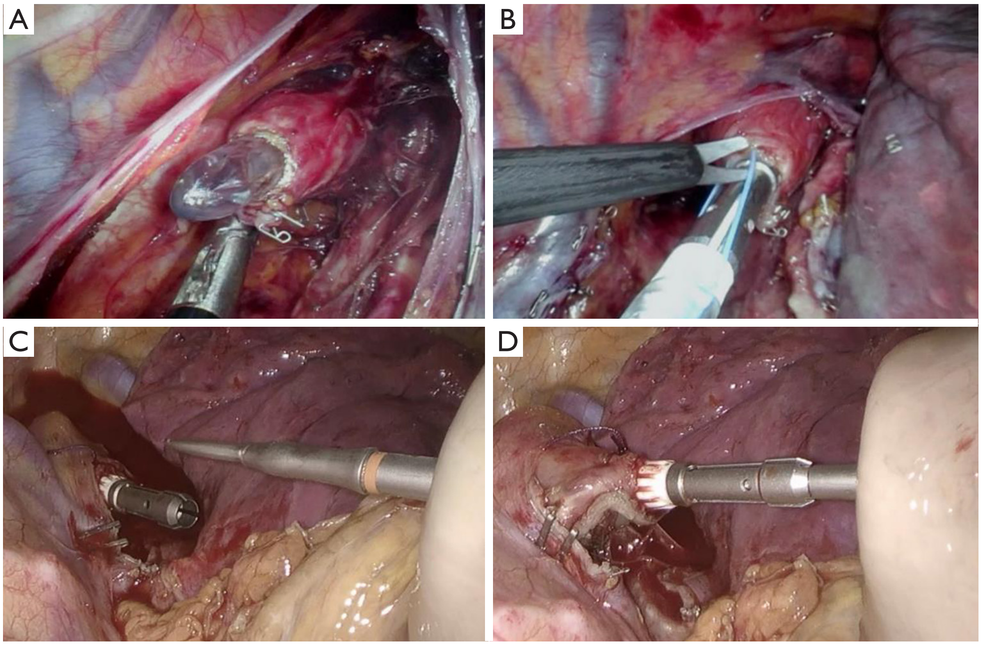

Figure 3 Intrathoracic end-to-end circular anastomosis using the transoral OrVil device. (A) Advancement of the orogastric tube through the esophagotomy made in the esophageal stump until the EEA anvil is comfortably positioned in the proximal esophagus; (B) The anchoring suture to the anvil is cut to release the PVC tube from the anvil; (C) After placement of the stapler base within the gastric conduit, the pin is advanced through the posterior gastric wall; (D) The spike from the circular stapler is connected to the anvil and the stapler is fired to complete the anastomosis.

esophagus is transected, as transoral placement of the anvil requires that the proximal esophagus be divided by means of linear stapler (102,103). The PVC delivery tube in then inserted through the patient's mouth by the anesthesiologist until pressure from the orogastric tube is visualized at the staple line of the esophageal stump.

Once the tip of the oral-gastric tube is observed within the esophageal stump, a small esophagotomy is performed perpendicular to the staple-line of the esophageal stump, allowing advancement of the orogastric tube until it can be grasped by the surgeon, who pulls it out through a thoracic trocar until the EEA anvil is comfortably positioned in the proximal esophagus (103,104). While holding the anvil in place, the tubing is disconnected from the anvil and an EEA anastomosis is performed in standard fashion (see *Figure 3*). This technique is especially useful when creating an intrathoracic anastomosis as it avoids the need to secure the anvil in the esophagus with purse string sutures (9,42). As a result, less technical skill is required, and the anastomosis can be created more quickly as compared to hand-sewn techniques. In a prospective randomized controlled trial, when compared with the hand-sewn method, the circular stapler method for esophagogastric anastomoses was associated with reduced incidence of anastomotic leak, shorter operative times, and increased risk of anastomotic strictures (100). *Tables 5* and *6* highlight relevant studies comparing semi-mechanical linear stapled (LS), circular stapled (CS), and handsewn (HS) intrathoracic anastomoses.

Other factors to improve anastomotic outcomes

Perfusion assessment

Successful esophageal anastomosis following esophagectomy relies on preservation of the right gastric and right gastroepiploic arteries for adequate perfusion and is critical for wound healing and prevention of postoperative anastomotic complications. Often, anastomotic leaks are attributed to technical errors that stem from a perfusion deficiency of the gastric conduit or tension on the anastomosis as a result of rough handling, poor preparation, and suboptimal technique, and ultimately compromised perfusion of the gastric conduit perioperatively has been

Table 5 Studies comparing semi-mechanical linear stapled (LS), circular stapled (CS), and handsewn (HS) intrathoracic anastomoses

First author	Year	Study design	Type	Patients	Leak rate	Stricture rate	Main results
Craig (105)	1996	Prospective randomized	HS	50	6.0%	26.0%	No significant difference in anastomotic leak, length of stay, stricture formation and survival
			CS	50	8.0%	26.0%	
Law (60)	1997	Prospective randomized	HS	61	1.6%	8.2%	No difference in anastomotic leak rate but increased stricture with stapled technique
			CS	61	4.9%	32.8%	
Blackmon (76)	2007	Retrospective cohort	HS	23	4.3%	34.8%	Higher incidence of stricture with handsewn technique; no difference in anastomotic leak, perioperative morbidity, mortality, and survival
			LS	44	6.8%	9.1%	
			CS	147	7.5%	13.6%	
Luechakiettisak (106)	2008	Prospective randomized	HS	59	6.7%	16.9%	No difference in anastomotic leak, stricture, perioperative morbidity, or 30-day mortality
			CS	58	3.4%	32.8%	
Wang (107)	2013	Prospective randomized	HS	52	5.8%	9.6%	No difference in anastomotic leak, but decreased stricture formation with handsewn technique
			LS	45	0%	0%	
			CS	47	2.1%	19.1%	
Harustiak (108)	2016	Retrospective cohort	HS	134	20.9%	20.3%	Lower rate of anastomotic leak and stricture formation with stapled technique
			LS	281	10.0%	6.3%	

Table 6 Studies comparing linear stapled (LS) and circular stapled (CS) intrathoracic anastomoses

First author	Year	Study design	Type	Patients	Leak rate	Stricture rate	Main results
Xu (109)	2011	Retrospective cohort	LS	166	1.2%	1.8%	No significant difference in anastomotic leak, but decreased stricture formation with linear technique
			CS	68	1.5%	20.6%	
Blackmon (76)	2007	Retrospective cohort	LS	44	6.8%	9.1%	No significant difference in anastomotic leak or stricture
			CS	147	7.5%	13.6%	
Yanni (110)	2019	Retrospective cohort	LS	74	4.1%	5.4%	Decreased incidence of anastomotic leak with linear technique; no difference in length of stay, or 30-day mortality
			CS	85	15.3%	9.4%	
Zhang (111)	2019	Retrospective cohort	LS	35	8.6%	5.7%	No significant difference in anastomotic leak or stricture
			CS	42	4.8%	16.7%	
Wang (107)	2013	Prospective randomized	CS	47	2.1%	19.1%	No statistically significant difference in rate of leak, decreased rate of stricture in linear anastomosis
			LS	45	0%	0%	

reported to be a major risk factor for benign anastomotic stricture following esophagectomy (21,112,113). Prevention strategies are aimed at correction of patient related factors and systemic variables can influence anastomotic integrity, including patient nutritional status, medical comorbidities, and fluid balance and precise gastroesophageal mobilization and dissection to ensure the formation of a tension-free anastomosis (35,65,114).

The proximal portion of the conduit is particularly prone to ischemia because the gastroduodenal artery rarely reaches the tip of the graft (115). Therefore, intraoperative assessment of perfusion is critical for the early detection of compromised perfusion and may be used to guide surgical decision making with regards to the location of the anastomosis or may highlight the need for additional surgical intervention (115,116). Traditionally,

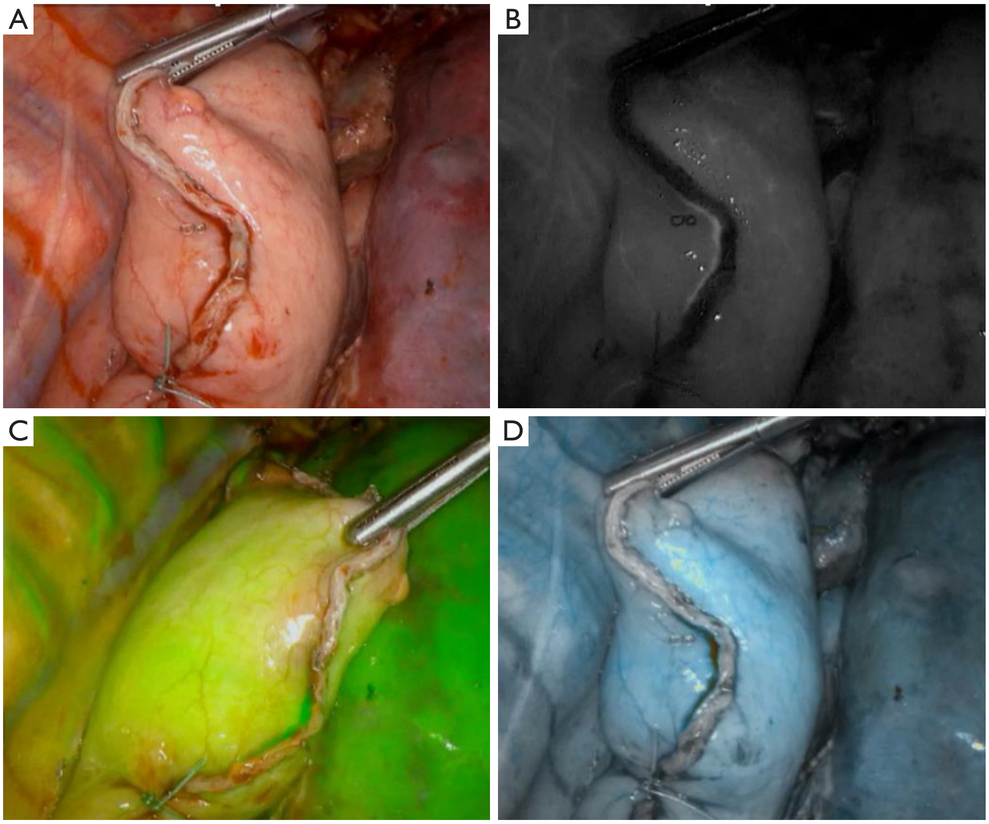

Figure 4 Intraoperative determination of gastric conduit perfusion with intraoperative fluorescence angiography (FA) using near-infrared imaging (NIFI) with indocyanine green (ICG) showing adequate perfusion in all four views. (A) White light mode showing the natural image; (B) near infrared fluorescence (NIRF) mode; (C) Merge view which superimposes the NIRF view onto the standard thoracoscopic image; (D) Semi-quantitative colorized fluorescence mode.

assessment of intraoperative conduit perfusion was with visual clinical inspection of the intestinal color, pulsations of the vessels, bleeding from the cut edge, and temperature of the anastomosis site (115,117). However, the accuracy of this method is greatly limited as it relies on subjective assessment of parameters that do not reliably correspond to perfusion (17,18,117).

Newer methods have subsequently been developed to aid assessment of gastric conduit viability and currently, there are several noninvasive optical techniques that allow intraoperative assessment of perfusion in real time. The first of these optical techniques developed was intraoperative laser doppler flowmetry (LDF), which uses a low-power laser to measure the Doppler shift of moving red blood cells within the microcirculation (118). Using this technique, perfusion is assessed prior to creating the anastomosis so that the optimal location can be chosen, taking care to minimize tension in the conduit (119).

Intraoperative fluorescence angiography (FA) using near-infrared imaging (NIFI) with indocyanine green (ICG) is the most commonly used method at our institution. This method provides visual mapping and accurate quantitative measurement of the arterial blood flow and venous return of the reconstructed gastric tube in patients undergoing esophagectomy (120-122). The system provides four images to aid in the assessment of perfusion (*Figures 4,5*).

Omental flap or other reinforcement techniques

The greater omentum is a free-hanging mesenteric tissue that hangs down from the greater curve of the stomach to cover the surface of the intra-peritoneal organs. As a result of unique inherent anatomic and physiologic properties, the omentum is often exploited during various surgical procedures to promote local control of infection, wound

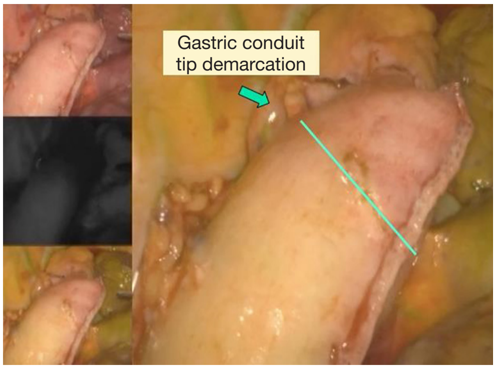

Figure 5 Using indocyanine green fluorescence imaging, there is clear demarcation of the gastric conduit tip indication poor perfusion to this area.

healing, and tissue regeneration (117,118). Regardless of the approach chosen, whenever feasible, often surgeons will perform an omentoplasty during esophagectomy to reinforce the esophagogastric anastomosis. During this procedure, a pedicled omental flap based of the right gastroepiploic arcade is created by dividing the omentum off the transverse colon in the avascular plane, which is then used to envelop the entire anastomosis as well as the gastric staple line (123,124). The omental pedicle promotes healing and regeneration of the injured tissue as a result of its rich blood supply, innate immune function, high absorptive capacity, and secretion of pro-angiogenic and chemotactic factors that promote angiogenesis and neovascularization (125-129).

A recent metanalysis that included 6 randomized controlled trials with a total of 1,608 patients reported a significant reduction in the incidence of anastomotic leak and length of hospital stay when an omentoplasty was performed (130). Notably, the addition of omentoplasty was not associated with a significant change in hospital mortality, duration of hospital stay, or incidence of anastomotic stricture, pulmonary and cardiac complication, infection, vocal cord palsy, and peri-jejunostomy leakage. While some retrospective reviews have reported similar results, citing reduced cases of anastomotic leak in both cervical and intrathoracic anastomoses when an omentoplasty was performed (126,128,131-133), others have failed to show any significant difference in anastomotic leak rate with the addition of omentoplasty (134), Larger clinical trials are needed to further define the role of omentoplasty after esophagectomy.

Conclusion

Anastomosis creation remains the most critical step during esophagectomy. As perioperative outcomes continue to improve, further emphasis is placed on the construction of a durable anastomosis without complication. Despite a large volume of research investigating this topic, considerable debate remains on the optimal technique. While continued research is needed to ensure adequate conduit perfusion and prevent anastomotic complications, it is probably more important for surgeons to have a standardized method that they can confidently perform.

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