Supercharged Jejunal Interposition: A Reliable Esophageal Replacement in Pediatric Patients

Joseph M. Firriolo, M.D.
Laura C. Nuzzi, B.A.
Ingrid M. Ganske, M.D., M.P.A.
Thomas E. Hamilton, M.D.
C. Jason Smithers, M.D.
Oren Ganor, M.D.
Joseph Upton III, M.D.
Amir H. Taghinia, M.D., M.P.H., M.B.A.
Russell W. Jennings, M.D.
Brian I. Labow, M.D.

Boston, Mass.

Background: There is no consensus for esophageal reconstruction in the pediatric population. Long defects are commonly repaired with gastric pull-up or colonic interposition; however, jejunal interposition offers several potential advantages in children. One historical concern with jejunal interposition has been the risk of flap infarction following transposition. The use of neck and intrathoracic vessels to "supercharge" the jejunum has been reported in adults. This study reports outcomes of supercharged jejunal interposition in pediatric and young adult patients with long esophageal defects.

Methods: The authors reviewed the medical records of patients who underwent supercharged jejunal interposition for esophageal reconstruction at their institution from 2013 to 2017. The authors collected data pertaining to patient characteristics, operative technique, and postoperative outcomes.

Results: Twenty patients, 10 female and 10 male, aged 1.4 to 23.8 years, underwent esophageal reconstruction with supercharged jejunal interposition and were followed for a median of 1.4 years. Seventeen patients had a primary diagnosis of long-gap esophageal atresia, and three required reconstruction following caustic ingestion. Eighty percent of patients had undergone prior attempts at surgical reconstruction. Postoperatively, all conduits demonstrated coordinated peristalsis, and no flap losses were noted. Major complications occurred in seven patients, stricture dilation was performed in four patients, and there was no mortality.

Conclusions: Jejunal interposition with supercharging can be safely performed for management of long esophageal gaps in the pediatric setting; it is useful where the stomach or colon has been used previously or is unavailable. Long-term outcome studies are required to determine whether jejunal interposition provides a more durable and safe conduit than gastric pull-up or colonic interposition over time. (*Plast. Reconstr. Surg.* 143: 1266e, 2019.)

CLINICAL QUESTION/LEVEL OF EVIDENCE: Therapeutic, IV.

Long esophageal gaps pose a reconstructive challenge in children and young adults.[1,2] These defects may result in considerable morbidity, including failure to thrive and psychosocial concerns. Although esophageal reconstruction in adults is mainly necessitated by surgical extirpation of malignancy, causes in the pediatric population are more diverse. Long esophageal gaps in children are commonly congenital (e.g., esophageal atresia) and either isolated or syndromic [e.g., VACTERL (i.e., vertebral defects, anal atresia, cardiac defects, tracheoesophageal fistula, renal anomalies, and limb abnormalities) and trisomy 21].[3] Long acquired defects can also occur from caustic ingestion or iatrogenic injury from failed attempts at other forms of reconstruction.

Over the past century, many techniques have been reported to reconstruct the esophagus.

From the Department of Plastic and Oral Surgery and the Department of Surgery, Boston Children's Hospital, Harvard Medical School.
Received for publication May 14, 2018; accepted October 18, 2018.
Dr. Jennings and Dr. Labow are co–senior authors.
Presented at the 9th Congress of the World Society for Reconstructive Microsurgery, in Seoul, Republic of Korea, June 14 through 17, 2017; the 34th Annual Meeting of the Northeastern Society of Plastic Surgeons, in Newport, Rhode Island, September 8 through 10, 2017; Plastic Surgery The Meeting 2017, Annual Meeting of the American Society of Plastic Surgeons, in Orlando, Florida, October 6 through 10, 2017; and the American College of Surgeons Clinical Congress 2017, in San Diego, California, October 22 through 26, 2017.

DOI: 10.1097/PRS.0000000000005649

Disclosure: *The authors have no financial interest to declare in relation to the content of this article.*

Although there is agreement that short gaps are best managed using native esophagus, no consensus exists for restoration of esophageal continuity in longer defects.[4] When immediate direct repair of the esophagus is not feasible, the Foker process may be used; this involves mobilizing the upper and lower esophageal segments, lengthening the segments with traction sutures, and subsequently performing a tension-free esophageal repair.[5] However, our group's lack of success using this technique led us to consider other forms of repair.

The three major options for reconstruction using nonesophageal conduits are gastric pull-up, colonic interposition, and jejunal interposition.[4,6] Ease of mobilization and a reliable intrinsic blood supply have favored the stomach or colon for esophageal replacement. However, considerable short-term and long-term complications exist for both conduits. Gastric pull-up can result in acid reflux, with potential pulmonary injury and positional emesis; whereas colonic interposition often results in progressive conduit dilatation and redundancy, with long-term failure.[4] In addition, both options have a significant rate of early stricture requiring revision.[4]

The jejunum was first recognized as a potential esophageal replacement by Roux in 1907.[7] The jejunum is an excellent size match for the esophagus; it also maintains its intrinsic peristalsis following transposition.[8,9] The primary drawback of jejunal interposition is difficulty mobilizing the jejunum while maintaining adequate perfusion throughout the conduit. Recent studies in adults have demonstrated that vascular augmentation, or "supercharging" the cranial end of the transposed jejunum can prevent ischemia during jejunal interposition.[6,10–16] Unlike a free jejunal transfer, supercharged jejunal interposition involves a pedicled transfer of a long segment of jejunum maintaining the distal jejunal vascular supply while augmenting the proximal with microvascular anastomosis.[6,10–17] Late complications and failures using other techniques led our group to examine the viability of using a supercharged jejunal interposition to reconstruct long esophageal defects in children.

PATIENTS AND METHODS

After approval by the Boston Children's Hospital Committee on Clinical Investigation (protocol number IRB-P00024103), the medical records of patients who underwent supercharged jejunal interposition for esophageal reconstruction at our institution from 2013 to 2017 were reviewed. All eligible patients were younger than 18 years at the time of diagnosis or treatment. Records were reviewed for patient demographics, medical and surgical history, operative technique, complications, and esophageal function. Frequency distributions were calculated for demographic and clinical characteristics, previous surgical interventions, complications, and postoperative outcomes. As age at the time of surgery and postoperative follow-up time were skewed, median values and interquartile ranges are reported. Weight-for-age percentiles were calculated using the Centers for Disease Control and Prevention clinical growth charts.[18]

Although used in previous comparable case series, the Functional Outcomes Swallowing Scale was not used in our outcomes analysis, as this scale is primarily a measure of oropharyngeal dysphagia, as opposed to esophageal dysphagia, and is not pertinent to congenital disease, as it relies on reports of weight loss.[19]

Operative Approach

Preoperative Planning

Esophageal reconstruction with supercharged jejunal interposition was performed using a multidisciplinary approach involving plastic surgeons, pediatric surgeons, and in some cases cardiothoracic surgeons. All members of this esophageal reconstruction team met preoperatively to review the operative plan. Preoperative assessment by gastroenterologists and anesthesiologists was also undertaken. In most cases, old conduits were removed and a diverting cervical esophagostomy and feeding gastrostomy or jejunostomy was created before jejunal interposition. Surgical candidates are often chronic aspirators with impaired respiratory function and may have nutritional deficiencies and failure to thrive. In addition to a full workup, optimization of pulmonary function and nutritional status was achieved preoperatively.

Operative Technique

The patient is positioned in the supine position with the neck slightly extended. The standard monitoring tubes and lines are placed, preserving the neck and one arm as recipient vessel options when possible.

Wide exposure is achieved through a hockey-stick incision around the cervical esophagostomy (when present) and extended inferiorly as a sternotomy and upper midline laparotomy. A median sternotomy is advantageous in pediatric patients, as it (1) provides the best exposure to assess and dissect the internal mammary vessels, which often vary in size and quantity within the same patient; (2) allows the surgeon to assess the entire flap following supercharging; (4) enables the optimal positioning of the jejunal conduit, and donor and receipt vessels to avoid tension or slack; (5) enables the surgeon to preserve mesenteric blood supply to the remaining intraabdominal area and transposed segment of jejunum; (6) minimizes the risk inherent in less invasive methods in these patients who frequently have mediastinal and neck scarring from prior procedures; and (7) may minimize contour defects associated with total manubriectomy. The cervical esophageal remnant is mobilized and traction sutures are placed. The abdomen is inspected and adhesions are lysed. The internal mammary vessels are inspected and the larger of the two is selected (Fig. 1). Dissection of the internal mammary pedicle is performed in a retrograde manner and includes the artery and both venae comitantes. All intercostal side branches are taken, but the pedicle is left in continuity and protected with a neurosurgical patty saturated with papaverine. If the venae comitantes are insufficient in size or quality, a neck vein or cephalic vein is sought to turn back into the mediastinum for venous drainage. The thoracic inlet is enlarged by means of partial resection of the manubrium, clavicular head, and first rib on the side ipsilateral to the eventual location of the esophagojejunal anastomosis (Fig. 2). This maneuver alleviates pressure on the conduit during sternotomy closure.

Before mobilizing the jejunum, intraoperative heparin is infused at 10 units/kg/hour. A heparin bolus (20 units/kg) is also administered just before the jejunal vessels are divided. Mobilization of the jejunum begins with the identification of the ligament of Treitz and a thorough lysis of intraabdominal adhesions. The cephalic side of the jejunal mesentery is opened, and the first four or five arterial branches are identified and dissected proximally to their origin from the superior mesenteric artery (Fig. 3). There is substantial variation in the size and branching pattern of these vessels. Careful assessment of the branching arcade helps to localize the optimal location to divide the bowel and vessel(s) to divide. Surgical lights are used to transilluminate the mesentery and visualize the jejunal arcade. In general, at least one vessel should be left to supply the duodenum proximal to the site of division. After choosing a suitable donor vessel for coaptation,

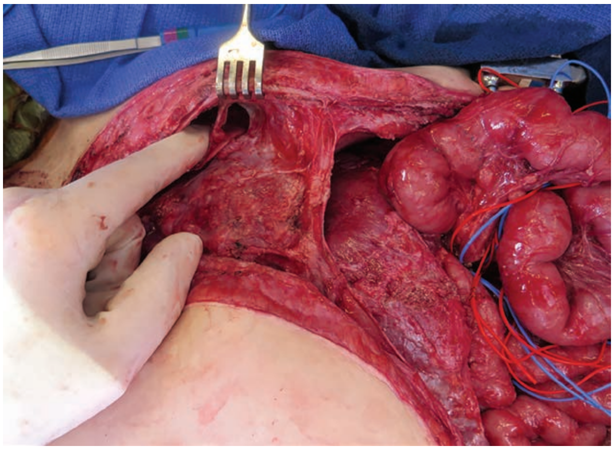

Fig. 1. Internal mammary artery harvest.

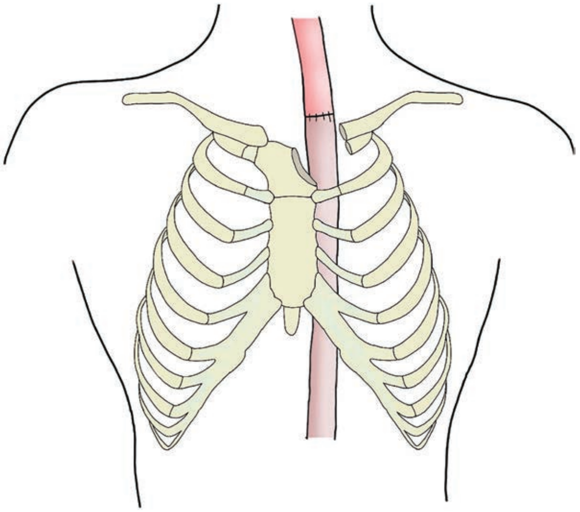

Fig. 2. Enlargement of the thoracic inlet. Partial resection of the manubrium, clavicular head, and first rib improve visibility of the microsurgical field and decrease pressure on the conduit.

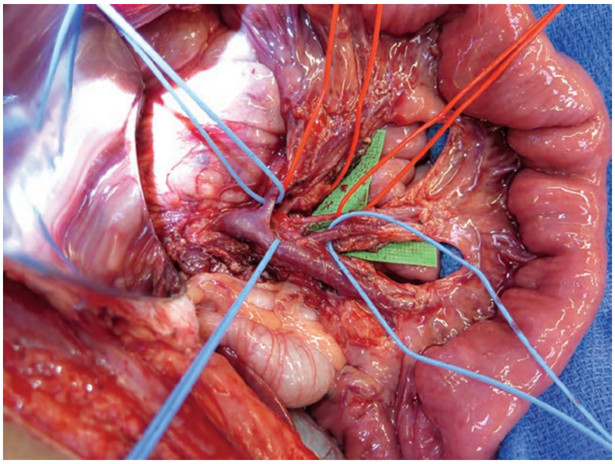

Fig. 3. Jejunal vessels dissected down to their origin to the superior mesenteric artery and vein. *Red* and *blue vessel loops* label arterial and venous branches, respectively.

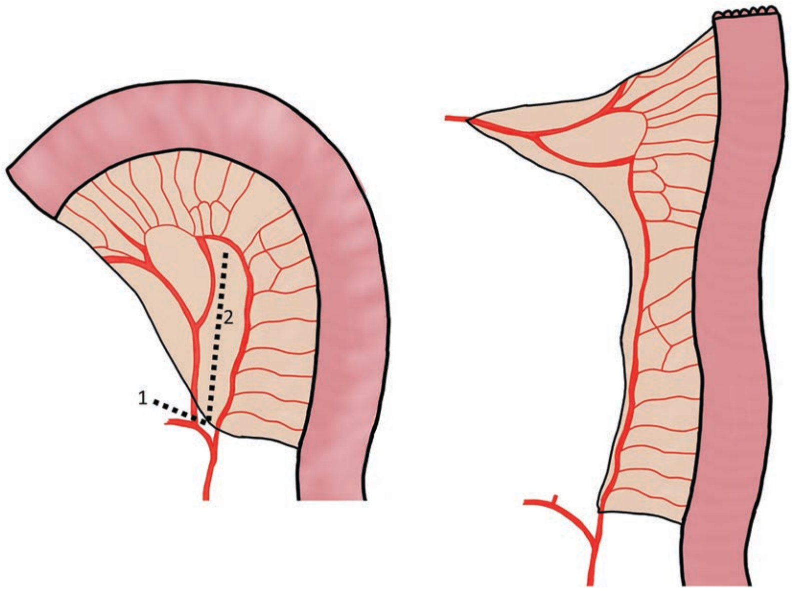

Fig. 4. (*Left*) The mesentery of jejunum causes it to curve. Microsurgeons divide (*1*) an artery and vein supplying a segment of jejunum, and (*2*) the jejunal mesentery. (*Right*) The flap is unfurled and lengthened; the marginal vessels are preserved.

the most proximal portion of jejunum supplied by this vessel is marked for division. A corresponding vein is then identified, usually on the caudal side of the mesentery, and dissected to its junction with the superior mesenteric vein. A GIA Stapler (Covidien, New Haven, Conn.) is used to divide the bowel; vessels are ligated between hemoclips and microvascular clamps. The mesentery adjacent to the divided vessels can be divided to unfurl and effectively lengthen the flap (Fig. 4). Only avascular territories of the mesentery are divided, leaving any marginal vessels intact. The jejunum is passed through a small defect created in the transverse mesocolon in a retrocolic manner. The anterior diaphragmatic attachments may need to be released to facilitate transposition of the jejunum into the mediastinum. Temporary stay sutures are used to fix the jejunum to the native esophageal stump, and the jejunum is positioned with its mesenteric vessels directed toward the prepared mammary artery and a recipient vein. End-to-end arterial and venous coaptations are performed using standard microsurgical technique. When more than one jejunal arterial vessel is divided, and when a prior conduit (e.g., stomach or colon) is available, a second pair of anastomoses can be performed using the pedicle from the old conduit. The jejunum is then assessed for improvement in color and restoration of peristaltic motion. It should be noted that the jejunum is quite metabolically active; when the jejunal vessels are ligated, the supplied segment of jejunum can quickly become ischemic and susceptible to infarction. It is highly preferable to prepare the recipient vessels and a pathway for the jejunal transposition before dividing jejunal vessels to minimize ischemic time. Gastrointestinal continuity is then restored (either by jejunal gastrostomy or a Roux-en-Y jejunojejunostomy) (Fig. 5) and a feeding gastrostomy is placed. Cervical, mediastinal, and retroperitoneal drains are left in place.

Postoperative Management

The patient remains sedated and intubated in the intensive care unit. Regular arterial blood-gas

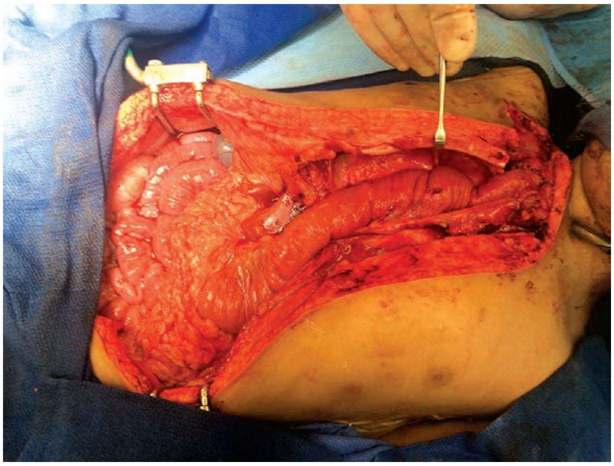

Fig. 5. Jejunum transposed and revascularized.

measurements are performed to monitor for acidemia. Implantable Doppler probes and exteriorized segments of jejunum are not routinely used for monitoring. Although implantable Doppler probes are commonly used in adults, in pediatric microsurgical patients, we have found substantial complication rates with vessels 1 to 2 mm in size. These complications include false alarms because of difficulty seating the probe and vascular disruptions on removal. Similarly, externalizing a distal loop of the jejunal flap provides limited information that can be difficult to interpret. For instance, although this loop provides information on the most distal and ischemic part of the flap, it provides no information about the flap proximally.

A heparin infusion is maintained at 10 units/kg/hour until the patient transitions to daily acetylsalicylic acid (81 mg) for a total of 1 month. The transition to acetylsalicylic acid typically occurs within the first postoperative week. After extubation, patients undergo a swallow study assessing for leaks, conduit obstruction, and peristaltic function (Fig. 6). Endoscopy is performed before discharge to assess the mucosal surface, anastomotic patency, early stricture formation, and peristalsis. Enteral feeding is initiated after extubation and oral feeding is resumed as tolerated.

RESULTS

A total of 20 patients underwent esophageal reconstruction with supercharged jejunal interposition (Table 1); a total of four patients included in the present study have been reported in previous case series.[1,20] Ten patients were female, and the median age and weight at operation were 4.1 years (interquartile range, 3.0 to 6.7 years) and 15.9 kg (interquartile range, 13.0 to 24.3 kg), respectively. Seventeen patients (85.0 percent) underwent repair of long-gap esophageal atresia and three patients underwent reconstruction for severe, diffuse esophageal strictures secondary to caustic ingestion. Sixteen patients had undergone previous surgical attempts to establish esophageal continuity, including gastric pull-up (n = 7), Foker process (n = 5), direct repair (n = 1), colonic interposition (n = 2, one of whom also tried the Foker process), and placement of an esophageal stent (n = 1).

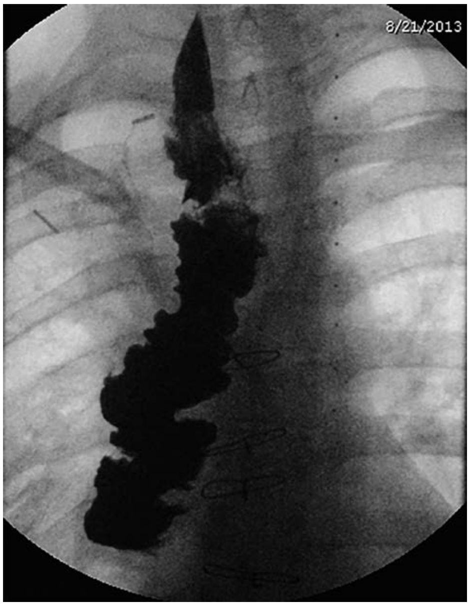

Fig. 6. Postoperative barium swallow study with no evidence of conduit obstruction or leakage.

Preoperatively, all patients experienced failure to thrive and poor weight gain. Five patients had the VACTERL association, one had trisomy 21, one suffered from spastic quadriplegic cerebral palsy, one had severe hydrocephalus, and another held diagnoses of metopic craniosynostosis and a horseshoe kidney. In addition, gastroesophageal reflux was common among our patients (n = 15), and five patients had a history of recurrent aspiration pneumonia.

All patients underwent supercharged jejunal interposition, as described above. Four patients received double-supercharged flaps, with one set of recipient vessels derived from the preserved pedicles of previous conduits (patients 1, 2, 5, and 14) (Table 1). The mean total operative time was 12.7 ± 3.3 hours. The majority of cases [n = 19 (95.0 percent)] used one of the internal mammary arteries and veins to supercharge the jejunum following transposition.

Patients remained intubated for an average of 8.6 ± 5.2 days postoperatively. Following extubation, all patients underwent contrast swallow studies, which demonstrated coordinated peristalsis and no contrast leak (n = 20). However, two patients (patients 10 and 11) (Table 2) required revision of the distal (abdominal) jejunal anastomosis following swallow study findings: one because of conduit obstruction, and another because of ongoing reflux. Endoscopic evaluation was also performed in all patients before discharge. In all cases (n = 20), the jejunal conduit was well perfused, with healthy appearing mucosa and no evidence of ischemia. Strictures were noted in four patients; three cases were successfully treated with a single endoscopic dilation, and one case required subsequent stenting. Patients were discharged after a median of 28.5 days (interquartile range, 23.8 to 40.0 days), and by postoperative day 73, all were

Table 1. Patient Characteristics, Previous Surgical Repair Attempts, and Microvascular Anastomoses Performed

Patient	Age (yr)	Sex	Weight (kg)	Weight-for-Age Percentile*	Primary Diagnosis	Previous Repair Attempts (Excludes Cervical Esophagostomy)	Arterial Recipient Vessel(s)	Arterial Donor Vessel(s)	Venous Recipient Vessel(s)	Venous Donor Vessel(s)
1	18.6	F	44.7	3.1	LGEA	Colonic interposition†	RIMA	Second jejunal arterial branch	Right cephalic vein	Second jejunal venous branch
						Foker process	Right colic artery	Fourth jejunal arterial branch	Right colic vein	Fourth jejunal venous branch
2	23.8	M	49.7	N/A	LGEA; trisomy 21	Gastric pull-up†	Left common carotid artery	First jejunal arterial branch	Small branch of subclavian vein	First jejunal venous branch
							Gastroepiploic artery	Third jejunal arterial branch	Gastroepiploic vein	Third jejunal venous branch
3	4.0	F	13.3	6.8	LGEA	Foker process	RIMA	Second jejunal arterial branch	Right external jugular vein	Second jejunal venous branch
4	8.2	M	24.6	33.7	Caustic injury	None‡	LIMA	Second jejunal arterial branch	LIMV	Second jejunal venous branch
5	10.8	M	25.4	2.0	LGEA; VACTERL	Colonic interposition†	LIMA	First jejunal arterial branch	LIMV	First jejunal venous branch
							Middle colic artery	Third jejunal arterial branch	Middle colic vein	Third jejunal venous branch
6	3.4	F	16.7	84.8	LGEA	None§	LIMA	First jejunal arterial branch	LIMV	First jejunal venous branch
7	4.6	F	16.1	32.3	LGEA; VACTERL	Foker process	LIMA	Second jejunal arterial branch	LIMV	Second jejunal venous branch
8	5.3	F	15.8	10.4	LGEA; VACTERL	Foker process	LIMA	Second jejunal arterial branch	LIMV	Second jejunal venous branch
9	8.5	F	23.9	20.6	LGEA	Gastric pull-up	LIMA	Second jejunal arterial branch	LIMV	Second jejunal venous branch
10	4.5	F	15.9	31.6	LGEA	Gastric pull-up	LIMA	Second jejunal arterial branch	Left external jugular vein	Second jejunal venous branch
11	4.1	M	17.5	68.4	LGEA	Gastric pull-up	RIMA	Second jejunal arterial branch	RIMV	Second jejunal venous branch
							—	—	Right external jugular vein	Third jejunal venous branch
12	1.4	M	10.7	27.4	LGEA	Gastric pull-up	LIMA	Second jejunal arterial branch	LIMV	Second jejunal venous branch
13	2.6	M	13.3	39.4	Caustic injury	Stent placement	RIMA	Second jejunal arterial branch	RIMV	Second jejunal venous branch
14	20.0	F	45.8	N/A	Caustic injury	Gastric pull-up†	RIMA	Second jejunal arterial branch	Left cephalic vein	Second jejunal venous branch
							Left gastroepiploic artery	Third jejunal arterial branch	—	—
15	4.1	M	14.6	14.2	LGEA	Foker process	LIMA	Fourth jejunal arterial branch	Left anterior jugular vein	Fourth jejunal venous branch
16	2.1	M	11.4	12.7	LGEA	Foker process	LIMA	Second jejunal arterial branch	LIMV	Second jejunal venous branch

(*Continued*)

Table 1. *Continued*

Patient	Age (yr)	Sex	Weight (kg)	Weight-for-Age Percentile*	Primary Diagnosis	Previous Repair Attempts (Excludes Cervical Esophagostomy)	Arterial Recipient Vessel(s)	Arterial Donor Vessel(s)	Venous Recipient Vessel(s)	Venous Donor Vessel(s)
17	4.0	M	12.4	0.5	LGEA; VACTERL	None§	RIMA	Third jejunal arterial branch	Anterior jugular vein	Second jejunal venous branch
18	3.2	F	12.7	15.6	LGEA	Gastric pull-up	RIMA	Second jejunal arterial branch	Left external jugular vein	Second jejunal venous branch
19	2.5	M	10.2	0.3	LGEA; VACTERL	Direct repair	LIMA	Second jejunal arterial branch	Left external jugular vein	Second jejunal venous branch
20	2.1	F	14.9	95.1	LGEA	None§	RIMA	Second jejunal arterial branch	Left anterior jugular vein	Second jejunal venous branch

F, female; M, male; LGEA, long-gap esophageal atresia; VACTERL, vertebral defects, anal atresia, cardiac defects, tracheoesophageal fistula, renal anomalies, and limb abnormalities; LIMA, left internal mammary artery; RIMA, right internal mammary artery; LIMV, left internal mammary vein; RIMV, right internal mammary vein.

*Weight-for-age percentiles calculated for patients younger than 20 yr using Clinical Growth Charts from the Centers for Disease Control and Prevention (Centers for Disease Control and Prevention, National Center for Health Statistics. Clinical growth charts. Available at: https://www.cdc.gov/growthcharts/clinical_charts.htm. Accessed May 8, 2018).

†Pedicle preserved for double supercharging.

‡Treated with tracheostomy and gastric tube for 7 yr since esophageal injury.

§Treated with cervical esophagostomy to prevent aspiration.

able to meet their caloric needs enterally (range, 12 to 73 days).

Patients were followed for a median of 1.4 years (interquartile range, 0.7 to 2.0 years). At most recent follow-up, 11 patients are tolerating oral feeds of all consistencies without dysphagia (Table 2); five of these patients receive all of their calories exclusively by means of the oral route, whereas the remaining six patients require caloric supplementation by means of gastrostomy tube. Five patients tolerate oral feeds but require more substantial gastrostomy tube dietary supplementation because of dysphagia and emesis/retching. At most recent follow-up, four patients were not able to tolerate any oral feeds. Despite the variability in feeding outcomes, all 20 patients were able to manage their oral secretions with swallowing alone.

Two patients had sternal wound infections, and another required delayed sternal wound closure because of edema (Table 2). As stated previously, two patients required reoperation to address bowel obstruction and reflux. Other complications included difficulty weaning from methadone and lorazepam, sepsis secondary to a line infection, pneumatosis of the ascending colon, hypotension requiring fluid resuscitation and blood transfusion, and an upper gastrointestinal tract bleed (summarized in Table **2**).

DISCUSSION

We report our experience managing large esophageal defects in 20 patients, aged 1.4 to 23.8 years, with supercharged jejunal flaps. All patients were discharged with intact flaps and with no mortality. Several major complications were observed but in most cases were nonspecific to the use of jejunal conduits or microsurgical anastomoses, demonstrating the feasibility and safety of supercharged jejunal interposition in the pediatric population.

When esophageal defects are large, reconstruction attempts must exceed direct repair of the native esophagus; alternative conduits must be sought. Historically, gastric pull-up and colonic interposition are the most common procedures performed for this purpose, yet both have drawbacks.[6] Gastric pull-up is associated with reflux, positional emesis, and esophageal metaplasia and malignancy.[21–23] Issues concerning dilation/redundancy are common following colonic interposition, and conduits are susceptible to the development of diverticular disease and colorectal cancer.[24,25] We found that late failure of gastric

Table 2. Postoperative Outcomes and Complications

Patient	Follow-Up Time (yr)	Postoperative Feeding and Swallowing	Postoperative Supplemental Nonoral Intake	Complication	Treatment of Complication
1	4.6	Tolerates oral feeds of all consistencies; no dysphagia	None	Difficulty weaning from medications used in intensive care: methadone and lorazepam	Weaned from drugs with conservative treatment
2	3.7	Tolerates oral feeds of all consistencies; no dysphagia	None	Esophageal stricture	Endoscopic stricture dilation and stenting
3	3.2	Tolerates oral feeds of all consistencies; no dysphagia	Gastrostomy tube for medications only	Esophageal stricture	Endoscopic stricture dilation
4	2.1	Tolerates oral feeds of all consistencies; no dysphagia	Gastrostomy tube for medications only		
5	2.6	Tolerates oral feeds of all consistencies; no dysphagia Requires extra time for meals	Gastrostomy tube for caloric supplementation	Sternum could not be immediately closed because of to edema Small bowel obstruction causing emesis and secondary aspiration pneumonitis Sepsis from peripherally inserted central catheter line infection	The sternum was closed on postoperative day 5 with hemodynamic monitoring Lysis of adhesions Antibiotics
6	2.1	Oral feeding aversion	Gastrostomy tube feeds for all caloric intake	Delayed gastric emptying	Pyloroplasty and lysis of adhesions
7	1.9	Oral feeding aversion	Gastrostomy tube feeds for all caloric intake	Sternal wound infection, mediastinitis, and osteomyelitis	Débridement, antibiotics
8	1.8	Tolerates oral feeds of all consistencies; no dysphagia	Gastrostomy tube for caloric supplementation	Sternal wound infection, mediastinal abscess	Incision, drainage, débridement, negative-pressure wound therapy, antibiotics
9	1.5	Tolerates oral feeds of all consistencies; no dysphagia	Gastrostomy tube for caloric supplementation		
10	1.5	Tolerates oral feeds of all consistencies; no dysphagia	Gastrostomy tube for caloric supplementation	Redundant jejunal conduit with dilation because of obstruction	Creation of Roux-en-Y jejunojejunostomy
11	1.3	Does not tolerate oral feeds; experiences emesis/retching with oral intake	Gastrojejunal tube for all caloric intake	Ongoing reflux with jejunal conduit	Relocation of jejunogastric anastomosis
12	1.2	Tolerates liquids and pureed foods; inconsistent intake of solid foods	Gastrostomy tube for caloric supplementation		
13	1.1	Tolerates oral feeds of all consistencies; no dysphagia	Gastrostomy tube for caloric supplementation	Esophageal stricture	Endoscopic stricture dilation
14	1.1	Tolerates oral feeds of most consistencies; some discomfort swallowing	Gastrostomy tube for caloric supplementation	Pneumatosis of ascending colon	Bowel rest and antibiotics
15	0.8	Tolerates oral feeds of all consistencies; no dysphagia	None		
16	0.6	Not yet tolerating oral feeds	Gastrostomy tube feeds for all caloric intake		
17	0.4	Tolerates liquids and small quantities of solid food	Gastrostomy tube for caloric supplementation		
18	0.4	Oral phase dysphagia; drinks water	Gastrostomy tube for caloric supplementation	Esophageal stricture	Endoscopic stricture dilation
19	0.3	Tolerates oral feeds of all consistencies; no dysphagia	Gastrostomy tube for caloric supplementation		
20	0.3	Minimal oral intake; cleared to take thin liquids and smooth purees; retching with feeds	Gastrostomy tube for caloric supplementation	Hypotension Elevated INR Upper gastrointestinal bleed	Fluid resuscitation with crystalloid fluids, colloid fluids, and packed red blood cells Fresh frozen plasma Heparin stopped and packed red blood cells given

INR, international normalized ratio.

pull-up and colonic interposition for esophageal reconstruction is not uncommon. Currently, children with failed conduits have limited reconstructive options, with many accepting long-term gastrostomy tube feeds. Although technically demanding, jejunal conduits have gained popularity in the context of esophageal reconstruction as a salvage operation when alternative conduits fail.

The jejunum has been recognized for its potential as an excellent esophageal replacement, avoiding some limitations of gastric pull-up and colonic interposition and providing potential advantages.[4,26] For example, when interposed, jejunal flaps nicely approximate the diameter of the esophagus and maintain intrinsic peristaltic activity.[8,9] This facilitates effective deglutition and decreases the likelihood of reflux, emesis, and dilation.[10] The jejunum is also less susceptible to intrinsic disease than the stomach and colon. As such, the jejunum may prove to be a superior long-term esophageal conduit in certain clinical situations. However, the jejunal interposition flap has limitations pertaining to its vascularity. Jejunal vessels must be divided to unfurl, mobilize, and appropriately position the proximal end of the flap at the level of the thoracic inlet. Although others have advocated dividing the mesentery to the serosal surface of the jejunum, we preferred to preserve the marginal vessels (Fig. 4).[27,28] This modification allows for some native perfusion to be maintained and does not preclude appropriate positioning of the flap. Despite this, ischemia of the proximal portion of the flap may still occur. We used microvascular techniques (supercharging) to augment the blood supply to the cranial end of the interposed conduit, preferentially using the internal mammary arteries and veins as recipient vessels. In patients with prior surgery and extensive abdominal adhesions, multiple jejunal vessels may need to be divided to allow for sufficient jejunal translocation. For such patients, we have opted to double supercharge their jejunal conduits (patients 1, 2, 5, and 14) (Table 1), using the pedicles from their previous reconstructions as a second set of recipient vessels to ensure robust flap perfusion.[20] In all cases, early endoscopy demonstrated pink, well-perfused, peristaltic conduits.

Supercharging increases the difficulty and length of surgery for jejunal interposition compared with gastric pull-up and colonic interposition procedures.[1,6] As with other reports, operations in our series were lengthy, with a mean time greater than 12 hours. In certain clinical situations, the added complexity and risk of supercharging make gastric pull-up and colonic interposition the more attractive options.[13] For example, in a geriatric population, fewer life-years precludes the need for a functional conduit 15 years or more after surgery. In a pediatric population, however, the newly constructed esophagus should ideally last the entirety of the patient's lifespan. If long-term follow-up demonstrates superior long-term function among jejunal conduits, a supercharged jejunal interposition as a first-line operation for long esophageal gaps in children may justify the added operative time and technical challenges.[1] Nevertheless, supercharged jejunal interposition should be recognized as a viable surgical option when traditional reconstructive avenues are unavailable.

Early outcomes in this study were largely similar to or favorable compared with those observed in adult studies of supercharged jejunal interposition.[4,6,12–17,29–32] Our mortality rate was 0 percent; compared to one study by Blackmon and colleagues[12] in which a 10 percent mortality rate among adults was reported, and a separate study[29] reporting a 40 percent mortality rate following long-gap esophageal atresia repair in a pediatric population. Our cohort experienced no instances of conduit leak or flap loss; corresponding adult literature reported leak rates ranging from 7 to 36 percent[6,12–17,30–32] and flap loss rates ranging from 0 to 18 percent.[5,12–15,31] Likewise, the 20 percent stricture rate in our sample mirrored the 0 to 50 percent stricture rate seen in adult supercharged jejunal interposition.[6,12–15,17] Our early postoperative outcomes also compare favorably to those reported in pediatric colonic interposition and gastric pull-up for long-gap esophageal atresia repair.[4] Although patients in the present study experienced no mortality, flap loss, or leaks, a meta-analysis[4] reported higher rates of all three of these outcomes in pediatric colonic interposition (4, 4, and 17 percent, respectively) and gastric pull-up (10, 5, and 28 percent, respectively). In summary, the observed outcomes for supercharged jejunal interposition among our own patients demonstrate the relative safety and efficacy of our group's approach.

Esophageal reconstruction in a pediatric population brings unique challenges. Most esophageal defects in pediatric patients are congenital. Affected children frequently have a history of a failure to thrive, chronic aspiration (with secondarily impaired respiratory function), and multisystem dysfunction.[2] Unlike their adult counterparts, most affected children have little to no experience with oral feeding and swallowing. In addition, some patients in our series have developmental delays that may delay their ability to tolerate oral feeding. The majority of our patients require feeding therapy, which can be difficult in patients with neurocognitive differences. Because of the unique nature of these patients, surgeons should anticipate feeding delays and appropriately counsel parents before surgery. In this study, patients with superior feeding outcomes (Table 2) tended to have longer follow-up and history of feeding. Excluding those with oral feeding aversions ($n = 2$), patients with persistent dysphagia ($n = 7$) had the shortest follow-up (range, 0.3 to 1.3 years) (Table 2). Postoperatively, all patients managed their oral secretions through swallowing alone and did not require a diverting cervical esophagostomy.

The present study is limited by its small sample size, retrospective nature, variable follow-up, and tertiary center referral bias. The short follow-up prevents assessment of long-term esophageal-jejunal performance, critical for characterizing the long-term anatomical and physiologic integrity of these conduits and the ability to observe sustained weight gain.[1,2,33] Future research must establish a treatment algorithm for pediatric esophageal reconstruction. Long-term prospective studies are needed to determine whether supercharged jejunal interposition should supplant gastric pull-up and colonic interposition for large esophageal defects.

CONCLUSIONS

We demonstrate the feasibility and safety of supercharged jejunal interposition in very young patients. When performed by an experienced, multidisciplinary team, this approach is reliable and should be considered as a valuable solution for children with otherwise limited reconstructive options. With further follow-up, the jejunum may prove to be a superior long-term conduit.

Brian I. Labow, M.D.
Department of Plastic and Oral Surgery
Boston Children's Hospital and Harvard Medical School
300 Longwood Avenue
Hunnewell 1
Boston, Mass. 02115
brian.labow@childrens.harvard.edu

REFERENCES

1. Bairdain S, Foker JE, Smithers CJ, et al. Jejunal interposition after failed esophageal atresia repair. *J Am Coll Surg.* 2016;222:1001–1008.
2. Gottrand M, Michaud L, Sfeir R, Gottrand F. Motility, digestive and nutritional problems in esophageal atresia. *Paediatr Respir Rev.* 2016;19:28–33.
3. Longmire WP Jr. Antethoracic jejunal transplantation for congenital esophageal atresia with hypoplasia of the lower esophageal segment. *Surg Gynecol Obstet.* 1951;93:310–316.
4. Gallo G, Zwaveling S, Groen H, Van der Zee D, Hulscher J. Long-gap esophageal atresia: A meta-analysis of jejunal interposition, colon interposition, and gastric pull-up. *Eur J Pediatr Surg.* 2012;22:420–425.
5. Foker JE, Linden BC, Boyle EM Jr, Marquardt C. Development of a true primary repair for the full spectrum of esophageal atresia. *Ann Surg.* 1997;226:533–541; discussion 541–543.
6. Ascioti AJ, Hofstetter WL, Miller MJ, et al. Long-segment, supercharged, pedicled jejunal flap for total esophageal reconstruction. *J Thorac Cardiovasc Surg.* 2005;130:1391–1398.
7. Roux C. A new operation for intractable obstruction of the esophagus (L'oesophago-jejuno-gastrosiose, nouvelle operation pour retrecissement infranchissable del'oesophage). *Semin Med.* 1907;27:34–40.
8. Bax KM. Jejunum for bridging long-gap esophageal atresia. *Semin Pediatr Surg.* 2009;18:34–39.
9. Chen HC, Rampazzo A, Gharb BB, et al. Motility differences in free colon and free jejunum flaps for reconstruction of the cervical esophagus. *Plast Reconstr Surg.* 2008;122:1410–1416.
10. Swisher SG, Hofstetter WL, Miller MJ. The supercharged microvascular jejunal interposition. *Semin Thorac Cardiovasc Surg.* 2007;19:56–65.
11. Sekido M, Yamamoto Y, Minakawa H, et al. Use of the "supercharge" technique in esophageal and pharyngeal reconstruction to augment microvascular blood flow. *Surgery* 2003;134:420–424.
12. Blackmon SH, Correa AM, Skoracki R, et al. Supercharged pedicled jejunal interposition for esophageal replacement: A 10-year experience. *Ann Thorac Surg.* 2012;94:1104–1111; discussion 1111–1113.
13. Chana JS, Chen HC, Sharma R, Gedebou TM, Feng GM. Microsurgical reconstruction of the esophagus using supercharged pedicled jejunum flaps: Special indications and pitfalls. *Plast Reconstr Surg.* 2002;110:742–748; discussion 749–750.
14. Barzin A, Norton JA, Whyte R, Lee GK. Supercharged jejunum flap for total esophageal reconstruction: Single-surgeon 3-year experience and outcomes analysis. *Plast Reconstr Surg.* 2011;127:173–180.
15. Iwata N, Koike M, Kamei Y, et al. Antethoracic pedicled jejunum reconstruction with the supercharge technique for esophageal cancer. *World J Surg.* 2012;36:2622–2629.
16. Stephens EH, Gaur P, Hotze KO, Correa AM, Kim MP, Blackmon SH. Super-charged pedicled jejunal interposition performance compares favorably with a gastric conduit after esophagectomy. *Ann Thorac Surg.* 2015;100:407–413.
17. Baker CR, Forshaw MJ, Gossage JA, Ng R, Mason RC. Long-term outcome and quality of life after supercharged jejunal interposition for oesophageal replacement. *Surgeon* 2015;13:187–193.
18. Centers for Disease Control and Prevention, National Center for Health Statistics. Clinical growth charts. Available at: https://www.cdc.gov/growthcharts/clinical_charts.htm. Accessed May 8, 2018.
19. Salassa JR. A functional outcome swallowing scale for staging oropharyngeal dysphagia. *Dig Dis.* 1999;17:230–234.
20. Ganske IM, Firriolo JM, Nuzzi LC, et al. Double supercharged jejunal interposition for late salvage of long-gap esophageal atresia. *Ann Plast Surg.* 2018;81:553–559.
21. Lord RV, Wickramasinghe K, Johansson JJ, Demeester SR, Brabender J, Demeester TR. Cardiac mucosa in the remnant esophagus after esophagectomy is an acquired epithelium with Barrett's-like features. *Surgery* 2004;136:633–640.

22. Davenport M, Hosie GP, Tasker RC, Gordon I, Kiely EM, Spitz L. Long-term effects of gastric transposition in children: A physiological study. *J Pediatr Surg*. 1996;31:588–593.
23. Lindahl H, Rintala R, Sariola H, Louhimo I. Cervical Barrett's esophagus: A common complication of gastric tube reconstruction. *J Pediatr Surg*. 1990;25:446–448.
24. Cense HA, Visser MR, van Sandick JW, et al. Quality of life after colon interposition by necessity for esophageal cancer replacement. *J Surg Oncol*. 2004;88:32–38.
25. Louhimo I, Pasila M, Visakorpi JK. Late gastrointestinal complications in patients with colonic replacement of the esophagus. *J Pediatr Surg*. 1969;4:663–673.
26. Ring WS, Varco RL, L'Heureux PR, Foker JE. Esophageal replacement with jejunum in children: An 18 to 33 year follow-up. *J Thorac Cardiovasc Surg*. 1982;83:918–927.
27. Cauchi JA, Buick RG, Gornall P, Simms MH, Parikh DH. Oesophageal substitution with free and pedicled jejunum: Short- and long-term outcomes. *Pediatr Surg Int*. 2007;23:11–19.
28. Blackmon SH. Long-segment, supercharged pedicled jejunal interposition for esophageal replacement: How I teach it. *Ann Thorac Surg*. 2018;105:345–350.
29. Cusick EL, Batchelor AA, Spicer RD. Development of a technique for jejunal interposition in long-gap esophageal atresia. *J Pediatr Surg*. 1993;28:990–994.
30. Ueda K, Kajikawa A, Suzuki Y, Okazaki M, Nakagawa M, Iida S. Blood gas analysis of the jejunum in the supercharge technique: To what degree does circulation improve? *Plast Reconstr Surg*. 2007;119:1745–1750.
31. Poh M, Selber JC, Skoracki R, Walsh GL, Yu P. Technical challenges of total esophageal reconstruction using a supercharged jejunal flap. *Ann Surg*. 2011;253:1122–1129.
32. Doki Y, Okada K, Miyata H, et al. Long-term and short-term evaluation of esophageal reconstruction using the colon or the jejunum in esophageal cancer patients after gastrectomy. *Dis Esophagus* 2008;21:132–138.
33. Mahoney L, Rosen R. Feeding difficulties in children with esophageal atresia. *Paediatr Respir Rev*. 2016;19:21–27.