Indications, Surgical Technique, and Long-Term Functional Results of Colon Interposition or Bypass

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Over a 17-year period, 92 patients with esophageal disease underwent colon interposition or bypass, with each operation performed by the same surgeon. The indication was cure of cancer in 20 patients, relief of dysphagia in 55 (cancer in 17 patients and benign in 38), loss of gastrointestinal (G.I.) continuity in ten, and tracheoesophageal fistula in seven patients (malignant in five, benign in 2). The thirty-day operative mortality rate was 5%, and the hospital mortality rate was 9%. Graft necrosis occurred in seven of 92 patients, four of whom later underwent a successful second reconstruction. Thirteen patients required subsequent revisional surgery. In 85 patients, the left colon based on the inferior mesenteric artery was used, and in seven, the right colon was used. Technical insights were gained to help preserve the blood supply to the graft and improve its function in transporting food. Thirty-four patients were available for interview 2–17 years after operation (median of 5 years) 28 of whom had benign disease, and six of whom had malignant disease); 82% of the patients felt they were cured of their preoperative symptoms, 18% improved, and none worsened. Eighty-eight per cent of the patients were able to receive an unrestricted diet. All patients except one were satisfied with the results of surgery, and, asked what they would do if they had to make the choice again, all responded that they would have the operation. Twenty-six of the interviewed patients had their eating ability evaluated with a test meal and the transit time of a liquid and solid barium bolus measured. Compared to controls, patients with colon interpositions consumed a smaller capacity meal over a longer period of time and were not dependent on liquids to flush the food through the colon graft. A colon interposition provides good quality of deglutition, is very durable, and is the organ of choice for patients who require an esophageal substitute and are potential candidates for long survival.

THE USE OF LONG SEGMENTS of colon, either for replacement or bypass of all or part of the thoracic esophagus, was introduced independently by Kelling[1] and Vulliet[2] in 1911. Since then, the colon has emerged as a well-functioning and durable esophageal substitute.[3–5] Two critical factors in the success of using colon as an esophageal substitute are the adequacy of the blood supply to the colon graft used and its ability to transport food effectively from pharynx to stomach. Consequently, seemingly minor judgmental or technical errors can have disastrous consequences on the initial viability or long-term function of the graft.

We have used the colon as an esophageal substitute in 92 patients. This experience has provided technical insights for constructing a well-functioning colon interposition associated with low morbidity and mortality rates, and long-term follow-up studies have substantiated the colon as a durable and highly acceptable esophageal substitute.

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Presented at the 108th Annual Meeting of the American Surgical Association, San Francisco, California, May 2–4, 1988.

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Submitted for publication: May 5, 1988.

Population Study

Patient Population

Between January 1971 and April 1988, the senior author (T. DeMeester) performed a colon interposition or bypass in 92 patients with esophageal pathology. Figure 1 shows our experience with the operation over a 17-year period. The age distribution of the patients, as it regards the type of disease (*i.e.*, benign or malignant) for which the operation was performed, is shown in Figure 2. The indications for the operation are shown in Table 1, and the etiology of the problem that led to interposition or bypass is shown in Table 2. In patients who had carcinoma, the operation was performed either for cure or to

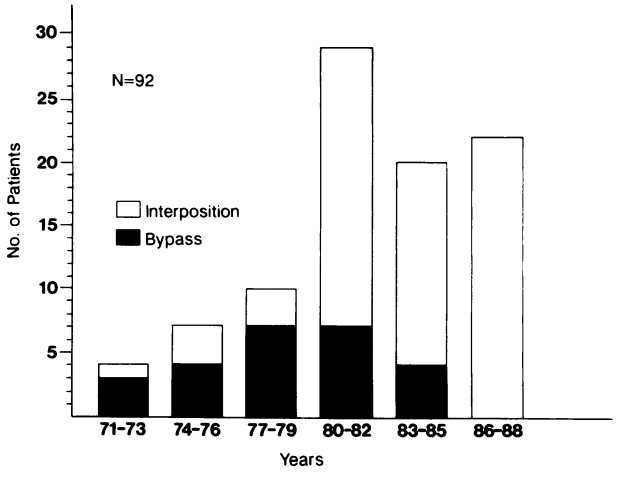


FIG. 1. Experience, divided into three year intervals, with colon interposition or bypass over the studied period. (N = 92)

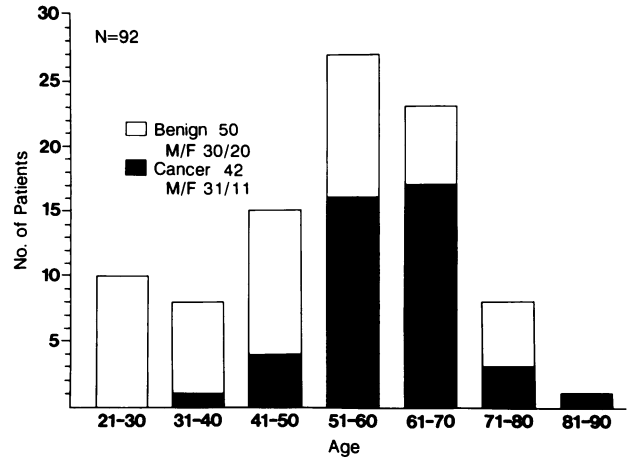


FIG. 2. The age distribution of patients who underwent a colon interposition or bypass for benign or malignant disease, and their respective male:female ratios.

palliate the symptoms of dysphagia. In patients who had a benign etiology, the operation was performed because of the severity of dysphagia and the patient's inability to enjoy social eating. In these patients, a number of alternate therapies had been attempted before proceeding with esophageal resection and colon interposition. Their mean preoperative weight was 62.2 ± 17.4 kg. In only six instances was the operation performed in a patient with benign disease because of an inability to maintain adequate nutrition.

Preoperative evaluation consisted of a barium swallow and peroral endoscopy. In patients who had received an esophagectomy previously, endoscopic evaluation of the pharynx and remaining cervical esophagus was made in order to evaluate the site of the proposed proximal anastomosis. Before the operation, the status of the colon was evaluated initially with a barium enema, and by colonoscopy during the last 4 years. The most recent 58 patients received preoperative angiography of the superior and inferior mesenteric arteries to provide the surgeon with precise information regarding the vascular supply of the colon and help select the segment of colon to be used for the bypass or interposition.

Operative Approach

In 51 patients, the operation was performed in combination with a resection of the esophagus, 16 had a prior esophagectomy, and 25 had their esophageal pathology bypassed. (The indications for the procedures are shown in Table 1.) The colon graft was placed in the posterior mediastinum in 48 patients, substernally in 38, and subcutaneously in two. In four patients, the operation was abandoned because of immediate graft ischemia. Of those patients who had the graft placed in the posterior mediastinum, 19 had the esophageal anastomosis below the aortic arch and were performed through a left posterolateral thoracoabdominal incision; 15 had the anastomosis above the aortic arch and were performed through a right thoracotomy and an upper midline abdominal incision; and 14 patients had the esophageal anastomosis in the neck and were performed through a right thoracotomy, upper midline abdominal, and a left neck incision. Of those patients who had the graft placed substernally, a tunnel was constructed in 19, with an anastomosis to the cervical esophagus in 18 patients, and pharynx in one. Of these patients, 13 had the left half of the manubrium and sternal head of the left clavicle resected to enlarge the thoracic inlet. The remaining 19 patients received a sternotomy, with an anastomosis made to the pharynx (two patients), to the cervical esophagus (eleven patients), and to the transposed thoracic esophagus below the thoracic inlet within the anterior mediastinum (six patients). The latter patients did not require resection of the manubrium and sternal head of the left clavicle.

In 85 patients, a left colon graft was used, based on the left colic artery and the inferior mesenteric vein. The normal arterial supply of the left colon is shown in Figures 3A and B. In seven patients, a right colon graft was used, based on the midcolic artery and superior mesenteric vein. The reasons for using the midcolic artery were stenosis

TABLE 1. *Indication for Colon Interposition or Bypass*

Indication	Number of Patients
Cure of cancer	20
Relief of dysphagia (Cancer in 17, Benign in 38)	55
Loss of G.I. continuity	10
TEF (Malignant in 5, Benign in 2)	7
Total	92

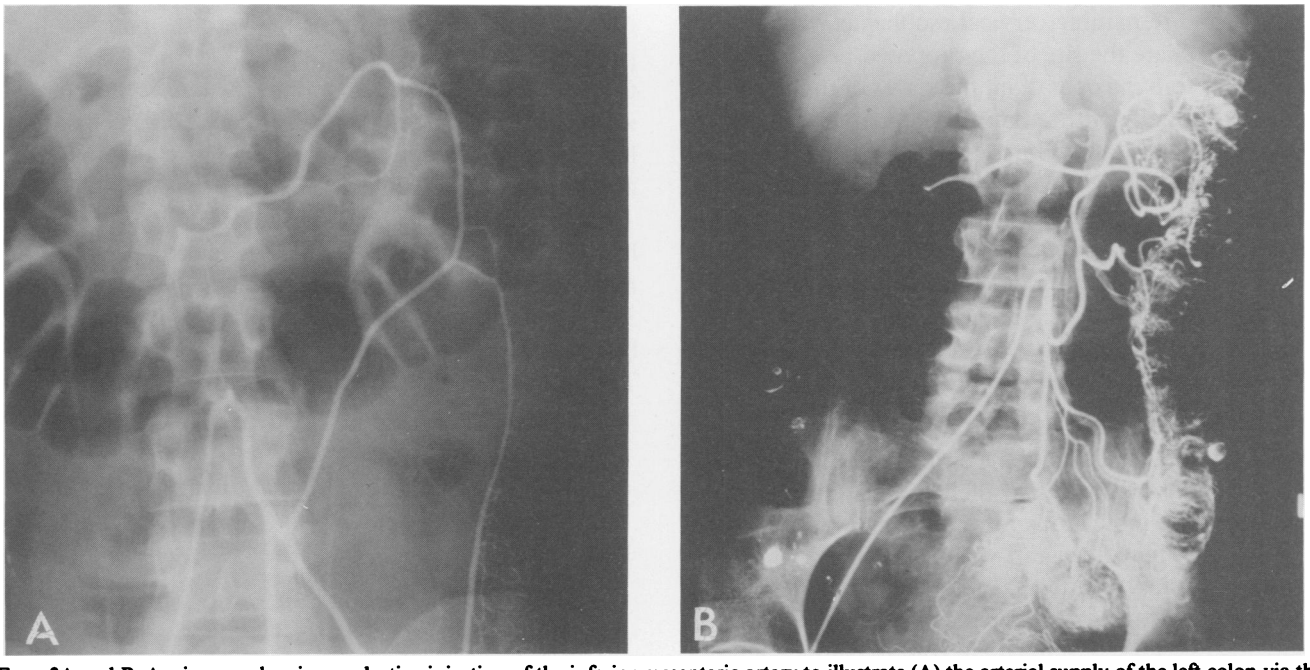
TABLE 2. *Etiology Leading to Esophageal Substitute or Bypass*

Indication	Total Number of Patients	Procedure											
		Concomitant Resection and Interposition				Interposition After Previous Resection				Bypass Alone			
		Number of Patients	Failed Graft	Hospital <30 days	Mortality >30 days	Number of Patients	Failed Graft	Hospital <30 days	Mortality >30 days	Number of Patients	Failed Graft	Hospital <30 days	Mortality >30 days
Cancer	42	18	2	1	1	8	1	1	0	16	1	2	1
Failed esophageal surgery	24	20	1	0	1	3	0	0	0	1	0	0	0
Benign stenosis	9	6	0	0	0	1	0	0	0	2	0	0	0
Caustic injury	6	2	1	0	0	2	0	0	0	2	0	0	0
Advanced motility disease	5	5	1	0	0	0	0	0	0	0	0	0	0
Trauma/ Iatrogenic	3	0	0	0	0	1	0	0	0	2	0	0	0
Benign TEF	2	0	0	0	0	0	0	0	0	2	0	1	0
Spontaneous esophageal perforation	1	0	0	0	0	1	0	0	0	0	0	0	0
Total	92	51	5	1	2	16	1	1	0	25	1	3	1

of the inferior mesenteric artery upon preoperative angiography (four patients), a fixed left colon mesentery (one patient), malrotation of the colon (one patient), and the surgeon's choice (one patient).

Technique of Left Colon Interposition or Bypass

Over the period of this experience, the senior author has become aware of a number of technical insights that protect the adequacy of blood supply and improve the function of the colon transplant. The following description of the technique of left colon interposition or bypass includes these developments. The colon is prepared through an upper midline abdominal incision unless the esophagocolic anastomosis is to be made below the aortic arch. In this case, a left posterolateral thoracoabdominal incision is used, and the diaphragm is incised peripherally to allow access into the abdomen for preparation of the colon graft.



FIGS. 3A and B. Angiogram showing a selective injection of the inferior mesenteric artery to illustrate (A) the arterial supply of the left colon via the ascending branch of the left colic artery and the marginal branch and (B) its venous drainage via the inferior mesenteric vein and superior hemorrhoidal veins.

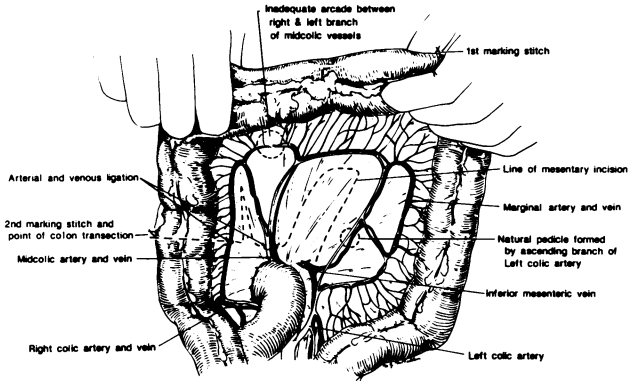


FIG. 4. Preparation of a left colon graft by mobilizing the colon and displaying its arterial supply and venous drainage. The position of the marking sutures, the sites of arterial and venous ligation, the point of proximal colon transection, and the incision of the mesentery are illustrated.

The omentum is dissected off the transverse mesocolon, the splenic and hepatic flexures are taken down, and the ascending and descending colon are mobilized to the midline so that the whole colon from the sigmoid to the cecum is free on its mesentery. The ascending branch of the left colic artery can be clearly identified when the mesentery is stretched in a cephalad direction by its tendency to form a natural pedicle ascending in the direction of the splenic flexure adjacent to the ligament of Treitz. Similarly, the arterial arcades can be seen when the mesentery is stretched transversely, as shown in Figure 4.

The length of the colon graft is measured by tethering the colon as much as possible in a cephalad direction on the natural pedicle made by the ascending branch of the left colic artery (Fig. 5). The tethering artery will usually allow the colon to reach up to or slightly above the xiphoid. A marking stitch is placed on the antimesenteric border of the colon directly opposite the tethering artery. The distal colon is usually somewhat redundant if the tethering artery is the limiting factor. The anterior chest wall is marked at the level of the marking stitch. The distance from this point to the level of the planned proximal anastomosis is measured liberally with an umbilical tape. Using the tape, the same distance is measured from the marking stitch proximally along the transverse colon and marked with a second marking stitch. When the proximal anastomosis is planned in the neck, the second marking stitch will usually lie to the right of the right branch of the midcolic artery; if planned below the aortic arch, the marking stitch will lie between the right and left branch. The marginal artery and vein are ligated at the point of the second marking stitch. The midcolic artery and vein are ligated proximal to their right and left branches for long grafts (Fig. 4); whereas only the left branch is ligated for short grafts. Proximal ligation of the midcolic artery and vein is done for long grafts because of the poorly developed peripheral arcade between the right and left branches. At

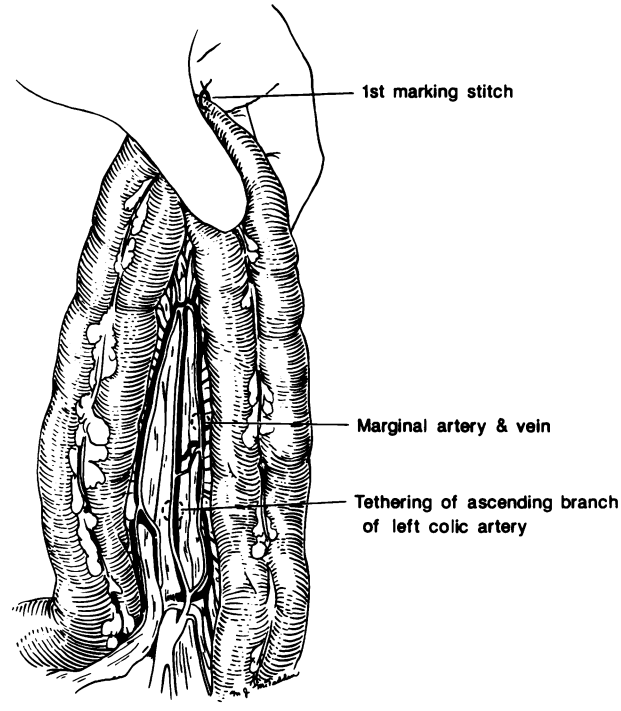


FIG. 5. Tethering of the ascending branch of the left colic artery in its natural pedicle and the position of the first marking stitch.

times, this may require excising a button of superior mesenteric artery and vein and suturing the margins together in order to maintain patency between the left and right branches (Fig. 6). Before ligation and division of the vessels, it is wise to occlude them temporarily with a small bulldog clamp to test the adequacy of the blood supply from the left colic artery by palpating a pulse in the proximal end of the colon graft. Similarly, venous outflow is tested by observing that the veins do not become overly distended, indicating venous hypertension. If the arterial supply and venous drainage is adequate, the arteries can be divided. The mesentery is divided as shown in Figure 4. To properly prepare the colon for anastomosis, the small

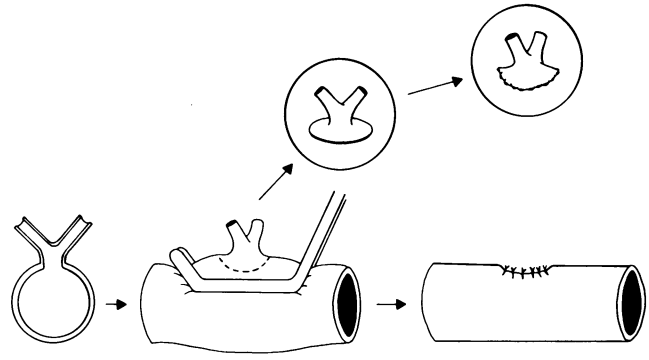


FIG. 6. Illustration of the management of an early branching midcolic artery or vein through excision of a button of the superior mesenteric artery or vein and suturing together of the margins to maintain the patency between the left and right branches.

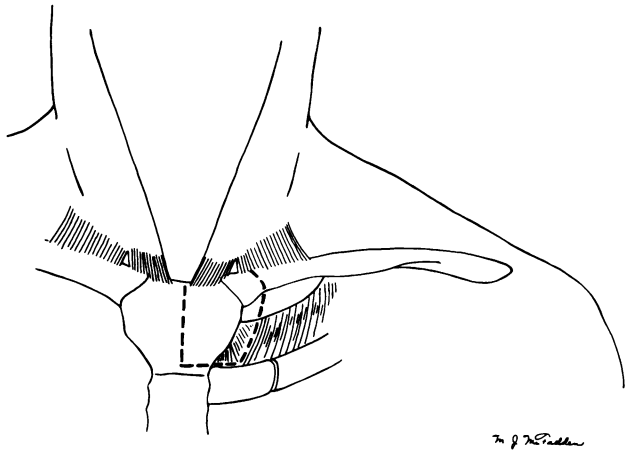


FIG. 7. The boundaries for resection of the manubrium, first rib, and sternal head of the left clavicle to increase the size of the thoracic inlet when the substernal route is used to bring the colon into the neck.

end arteries to the colon at the point of its transection are divided. The transection of the colon is delayed until later in the operation.

The site of the proximal anastomosis is prepared, either within the thorax or neck. If the substernal route is used and the anastomosis will lie within the neck, the left half of the manubrium, the medial end of the first rib, and the sternal head of the left clavicle are removed to increase the size of the thoracic inlet (Fig. 7). This is achieved by an extra pleural dissection, leaving the intact internal mammary artery and vein on the pleural surface. These vessels may be a source of blood supply for a free bowel graft if there is a failure. The left clavicle is divided just lateral to its sternal head by passing a Gigli's saw underneath it at the angle made with the first rib. The bone is sawed as close as possible to the angle so that some of the costoclavicular ligament is preserved to anchor the remaining clavicle to the first rib. If there is sufficient length of proximal esophagus to place the anastomosis below the thoracic inlet and the colon graft is long enough to reach the neck, the anastomoses is performed in the neck without resecting the manubrium and sternal head and pulled into the substernal space. If the length of the colon is insufficient to reach the neck, a mediasternotomy is performed. In this situation, there is no need to resect a portion of the manubrium and the left clavicle, since esophageal peristalsis in the proximal esophagus will propel the bolus into the thorax through the existing thoracic inlet.

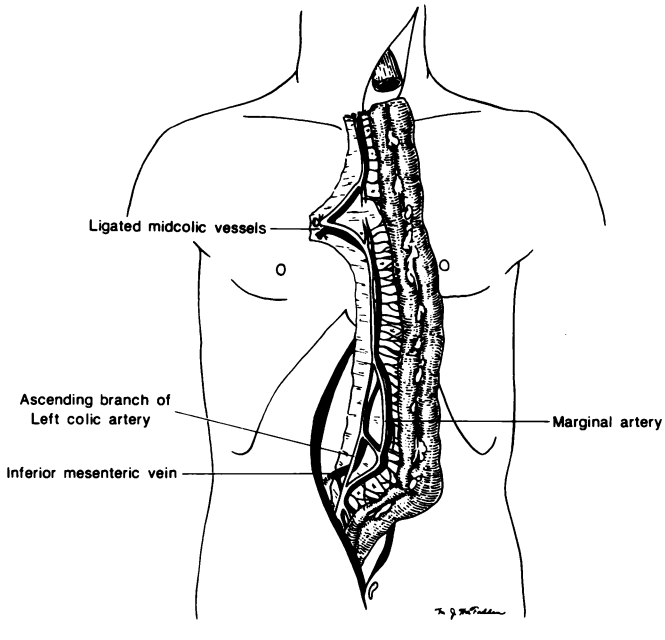


FIG. 8. The prepared colon graft laid out on the anterior chest wall.

After the site of the proximal anastomosis has been prepared, the colon transplant is re-examined in order to evaluate the status of its vascular supply. If there is any doubt about the adequacy of the arterial supply or venous drainage of the graft, the cardiovascular stability of the patient, or if the length of the operation has been prolonged because of a concomitant esophageal resection, a decision can be made to delay the reconstruction. To do so requires performing a cervical esophagostomy, placing all the small bowel through the incision in the transverse mesocolon so that it lies cephalad to the transverse colon, fixing the transverse colon to the anterior abdominal wall in the right lower quadrant, and constructing a feeding jejunostomy fixed to the anterior abdominal wall above the transverse colon. The mobilized colon is placed underneath the small bowel and fixed to the abdominal wall so that it will not adhere to the denuded posterior peritoneal surfaces left behind by its mobilization. Such an adherence can result in a loss of length due to scarring of the mesentery and make subsequent mobilization of the colon extremely difficult and hazardous to its vascular structures. The serosal covering of the small bowel, however, envelopes the mobilized colon in a way that allows ease of mobilization at a second procedure. This technique was used in three of the 92 patients. In each, the colon was mobilized easily at the second procedure, did not show any evidence of shortening, and had a hardy blood supply.

If it is decided that the procedure should be completed, the colon is transected at the site planned, using a GIA stapler. The unfolded colon is laid on the anterior chest wall to assure there is no twisting of the mesentery (Fig. 8). The mesentery of the descending and sigmoid colon below the pedicle is not divided. This allows additional arterial supply to the colon graft through the sigmoidal branches of the inferior mesenteric artery via the marginal artery. It similarly allows for additional venous drainage through the superior and middle hemorrhoidal veins into the inferior vena cava via the hemorrhoidal plexus and the inferior hemorrhoidal vein.

The proximal end of the colon graft is sutured inside

the funnel of an inverted 14 mm-Mousseau-Barbin tube (Porges Catheter Corp., New York, NY). A bowel bag is cut so that it can be wrapped around the colon graft and tied around the inverted funnel of the Mousseau-Barbin tube (Fig. 9). This allows an atraumatic passage of the colon through a posterior or substernal tunnel. All tension is applied to the bag, which glides through the tissues with minimal friction while protecting the colon graft. The abdominal course of the graft is posterior to the stomach and through the esophageal hiatus into the posterior mediastinum or up through the gastrohepatic ligament and substernal opening in the diaphragm into the substernal tunnel.

The esophagus is divided at the planned level of the proximal anastomosis and the mucosa is fixed to the esophageal wall with three or more silk sutures to prevent its retraction and aid in the construction of the anastomosis to the esophagus and colon. Before performing the anastomosis, the stapled closure of the proximal end of the colon graft is excised. The esophago-colic anastomosis is performed with a single layer of permanent 4-0 monofilament interrupted sutures. All knots are tied within the lumen, except for the final four or five modified Gambee stitches tied on the outside (Figs. 10A and B).

The colon is placed on sufficient stretch to prevent redundancy within the chest or in the substernal area, but not stretch so excessive as to jeopardize the anastomosis.

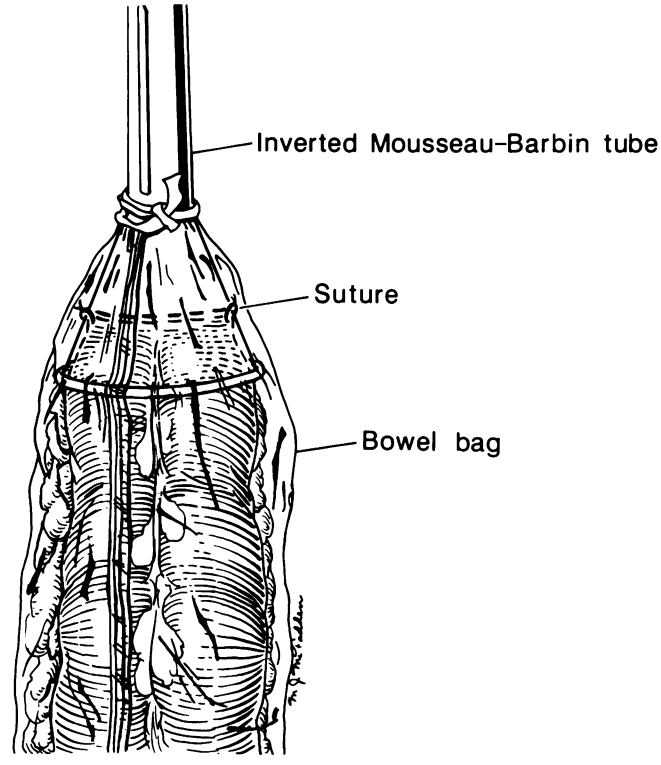
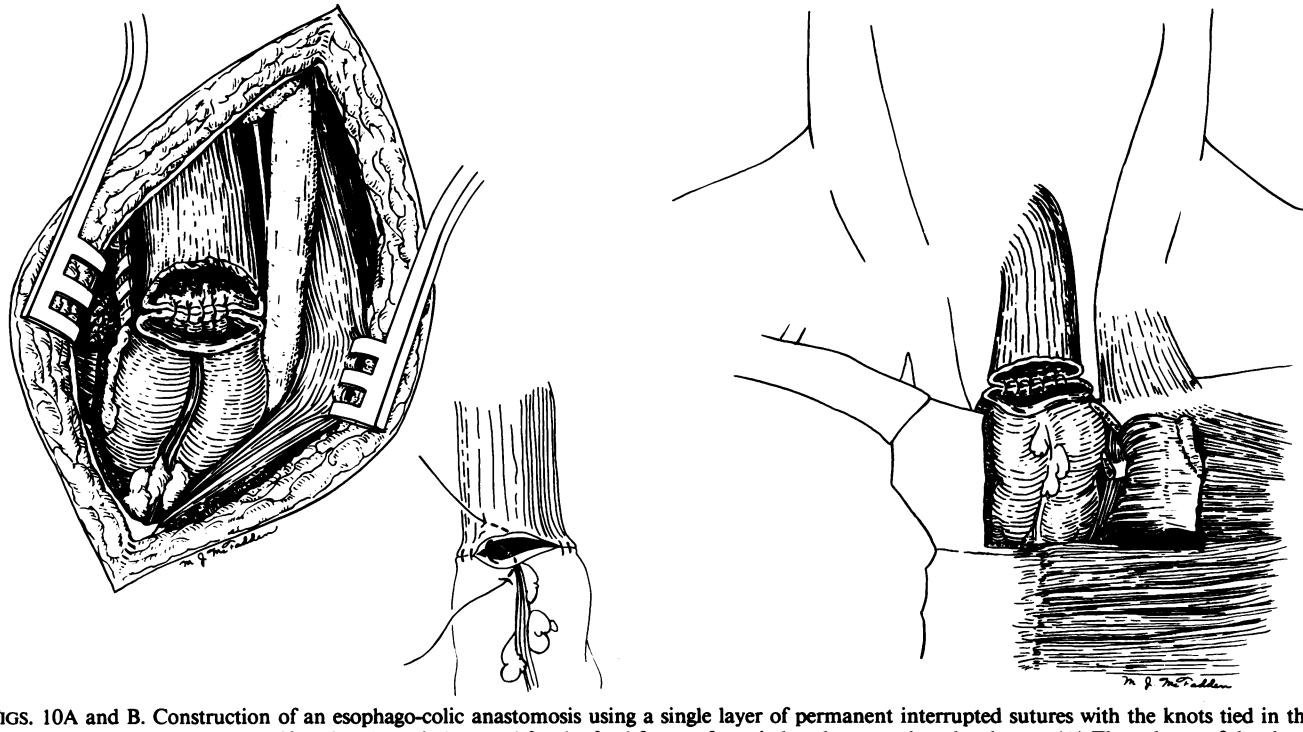


FIG. 9. The proximal end of the colon graft sutured inside the funnel of a Mousseau-Barbin tube and covered with a plastic bowel bag in preparation for passage through a substernal or posterior mediastinal tunnel.



FIGS. 10A and B. Construction of an esophago-colic anastomosis using a single layer of permanent interrupted sutures with the knots tied in the lumen. Insert illustrates the modified Gambee stitches used for the final four or five stitches that complete the closure. (A) The colon graft has been brought up through the posterior mediastinal route. (B) The colon graft has been brought up through the substernal route after the left half of the manubrium and sternal head of the left clavicle have been removed.

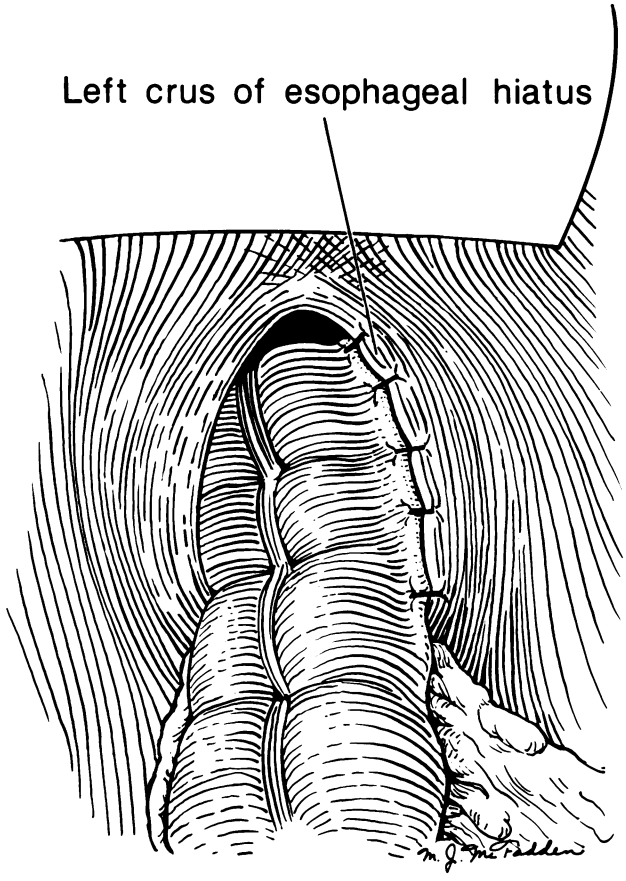


FIG. 11. Anchoring the colon graft to the left crus of the diaphragm in order to maintain its straight position and avoid redundancy within the chest.

The straighter the colon, the better its postoperative function. It is anchored in its straightened position by sutures to the left crura margin of the hiatus (Fig. 11), or the left margin of the opening in the diaphragm into the substernal tunnel. The colon is not sutured circumferentially around the hiatus or the substernal diaphragm opening because of the tendency to bow string the colon transversely and produce a functional obstruction. When the substernal route is used, it is important to avoid kinking the vessels to the colon graft on the edge of the diaphragm at the entry into the substernal tunnel. This is best managed by making a 2–3 cm longitudinal incision into the pericardium above and below the edge, and closing it in a transverse plane, similar to a Heineke-Mikulicz pyloroplasty. By so doing, the acute angle formed by the diaphragm and pericardium is converted to a gentle rounded curve.

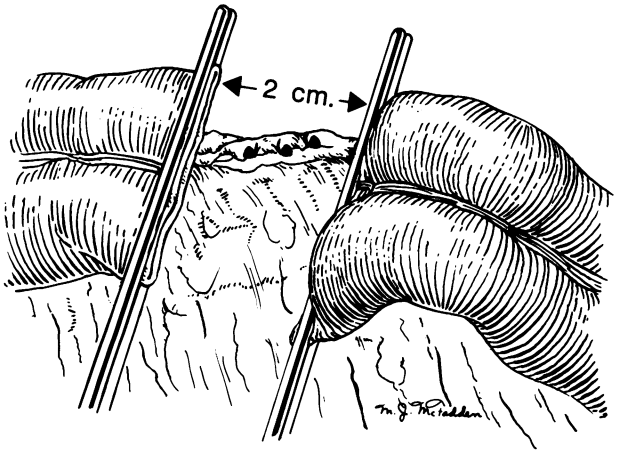


FIG. 12. Transection of the distal end of the colon graft without dividing the mesentery other than 2 cm along its mesenteric border. This avoids injury to the marginal artery and preserves additional arterial supply and venous drainage.

The distal end of the colon graft is transected 10 cm below to the diaphragmatic opening. At the site of division, the colon is freed from its mesentery for a longitudinal distance of 2 cm along its mesenteric border by dividing the small end vessels. Care is taken not to injure the marginal artery. The colon is transected without dividing the mesentery other than just along its mesenteric border (Fig. 12). This preserves additional blood supply from the marginal artery via the sigmoid arteries and venous drainage through the hemorrhoidal and sigmoid veins (Fig. 3). The distal end of the colon graft is anastomosed to the posterior surface of the stomach at a point one third the distance between the tip of the fundus to the pylorus. The anastomosis is performed by rotating the greater curvature of the stomach to expose its posterior wall (Fig. 13). It is placed in this position to reduce the amount of postoperative regurgitation and the likelihood of developing an ulcer in the graft. A double-layer anastomosis is constructed with interrupted 3-0 silk sutures. To reduce the possibility of bile reflux gastritis and colitis, a pyloroplasty is not performed. Should a pyloroplasty be necessary, it is relatively simple to perform at a subsequent procedure, since the duodenum and stomach have not been mobilized.

Colonic continuity is re-established by bringing the previously mobilized right colon over to the distal end of the divided colon graft and performing an end-to-end double-layer anastomosis with interrupted 3-0 silk sutures (Fig. 14). When finished, the colo-colic and the gastrocolic anastomosis lie posterior to the stomach in close proximity to each other. This is necessary in order to preserve the arterial supply and venous drainage to the colon graft from the sigmoid arteries and by the hemorrhoidal veins via the marginal artery and vein. The descending and sigmoid colon mesentery is not divided. The mesentery of the right colon is sutured to the mesentery of the descending colon to avoid an internal hernia. An intramural feeding jejunostomy tube is inserted 25 cm distal to the Treitz ligament. This allows for early postoperative feeding with gradual withdrawal of nutritional support as an adequate oral diet is resumed.

Perioperative and Postoperative Evaluation

The perioperative evaluation was obtained by a retrospective review of the patients' hospital records. Particular attention was focused on operative mortality (*i.e.*, death within 30 days of the operation), hospital mortality, the reason for failure to re-establish gastrointestinal (G.I.) continuity, the occurrence of anastomotic leaks, and significant postoperative complications. The incidence for the need of revisional surgery and the occurrence of anastomotic stenosis emerged during postoperative outpatient visits that was obtained from a retrospective review of the patients' office records. Patients who did well or who lived a considerable distance from the senior author's office were seen less frequently as the postoperative years increased. The uniqueness of the nature of their illness and surgery were such that subsequent encounters with other physicians regarding G.I. complaints resulted in phone inquiries to the senior author's office or a written request for information. Consequently, we are confident of the accuracy of our data regarding late postoperative complications that required revisional surgery.

Long-term Clinical Evaluation

We attempted to contact all patients who had had their operation 2 or more years before the study. We were successful in reaching 34 unselected patients who had experienced eating with a colon interposition for 2–17 years (median of 5 years). The indication for their colon interposition was benign disease in 28 and curable malignant disease in six. They were interviewed in person or by phone. A standard questionnaire was used to assure consistency and completeness of the evaluation. Questions were directed towards assessing the patient's eating habits, ability to swallow, and symptomatic side effects of the operation. The patients were also asked to give their own evaluation of the success of the operation. Each patient's current body weight was obtained and the weight gained or lost was calculated from the preoperative weight recorded in the hospital or office record.

Long-term Functional Evaluation

Twenty-six of the 34 patients who were interviewed volunteered to have postoperative function studies. All received a left colon interposition using the posterior mediastinal route. The function studies consisted of a fluoroscopically measured transit time of liquid barium, barium burger, and acidified liquid barium between pharynx and stomach, and the ability to consume a test meal. The function studies were performed at a median of 5 years after the operation, with a range of 2–12 years. Similar studies, with the exception of the transit time of acidified barium, were performed on twelve asymptomatic

FIG. 13. Anastomosis of the distal end of the colon graft to the posterior wall of the stomach at a point one third the distance between the tip of the fundus to the pylorus.

FIG. 14. Anastomosis of the right colon to the distal left colon is performed in close approximation to the completed gastro-colic anastomosis.

TABLE 3. *Failure to Establish G.I. Continuity*

Postop Day	Procedure	Cause	Outcome
0	Prep of graft	Ven obst	Death*
0	Prep of graft	Ven obst	Skin tube interpo
0	Prep of graft	Sten IMA	Jejuno interpo
0	Prep of graft	Malrot	No bypass
12	Comp interpo	Ven obst	Jejuno interpo
1	Comp interpo	Ven obst	Stomach pull-up
12	Comp interpo	Sten IMA	Death

* Compromise graft retained in abdomen for second look.
Prep of graft = preparation of colon graft. Comp = completed. Ven obst = venous obstruction. Malrot = malrotation of the colon. Sten IMA = stenosis of the inferior mesenteric artery. Jejuno = jejunum. Interpo = interposition.

control subjects in order to obtain normal values for comparison.

The transit time of a standard liquid barium suspension (20 ml), acidified liquid barium (20 ml), and a solid barium bolus (one large bite, well-chewed), was measured in the fasting state, using a digital time signal superimposed on the fluoroscopic screen and recording the time from the initiation of the swallow to the time that all the contrast left the colon graft and entered the stomach. The acidified barium was prepared by mixing 0.5 ml of concentrated hydrochloric acid (37%) with 100 ml of a standard barium liquid suspension and adding additional acid to adjust the pH to 1.7 using a pH meter.[6] The solid barium bolus was prepared by mixing hamburger with barium powder and frying the hamburger in the form of a patty. The patients were studied in the upright position. In both tests, the patient indicated when he was ready to swallow by raising his left hand. If the liquid or solid barium bolus failed to clear within 60 seconds, the patient was given 10 cc of room temperature water at 20-second intervals until the barium cleared. The test was continued for a total of 4 minutes. The results were based on the mean of three swallows with liquid barium and two swallows with solid barium.

The test meal consisted of three parts: 1) one cup of macaroni and cheese and one-half cup of green beans cooked and served at eating temperature, 2) one roll and one teaspoon of margarine, and 3) two peach halves with one ounce of pound cake. The total caloric content of the meal was 824 calories. The patients and subjects were instructed to ingest each part of the meal in a socially acceptable manner and as quickly as possible without causing discomfort. Each part of the meal was presented with a 6-ounce glass of water, but more water could be obtained if desired. The time required for eating as well as the amount of water needed for each part of the meal were recorded. Each successive part of the meal started as soon as the previous part was finished. The time between the beginning and end of the meal, or when the individual stated that he had had enough, was recorded. The amount of food and water not ingested were measured. From this data, the meal capacity (percentage of available calories consumed), eating time (minutes to consume 100 calories), and the liquids required (cubic centimeters of water per 100 calories consumed) were calculated.

TABLE 4. *Anastomotic Failure*

	Leak		Stenosis	
Location	Number of Patients (N = 85)	%	Number of Patients (N = 85)	%
Esophago-colic	3	4	2*	2
Colo-gastric	0	0	2	2
Colo-colic	1	1	0	0
Total	4	1.5†	4	1.5†

* Associated with leak in one patient.
† Calculated from a total of 255 anastomoses in 85 patients.

Results

Overall Operative Results

Of the 92 patients in whom colon interposition or bypass was attempted, the procedure was successful for 92%. In seven patients, G.I. continuity was not accomplished because of intraoperative graft ischemia in four patients, and postoperative graft necrosis in three patients. The cause for these failures is shown in Table 3. Of the four patients who developed intraoperative graft ischemia, one died of sepsis. In this patient, the colon graft, because of its questionable viability, was not interposed, but was retained in the abdomen as a blind colostomy in anticipation of doing a second look in 24 hours. Of the three patients who developed postoperative graft necrosis, one died of sepsis. In four of the seven patients, G.I. continuity was subsequently established by a second procedure using jejunum (in two patients), stomach (in one patient), and a skin tube (in one patient). Nothing further was performed in the patient with a failed bypass. Six of the seven patients had their colon graft based on the left colic artery; in one, who had a complete malrotation of the colon, a right colon graft based on what appeared to be the midcolic artery was the only choice.

Table 4 shows the number of failed anastomoses of 255 performed in the 85 patients whose colon graft survived. There were four leaks and four stenoses. All leaks occurred in patients who had a right colon graft based on the midcolic artery. In the three patients who developed an esophago-colic anastomotic leak, the anastomosis was in the anterior mediastinum. In our total experience, there were six anterior mediastinal anastomoses, and three leaked. All healed spontaneously. The four stenoses were initially dilated, but eventually required surgery. All were successfully revised. Of the two esophago-colic stenoses, one

was due to a leak, the other medication-induced. Of the two colo-gastric stenoses, one was due to bile reflux colitis and the other to ischemia. All other anastomoses healed normally and did not require dilation.

Table 5 shows the operative and hospital mortality in relationship to the type of procedure. The highest operative and hospital mortality occurred in patients who underwent bypass and reflects the severity of their disease rather than the difficulty of the procedure. In two patients, the operative mortality was caused by graft necrosis, in two who had a preoperative tracheoesophageal fistula, the cause was respiratory failure, and in one, it was congestive heart failure. The hospital mortalities were due to respiratory failure in a third patient with a preoperative tracheoesophageal fistula, a pulmonary embolus in one, and metastatic cancer in one.

Postoperative Complications

Table 6 lists the significant postoperative complications other than graft necrosis or anastomotic leaks. Postoperative bleeding that required surgical exploration occurred only in patients who had a concomitant esophageal resection. A sternal infection occurred in five of the 21 patients who had a mediasternotomy, and in three patients, the cause was a leak of an anastomosis in the anterior mediastinum.

Revisional Surgery

The indications for revisional surgery in 13 patients are listed in Table 7. Three patients required a bile diversion procedure for reflux gastritis or colitis that was unresponsive to medical therapy. All three of these patients had a pyloroplasty either before or concomitantly with their colon interposition. Thirty-four patients, all with benign disease and a probable vagotomy after esophageal resection, had a nonresected stomach at the completion of the procedure. In 19, a previous pyloroplasty had been performed, or, if it had not been performed, a pyloroplasty or myotomy was performed with the interposition. In 15 patients, no pyloric procedure was performed. Of the latter patients, three required a subsequent pyloroplasty because of delayed gastric emptying. Before the routine resection of the left half of the manubrium and the sternal head of the left clavicle when using the substernal route, one patient developed sternoclavicular compression and obstruction of the colon graft. This has not occurred after its routine resection. Two patients developed bowel obstruction due to intestinal adhesions.

Long-term Clinical Evaluation

Table 8 shows the eating habits of the 34 patients who were specifically interviewed in obtaining a long-term functional evaluation of their colon interposition. Their swallowing ability is shown in Table 9. Of significance is

TABLE 5. *Mortality*

Procedure	Operative (N = 92) (%)	Hospital (N = 92) (%)
Resection and interposition	1 of 51 (2)	3 of 51 (6)
Interposition alone	1 of 16 (6)	1 of 16 (6)
Bypass	3 of 25 (12)	4 of 25 (16)
Total	5 of 92 (5)	8 of 92 (9)

TABLE 6. *Postoperative Complications (N = 92)*

Cause	Number of Patients	%
Reoperative bleeding	6	6.5
Perforated diverticulum	1	1.1
Sternal infection	5	5.4
Wound separation	2	2.2

TABLE 7. *Revisional Surgery (N = 92)*

Indications	Number of Patients
Anastomotic stenosis	4
Redundant colon	3
Bile reflux gastritis or colitis	3
Sternoclavicular compression of colon	1
Incisional hernia	1
Delayed gastric emptying	3
Bowel obstruction	2

TABLE 8. *Long-term Follow-up: Eating Habits (N = 34)*

Number of meals per day	3 (range 2–8)
Estimated meal capacity	
Cup	18%
Airline meal	30%
Steak dinner	52%
Unrestricted diet	88%

TABLE 9. *Long-term Follow-up: Swallowing Ability (N = 34)*

	Percentage of Patients
Require liquids with meal	35
Last to finish meal	53
Sensation of hold-up*	18
Pain with swallowing	6
Choking with swallowing	6
Recovery time†	2 mos (range 1–24)

* No patients required dilatation.
† Return of good swallowing.

TABLE 10. *Long-term Follow-up: Side Effects of Operation (N = 34)*

Related to Colon Interposition		Related to G.I. Function	
Side Effect	Number of Patients	Side Effect	Number of Patients
Nocturnal regurgitation	6	Diarrhea	3
Gurgling	4	Dumping	2
Early satiety	5	Nausea	4
Bad breath	1	Bloating	3

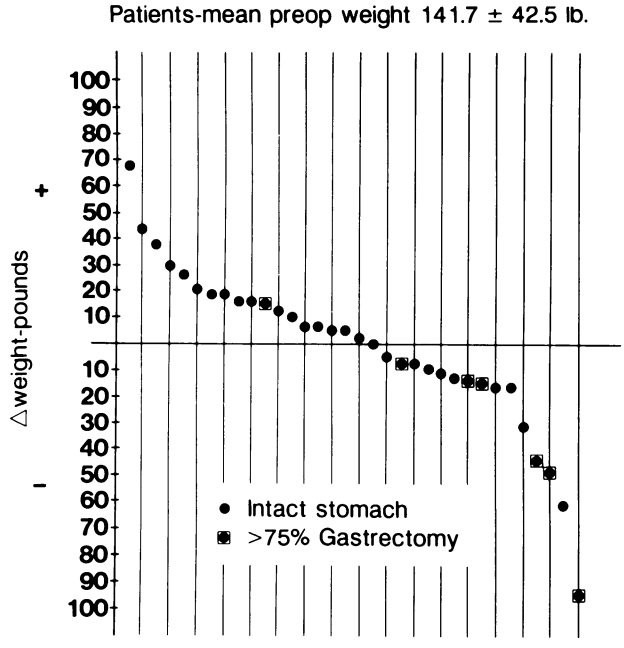


FIG. 15. The change in body weight in 34 patients who were followed 2–17 years (median 5 years) after colon interposition. Six patients who had greater than a 75% gastric resection had weighed less than their preoperative weights.

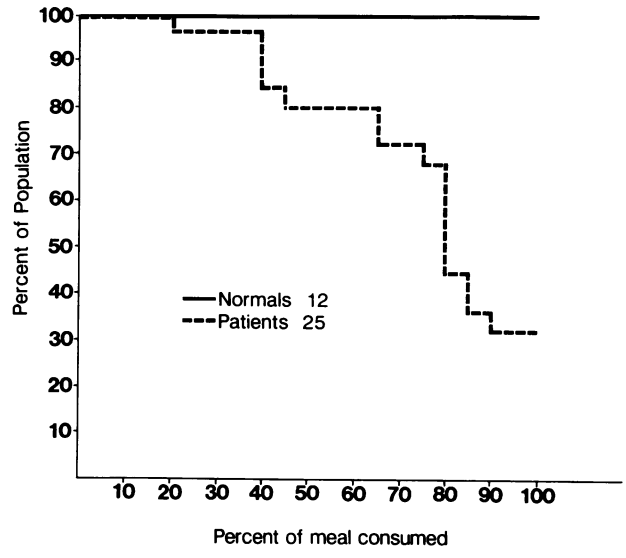


FIG. 16. The meal capacity in patients with a colon interposition compared to normal subjects. The test meal consisted of 824 calories.

that a median of 2 months was required for the patients to recover their swallowing ability. None of the patients required dilatations after the operation.

Significant side effects of the operation occurred in 15 patients. They were related to G.I. function in four patients, to the function of the colon interposition in seven patients, and to both functions in the remaining four. The detailed symptoms are given in Table 10. For the most part, these symptoms were mild. Only diarrhea and nocturnal regurgitation required specific treatment; diarrhea necessitated paregoric, and regurgitation necessitated elevation of the head of the bed.

Figure 15 shows the patient's change in weight after the operation. As many patients gained as lost. Of the seven patients who had more than a 75% gastrectomy, six lost weight after the operation and never regained their preoperative weight. The patient with the most profound weight loss had a total gastrectomy. Table 11 shows the patients' evaluation of their operative results; all believed that they were improved or cured by the operation and, when asked what they would do if they had to make the choice again, all responded that they would have the operation.

TABLE 11. *Patients' Evaluation of Operative Results*

	Percentage of Patients
Cured by operation	82
Improved by operation	18
Worsened by operation	0
Satisfied with operation	97
Would have operation again	100

Long-term Functional Studies

The ability of 26 patients to eat a test meal was measured. One patient was excluded because of cricopharyngeal dysfunction related to previous laryngeal surgery. The results are shown in Figure 16. All of the patients were able to consume at least 20% of the meal, 65% were able to consume 80% of the meal, and 30% were able to consume the entire meal. All of the normal subjects were able to consume the whole meal.

Figure 17 shows the rate of eating, as measured in minutes, required for consuming 100 calories. The median time for control subjects was 1 minute *versus* 3 minutes for the patients. The longest time for controls was 1.75 minutes, whereas for patients it was 6.25 minutes. Figure 18 shows that there was no difference between patients and control subjects in the amount of water required to consume 100 calories. Taken together, the results of the test meal show that, in comparison with normal subjects, patients with a colon interposition consumed a smaller meal over a longer period of time, but are not dependent on liquids to flush the food through their interposed colon.

Figure 19A shows that controls were able to transport 20 cc of liquid barium through their esophagus within 10 seconds (mean of 5 seconds). Patients, on the other hand, required up to 180 seconds (mean of 40 seconds). Transit time was statistically increased when the barium was acidified: 57.1 ± 47.8 seconds for liquid barium *versus* 41.5 ± 42.9 seconds for acidified barium ($p < 0.05$). Two patients were excluded because of technical difficulties.

The ability of the colon to transport solids was evaluated

with a barium burger. Controls had a median solid transit time of 10 seconds and did not require the use of water. Patients, on the other hand, had a median solid transit time of 120 seconds and required the use of water to achieve this rate (Figure 19B). One patient had a solid transit time of less than 60 seconds, and for four additional patients, solid transit time was in excess of 240 seconds. Two patients were excluded for technical reasons.

Together, the measurement of transit time of a liquid and solid barium bolus indicates, as might be expected, that patients with colon interpositions transport both slower than subjects who have a normal esophagus. The timely transit of solids requires liquids, and the transit of liquids can be augmented if they are acidic.

Fluoroscopic observations at the time of the test suggest that most patients transported liquids and solids through their colon by gravity, with only an occasional contraction from the colon. Patients who have a colon graft with a straight longitudinal axis emptied better. Those with redundancy emptied more slowly. The ingestion of acidified liquid barium appears to cause a shortening and narrowing of the colon that reduces redundancy and improves emptying. Acidified barium causes little improvement in transit time in those patients who had a colon graft with a straight longitudinal axis, and in some, caused colonic spasms that compartmentalized the colon graft with evacuation of the distal barium and retention of the proximal barium.

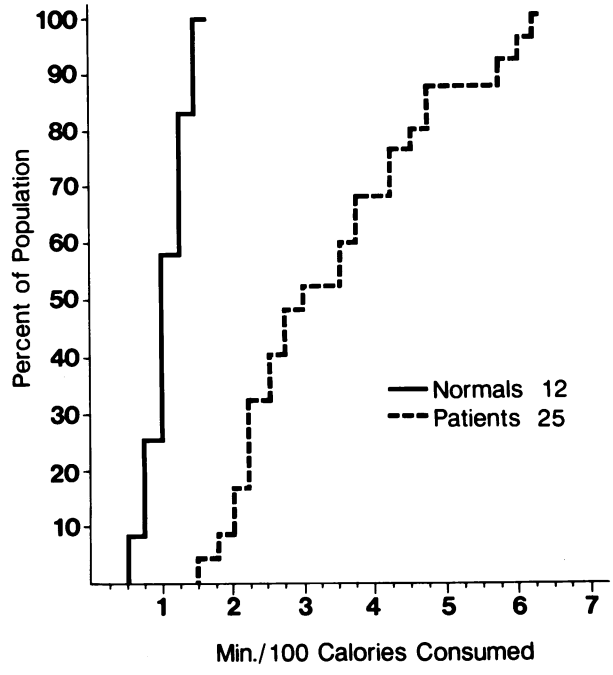


FIG. 17. The rate of eating the test meal (i.e., to comfortably ingest 100 calories) by patients with a colon interposition and by controls, expressed in minutes.

Discussion

This 17-year experience with colon interposition or bypass as an esophageal substitute has shown that the procedure can be safely accomplished and results in good long-term function. Our procedure-related mortality rate is 5%. We infrequently encountered problems with graft ischemia, anastomotic leakage, or stenosis. The colon functions well as an esophageal substitute in that it is able to accept and transport an adequate meal volume to maintain good nutrition. The patients were satisfied with their procedure and were able to return to social eating.

Successful esophageal replacement with colon is dependent on two factors: preserving adequate blood supply to the colon segment used and inserting the graft in such a manner so as to maximize its ability to transport food. As regards the former, a left colonic segment based on the inferior mesenteric artery appears to be better than a right segment based on the midcolic artery. One of seven of our right colon grafts failed, compared with six of 85 of the left grafts. Although the numbers are too small to provide statistical significance, they are similar to that reported by Wilkins.[3] There are five techniques that are helpful in preserving optimal blood supply to a left graft based on the left colic artery. The first is to preserve both the ascending branch of the left colic artery and the distal marginal artery and vein when mobilizing the colon. This allows further blood supply to the graft from the sigmoid arteries and venous drainage via the hemorrhoidal and sigmoid veins. The second technique is to ligate the midcolic artery and vein below the division into their right and left branches. This provides an adequate arcade between the two branches to maintain the blood supply to the right half of a long graft. The third technique is to

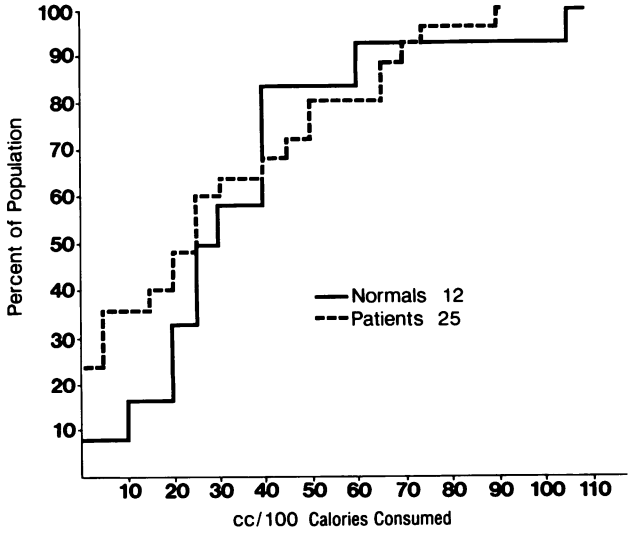
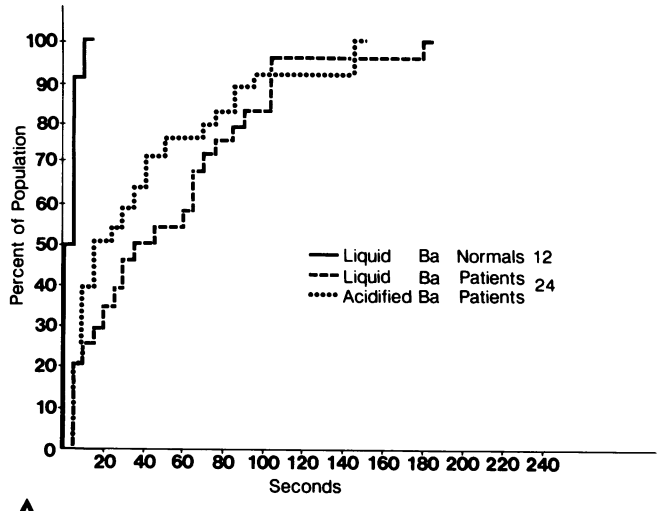
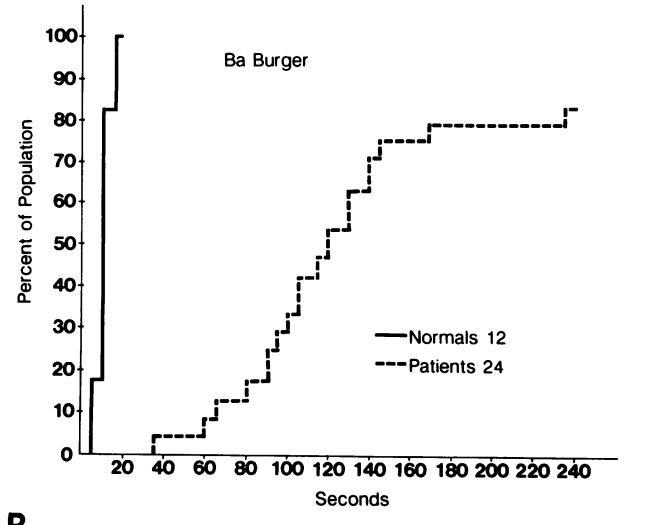


FIG. 18. The amount of water required by patients with a colon interposition for consuming the test meal compared with the amount required by controls. Volume is expressed as cubic centimeters required to ingest 100 calories. There was no difference between controls and patients.



A



B

FIGS. 19A and B. The transit time of (A) liquid barium, acidified liquid barium and (B) a solid barium bolus in patients with a colon interposition. Transit time of liquid barium and a solid barium bolus is compared with normal subjects.

transect the distal end of the graft without dividing the mesentery and its vessels. The fourth technique is that, when using the substernal route, the acute angle at the diaphragm should be changed to a smooth rounded curve to prevent kinking the vessels of the graft. The fifth technique is to delay the graft if there is any concern regarding its blood supply.

Five techniques are important in inserting the colon graft in a manner so as to maximize its transport function. The first technique is to perform the proximal anastomosis with a single layer of interrupted sutures to prevent narrowing. The second technique is to anchor the colon graft in as straight a line as possible to the diaphragm. This avoids redundancy and upper movement of the colon into the chest. The third technique is to construct the gastric anastomosis on the posterior wall of the stomach one third the distance from the fundus to the pylorus. This reduces regurgitation and the development of an ulcer in the graft.[7] The fourth technique is to avoid performing a pyloroplasty unless, based on postoperative gastric emptying studies, it is deemed necessary. This protects against bile reflux gastritis in the stomach and colitis in the graft.[8] The fifth technique is that, when using the substernal route, the left half of the manubrium and the sternal head of the left clavicle should be resected to avoid compression and obstruction of the graft.

When applying these technical aids, the chance of achieving a well-functioning colon graft are excellent, as attested to by the long-term clinical evaluation and function test. In addition, we found that the ingestion of acidified barium improved the graft's function and have encouraged our patients to take acid liquids, such as carbonated beverages, with their meals. Since we have shown that the transit of solids through the graft is slow, we advise our patients to take all medication in liquid or crushed form to avoid a drug-induced injury of the interposed colon.

As shown in Figure 1, we have not performed a colon bypass since 1986. There are two reasons for this. First, we are convinced that the patient with benign disease who requires an esophageal substitute fares better if his esophagus is removed. This obviates the threat of rupture of a totally excluded esophagus, the risk of developing cancer in an esophagus previously damaged by caustic chemicals or lined with Barrett's epithelium, and the potential for ulceration and bleeding from the continued reflux of bile or gastric juice. Secondly, we are impressed by the palliation achieved in unresectable cancer using an internal esophageal stent and are discouraged by the high operative mortality rate associated with a bypass done for palliation.

There is controversy over whether colon or stomach is the better substitute for the esophagus in benign disease. Those who prefer the stomach admit that an intrathoracic stomach does not function as well as a native esophagus; indeed, they point out that most patients experience discomfort during or shortly after eating.[9] The most common symptom is a postprandial pressure sensation and early satiety. This probably results from the loss of the gastric reservoir. These symptoms are less common when the colon is used as an esophageal substitute, probably because the remaining stomach is retained in the abdomen and the interposed colon provides an additional reservoir function.

Dysphagia is a more common complaint when the stomach is used to replace the esophagus. Orringer,[10] after using the stomach to replace the esophagus in 87 patients with benign disease, noted a 61% incidence of dysphagia after operation, and that two thirds of these patients required postoperative dilatation and one fourth had persistent dysphagia and required home dilatation. By con-

trast, dysphagia occurred in only 18% of our patients and was more a sensation of early filling than a difficulty with swallowing. Only 4% of our patients required dilatation, and this was relieved by revising the involved anastomosis in all four.

There is general acceptance of the concept that an esophagogastric anastomosis in the neck results in less postoperative esophagitis than that located at a lower level. According to Belsey,[5] the development of reflux esophagitis after a cervical anastomosis occurs at a slower rate than when the anastomosis is at a lower level. In our own experience with patients who have had a cervical esophagogastrostomy for benign disease, problems associated with the anastomosis occur around the fourth and fifth postoperative year, and some have required revision of the anastomosis. This late stenoses has occurred in only one patient who had a colon interposition for esophageal replacement and was due to drug-induced injury. In this regard, the interposed colon appears to protect the remaining esophagus from damage by gastric juice.

Duodenogastric reflux also occurs after the transposition of the stomach into the chest, as recognized by several authors.[11] From a mechanical view, it is not surprising that duodenogastric reflux is increased after transposition of the stomach into the chest. After such a maneuver, the pylorus lies at the level of the esophageal hiatus and a distinct pressure differential develops between the intragastric and duodenal lumen. The former reflects a negative intrathoracic pressure, whereas the latter indicates a positive intra-abdominal pressure. Unless the pyloric valve is extremely efficient, the pressure differential will encourage reflux of duodenal contents into the stomach. It has been our experience that this is less likely to occur after colonic interposition because there is sufficient intra-abdominal colon to be compressed by intra-abdominal pressure, and because the pylorus and duodenum remain in their normal position.

Our experience and studies have convinced us that the colon is a more durable esophageal substitute and provides a better quality of deglutition than the stomach. Consequently, it should be used in patients with benign or malignant esophageal disease who are potential candidates for long survival. The demanding technical expertise required and the additional operating time needed for performing a colon interposition is more than compensated by its durability and function.

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Discussion

DR. WILLIAM E. NEVILLE (Newark, New Jersey): I rise to congratulate Tom for presenting so elegantly his personal operative experiences concerning a topic that I have been interested in for many years. We have all learned something today. He has given us new ideas regarding various methods for replacing the esophagus with colon segments. Also, I am proud of him for what he has done at my old alma mater, Creighton University.

At our New Jersey Medical School in Newark, we recently analyzed the results of patients with benign esophageal disease in whom we have used all or part of the colon for replacing the esophagus. Admittedly, over the years, I have used this technique in patients with cancer, but I believe that the life expectancy for this group of patients is not long. The only way to truly evaluate the operation is to evaluate it for those individuals who have benign disease.

Over the years, I have transplanted the colon subcutaneously, substernally, and intrathoracically. (Slide) The man shown in this slide required an anterior subcutaneous colon implant. He had swallowed lye after a fight with his wife and destroyed his larynx and esophagus. Dr. Rush did a laryngectomy and we placed his colon subcutaneously so that he could swallow. It is now 9 years since the operation was performed, and he is doing very well. He simply facilitates his swallowing by pressing on the colon beneath the skin on the anterior chest wall which propels the food down into his stomach.

I operated on this baby with a congenital tracheo-esophageal fistula 35 years ago. Initially, I did a cervical esophagostomy, disconnected the lower end of the esophagus from the trachea, and placed the right colon beneath the sternum from the neck to the stomach. As you can see, 35 years later, he is in excellent condition.

Over the years, our nonfatal complications have exceeded those of Dr. DeMeester. Early in our series, we had two patients who experienced a breakdown of their esophago-colon anastomosis. We had been performing these intrathoracically. We re-operated on both of these patients and revised their leaks. We have observed seven esophago-colon anastomotic leaks in the neck, which are certainly easier to manage. The strictures that occurred were either dilated or the anastomosis was revised. From this experience, we would advise that, if possible, all anastomoses should be performed in the neck. Over the years, our signficant observations have been that any leaks are due mainly to venous congestion from impingement of the bulky cecum at the thoracic inlet. To prevent this, we remove a segment of the sternoclavicular junction or retain a segment of the ileum attached to the cecum. In the latter operation, the cecum lies in the anterior mediastinum, and the distal ileum is the anastomotic section of the neck.

I do not believe that it makes any difference whether the colon is