0003-4975
https://doi.org/10.1016/j.athoracsur.2025.02.028

INVITED EXPERT REVIEWS

Complex Esophageal Reconstruction: Challenges and Techniques

Mohamad K. Abou Chaar, MD,[1] Yahya Alwatari, MD,[1] Frank M. Corl, MS,[2] Sameh Taki Aldin, MD,[1] Samir Mardini, MD,[3] and Shanda H. Blackmon, MD, MPH[4]

ABSTRACT

BACKGROUND The objective of this invited expert guide is to discuss options for complex reconstruction for patients presenting with esophageal discontinuity, loss of a gastric conduit, fistula, or other complex esophageal conditions.

METHODS On the basis of a series of complex esophageal reconstructions in adults, from multiple institutions, solutions are reviewed and organized by conduit, circumstance, and technique. Patient-specific data are excluded, and the scenarios focus on a summarized presentation of options.

RESULTS Surgical techniques for esophageal salvage reconstruction and revision are discussed. Esophageal salvage includes stenting, endoscopic vacuum therapy, plication, dilation, assisted emptying, untwisting, endoluminal repair, and operative revision. Esophageal reconstruction includes a variety of routes, timing, and conduits for replacement. Three predominant reconstruction approaches are reviewed, including local or primary options, interposition grafts, and tissue-engineered constructs.

CONCLUSIONS A standard tubularized pedicled gastric conduit is the first choice for esophageal reconstruction. Attempts to salvage leaks and initial esophageal reconstruction conduits should be made before selecting a secondary option. Complex reconstruction can be staged by diversion and later reconstruction when nontraditional conduits are used. The esophagus can be successfully reconstructed from small bowel, colon, myocutaneous, cutaneous, or biomatrix material.

(Ann Thorac Surg 2025;120:244-55)

The field of complex esophageal reconstruction has rapidly evolved over time, revolutionizing the management of patients with challenging esophageal conditions. This comprehensive review of the various techniques used in esophageal salvage and reconstruction includes scenarios and illustrations to enhance understanding of these intricate surgical procedures and outline comprehensive options that have been performed by the author(s).

The esophagus is a vital component of the digestive system, averages 40 cm from the incisors at the esophagogastric junction, and is responsible for transporting food from the mouth to the stomach (Figure 1). However, various scenarios, such as trauma, cancer, congenital abnormalities, and caustic ingestion, can lead to esophageal defects or strictures, necessitating surgical intervention.

The Supplemental Figures can be viewed in the online version of this article [https://doi.org/10.1016/j.athoracsur.2025.02.028] on https://www.annalsthoracicsurgery.org.

Presented at the Seventieth Annual Meeting of the Southern Thoracic Surgical Association, Orlando, FL, Nov 2-5, 2023.

[1]Division of Thoracic Surgery, Mayo Clinic, Rochester, Minnesota; [2]Division of Biomedical and Scientific Visualization, Mayo Clinic, Rochester, Minnesota; [3]Division of Plastic and Reconstructive Surgery, Mayo Clinic, Rochester, Minnesota; and [4]Division of Thoracic Surgery, Baylor College of Medicine, Houston, Texas

Address correspondence to Dr Blackmon, Baylor College of Medicine, 7200 Cambridge St, Flr 6- 621, Houston, TX 77030; email: shanda.blackmon@bcm.edu.

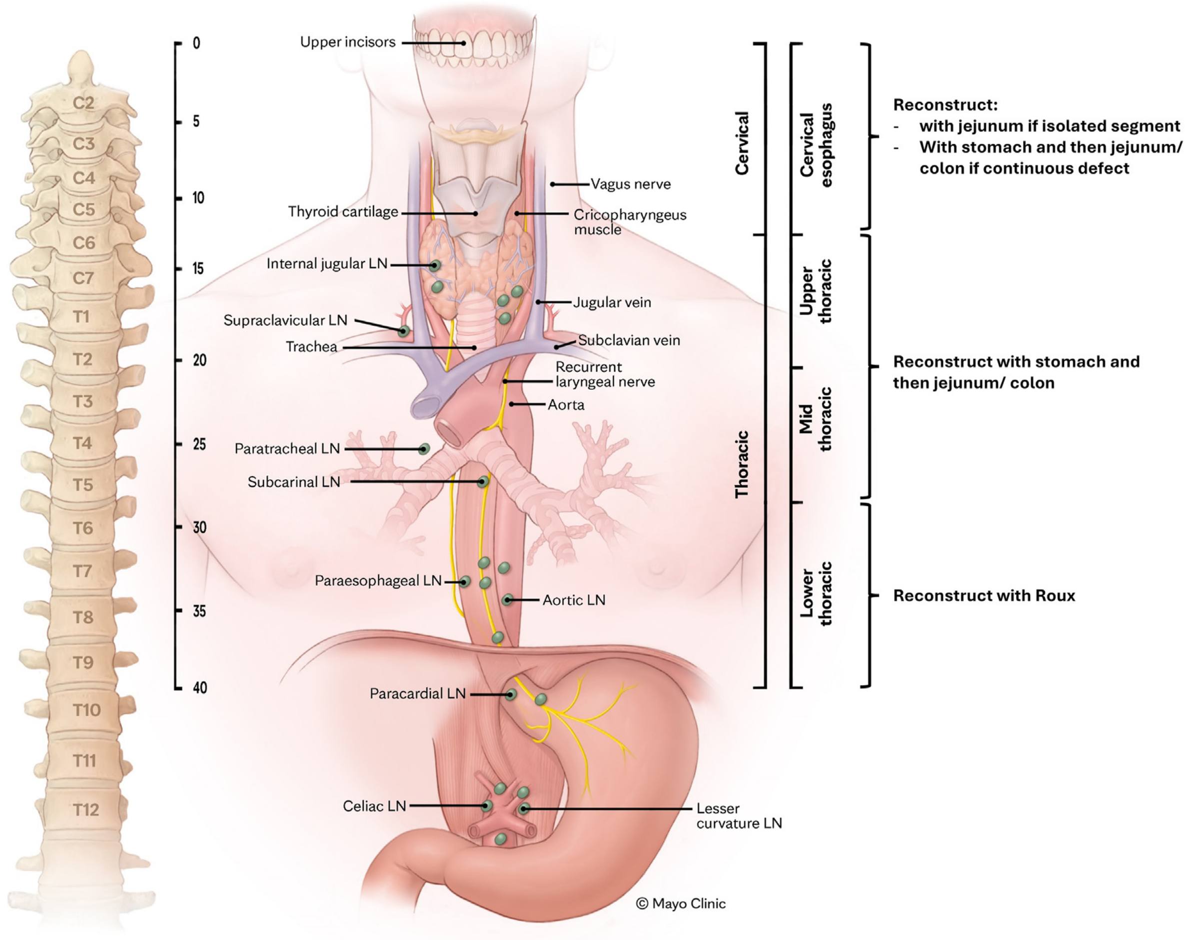

FIGURE 1 Esophageal length and landmarks in relation to the incisors, spine, diaphragm, and other anatomic organs with types of reconstruction. (LN, lymph node.) Used with permission of Mayo Foundation for Medical Education and Research, all rights reserved.

Historically, the treatments for complex esophageal conditions pose significant challenges to surgeons. These challenges arise from the limited availability of viable reconstruction options and the need for familiarity with multiple body regions. Surgeons must be comfortable working in the neck, chest, and abdomen. Complex salvage teams need access to or skills in microvascular techniques and endoscopic technology. Additionally, ensuring the viability of vessels necessitates preoperative 3-dimensional computed tomographic angiographic imaging to assess the condition of both donor and recipient vessels.

The range of treatment options has expanded, providing patients with better outcomes, enhanced esophageal preservation, and improved quality of life. These techniques can be broadly categorized into 3 main approaches: primary repair and salvage, interposition grafts, and tissue-engineered constructs.

Primary repair involves the direct closure of the esophageal defect or stricture using local tissue. This technique is suitable for small, localized defects and strictures. The use of sutures and tissue flaps can facilitate the restoration of esophageal continuity. Stents can buttress while the repair heals. Endoscopic clips, such as Ovesco (Ovesco Endoscopy USA Inc) and Resolution (Boston Scientific), or endoluminal suturing using the Apollo device (Apollo Endosurgery) can facilitate endoluminal repair of defects within the esophagus. These endoluminal closure techniques can be used as an adjunct to stenting, functioning as a bridge to definitive therapy, or used to secure the stent and prevent migration, thereby providing a permanent therapeutic solution.

Temporary stenting of the esophagus can endoluminally seal wounds and is typically performed with a silicon-covered self-expanding metal stent, such as Alimaxx (Merit Medical) and Wallflex (Boston Scientific). Many of these devices include antimigration struts to prevent movement after placement. Today, covered stents are typically sutured into place with the Apollo endoluminal suturing device. All collections must be drained in addition to stenting. Stents should be repositioned to avoid erosion every 2 to 4 weeks.

Esophageal salvage is enhanced with vacuum-assisted wound closure (VAC) therapy. Endoluminal VAC therapy is a more novel technique that has been implemented, with some modifications, using a glove over the VAC to facilitate easy removal of the sponge during interval exchanges. Suction therapy requires frequent sponge exchange along with a chronic indwelling nasogastric tube or pigtail catheter to apply suction to the sponge and collapse cavities. Often, in-patient hospitalization is required for chronic negative pressure therapy. Devices that can apply constant suction in the esophagus are needed for home use. Direct suture repair often fails to close chronic or large defects in the esophagus with friable tissue.

More often, a combination of therapies is required. An esophageal defect heals better and is less likely to erode into the airway or aorta when muscle flaps are interposed, which serve as a buffer and also a source of healthy blood supply to augment wound healing. When these techniques fail, diversion is required to control sepsis with planned later reconstruction.

A final alternative to complete diversion to preserve continuity but exclude esophageal perforations includes exclusion with sidewall proximal diversion and an occluding seton-style Vicryl (Ethicon) suture to limit flow below the side diversion at the neck. This technique can allow for proximal side diversion while the occluding temporary Vicryl suture excludes ongoing passage of saliva. By the time the Vicryl dissolves, which is at 90 days, the perforation has healed. Another option would be using a noncutting TA (Medtronic) stapler, where the created staple line will prevent leakage and can later be mechanically dilated, allowing for gradual restoration of esophageal patency. A more traditional approach includes complete esophageal diversion.

Interposition grafts involve the use of alternative tissue to bridge a gap created by the esophageal defect or stricture. When a large hole requires patching without interposition, an intercostal muscle flap may suffice. Common graft options include the use of stomach, colon, or jejunum segments to replace longer segments of damaged esophagus. These grafts can be used as isoperistaltic conduits in the abdomen or antiperistaltic conduits. The tunnel can be in the anterior or posterior mediastinum and rarely includes a subcutaneous route. The graft can be brought anterior or posterior to the transverse colon, depending on the length of interposition required. Most conduits, other than the jejunum, are aperistaltic. When there is a tissue defect, myocutaneous flaps are favored.

Finally, tissue-engineered reconstruction represents a promising field in complex esophageal reconstruction. These constructs involve the use of bioengineered scaffolds, seated with patient-derived cells or stem cells to create functional esophageal tissue. Although still in the experimental phase, tissue-engineered constructs hold the potential for personalized and regenerative approaches to esophageal reconstruction without the necessary use of other organs.

PATIENTS AND METHODS

PATIENT RECRUITMENT AND DATA ACCESS. Most patient reconstructions and interventions were retrospectively selected from 3 institutions. Because specific data are not presented and case outcome is not the focus of this review, specific cases are not described. Rather, a collective series based on expert experience is described to present options for other surgeons who find themselves in similar circumstances. Because these events are rare, knowing all possible options allows multidisciplinary teams to best understand the landscape of possibility and consider their own skill sets as well as the skill sets within expert institutions to determine the best path of treatment for their patients. Deidentified notes from adult patients aged >18 years, who presented with esophageal defects or segmental gaps, injury, fistulae, or other discontinuity of the esophagus, are used for this review. Options and strategies were placed into categories according to the ultimate reconstruction method. Specific varieties of presentation and operative challenges are catalogued according to solution. For brevity, details of outcome are not included.

RESULTS

The process for evaluating a patient with a complex esophageal problem begins with a thorough history, physical examination, review of prior patient records, and anatomy. When administering a complex esophageal clinic, various digital and printed patient education handouts enable surgeons to

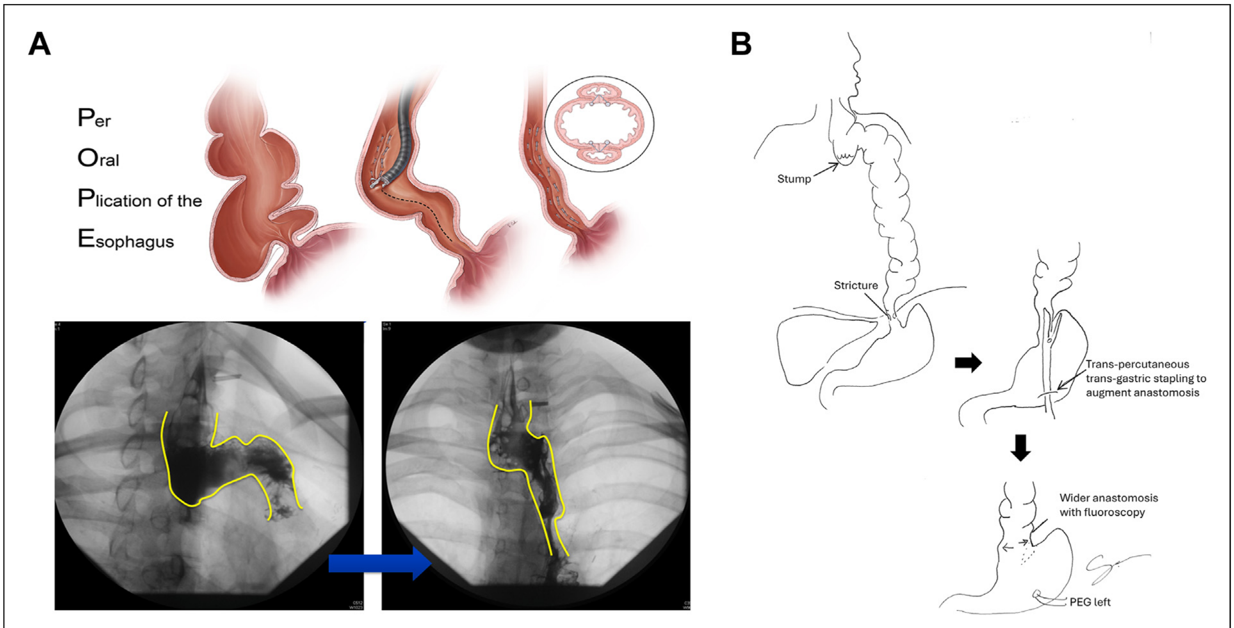

FIGURE 2 (A) Peroral plication of the esophagus (POPE) with improved postoperative emptying. Straightening the conduit and eliminating redundancy is seen in the radiograph prior to internal plication (left radiograph) and after plication (right radiograph). Must be repeated yearly because it is endoscopic plication. (B) Patient with congenital esophageal atresia with colon interposition and redundancy with distal obstruction treated with internal plication and laparoscopic-assisted endogastric stapling of cologastric anastomosis strictureplasty. (PEG, percutaneous endoscopic gastrostomy.) Used with permission of Mayo Foundation for Medical Education and Research, all rights reserved.

communicate better with their patients. These may include customized illustrations of tumor or fistula location (Supplemental Figure 1), completed study results, illustrate expected operations, detail resection locations, and sequence the series of events necessary to complete the reconstruction process. Algorithmically building this often enables the patient to understand each step along the way as well as comprehend potential complications that may ensue. We find listing anticipated problems, proposed plans, and decision trees quite helpful for the patient to understand the clinical pathway with the hope of graduating them to the survivorship care clinic after their operative, reconstructive, and sometimes oncologic management.

SALVAGE.

Stenting/VAC Therapy. Salvage procedures can be performed when esophageal perforation, abscess, or leak is identified. In these circumstances, stenting, suturing, or endoscopic vacuum suction are viable options. Endoscopic covered stenting has been in practice since the early 2000s and has become more widespread since 2010.[1] Patients who present with esophageal perforation or leakage from anastomotic dehiscence can be treated with stenting and drainage. We typically use an Apollo OverStitch Endoscopic Suturing System (Apollo, recently purchased by Boston Scientific) to secure the stent in place, preventing migration and potentially closing small discreet perforations. While healing, the stent is typically left in for 2 to 4 weeks so that there is no erosion into adjacent structures. Complications of stents include erosion, pain, migration, bleeding, reflux, aspiration, fistulization, and failure to seal the leak.

One of the most important tenets of stenting is making sure the abscess cavity is drained before placing the stent. This may be drained by an internal or externally placed pigtail catheter, sponge, or hybrid surgical repair, followed by placement of the stent. Stenting without drainage of the infection can lead to sepsis and worsening of the esophageal erosion. Stents that are left in place too long can erode into the adjacent trachea, aorta, or other structures worsening the problem.[2]

When endoluminal vacuums are placed (KCI) we typically try to make sure that the VAC sponges (3M Corporation) are routinely exchanged so that there is no corrosion of the sponge. Comellas and colleagues[3] demonstrated covering the sponge with a glove finger to prevent corrosion and lessen sponge fragment retention while promoting negative pressure within the cavity.

An alternative to a VAC sponge is simply placing a pigtail catheter into the cavity of the abscess adjacent to the esophageal wall through the perforation. Although this has less evidence of efficacy compared with a sponge, it remains a viable alternative with fewer requirements for repetitive exchange.

Internal Plication. Salvage of the esophagus for patients presenting with a dilated esophagus secondary to end-stage achalasia or an esophageal leak can be potentially improved with repeated endoluminal suturing. Endoluminal suturing of a dilated redundant esophagus can help to narrow the esophagus and promote better emptying with minimal reflux of retained fragments due to sump formation. The sump of a redundant esophagus or conduit can function like a kitchen sink trap, collecting food and preventing an effective functional swallow. Furthermore, food sitting in a dependent redundant portion of the esophagus can be prone to fermentation and cause enhanced injury.

An extreme example of this technique remains a peroral plication of the esophagus (POPE) (Figure 2A). In this novel procedure, the endoscopist begins by using an argon plasma coagulator (Erbe) to mark the endoluminal mucosal track for plication.[4] The argon plasma coagulator markings provide orientation while preventing inadvertent narrowing of the esophagus. An endoscopic suturing system (Apollo; Boston Scientific) is used to capture the walls of the esophagus and narrow the lumen. Although this can successfully narrow the lumen of the esophagus, the procedure often does not last, and frequently, this must be repeated yearly because the sutures inevitably fail to hold over time. Full-thickness sutures may be more difficult to achieve due to adhesions and immobility of the conduit. Ability to achieve the correct angle due to limiting adjacent structures may also play a role. These more superficial sutures often mandate regular repeat plication when the POPE approach is taken. A similar application is also now used for endoscopic gastroplasty.

Patients with congenital esophageal atresia reconstructed with colon interpositions can present with redundancy, stump formation, and distal obstruction (Figure 2B). It is this patient population that may benefit from the POPE to avoid complex revisional surgery. One particular patient who presented with colonic redundancy and a cologastric stricture was treated with a combination of internal plication with laparoscopic transgastric stapling of the cologastric anastomotic stricture. One arm of the linear stapler was introduced into the lumen of the stomach and another arm into the lumen of the colon, and the device was deployed to seal and widen the anastomosis with a "stricturoplasty" effect. Although this may be the first description of such a technique, it successfully facilitates emptying of the colon interposition without requiring extensive open laparotomy and open surgical revision. The POPE technique has also been offered to a variety of achalasia patients with variable success, always requiring repetitive plication. Many patients return yearly for scheduled replication to avoid esophagectomy.

Dilations. Another way to salvage the esophagus in patients with esophageal stricture is by using a bougie (Diversatek Healthcare) or Savary-Gilliard (Cook Medical) dilator, controlled radial expansion (Boston Scientific) endoscopic ballon, or self-dilation.[5] Teaching a patient to self-dilate can prevent repeated endoscopic intervention. After dilation, patients can be monitored by severity of dysphagia by using a patient-reported outcome monitoring system, such as the upper digestive disease tool.[6] The best success stories include patients who had prior caustic ingestion and required cervical dilations or those with isolated benign strictures. Other endoscopic options can include cryotherapy, incision and dilatation, and mitomycin C application. When dilation fails, the patient may require surgical augmentation or reconstruction of the esophagus. When appropriate, recurrence of cancer must always be ruled out regularly.

Untwisting. After esophagectomy, conduits can stricture, necrose, or twist. Supplemental Figure 2A demonstrates an illustration of a patient who presented with a twisted colon interposition. This was identified with a computed tomographic angiogram that showed an intact blood supply but complete twisting that created dysphagia from blockage when swallowing. Endoluminal exploration with endoscopy confirmed a swirling of the mucosa, and an esophagram demonstrated poor emptying of the colon interposition. The patient underwent a minimally invasive transection of the interposition with a staple side-to-side functional end-to-end anastomosis with mesenteric preservation. This technique allowed preservation of the colon conduit with minimal mobilization. Such a dissection enabled potential preservation of the blood supply, allowing the patient to have a less complicated intervention than complete reconstruction.

Supplemental Figure 2B shows a patient who had minimally invasive esophagectomy with gastric conduit complicated by twisting and poor

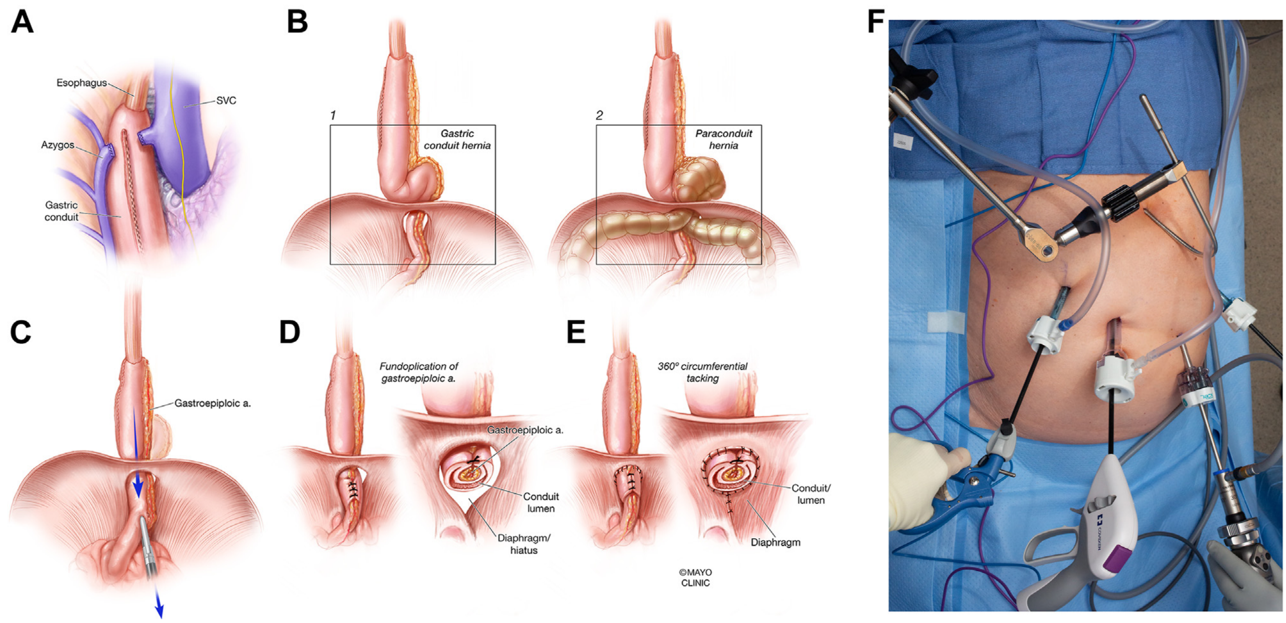

FIGURE 3 Technique for the imbricated repair of a paraconduit hernia after esophagectomy. (A) Normal anatomy of a gastric conduit. (SVC, superior vena cava.) (B1) Herniation of the conduit through the hiatus can result in tortuosity and poor conduit emptying. (B2) Herniation of other abdominal organs. (C) The laparoscopic view of the conduit reduction. (D) The gastroepiploic vessels can be tucked inside the conduit and imbricated. (E) To prevent repeat herniation, 360° imbrication is performed. (F) Laparoscopic instrument placement and positioning for paraconduit hernia repair. Used with permission of Mayo Foundation for Medical Education and Research, all rights reserved.

emptying with recurrent aspiration events. The patient underwent successful video-assisted thoracoscopic surgery/laparoscopic revision, including transection of the distal conduit and delivery of a Roux-en-Y limb to the untwisted gastric conduit to facilitate emptying. Peterson defects should be closed after untwisting and creating the Roux-en-Y limb. Kent and colleagues[7] have also described untwisting of esophageal conduits.

Redundant Conduit Repair. A redundant conduit may develop in patients who undergo minimally invasive esophagectomy, which refers to sagging or excess length of the esophageal conduit leading to kinks or folds. This condition can lead to complications such as poor emptying and may require revisional surgery to straighten and reorient the conduit for better gastric emptying. Kent and colleagues[7] reported a series of patients who required revisional surgery after esophagectomy, involving laparoscopic or thoracoscopic intervention. Techniques such as the Puig and Blackmon[8] method, which involves a 360° plication by imbricating the gastroepiploic artery into the conduit at its widest portion, have been reported. This is usually done during an Ivor Lewis approach or after transposition in a 3-field approach, particularly effective when the conduit has a sufficiently large diameter. Laparoscopic correction often uses a V-lock suture to facilitate this process.

Paraconduit Hernia Repair. Paraconduit hernia involves the herniation of adjacent bowel through the hiatus or other anatomical defects, causing compression on the conduit. This condition can complicate the postoperative course by affecting the conduit's ability to empty effectively and may lead to symptoms such as nausea, vomiting, or obstructive complications. In cases where herniation involves the bowel, diagnostic tools, such as a barium esophagram, are invaluable in differentiating between issues such as diaphragm compression, conduit twisting, or pyloric obstruction. In <20% of patients who did not have a pyloromyotomy or pyloroplasty, pyloric spasm may interfere with conduit emptying.[9] Management often includes surgical revision to correct the hernia, and if the patient continues to have emptying problems despite the resolution of herniation, Figure 3 interventions such as gastric peroral endoscopic myotomy (G-POEM) or botulinum toxin (Botox, Allergan) injections may be necessary to relieve pyloric spasm.

External Plication. In some cases, a more definitive approach to narrow and straighten a conduit can include external plication. In one particular case, a patient presented with congenital esophageal atresia, and a whole gastric conduit was used for reconstruction. The patient presented with a complete intrathoracic gastric conduit and sump formation. Right transthoracic plication facilitated narrowing and straightening of the gastric conduit. Redundancy of the conduit was reduced back into the abdomen. Dysphagia resolved, but postoperative reflux worsened. With every intervention to treat one problem, subsequent new problems can arise. Often, the most severe problems need to be addressed, and a reevaluation can facilitate prioritization and technique selection to address subsequent issues.

REPLACEMENT.

Routes and Diversion. Esophageal reconstruction can be routed subcutaneously, anterior mediastinal, or through a posterior mediastinal route and can be antecolic (in front of the colon) or retrocolic (behind the colon) (Supplemental Figure 3). Subcutaneous conduit placement is always a last resort. A retrocolic pathway may provide additional conduit length when needed. However, there are also anecdotal reports of antecolic conduits causing compression and obstruction of the colon.

Most of the cases performed in the past 10 years at Mayo Clinic have included staged reconstruction with diversion being performed as a separate operation.[10] For example, the published series contained multiple prior patients who underwent esophagectomy complicated by strictures and were then treated by stent and dilation that resulted tracheoesophageal fistulae requiring repair (Supplemental Figure 4 is only one example).

Pulmonary optimization should be performed before repair of the airway to ensure that patients can be extubated after tracheal repair. With a long tracheal defect, intercostal muscle or latissimus muscle can be used for reconstruction. Often, both muscles are best to be used in the event one fails. Tracheal repairs can be performed with jet ventilation, minimal ventilation, frequent bronchoscopy, selected main stem intubation, or extracorporeal membrane oxygenation (ECMO). In this case, the patient was placed on venovenous ECMO for the repair. The current approach for esophageal diversion includes placing the esophagostomy in line with planned future incisions[11] (Supplemental Figure 5).

What to Do When the Gastric Conduit Becomes Necrotic?. The gastric conduit can sometimes be salvaged by only resecting the necrotic portion of the conduit, returning the viable part back into the abdomen, placing a feeding tube into the tip, and then rerouting the remaining portion with a substernal route. The gap can be bridged with a jejunal interposition.

The first stage of such a repair also includes removal of the gastric conduit and repair of tracheoesophageal fistula with proximal esophageal diversion and placement of additional viable remnant conduit back into the abdomen. If enough length is remaining, a feeding tube can be placed directly into proximal viable bowel. Patients prefer placement of a gastrostomy tube into the gastric remnant if there is enough length to allow them to use bolus gastric feeding and avoid jejunal pump feeding, which is more inconvenient and more expensive. Most repairs of tracheal defects are performed with muscle flaps. End esophagostomy should preferably be placed below the clavicle. This low placement preserves length of the esophagus and allows the ostomy wafer to be placed on a flat surface, which makes application easier for the patient and enables a more cosmetic appearance because the ostomy can more frequently be hidden behind a garment on the chest.

Conduits. There are multiple different esophageal replacement options. A gastric conduit is the standard of care. When a patient presents with a paucity of gastric conduit (necrotic gastric conduit, undilatable stricture, cancer extending into the esophagus and stomach, recurrent cancer after esophagectomy, damaged gastric conduit, prior foregut surgery precluding use of the stomach, including sleeve gastrectomy, prior Whipple, damage to the gastroepiploic vessels, or inadequate length of stomach available) then an alternative conduit must be chosen. This choice is made based on location and length required for reconstruction (Figure 4).

Free Jejunum and Stomach. When a gastric conduit cannot reach the terminal end of the esophagus for reconstruction, one alternative includes jejunum. The jejunum can be attached to the stomach and bridged off the gastroepiploic artery (while being left in the abdomen in situ before delivery and connection to the esophagus). Once this has matured in the abdomen, it can be transposed through the retrosternal route to be connected to the terminal end of the esophagus. If the pedicled jejunal graft will not reach, the mesentery can be split to route the upper mesenteric arcade to a mammary or cervical vessel to provide additional length. Essentially, jejunum can be pedicled or used as a free flap (Figure 5). An alternative to this approach is using the jejunum as a Roux conduit that is

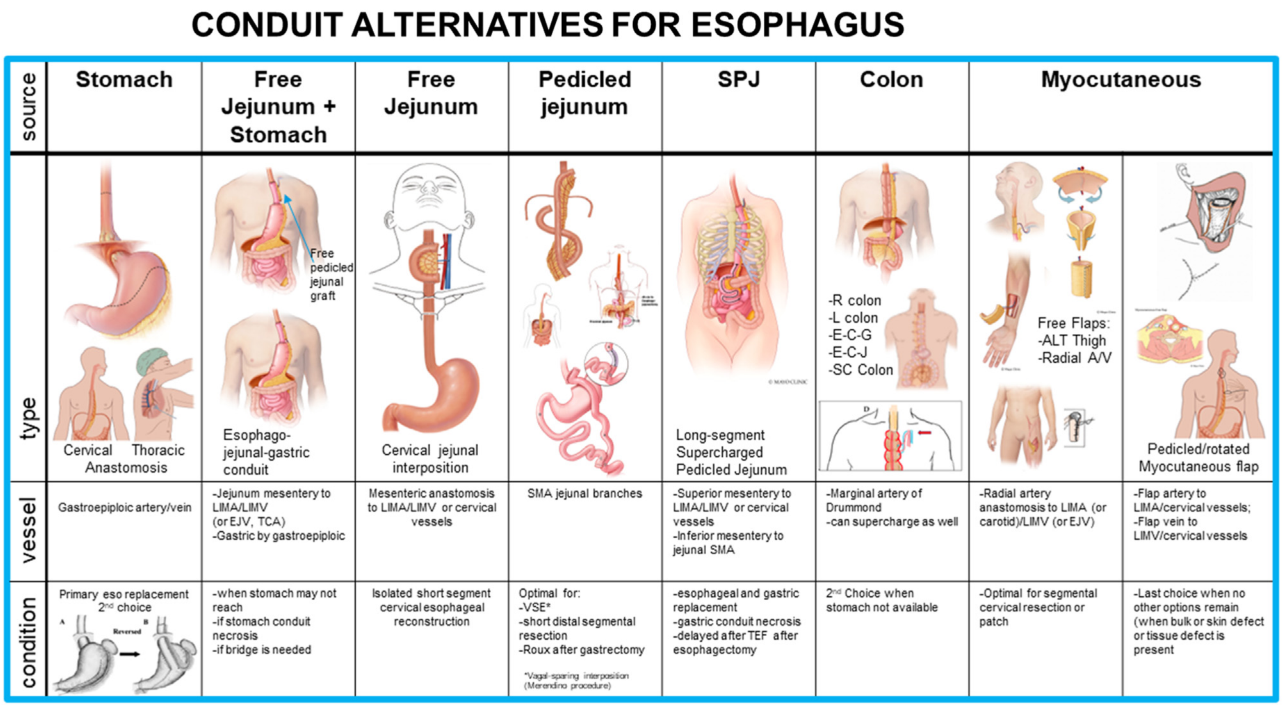

FIGURE 4 Esophageal replacement conduit alternatives, their blood supply, and condition to use. (ALT, anterolateral thigh; A/V, artery/vein; C, colon; E, esophagus; EJV, external jugular vein; G, gastric; J, jejunum; L, left; LIMA, left internal mammary artery; LIMV, left internal mammary vein; R, right; SC, supercharged; SMA, superior mesentric artery; SPJ, supercharged pedicled jejunum; TCA, transverse cervical artery; TEF, tracheoesophageal fistula.) Used with permission of Mayo Foundation for Medical Education and Research, all rights reserved.

supercharged from long segment reconstruction or a short segment of jejunum that is transposed as a free graft. For example, a mechanical small bowel obstruction developed in a patient with prior esophageal cancer after Ivor Lewis esophagectomy that required a free jejunal flap with microvascular reconstruction when the gastric conduit became necrotic.

A Cook-Schwartz Doppler monitor (Cook Medical) can be used for the vascular anastomosis. For longer segment bipedicled jejunum (the lower pedicle coming off the gastroepiploic artery and the upper pedicle going to the left internal mammary artery and vein), resection of the medial aspect of the clavicle, medial aspect of the left first rib, and a hemi-manubriumectomy for microvascular augmentation will be required.[11]

Free Jejunum. Free jejunal interposition can be considered over cervical esophagostomy in patients presenting with cervical esophageal cancer. In these patients, esophageal cancer can erode into the larynx, requiring laryngectomy with mediastinal tracheostomy. However, esophagectomy with reconstruction can be performed for isolated tumors of the cervical esophagus that do not invade the larynx. A free jejunal interposition segment can be performed with microvascular augmentation based on the transverse cervical artery and external jugular vein or based on the left internal mammary artery and vein, depending on the location of the tumor.

Supplemental Figure 6A illustrates a patient who was referred with a necrotic superior aspect of colon interposition and Malecot tube placed at the top of the colon at an another facility for drainage. A proximal esophageal diversion was performed. The patient was eventually treated with free jejunal interposition. The interposition connected the terminal end of the esophagus to the top of the colon.

Supplemental Figure 6B demonstrates another case of colon interposition complicated by redundant and tortuous migration within an undilatable stricture. Initially, stenting resulted in migration, rotation, and erosion. The leak from erosion required proximal esophageal diversion and free jejunal reconstruction. Alternatively, free jejunal grafts can be used to bridge gaps between the esophagus and foreshortened gastric conduits that no longer reach to the neck after diversion.

Pedicled Jejunum. A pedicled jejunum interposition is a reasonable choice for a vagal-sparing esophagectomy (Merendino procedure),[11] short distal segmental resections, or patients who require gastrectomy with Roux limb reconstruction (Supplemental Figure 7). Because lymphadenectomy is not performed, this is more appropriate for patients with complex leiomyoma or gastrointestinal stromal cell tumor. For example, a patient, with a prior history of a hiatal hernia, presented with a gastrostomy tube remaining in the remnant stomach with inadequate length to replace the esophagus. This patient had an undilatable stricture that developed after a LINX (Ethicon) device was placed. A distal esophagectomy and proximal gastrectomy was performed with Roux reconstruction.

Supercharged Jejunum Flap. Supercharged pedicled jejunum (SPJ) longitudinal esophageal interposition relies on both superior mesentery vessels connected, with some remaining connected as a pedicle and others connected to upper thoracic artery and vein. (Supplemental Figure 8). Left internal mammary artery or vein are the most common vessels used. This long esophageal interposition can replace both esophagus and stomach. Patients with a history of whole gastric conduit necrosis, tracheoesophageal fistula, failed reconstruction, or extensive tumor are uniquely suited for this procedure. A collective review of prior published outcomes includes 290 patients, mortality spanning from 1% to 11%, a leak rate spanning from 0% to 36%, and graft loss rates from 0% to 11%.[12]

Supplemental Figure 9A demonstrates a patient who with prior bariatric surgery and a cT3 N1 M0 invasive, poorly differentiated adenocarcinoma treated with neoadjuvant chemoradiotherapy, diversion, and subsequent SPJ reconstruction. We recommend a 50-cm Roux limb measuring from the diaphragm to the jejunojejunal anastomosis. We recommend placing the feeding tube proximal to the jejunojejunostomy and the afferent limb to be guided distally into the common limb. This will prevent bile from exuding from the orifice. Supplemental Figure 9B demonstrates a case of extensive tumor spanning 10 cm in the esophagus and 6 cm into the stomach. An esophagogastrectomy was performed with proximal esophageal diversion, and delayed SPJ was performed.

Supplemental Figure 9C demonstrates a patient who underwent robotic minimally invasive esophagectomy, developed gastric conduit necrosis and airway injury, and required transfer to Mayo Clinic for tracheal repair on ECMO. The patient underwent a staged approach to treat the tracheoesophageal fistula. We first performed a right thoracotomy and mobilized latissimus and intercostal muscle flaps to repair the right main stem bronchus. After the right mainstem bronchial repair, a right thoracotomy was used to repair the left mainstem bronchus, and further revision required an anterior sternal approach. Proximal esophageal diversion was performed. The patient underwent a staged approach with the median sternotomy and a medial approach for the thymic fat pad with repair of the trachea. After SPJ reconstruction, successful continuity was established.

Supplemental Figure 9 Ddescribes a patient who presented with a cT3 N3 M0 invasive, poorly differentiated adenocarcinoma. The patient underwent robotic minimally invasive esophagectomy at another facility, developed conduit necrosis, was treated with diversion, and underwent successful delayed SPJ reconstruction with staged approach.

Colon. A colon interposition conduit is almost always based on the marginal artery of Drummond and can be supercharged. It is typically our second choice when the stomach is not available. Supplemental Figure 10 illustrates a patient who required a free colon interposition. Because of prior complications from former surgery, the patient underwent gastrectomy and esophagojejunostomy. Unfortunately, a proximal margin leak developed, which was stented. This was complicated by stent erosion. The colon mesentery was severely scarred from a prior stent erosion preventing us from performing a supercharge pedicled colon interposition and thus free colon interposition. Kesler and colleagues[13] report good outcomes with performing microvascular augmented supercharged isoperistaltic colon interposition for long-segment esophageal reconstruction.

Myocutaneous Flaps. Myocutaneous flaps can be used to augment undilatable esophageal strictures where a pedicled skin conduit is used. Supplemental Figure 11 illustrates a right-arm dominant patient who underwent a left forearm radial artery-based free flap. The radial artery and vein were microvascularized to the transverse cervical vessels. A second example includes a patient who presented after undergoing 70-Gy radiation with a tracheostomy and transesophageal echocardiogram esophageal perforation. Initially, a jejunal interposition remained healthy, but the proximal anastomosis of the esophagus to the jejunum failed to heal.

We bridged this gap by doing what we call the "bring your own blood (BYOB) supply" procedure, where the patient has a saphenous vein conduit connecting the right axillary artery and vein as a fistula. After 2 to 3 weeks of maturation, the distal tip of the fistula is transected, enabling microvascular augmentation with or without a connected muscle through the cutaneous flap (Supplemental Figure 11). This technique could be used to bring an arterial and venous connection to almost any remote portion of the body. This staged approach allows maturation of a venous fistula that becomes arterial inflow and venous outflow when divided. A myocutaneous pedicled flap attached to this can deliver muscle, fat, and skin to rebuild neck defects or an esophagus in this case.

Alternatively, an anterolateral thigh flap is another option that can be used to reconstruct the cervical esophagus. The anterolateral thigh flap is usually used as a free flap when used to replace the cervical esophagus.[14]

Synthetic Esophageal Replacement. Synthetic esophageal replacement is also possible, where a clinical-grade tissue-engineered esophageal graft can be used for segmental esophageal reconstruction in a patient. Aho and colleagues[15] reported regeneration of an esophageal conduit and histologic analysis of the tissue postmortem after implantation. The development of stem cell therapy, exosome therapy, and material bioscience has led to multiple applications for United States Food and Drug Administration approval. Transplantation has yet to be successfully performed for long segmental esophageal replacement and likely will never be an option when so many other better alternatives exist.

COMMENT

Complex esophageal reconstruction requires extensive skill and experience, often collectively formed by a multidisciplinary expert team working together over years. Standardized reconstruction pathways and checklists focus on optimization, allowing time for recovery and staged reconstruction.[15] Often there is insufficient evidence to guide therapy, and surgeons must rely on a multidisciplinary team's collective wisdom based on experience with what works. We recommend surgeons who plan to perform complex esophagea reconstruction have extensive training and consider undergoing additional fellowship experience when needed before undertaking such a practice. As always, finding key personnel who have experience in microvascular reconstruction techniques will often be necessary for the best outcome.

A prime example of using an iterative approach to improving a complex reconstruction practice is seen in the series of publications detailing SPJ reconstruction. Root cause analysis and continued process improvement have enabled modifications in many programs, such as staged reconstruction and replacing an externalized bowel indicator with an internal Doppler monitoring device.[16] Standardization of jejunal arcade selection now includes preservation of the first jejunal arcade and use of the second for arterial augmentation. The third arcade is left as a bridging pedicle, and the fourth arcade can also be a bridging pedicle or can be left connected to its native superior mesenteric artery. Performing the bowel anastomosis before microvascular work has reduced the need for repeated vascular revision. Standardizing to an antecolic and retrosternal Roux approach has reduced operating time and maintained consistency. Modifying our perioperative care experience with standardization has successfully reduced our length of stay by 8 days and eliminated 90-day mortality in our most recent series.[15]

Standardization of postoperative care pathways, including enhanced recovery after surgery (ERAS) pathway development,[17] can be an effective and essential method for reproducible success. An iterative analysis of problems can lead to solutions. Process modeling, determination framework, Gemba walks, Six Sigma techniques, evaluation frameworks, and other techniques learned from implementation scientific study can augment development of complex esophageal reconstructive clinics and care programs.[15]

Hospitals and surgeons often underestimate the complexity of caring for this population. We looked at the intraoperative problems and complications that occurred during our experience at Mayo Clinic over the past 10 years and created targeted modifications to the interoperative algorithm accordingly. During this same time, we implemented the Multidisciplinary Esophagectomy Enhanced Recovery Initiative (MERIT) pathway and tested this program on many of the SPJ patients, demonstrating implementation of such a program was effective in reducing postoperative ileus and atrial arrhythmia rates.[17]

Although the focus of this review is on techniques, monitoring patient-reported outcomes after reconstruction should be part of any established program. These populations are rarely reconstructed and then recover without postoperative problems. Recovery and optimization of the

Ann Thorac Surg
2025;120:244–55

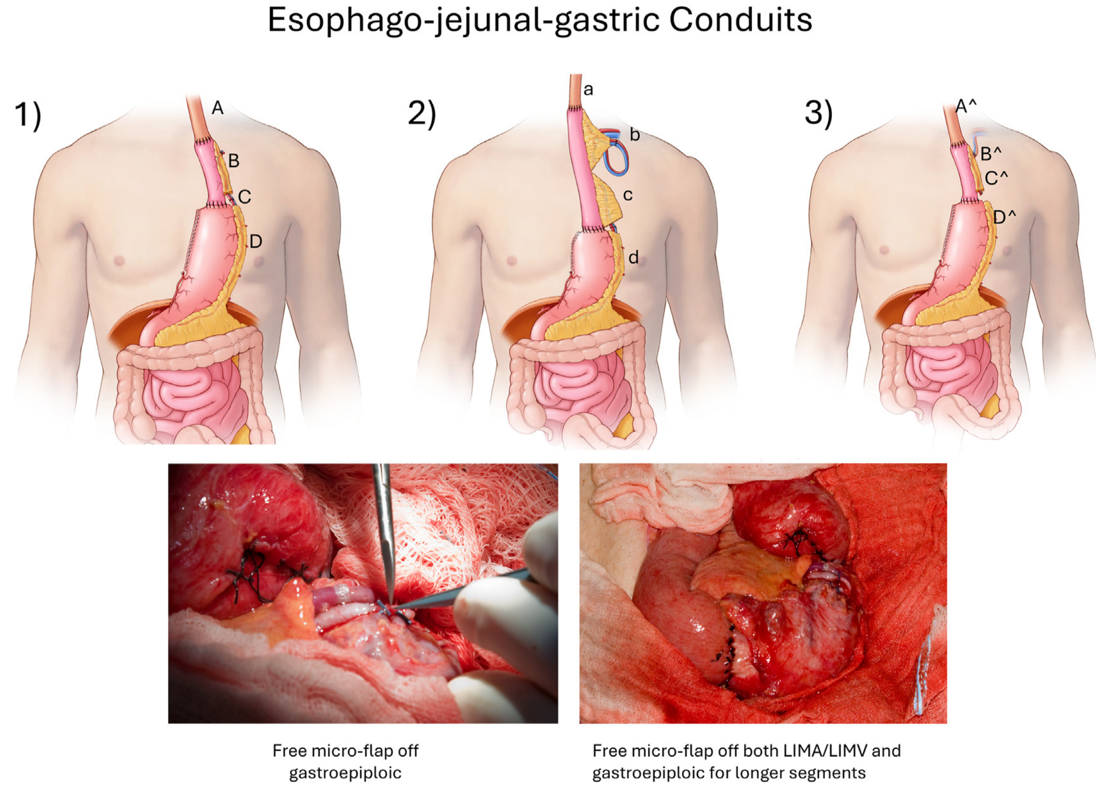

FIGURE 5 Jejunal interposition connecting the esophagus to the gastric conduit remnant. (1) Microvascular free jejunal interposition with gastroepiploic source to mesenteric vessels where the (A) esophagus, (B) mesenteric artery/vein anastomosed to gastroepiploic artery/vein, (C) mesenteric artery/vein anastomosed to gastroepiploic artery/vein, and (D) gastroepiploic artery supply the gastric conduit. (2) Microvascular free jejunal interposition with gastroepiploic and left internal mammary artery (LIMA)/left internal mammary vein (LIMV) to mesenteric pedicles that have been separated where the (a) esophagus, (b) mesenteric artery/vein anastomosed to LIMA/LIMV, (c) mesenteric artery/vein anastomosed to gastroepiploic artery/vein, and (d) gastroepiploic artery supply the gastric conduit. (3) Microvascular free jejunal interposition with LIMA/LIMV source to mesenteric vessels where the (A^) esophagus, (B^) mesenteric A/V anastomosis to LIMA/LIMV, and (C^ + D^) mesenteries do not connect. Used with permission of Mayo Foundation for Medical Education and Research, all rights reserved.

postoperative state will include access to experts in nutrition, endocrinology, gastroenterology, speech pathology, psychiatry, and pulmonary disease at a minimum. Identifying postoperative symptoms and providing adequate management is an intricate part of survivorship for this cohort of patients.[6] Examples of the complexity of caring for these patients and novel digital solutions for longitudinal care delivery are detailed in *The Support Group: Connection, Hope & Healing for Patients + Providers*" by the senior author (S.H.B).[18]

Esophageal salvage and reconstruction can be accomplished with a variety of different techniques. Organs should always be salvaged when possible. Care pathways and constant root cause analysis can improve outcomes. A multidisciplinary and systematic approach with standardization can facilitate perioperative optimization, execution of the procedure, and reduction of errors using an iterative process. Using tumor boards and expert panels before complex reconstruction can ensure multiple viewpoints are taken into consideration. Extensive discussions with patients about perioperative risks are necessary. Delayed reconstruction can provide time for surgical and medical optimization. Despite improving outcomes, the incidence of surgical and medical complications is still significant in this cohort. When salvaging or reconstructing the esophagus, one must carefully consider the appropriate timing source, connection, type, blood supply, and circumstances.

The authors would like to thank Nav S. Buttar, Louis M. Wong Kee Song, Travis E. Grotz, Eddie Lee, and Marco Maricevich.

FUNDING SOURCES

The authors have no funding sources to disclose.

DISCLOSURES

The authors have no conflicts of interest to disclose.

REFERENCES

1. Stephens EH, Correa AM, Kim MP, Gaur P, Blackmon SH. Classification of esophageal stent leaks: leak presentation, complications, and management. *Ann Thorac Surg*. 2014;98:297-303 [discussion: 304].

2. Blackmon SH, Santora R, Schwarz P, Barroso A, Dunkin BJ. Utility of removable esophageal covered self-expanding metal stents for leak and fistula management. *Ann Thorac Surg*. 2010;89:931-936 [discussion: 936-937].

3. Comellas E, Bellomo FJ, Rosales I, et al. On the feasibility of the computational modeling of the endoluminal vacuum-assisted closure of an oesophageal anastomotic leakage. *R Soc Open Sci*. 2018;5:171289.

4. Hedberg HM, Attaar M, McCormack MS, Ujiki MB. Per-oral plication of (neo)esophagus: technical feasibility and early outcomes. *J Gastrointest Surg*. 2023;27:1531-1538.

5. Mayo Clinic. Esophageal Self Dilation Therapy: An Effective Alternative at Mayo Clinic. Video. YouTube. November 20, 2024. Accessed January 15, 2024. https://www.youtube.com/watch?v=jillwpNQQeQ

6. Chaar MKA, Yost KJ, Lee MK, et al. Developing & integrating a mobile application tool into a survivorship clinic for esophageal cancer patients. *J Thorac Dis*. 2023;15:2240-2252. https://doi.org/10.21037/jtd-22-1343

7. Kent MS, Luketich JD, Tsai W, et al. Revisional surgery after esophagectomy: an analysis of 43 patients. *Ann Thorac Surg*. 2008;86:975-983 [discussion: 967-974].

8. Puig CA, Blackmon SH. Technique for imbricated repair of paraconduit conduit hernia after esophagectomy. *Ann Thorac Surg*. 2021;112:e459-e461.

9. Zhang R, Zhang L. Management of delayed gastric conduit emptying after esophagectomy. *J Thorac Dis*. 2019;11:302-307. https://doi.org/10.21037/jtd.2018.11.101

10. Mohan AT, Mahajan NN, Mardini S, Blackmon SH. Outcomes of standardized protocols in supercharged pedicled jejunal esophageal reconstruction. *Ann Thorac Surg*. 2023;115:210-219.

11. Mohan AT, Mardini S, Blackmon SH. Supercharged jejunal interposition. *Thorac Surg Clin*. 2022;32:529-540.

12. Gaur P, Blackmon SH. Jejunal graft conduits after esophagectomy. *J Thorac Dis*. 2014;6(suppl 3):S333-S340.

13. Kesler KA, Pillai ST, Birdas TJ, et al. "Supercharged" isoperistaltic colon interposition for long-segment esophageal reconstruction. *Ann Thorac Surg*. 2013;95:1162-1168 [discussion: 1168-1169].

14. Dickinson KJ, Blackmon SH. Management of conduit necrosis following esophagectomy. *Thorac Surg Clin*. 2015;25:461-470.

15. Aho JM, La Francesca S, Olson SD, et al. First-in-human segmental esophageal reconstruction using a bioengineered mesenchymal stromal cell-seeded implant. *JTO Clin Res Rep*. 2021;2:100216.

16. Blackmon SH. Long-segment, supercharged pedicled jejunal interposition for esophageal replacement: how I teach it. *Ann Thorac Surg*. 2018;105:345-350.

17. Sims CR 3rd, Abou Chaar MK, Kerfeld MH, et al. Esophagectomy enhanced recovery after surgery initiative results in improved outcomes. *Ann Thorac Surg*. 2024;117:847-857. https://doi.org/10.1016/j.athoracsur.2023.10.032

18. Blackmon SH. *The Support Group: Connection, Hope, and Healing for Patients + Providers*. Mayo Clinic Press, 2024.