Esophageal Replacement

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Contents

Introduction (Definition, Overview) ................................................... 2
Indications for Esophageal Replacement .............................................. 2
Routes for Esophageal Replacement ................................................... 3
Mobilization of the Esophageal Stump ................................................ 3
Colon Interposition ............................................................................ 4
Assessment of the Vascularity ............................................................ 4
Technique ......................................................................................... 5
Treatment of Complications ............................................................... 7
Long-Term Outcome and Follow-Up .................................................. 8
Gastric Tube ..................................................................................... 8
Technique ......................................................................................... 10
Long-Term Outcome and Follow-Up .................................................. 10
Jejunal Graft ..................................................................................... 11
Technique ......................................................................................... 11
Complications ................................................................................... 12
Long-Term Outcome and Follow-Up .................................................. 12
Gastric Transposition ....................................................................... 12
Neonatal Gastric Transposition ........................................................... 13
Technique ......................................................................................... 13
Complications ................................................................................... 15
Conclusion and Future Directions ...................................................... 18
Cross-References ............................................................................. 18
References ......................................................................................... 18

Abstract

The most common indications for esophageal replacement in children are a wide-gap or long-gap esophageal atresia or an esophageal stricture developing after corrosive ingestion. There are currently four surgical techniques
for esophageal replacement in children, including colon interposition, gastric transposition, gastric tube, and jejunal interposition. Esophageal replacement is a complex procedure and involves a learning curve that involves identifying and managing the postoperative complications that may sometimes be serious.

**Keywords**
Esophageal replacement · Colon interposition · Gastric transposition · Gastric tube · esophagoplasty · Jejunal transposition

**Introduction (Definition, Overview)**

The esophagus in children may be insufficient congenitally or may get affected with acquired diseases like corrosive ingestion. In such cases, esophageal replacement may be a suitable option. The earliest reports of esophageal replacement in children date back to the 1950s (Sherman and Waterston 1957). The colon was the first organ used. The follow-up results and outcome still continue to be studied as surgeons strive for perfection (Sharma and Gupta 2017). There are currently four popular surgical techniques for esophageal replacement in children including colon interposition, gastric tube, gastric transposition, and jejunal interposition. There are various challenges associated with each of these procedures that are a major undertaking in young children. Colon interposition has stood the test of time and is the most popular procedure with minimal and less serious complications. Long-term complications include reflux, halitosis, colonic segment dilatation, and anastomotic stricture, sometimes requiring surgical interventions especially for dilatation and reflux. Redo surgeries on long-term follow-up are common with colonic interposition. As the stomach has a good vascular supply, there are two techniques that use the stomach as a conduit: the gastric tube and gastric transposition. Gastric tube involves a long suture line in the chest and is thus technically more risky and associated with early serious complications like prolonged leak in the neck or mediastinum, graft necrosis, and ischemia leading to stricture of the tube. However, if there are no immediate or early complications, the long-term results are favorable for this procedure. The procedure of gastric transposition is relatively easier as it involves a single anastomosis in the neck. However, the immediate postoperative period is stormy and requires constant monitoring and artificial ventilation. Postoperative complications include gastric stasis, bile reflux, restricted growth, and decreased pulmonary functional capacity. Jejunal interposition has been popular in European countries due to the fact that the lumen is narrow and adapts favorable in the position on the esophagus (Gallo et al. 2015). However, it has not been used extensively worldwide due to precarious vascularity. The long-term results are good in expert hands. Esophageal replacement is a complex procedure and involves a learning curve that includes identifying and managing the postoperative complications that may sometimes be life-threatening. The appropriate time for undertaking esophageal replacement is after infancy as the vascularity and lengths of the neo conduits are reliable. However, the procedure can also be performed in the newborn age if required for which a gastric transposition is preferred (Gupta et al. 2007; Gupta and Sharma 2011).

**Indications for Esophageal Replacement**

The indications for esophageal replacement in children include both congenital and acquired causes (Table 1) (Sharma and Gupta 2017).

An ideal esophageal substitute should have the ability to grow with the child and last for a lifetime with minimal gastric acid reflux. It should not cause mediastinal compression and compromise the respiratory or cardiac function. It should be technically simple, reproducible, and adaptable for small children (Soccorso and Parikh 2016). It should allow normal swallowing. The vascularity should be good to prevent major postoperative complications. It should not become tortuous or redundant and should not have increased malignant potential (Soccorso and Parikh 2016).
**Table 1** Indications for esophageal replacement

| Congenital                          | Acquired                                                      |
|-------------------------------------|---------------------------------------------------------------|
| Pure esophageal atresia             | Stricture of the esophagus (alkali ingestion – liquid or solid pallets) |
| Esophageal atresia with tracheoesophageal fistula with a long gap | Button battery injury to esophagus                           |
| Esophageal atresia with tracheoesophageal fistula with failed repair | Acid esophageal burns                                         |
| Long esophageal stenosis            | Trauma                                                        |
| Congenital short esophagus          | Epidermolysis bullosa                                         |
| Achalasia cardia                    | Candidiasis                                                   |
| Neuromotor abnormalities            | Bleeding varices                                              |
|                                     | Reflux esophagitis with stricture                             |
|                                     | Indolent stricture of the esophagus                           |
|                                     | Neuromotor abnormalities                                      |
|                                     | Advanced obliterative esophagitis                             |
|                                     | Perforation of the esophagus                                  |

**Routes for Esophageal Replacement**

Currently, there are basically two possible routes to be used for placing the organ in the chest.

1. Substernal (retrosternal): Adequate space should be created for the graft to be housed comfortably at the xiphisternal level, behind the sternum, and at the thoracic inlet. The sternal head of the sternomastoid muscle and the sternohyoid and sternothyroid muscles may have to be detached from the sternum, to prevent compression of the graft and its delicate blood supply especially in the neck region.

2. Mediastinal (transhiatal, native, orthotopic): Two routes of historical importance include the retrohilar route behind the hilum of the left lung and the subcutaneous route, under the skin over the sternum.

The route to place the graft is a major decisive factor in planning the procedure as surgeons would prefer to use a shorter route. The retrosternal route was found to be 1.9 cm longer than the transhiatal route on autopsy studies (Sharma and Gupta 2017). On the contrary, it was demonstrated that the retrosternal route is about 3 cm (>1 in.) shorter than the posterior mediastinal route when stomach is used for the esophageal replacement (Chen et al. 2009). The length of the route may thus vary depending on the type of the procedure used and the site of the anastomosis performed. The retrosternal route is shorter if the stomach is to be used, and the transhiatal route becomes shorter if the colon is to be used. As the colon graft has no problem regarding length, colon interposition can be done via the substernal or the hiatal route. The advantages and disadvantages of the two routes are depicted in Table 2.

**Mobilization of the Esophageal Stump**

The patient is placed in the supine position, with a folded towel under the shoulders to extend the neck and expose the esophagostomy site. The cervical esophagostomy is mobilized placing an elliptical incision around it in the neck, detaching it carefully from the sternocleidomastoid muscle. Care is also taken not to injure the esophagus wall and preserve the recurrent laryngeal nerve during its mobilization. The esophagus is mobilized for 2–3 cm. and the terminal few mm of its wall is freshened to resect the skin edges. The blood supply to this part of the esophagus is submucosal and does not pose any ischemic threat even after its extensive mobilization in the neck.
Colon Interposition

Colon interposition is a time-tested procedure based on the middle colic branch of the superior mesenteric artery or the left ascending colic branch of the inferior mesenteric artery, passing behind the stomach, with a cologastric anastomosis with the posterior wall of the stomach in the abdomen and an esophago-colonic anastomosis in the neck. The advantages of colonic interposition include a reliable vascular pedicle due to the marginal artery of Drummond; adequate length of graft; feasibility to use in both iso- and antiperistaltic direction; easily coursing over the liver edge, with due precaution; and hitching the liver properly. This technique is relatively safe and easy to perform and most importantly has less frequent and less serious complications compared to those seen with other procedures (Sharma and Gupta 2017).

Table 2  Advantages and disadvantages of the retrosternal and transhiatal routes

| Description | Retrosternal (substernal) | Transhiatal (mediastinal) |
|-------------|---------------------------|---------------------------|
| Advantages  | Preferred when the mediastinum is scarred with old exploration, infection, empyema, or a major leak following trachea-esophageal surgery | This route is most commonly utilized in newborns, infants, and children after the native esophagus has been removed |
|             | Technical simplicity | Maintains the natural route |
|             | Safe as less chance of damage to trachea, major thoracic vessels, and recurrent laryngeal nerve | There is also no risk of kinks and curves using this route |
|             | No pulmonary or cardiac compression by the interposed segment | |
| Disadvantages | Chances of kinking and obstruction while coursing over the edge of the liver | Technically more difficult, especially with scarred mediastinum |
|             | The pleura may also be injured resulting in pneumothorax, unilateral, or bilateral | Risk of damage to the trachea, major vessels, and recurrent laryngeal nerve |
|             | There is a narrow space between the manubrium and clavicle and the scalene muscles. This may compromise vascularity and may also cause obstruction to vascular flow resulting in the postoperative edema of the face | Risk of pulmonary compromise due to compression and need for an additional thoracotomy, to remove the esophagus and create enough space for this route |
| Method | The substernal route can be created easily by blunt finger dissection starting just behind the xiphisternum | This route is made by digital dissection progressively upward from the hiatus strictly in front of the vertebral body. A retrotracheal digital dissection is gently directed downward, within the posterior mediastinum in front of the prevertebral fascia. The transhiatal and cervical operator’s fingers should get together and finalize a wide and comfortable passage |

Assessment of the Vascularity

The colon has a rich blood supply from the ileocolic, right colic, middle colic, and left colic vessels, making it feasible to shape the colon graft of any length so as to reach even the highest point in the neck to be anastomosed, even with the pharynx, especially with high and multiple strictures in the neck. The options while using the colon conduit are commonly either the right colon and the transverse colon as an antiperistaltic conduit, based on the middle colic artery, or the transverse and left colon as an isoperistaltic conduit, based on the left colic vessels. The left antiperistaltic conduit is preferred over the right colon because it is less bulky and has a more reliable blood supply (Sharma and Gupta 2017). Cheng et al. studied the vascularity of the colon in 582 patients undergoing colonic interposition (Cheng et al. 2006). The left colic artery stemmed from the inferior mesenteric artery in 97.3% of the patients, with an absence rate of 0.7%. The middle
The right colic artery was absent in 9.8%. About 39.7% of the right colic artery stemmed from the superior mesenteric artery on its own; 23–28% stemmed together with the middle colic: ileocolic artery. The marginal artery was intact in 96.8%, 88.7% at the splenic, hepatic flexure of colon. Thus, the optimal artery of the colic segment during replacement is the left colic followed by the middle colic artery. A good vascular supply and isoperistaltic loop have been suggested to be beneficial in the prevention of anastomotic leakage and intestinal ischemia (Sharma and Gupta 2017). The nearest distance between the marginal artery and the colic wall has been noticed to be at the splenic flexure. As the origin of the right colic artery is variable, the use of the ascending branch of the left colic artery is more dependable for the blood supply to the transverse colon when planned for replacement of esophagus in an isoperistaltic fashion.

The middle colic artery, a major branch of the superior mesenteric artery, bifurcates into right and left branches to anastomose freely with the adjoining vessels to supply the right, transverse, and the left colon. Normally, the left branch is more prominent and supplies the larger segment of the transverse colon (Fig. 1). However, in about one quarter of cases, the right branch is more prominent. It is vital to examine which branch needs to be preserved so as to maintain a rich blood supply to the colonic graft. A bulldog clamp may be applied on the proposed branch to be divided, to check the reliability of the vascular supply to the proposed graft.

**Technique**

The required length of the colonic segment should be assessed by measuring with an umbilical tape, also keeping in mind that the colon graft shrinks after it has been transected at either end. The colon is transected between clamps for the desired length. Moreover, it is not the total length that is important but the two segments on either side of the vascular pedicle as that is the holding point. The longer part is the length of colon beyond the limits of its vascular pedicle that is required to reach the neck. The other part of the colon is taken to the back of the stomach for anastomosis. It is desirable to keep an extra cm of the colon on either side of the length measured that can be trimmed later if redundant.

The isolated colonic segment between clamps should be cleaned on the table with normal saline and diluted betadine until clear. It should be kept warm and moist to keep the vessels and graft supple. The adequacy of the colon segment length is reassessed, and the colon is placed in the desired place without any tension (Fig. 2). The colon graft on its pedicle is passed behind the stomach and then through the gastrohepatic ligament to take the desired route: retrosternal or mediastinal (Sharma and Gupta 2020). The excess of the pulled colon, if any, is trimmed, and the vascularity at its edges is again reassessed.

The anastomosis in the neck is usually performed first. A wide and single-layer end-to-end (rarely end-to-side if the vascularity is in doubt) esophago-colonic anastomosis is performed, using absorbable interrupted sutures. The colon is fixed with the prevertebral or deep cervical fascia to prevent its sagging. The distal end of the graft is anastomosed to the posterior (rarely anterior also) wall of the stomach in the mid body in two layers. Few sutures are placed at the angle of the stomach with the colon to

![](image1.jpg)

**Fig. 1** Vascular supply of the mobilized colon depicting that the left branch of the middle colic artery is more prominent than the right one in a 1-year-old child
incorporate the antireflux mechanism at the gastrocolic junction. The liver is hitched with the cut end of the round ligament behind the xiphisternum so as to allow the graft to have a smooth course over the liver edge. The angulating curve of the colon prevents reflux from the stomach into the colon. The ends of the divided colon are then anastomosed in two layers, in front and inferior to the pedicle of the isolated colon graft. The neck wound is closed with a soft drain around the anastomosis. The native diseased and strictured esophagus in patients with corrosive injuries should be removed. Pyloromyotomy or pyloroplasty as a drainage procedure is performed only if the vagus nerves have been damaged while removing the esophagus. The colon should be decompressed with a nasogastric tube and left open to the atmosphere to avoid colonic dilatation and also to drain the swallowed saliva. Most series have used the retrosternal approach with a posterior cologastric anastomosis to prevent gastrocolic reflux (Abou Zeid et al. 2016). A retrosternal route should, however, be avoided if the liver is large.

In the authors’ experience, esophagectomy has always been feasible in most cases, without a formal thoracotomy, except in one case with severe periesophagitis following corrosive injury. It is difficult and also unsafe to utilize the transtiatal approach in children with a past history of major leaks after tracheoesophageal repair leaving behind a scarred mediastinum due to peri-esophagitis and mediastinitis (Gupta and Sharma 2008b). The esophageal mucosa must be removed in all cases of corrosive injuries, even if one must perform a separate thoracotomy for fear of future malignant change.

Multiple relaxing incisions have been given on the taenia coli to elongate the graft, in cases with marginal tension (Sharma and Gupta 2017). In patients with associated airway anomalies, colonic interposition may be done along with airway reconstruction (Lobeck et al. 2016). An ileocolic replacement of esophagus in children has been described with the theoretical advantage of using the ileocecal valve as an antireflux action (Sharma and Gupta 2017). The successful use of colon patch esphagoplasty with preservation of the injured esophagus has been reported as an alternative to esophageal replacement for long caustic esophageal strictures (Sharma and Gupta 2017). Its advantage is preservation of the peristaltic and antireflux mechanisms of the

Fig. 2 (a) A child with left cervical esophagostomy and gastrostomy. (b) Length of colon used as replacement; cologastric anastomosis had been done first. (c) The cologastric anastomosis is shown with the colon taken through a retrosternal route
conserved esophagus. However, there is a risk of leak from the long suture line and difficulty in approaching the site for long anastomosis. A diverticulum may also form in the future in the colon segment. It is more feasible if the stricture is limited in the lower part of the esophagus. In that case, a postoperative leak can be avoided by fundoplication placed over the suture line (Sharma and Gupta 2017). Postoperative leak and the stricture have been found less common if a two-stage coloesophagoplasty is performed by delaying the cervical anastomosis, possibly, due to restoration of the microcirculation (Ergün et al. 2004). Microsurgical techniques today have enabled the possibility of using a free colonic graft (Chen and Tang 2000). The colonic interposition has been used successfully in infants with esophageal atresia at an early age of 5 months as well (Hernández et al. 2003). Fibrin glue has been used to prevent cervical leakage and strictures after esophageal reconstruction (Saldaña-Cortés et al. 2009) (Table 3).

### Treatment of Complications

In cases of acute ischemic graft necrosis, the presentation may vary from fever, brownish discharge in the nasogastric tube/mediastinal drain, and a crepitus over the chest wall to pneumothorax, sepsis, and shock. A fiber-optic endoscopy can confirm the diagnosis. Prompt reexploration with removal of the gangrenous graft is mandatory, necessitating diversion in emergency. Subsequently, gastric tube or stomach pull-up can be considered to replace the esophagus. Authors have used the residual colon for redo colon interposition with success in one such case of graft necrosis, after a gap of 1 year. Leakage from the proximal esophageal anastomosis is common and could be major or minor, with or without symptoms. Ischemia, tension, technically faulty suturing, and presence of the esophageal fibrosis at the anastomotic site are common causes. A tear in the pleura during dissection may present with pleural effusion (Fig. 3). Fortunately, the majority heal

### Table 3 Complications of colon interposition

| Immediate | Early | Late |
|-----------|-------|------|
| Graft necrosis | Anastomotic leak | Anastomotic stricture 20–30% cases |
| Anastomotic leak [20–50%] | Gastric outlet obstruction | Obstructive symptoms due the kinking of the lower end of the esophagus over the liver |
| Mediastinitis, mediastinal abscess | Colonic anastomotic leak, peritonitis | Redundancy of colon or upper esophageal pouching 5–10% (Glasser et al. 2006) |
| Respiratory complications –atelectasis, pneumothorax, pneumonia, empyema | Intestinal obstruction due to adhesions | Colonic segment dilation |
| Aorto-colonic fistula | Intussusception | Halitosis with fetid smell |
| Pleural effusion | Surgical wound evisceration | Acid reflux, Cologastric reflux and peptic ulcer disease |
| Mortality 1–10% | Sepsis | Graft-related complications – Colitis |

- Iron deficiency anemia and transient malabsorption
- Inflammatory colonic polyps
- Diaphragmatic hernia
- Pulmonary symptoms due to chronic acid reflux and aspiration
- Intestinal obstruction due to adhesions
- Dumping syndrome
- Late graft stenosis
- Respiratory problems due to pressure of esophagus

### Mortality

- Delayed fistulization
- Mortality – due to respiratory failure, sepsis
spontaneously provided an adequate drainage has been ensured along with antibiotics and proper nutrition. The anastomotic leak may also present as a late esophagocutaneous fistula or a stitch granuloma.

Most proximal anastomosis strictures respond to dilatation. Thirty to 50% may however need surgical revision, especially those following corrosive injuries as the surrounding tissues, and the esophagus are fibrotic. Lower-end strictures are less common and usually require surgical revision, as blind dilatation of the lower anastomosis is hazardous.

Colonic redundancy is the most common late complication following colonic interposition leading to malfunction of the neo conduit, causing disabling symptoms that may develop decades after the original surgery (Baggaley et al. 2018). The redundancy of the colonic conduit with stasis and dysphagia is believed to be due to the negative pressure in the thoracic cavity and the colonic conduit’s passive nature, emptying essentially by gravity (Soccorso and Parikh 2016). This complication may be reduced by avoiding a breach in the pleura and resecting excess colon at the cervical end prior to anastomosis (Soccorso and Parikh 2016).

Mild redundancy of the colon may not necessitate revision of the colonic conduit if there is no dysphagia. Redundancy may lead to pulmonary compression, food stasis, recurrent regurgitation, and aspiration. Surgical revision may be required if the patient is symptomatic with vomiting, poor weight gain, and dysphagia to improve quality of life and to prevent complications such as aspiration. Successful transhiatal mobilization of the intrathoracic colon and stapled tapering coloplasty has been described for redundancy (53).

Cologastric reflux and peptic ulcer disease are uncommon. A cologastric anastomosis on the posterior wall of the stomach may prevent the reflux (Abou Zeid et al. 2019). Abouzeid et al. have even treated one patient with hematemesis and failure to thrive by moving the anastomosis from the anterior stomach to the posterior position, with marked symptomatic and radiologic improvement (Abou Zeid et al. 2016). Formation of an antireflux submucosal gastric tunnel can eliminate gastrocolic reflux without impeding normal passage of food into the stomach. Redo surgery may be needed for persistent fistula.

Long-Term Outcome and Follow-Up

Colonic interposition is the safest alternative to the normal esophagus, with minimal short- and long-term complications. The parameters to follow and the reported results are documented in Table 4.

Corrosive strictures are common in many countries like Egypt, Turkey, and Romania. The largest experience in colonic interposition of more than 850 cases has been reported by Hamza et al. (2003). The reported complications in their last 475 cases included 10% cervical leakage, 5% proximal strictures, 2% postoperative intestinal obstruction, 1% mortality, and 0.6% late graft stenosis (Hamza et al. 2003). Long-term follow-up has substantiated the colon as a durable and highly acceptable esophageal substitute (Fig. 4).

Gastric Tube

The gastric tube was described in 1968 (Burrington and Stephens 1968). A gastric tube with a pyloric or fundal base (iso or reverse)
matches with the size of the esophageal lumen. However, as it is technically more demanding and associated with serious immediate and early post-operative complications, it has not been in vogue.

The gastric tube may be formed as an isoperistaltic antral-based tube or as an antiperistaltic fundus-based tube. As the acid cells are situated more in the fundus, while the gastrin is secreted from near the antrum, the majority of surgeons routinely use the reversed gastric tube as it would have less acid in the neck and thus less chances of leak. In the isoperistaltic tube, the food is

Table 4  Follow-up following colonic interposition

| Follow-up                        | Results                                                                 |
|----------------------------------|-------------------------------------------------------------------------|
| Growth                           | Mostly catch up growth                                                  |
| Digestive symptoms               | Reported in 85% (most frequently observed during the first 5 years of follow-up) |
| Gastroesophageal reflux          | Reported in 51/72 patients, and 62.8% had bothersome symptoms (Lima et al. 2015) |
| Feeding pattern                  | Feeding difficulties in 50%                                             |
| Manometry                        | 3–6 months no evidence of peristalsis in the neoesophagus               |
| Most patients demonstrated a high-pressure zone for about 4–5 cm in the intra-abdominal part of the transposed colon compared with that in the intrathoracic part of the colon, leading to low reflux (Prabhu et al. 2013) |
| Nutrition                        | Nutritional complications in 25% (Coopman et al. 2008)                  |
| Lung function                    | Abnormal lung function in 50–60%                                       |
| Orthopedic problems              | Scoliosis in 35%                                                        |
| Endoscopy                        | To assess for development of any malignancy in the long term may be ideal |
| Elshaféi et al. reported normal appearance of colonic mucosa in both upper and lower junctions on long-term endoscopy (Elshaféi et al. 2012). The pathologic changes in the thoracic colon included mild chronic nonspecific inflammation of the colonic mucosa in 23.4%, whereas only 1 case (3.3%) showed mildly active inflammation of colonic mucosa |
| Karnofsky Performance Status Index | 60% have a score of >80%; 35% have a score of 40–80% (Burgos et al. 2010) |

Fig. 4  Barium study (a, b) showing a long and tight post corrosive beaded stricture involving the pharynx and the esophagus. (c) Mobilized colon used for esophageal replacement for a high anastomosis with the pharyngeal wall
deposited directly near the pylorus bypassing the stomach body, thus resulting in dumping-like symptoms (Ionescu 2008).

**Technique**

Through a midline epigastric laparotomy, the stomach is approached and the gastrostomy site is separated from the abdominal wall. The left triangular ligament of the liver is divided, and the lower esophageal stump is carefully dissected. The vagus nerves are identified and separated from esophagus; often the posterior nerve is not clearly visible.

The proposed gastric tube is marked with stay sutures. The proximal end of the antiperistaltic gastric tube starts 2–5 cm away from the pylorus, on the antral segment. The course of the gastroepiploic vessels is identified but not yet divided; till the ideal procedure, isoperistaltic or reversed is decided. For an antiperistaltic tube, the gastrocolic ligament is progressively divided from right to left; the greater omentum is left attached to the colon and the gastroepiploic arcade to the stomach. The width of the tube after double suturing should be almost the same caliber as the native esophagus.

For modeling the tube, a red rubber catheter of approximately #18-22Fr is used. A 2 cm transverse incision is made on the antrum at the chosen level; the tube is inserted retrogradely within the stomach and placed close to the greater curvature. The gastric tube is then separated from the greater curvature. Whether a reversed or isoperistaltic tube is to be fashioned is decided and the gastroepiploic vessel ligated and divided at the right or left end of the gastroepiploic arcade accordingly. The proximal 3–5 cm of the tube should be approximated with interrupted sutures in double layer and should be larger than the rest and a little funnel-shaped for good cervical anastomoses. The rest of the tube and stomach may be sutured as per the surgeon’s choice by continuous, running or interrupted, double-layer sutures or sutured with staplers. However, it should be waterproof to avoid blood loss and also risk of leak from the suture line. Only the short gastric vessels are divided. The gastrostomy tube is repositioned, most commonly through the same site or a new one. Often the gastrostomy could be comfortably included in the long suture line. A feeding jejunostomy may be added for early feeding.

After the gastric tube is fashioned, the route for the replacement, transhiatal or retrosternal, is developed. The long suture line should be kept in the anterior position. About 2–5 cm of the length of the neo tube should be left in the abdomen to prevent gastro-neoesophageal reflux. A drain may be left in the posterior mediastinum. The cervical anastomosis is the most important part of the operation. The proximal tube is trimmed of 1–2 cm and examined for a good vascular supply. The cervical anastomoses is made end-to-end, in one layer, with interrupted 5/0 absorbable sutures. The operation ends by repositioning the gastrostomy and closure of the abdomen.

The removal of the damaged esophagus for esophageal stricture is recommended to avoid any risk of malignancy. The esophagectomy can be performed as a separate operation, by right or left thoracotomy, or as a transhiatal esophagectomy, by blunt digital dissection combined from above and below, performed concomitantly with the esophageal replacement. Some surgeons still prefer the isoperistaltic gastric tube believing it facilitates a better passage of the food (Table 5).

A leak in the neck is the most common complication, mostly closing spontaneously in due course of time. The second most common complication is a stricture that mostly resolves with dilatations. The severe ones may require resection and redo anastomosis.

**Long-Term Outcome and Follow-Up**

The long-term results following gastric tube have been quite satisfactory in the first few decades after the procedure in most children once they have survived the initial turmoil of the postoperative period (Ein 1998). However, complications may arise later. Lee et al. compared delayed primary anastomosis and esophageal replacement
with gastric tube in patients with long-gap esophageal atresia and found that gastric tube replacement had more long-term complications (86%) compared to delayed primary anastomosis (30%) (Lee et al. 2014). There have been reports of acid secretion from the gastric tube and cervical Barrett’s esophagus above the anastomosis indicating the need for lifelong endoscopic follow-up for these patients (Borgnon et al. 2004).

On comparing QoL scores and general life status patients who underwent gastric tube esophagoplasty with colon tube esophagoplasty, there was no difference (Gavrilescu et al. 2013).

### Isolated Isoperistaltic Gastric Tube Interposition

A new procedure involving isoperistaltic isolated gastric tube interposition with favorable short-and long-term functional results has been reported (Gounot et al. 2006).

### Jejunal Graft

A jejunal graft for esophageal replacement has been described way back in 1947 (Sharma and Gupta 2017). The procedure is the most technically demanding of all the four procedures and most time-consuming: it can take up to 24 h. Hence there is limited experience and a risk of life-threatening vascular compromise. Thus the usage of the jejunum as a substitute for the esophagus has not become very popular. Moreover, it involves discarding some length of jejunum to make a sufficient length of vascular pedicle due to arcades. The jejunum also has a short mesentery and may involve the need of microvascular anastomosis of the jejunal vessels with the neck vessels, with a chance of failure, graft loss, and leaks in the neck. Some experts believe that the disadvantage of a longer operation time is easily compensated by less chances of dilatation of the graft and better quality of life of the patients, as the function of the jejunal segment is much better than the other substitutes of the esophagus, and believe the jejunum is the most appropriate substitute for the esophagus in infants and children (Hashizume and Dessanti 2008).

The most disastrous complication is total necrosis of the interposed jejunum due to vascular insufficiency, i.e., arterial thrombosis or venous occlusion. Hence, it is not advisable to perform jejunum interposition in neonates with friable mesenteric arteries and veins. An age of 6 months or a minimal weight of 6 kg is considered adequate.

### Technique

The abdomen is opened with an upper midline incision, to approach the esophageal hiatus. The first jejunal artery with accompanying vein is preserved. The second and third jejunal arteries are usually divided and ligated near their origins, and the fourth artery is preserved and is used as part of vascular pedicle of the jejunal loop. With this, one can get adequate length of the vasculature pedicle. The distal end of divided jejunum is then placed on the anterior chest wall to ensure that this part

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### Table 5 Complications of gastric tube

| Immediate | Early | Late |
|-----------|-------|------|
| Leak in the neck (50–60%) | Leak in the neck | Stricture of the tube is quite common (20–30%) |
| Mediastinitis due to leakage from the long suture line | Respiratory symptoms usually due to aspiration secondary to a stricture in the neck | Broncho-gastric tube fistula |
| Necrosis of the graft | | Mild sacculation or tortuosity of the gastric tube, though rare |
| Aspiration of gastric contents | | Diaphragmatic herniation and obstruction |
| | | Gastric tube ulceration and hemorrhage |
can be brought to the level of the place designated for the upper anastomosis. The arcade is then ligated and divided just distal to the point of the confluence with the fourth jejunal artery. A longer length of the jejunal loop is usually redundant so the part is resected. The continuity of the jejunum is restored. The jejunal loop, so prepared, is brought to the upper abdomen through a small hole in the mesocolon. Concerning the route to the thoracic cavity, if the length of the lower esophagus is long enough to permit the lower anastomosis done in the right thoracic cavity, the loop should be brought anterior to the stomach and through a hole in the diaphragm. However, if the length of the lower esophagus is not adequate enough and the anastomosis should be done in the abdomen, the jejunal loop should be brought to the right thorax through a retrogastric route and through the esophageal hiatus. Maximum precision is necessary to avoid kinking and torsion of the vascular pedicle.

The end-to-side anastomosis of the upper esophagus and the jejunal loop is preferred to avoid undue tension to the vascular pedicle. The anastomosis of the interposed jejunum and the lower esophagus is accomplished in an end-to-end fashion. A thoracic drain is inserted into the right thorax and a Penrose or suction drain near the esophageal hiatus. A feeding jejunostomy distal to the anastomosis may be considered.

### Complications

If there is a leak, parenteral nutrition or enteral feeding through a gastrostomy should be initiated. Usually the leak heals spontaneously after 2 weeks (Table 6). The end-to-side anastomosis of the upper esophagus and the jejunal loop is preferred to avoid undue tension to the vascular pedicle. The anastomosis of the interposed jejunum and the lower esophagus is accomplished in an end-to-end fashion. A thoracic drain is inserted into the right thorax and a Penrose or suction drain near the esophageal hiatus. A feeding jejunostomy distal to the anastomosis may be considered.

### Gastric Transposition

Gastric transposition was first done in children only about four decades ago, although the procedure has been extensively used in adults for esophageal carcinoma. As the colon interposition was associated with complications like redundancy, reflux, stricture, and rarely graft loss, pediatric surgeons sought alternate procedures. The gastric transposition as a primary procedure for replacing the esophagus in children was popularized by Prof. Lewis Spitz, from the Institute of Child Health, Great Ormond Street, London, in 1981, after noting the unacceptably high complication rate with the use of colon interposition (Spitz et al. 2004).
The authors have been using this technique for 25 years (Gupta and Sharma 2008a). After the initial experience with the use of stomach in infants and children, its use was extended even to newborns. Being a simple surgical procedure comparatively, with very good vascularity, there has recently been a wider interest in using the stomach to replace the esophagus in children. Thus, several surgeons have now switched over from using colon interpositions to gastric transpositions for esophageal replacement in children, and now many large series have reported satisfactory early and long-term results in newborns, infants, and children (Ludman and Spitz 2003).

### Neonatal Gastric Transposition

The stomach is considered the best option available in newborns requiring esophageal replacement as the vascular supply to the colon and the jejunum is very precarious and limits the length of the intestinal segments to reach the neck without tension. Also, the size of the stomach in newborns and in infants less than 6 months of age is quite small and unfit for preparing the gastric tube. Moreover, the gastric wall is also quite vascular and muscular to withstand mediastinal infection if any. Thus, gastric transposition is the only option to replace the esophagus in the neonatal period following major postoperative leaks and also with the long- or wide-gap esophageal atresia and tracheoesophageal fistula to avoid diversion and offer definitive procedure even in the newborn stage to avoid repeated visits to the hospital (Gupta and Sharma 2011; Soccorso and Parikh 2016) (Table 7).

| Immediate | Early | Late |
|-----------|-------|------|
| Graft necrosis | Anastomotic leak | Cervical stricture Gupta et al. (2004) |
| Perforation of the graft | Cervical fistulas | Peptic strictures |
| Anastomotic leak | Necrosis of tip of graft | Cervical dysphagia |
| | | Esophageal diverticulum |
| | | Redundancy of the jejunum |
| | | Delayed swallowing |

The advantages and disadvantages of gastric transposition are mentioned in Table 3.

### Technique

The abdomen is opened with a supraumbilical midline incision. Access is gained to the gastroesophageal junction. The anterior and the posterior vagus nerves have to be invariably sacrificed while delivering the esophageal stump in pure esophageal atresia cases in the abdomen. The stomach is mobilized, starting from right to left through the gastrocolic ligament (Fig. 5). The right gastroepiploic vessel, the gastroepiploic arcade, and the right gastric vessels are preserved. The 4–5 short gastric vessels running between the stomach and the spleen are ligated away from the stomach individually to avoid any vessel spasm or even thrombosis.

The left gastric vessels are identified and ligated securely close to their origin. Kocherization of the second part of the duodenum is performed to gain length and bring the duodenum and the pylorus in a straight line. The spleen is preserved in all.

The esophageal stump is transected from its junction with the stomach, and the defect is closed in two layers (Fig. 6). The site of the gastrostomy is also closed in two layers. Two stay sutures are applied to the highest point in the fundus of the stomach with a right and left side mark, for taking it up to the neck for the anastomosis, taking due care to avoid any rotation (Fig. 6).

The appropriate route is now chosen. No thoracotomy is performed. The mediastinal route is quite feasible and preferred in all neonates. If the creation of the tunnel is found difficult due to
previous thoracotomy adhesions, the attempt is abandoned, and the substernal route is favored. In that case, the hiatus will be closed with a couple of Fig. 8 sutures. The substernal route can be created easily by a blunt finger dissection starting just behind the xiphisternum. The stomach is mobilized completely and taken up to the neck (Fig. 6).

A single-layer esophagogastric anastomosis is made at the highest point of the stomach using 5–0 polyglactin sutures. Pyloromyotomy or pyloroplasty is always performed to provide a drainage procedure as bilateral vagotomy has invariably been done. The pyloric antrum is fixed to the diaphragmatic edges at the hiatus. The stomach is also hitched to the prevertebral fascia in the neck to prevent any tension on the anastomosis. A soft glove drain is used to drain the neck wound. The stomach is decompressed with a nasogastric tube, the tip of which is carefully placed in the mid-thoracic region. A feeding jejunostomy is useful, especially for the critically ill patients who might take a longer time to recover from surgery and require prolonged nutritional support.

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**Table 7** Merits and demerits of gastric transposition (Gupta and Sharma 2008a)

| Merits                                           | Demerits                                                                 |
|-------------------------------------------------|--------------------------------------------------------------------------|
| Technically easier operation                    | Bulk of stomach in mediastinum/thorax can cause respiratory distress and may decrease venous return |
| Stomach has a thick muscular wall with reliable vascular supply | Reflux in the bulky stomach is common and can cause aspiration pneumonitis |
| Adequate length is possible for anastomosis without tension. If needed, duodenum can be kocherized | As vagotomy is part and partial with the procedure, gastric emptying may be delayed despite pyloromyotomy |
| A single anastomosis is required in the neck     | As the reservoir function of the stomach is lost, there may also be rapid gastric emptying leading to dumping |
| There is no suture line in the chest, except the closure sites of the gastrostomy and the esophageal hiatus | Loss of gastric reservoir function effects the growth and development of the patient |
| Least short-term morbidity and mortality         | Bile gastritis may result in change in gastric mucosa in the long term    |

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**Fig. 5** (a) Mobilization of the cervical esophagostomy. (b) Assessing the length of the mobilized stomach in a newborn.
In children with corrosive injuries, the stricture part is completely excised to have a pliable anastomosis with the upper esophagus. The esophagectomy is feasible and performed in the same sitting.

**Complications**

Gastric transposition has relatively few complications compared to other procedures when done repeatedly (Table 4). An aspiration may result from gastric stasis or inadequate swallowing reflex (Fig. 7). Anastomotic leaks in the neck are not uncommon, but most of them are minor and resolve within a few days. Major leaks result in stricture formation and thus need regular follow-up, including endoscopy at regular intervals. Most of these respond to dilatation. Few may however need a surgical correction. Anastomotic strictures are more common in patients with caustic esophageal injury. A contrast study is done in the
follow-up period to evaluate for any leak or stricture (Fig. 8) (Table 8).

Gastric transposition for esophageal substitution has been associated with a mortality rate of 3–5% of patients in the best hands. Most of the deaths in children have been reported in the early postoperative period due to ongoing sepsis and associated congenital heart disease besides chest aspiration that is preventable with close monitoring (Spitz 1992).

Vomiting and aspiration pneumonitis is also seen frequently. The most common indication for redo surgery is following stricture formation in the neck. Others include mechanical obstruction such as compression of the stomach at the diaphragm level and at the neck and jejunostomy-related complications besides the intestinal obstruction due to adhesions.

Symptoms mimicking obstruction have been reported due to stasis of food in the thoracic stomach (functional obstruction due to vagotomy) without any evidence of mechanical obstruction. This needs careful assessment for the need of jejunostomy to provide nutrition. It may also lead to aspiration pneumonia during sleep.

**Long-Term Outcome and Follow-Up**

In a large series of 173 children reported by Spitz et al., more than 90% had a good to excellent outcome in terms of absence of swallowing difficulties or other gastrointestinal symptoms (Spitz et al. 2004). Many, however, preferred to eat small frequent meals. The authors also have similar experience during the follow-up studies of patients who had undergone gastric transposition 10 years ago or more. The majority of the patients learned the habit of eating and swallowing in time (Jain et al. 2012). There has been no deterioration in the function of the stomach in those patients followed up for more than 10 years. There is no evidence of peristalsis in the thoracic stomach; however, it responds well to the food bolus by gravity. The manometric studies performed after gastric pull-up documented mass contractions without any propulsive or peristaltic waves (Gupta et al. 2004). The baseline pressure was a little higher in newborns compared to that in children. Also, the pressure increased by over 120%, both in newborns and children, in response to the food bolus (Gupta et al. 2004). The response was irrespective of the age at surgery and the route adopted. The gastric emptying has been shown to

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**Fig. 8 (a–c)**: Barium swallow study showing the good emptying of the stomach used for esophageal replacement in the chest.
be delayed in more than half and hurried in one third in another study (Ravelli et al. 1994). The emptying pattern was extremely irregular, suggesting that gastroesophageal as well as duodenogastric reflux episodes occurred in all patients (Ravelli et al. 1994). The quality of life for patients following gastric transposition was good with fewer disease-specific symptoms in the medium term compared with patients who had undergone previous unsuccessful attempts at reconstruction or replacement of their esophagus (Ludman and Spitz 2003).

It has now been shown that gastric transposition is compatible with normal life, though the growth and development remained subnormal in children followed up for 5–10 years in some series. Anemia has been found in 70% of the cases during long-term follow-up (Jain et al. 2012).

The authors have noted the decreased functional capacity of the lungs especially in those patients who had undergone previous thoracotomies. This may be secondary to the pulmonary compression or recurrent aspiations.

Gastric transposition has been reported to have excellent results, in terms of both surgical technique (simplicity, reproducibility, complication rate) and clinical follow-up (good oral feeding of young patients, normal social life, and regular growth curves) (Angotti et al. 2017).

Surgical experience has been a great factor in lowering the complication rates. The mortality rate in Spitz series reduced from 5.2% in 173 cases reported in 2004 to 2.5% in 236 gastric

| Immediate | Early | Late |
|-----------|-------|------|
| Leaks     | Anastomotic leak in neck [15–35%] | Stricture in the neck |
| Vascular compression in neck | Neck or abdominal wound infection | Intestinal obstruction due to adhesions |
| Chest infection | Recurrent aspiration | Dyspnea |
| Lung collapse | Delay in feeding | Uncoordinated swallowing |
| Acute gastric dilatation | Jejunostomy complications, leak, perforation | Reflux gastritis |
| Ventilation dependency | Pulmonary compression | Graft loss – rare |
| Cardiac compression | Dumping | Dumping syndrome |
| Twist of the stomach | Vomiting | Functional obstruction due to vagotomy |
| Perforation during pyloromyotomy | Adhesive intestinal obstruction | Anemia |
| Bleeding | Gastroesophageal reflux in the neck | Loss of reservoir function and poor growth |
| Pneumothorax | Duodenogastric reflux in the abdomen | Pulmonary function compromise |
| Aspiration pneumonitis | Perforation due to jejunum through the feeding tube | Problems during swallowing |
| Recurrent laryngeal nerve palsy | Broncho-gastric fistula | Malabsorption |
| Sepsis | Ischemia of the fundus of the stomach, if the diathermy has been used to divide the short gastric vessels, leading to a floppy stomach | Para-neo esophageal Hernia |
| Mortality | Mortality | Mediastinal abscess secondary to esophageal perforation as a result of dilatation procedure for stricture |

Table 8 Complications following gastric transposition (Sharma and Gupta 2017; Gupta and Sharma 2008a; Ludman and Spitz 2003; Davenport et al. 1996)
transpositions in 2014 (Spitz et al. 2004; Spitz 2014). However, the leak rate of 12% and stricture rate of 20% remained the same. The follow-up of 236 gastric transpositions in 2014 showed a satisfactory outcome in over 90% patients (Spitz 2014).

**Ileal Graft**
The pedicled ileum graft has also been successfully used in children (Sharma and Gupta 2017; Bax and Van Renterghem 2005). It has also been used for esophageal replacement in redo cases who had endured from one to four attempts of esophageal replacements by different methods, with good results (Ivanov et al. 2012).

**Minimally Invasive Esophageal Replacement**
Esophagectomy has been successfully performed thoracoscopically. This has been combined with laparoscopy for either colonic interposition or gastric transposition (Esteves et al. 2010; Ng et al. 2014; Chokshi et al. 2009).

Laparoscopic gastric transposition by minimally invasive techniques avoids the trauma of open access. On comparing outcomes of minimally invasive versus open gastric transposition in children, minimally invasive gastric transposition has been reported as a safe and acceptable alternative to open surgery in children (Ng et al. 2014).

**Conclusion and Future Directions**
The repair of the long-gap esophageal atresia still remains a challenge. Though it has been believed since ages that the native esophagus is the best esophagus, it may not always be a feasible option. In tertiary care centers worldwide, there has been a drift to preserve the native esophagus by promoting a delayed primary repair, but this has been found to be associated with high rate of postoperative strictures and gastro-neoesophageal reflux, requiring repeated surgeries, prolonged hospitalization, and the high costs. It may take many years to resume normal feedings orally with the need for balloon dilatations, gastrostomy closure, and antireflux surgery and even redo surgeries (Sharma and Gupta 2017).

The skill for esophageal replacement has to be mastered by focused surgeons in tertiary centers so that the best possible care can be given to these children who undergo major surgery. Colon is the most preferred and safest organ for replacement. Stomach is a vascular and muscular organ with lower risk of ischemia. Gastric tube is a demanding technique. Jejunum and ileum are good alternatives for redo cases.

With the advent of minimally invasive surgery, the morbidity of these complex procedures may be reduced. However, laparoscopy may not be feasible in presence of dense adhesions. Thoracoscopy is a feasible option for esophagectomy reducing the risk for malignancy in the redundant esophagus especially following corrosive injury. Robotic surgery may help in the future to perform in vivo anastomosis in the abdomen for colonic interposition in suitable cases.

Regenerative medicine and tissue engineering is the new ray of hope for a biologically functional esophagus. However, this will take at least two decades more for reality.

**Cross-References**

▶ Caustic Injuries of Esophagus

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