Surgical Treatment for Morbid Obesity: The Laparoscopic Roux-en-Y Gastric Bypass

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KEYWORDS

- Obesity
- Gastric bypass
- Roux-en-Y
- Laparoscopy

Obesity, defined as a body mass index (BMI) of 30 (ie, body weight of 30 kg divided by height in meters squared [30 kg/m²]) or greater, is the excess accumulation of body fat that adversely effects health and decreases life expectancy.¹² A body weight that exceeds the ideal body weight by more than 100 lb (45.4 kg) or a BMI greater than 35 has been termed morbid obesity. Historically obesity was widely perceived as a symbol of wealth and fertility, and still is in some parts of the world.² Viewed as one of the most serious public health problems of the twenty-first century, it is now the leading cause of preventable death in the United States, with increasing prevalence both in adults and children.³

During the past 20 years there has been a dramatic increase in obesity in the United States. In 2009, only Colorado and the District of Columbia had a prevalence of obesity less than 20%.⁴ Thirty-three states had a prevalence equal to or greater than 25%; 9 of these states (Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Missouri, Oklahoma, Tennessee, and West Virginia) had a prevalence of obesity equal to or greater than 30%.⁴ Medical weight reduction programs have not been able to yield substantial long-lasting success in comparison with surgical intervention.⁵

BRIEF HISTORY OF THE EVOLUTION OF THE LAPAROSCOPIC ROUX-EN-Y GASTRIC BYPASS PROCEDURE

The history of surgery for obesity dates back to the 1950s but because of the growing obesity epidemic, the most rapid advances have occurred in the last several decades.
A.J. Kremen is credited with the first bariatric operation in the United States, in 1954. He introduced the jejunoileal bypass procedure for weight loss. This procedure induced a state of malabsorption by bypassing most of the intestines while keeping the stomach intact, and was successful for weight loss. However, the morbidity of the procedure was high, having complications such as severe electrolyte imbalances, dehydration, bypass enteritis from bacterial overgrowth of the bypassed intestine, diarrhea, cirrhosis, interstitial nephritis, and various vitamin and mineral deficiencies. The mortality rate was high, and many patients have required reversal of the procedure. In the 1980s the jejunoileal bypass was abandoned and is no longer a recommended bariatric surgical procedure. Many experimental operations were tested on morbidly obese patients throughout the 1950s and 1960s. Surgery involving the stomach became the more prevalent choice for the surgical treatment of morbid obesity.

The development of the gastric bypass procedure for the treatment of morbid obesity has been credited to Dr Edward E. Mason. In 1966 Mason and Ito applied the concepts of partial gastrectomy to obese females for weight reduction, because of the observation that female patients undergoing partial gastrectomy for ulcer disease remained underweight and had difficulty gaining weight. Mason and Ito introduced the first case series of gastric restrictive procedures. The procedure, referred to as gastric bypass, involved horizontally transecting the stomach. The pouch was composed of cardia and fundus, and was completely divided from the distal part of the stomach. As with its predecessor, the Billroth II, their procedure incorporated a retrocolic “loop” with a hand-sewn gastrojejunostomy (Fig. 1).

The gastric outlet was measured and restricted to maximize weight loss. Mason and Ito modified the procedure and reported the specifics of the gastrojejunostomy as related to weight loss. Further refinements were made, such as calibrating the volume of the gastric pouch and changing the diameter of the gastrojejunostomy. The best

Fig. 1. Mason gastric bypass with loop gastrojejunostomy, 1966.
results were demonstrated with a calibrated 50-mL gastric pouch and a 12-mm stoma. After receiving criticism from surgeons worldwide because of an increased risk of the development of a marginal ulcer as a consequence of the gastric restriction and anastomosis, Mason and colleagues published a study reporting that the upper part of the stomach produces relatively little acid and that marginal ulceration would be unlikely. Later, in 1977, Alden introduced a modification of the gastric bypass that did not involve complete transection of the stomach and separation of the gastric pouch from the distal stomach. Instead, surgical staplers were used to create a partition across the upper portion of the stomach to reduce the intake of food and create the feeling of satiety, with a small amount of food. Surgeons continued to modify the initial attempts of Mason and Ito in gastric restrictive procedures, which ultimately contributed to the evolution of the current laparoscopic Roux-en-Y (RNY) gastric bypass procedure.

In 1977, Griffen and colleagues modified the early gastric bypass procedure by replacing the loop with the RNY gastrojejunostomy, which reduced bile reflux and became the accepted technique for the anastomosis (Fig. 2). Several years later the jejunoileal bypass was dismissed as an acceptable procedure for weight loss, due to the increased evidence of serious complications including cirrhosis, interstitial nephritis, and renal and liver failure. Fewer surgeons attempted to develop more technically challenging gastric bypass procedures, evidenced by the increased use of stapled gastroplasty techniques. The 1980s presented an opportunity for bariatric surgery as more centers became committed to improving the gastric bypass procedure. Improvements introduced by Torres and colleagues included the use of a vertical gastric pouch along the lesser curvature, which served as a prototype for

Fig. 2. Griffen Roux-en-Y gastric bypass, 1977.
the lesser curve vertical pouches currently used in today’s gastric bypass (Fig. 3). The
distal RNY was also introduced, describing various lengths of efferent and common
limbs.13 Other variations introduced by Fobi and colleagues16 in 1998 and Capella
and Capella17 in 1996 included the use of a silastic ring at the gastric pouch to prevent
dilatation of the gastric stoma. Although the concept behind the ring was intuitive,
many surgeons did not accept the use of these devices because of the added risk
of erosion.13

In 1991, the National Institutes of Health (NIH) Consensus determined that the RNY
and the vertical banded gastroplasty provided a significant benefit to patients with
morbid obesity, and were indicated for patients with a BMI greater than 35 and
obesity-related comorbidities or for all patients with a BMI greater than 40.13 However,
long-term evaluation of patients who had undergone vertical banded gastroplasty has
shown that frequent postoperative changes in dietary habits, including ingestion of
high-calorie soft foods and liquids, leads to weight regain.18 These long-term results
have largely caused this operation to be abandoned. Nowadays the RNY has emerged
and become the gold standard of surgical treatment for clinically severe or morbid
obesity because of sustained long-term weight loss, with acceptable short-term
and long-term complication rates.

Laparoscopy has had a tremendous impact on surgery by reducing perioperative
complications. Morbidly obese patients can be high-risk surgical candidates who
are more vulnerable to cardiopulmonary and wound-related complications, and stand
to benefit from a less invasive approach.19–22 Although the open RNY procedure has
been performed with a relatively low morbidity and mortality rate, the wound-related

Fig. 3. Torres Roux-en-Y gastric bypass with lesser curvature pouch, 1980.
complications have been challenging. The laparoscopic Roux-en-Y gastric bypass (LRNY) has reduced the number of wound complications seen in open bariatric surgical procedures.\textsuperscript{23} The development of laparoscopic surgical staplers changed bariatric surgery in the 1990s. The first case series to perform an LRNY was published in 1994 by Wittgrove and Clark.\textsuperscript{24}

**CURRENT TECHNIQUES OF THE LAPAROSCOPIC ROUX-EN-Y GASTRIC BYPASS**

Despite the technically demanding nature of the LRNY procedure, it has swiftly gained popularity over the open technique since its inception in 1994 and has become the procedure of choice for clinically severe obesity. The totally LRNY procedure requires the operating surgeon to have an advanced laparoscopic skill set. The long learning curve and inexperience with advanced laparoscopic techniques can be a major hitch to this procedure. An alternative to the totally laparoscopic approach is the hand-assisted LRNY. Hand-assisted laparoscopy typically has been used in colorectal surgery and less frequently in bariatric procedures. Several published studies containing small series of patients in which hand-assisted techniques are used in laparoscopic gastric banding\textsuperscript{23} and laparoscopic vertical banded gastroplasty show the benefits of hand-assisted laparoscopy in bariatrics.\textsuperscript{25,26}

An article in 2000 by Sundbom and Gustavsson\textsuperscript{27} highlighted the advantages of the hand-assisted technique over the total LRNY approach, as follows: (1) the avoidance of the blind abdominal puncture (Veress or trocar-assisted optical view entry, as the surgeon’s left hand inside the abdomen can guide the introduction of the first trocar); (2) the ability of the surgeon’s hand to directly palpate intra-abdominal structures, allowing for better anatomic orientation; (3) the surgeon’s hand being used for dissection of tissue as an alternative to conventional laparoscopic instruments such as hook cautery, dissecting instruments, and ultrasonic dissectors; (4) the surgeon’s hand being used for proper exposure of the surgical field without the use of mechanical retractors. In 2003, a follow-up randomized clinical trial of hand-assisted laparoscopic versus open RNY for the treatment of morbid obesity found that patients did not appear to derive any significant benefit from a hand-assisted LRNY technique in comparison with open surgery,\textsuperscript{28} as the results did not demonstrate the proposed advantages of laparoscopy over open surgery of early mobilization, reduction in postoperative pain, and shorter hospital stay.\textsuperscript{28} Although the bariatric surgeon who is trying to learn LRNY techniques may benefit early on from a hand-assisted approach, nonrandomized comparative studies have recently shown that hand assistance was more expensive than open surgery and did not improve patient outcome.\textsuperscript{29}

When compared with the open technique the LRNY has been validated in multiple studies over the span of a decade, being shown to have comparable weight loss, safety, cost effectiveness, and decreased morbidity.\textsuperscript{23,30,31} The LRNY has been shown to decrease wound complications, decrease operative blood loss, shorten hospital stay, improve postsurgical quality of life, and decrease the incidence of postoperative pulmonary complications.\textsuperscript{32–34} However, there is no consensus on one uniform way that the LRNY is performed. There are variations on whether the Roux limb is passed in an antecolic antegastric, antecolic retrogastric, or retrocolic retrogastric fashion to form the gastrojejunostomy. Multiple techniques of creating the gastrojejunostomy have been described. Described by Wittgrove and colleagues in 1994,\textsuperscript{24} the transoral circular-stapled technique is the most commonly used method for creating the gastrojejunostomy. Other techniques used by surgeons to create the gastrojejunostomy include the linear-stapled technique, the hand-sewn technique, and the transgastric circular-stapled technique.
After appropriate patient selection, the patient is brought to the operating room and placed supine on the operating room table. A time-out is taken to verify the patient’s identity, procedure, and procedure location. Appropriate preoperative antibiotics are given, deep venous thrombosis (DVT) prophylaxis is given, and sequential compression devices are placed to incision. A Foley catheter is optionally placed. The abdomen is prepped and draped in the usual sterile fashion. At this point in the procedure, many different variations are seen based on surgeon preference and training. Examples of this include how the abdominal cavity is accessed, size of ports, location of ports, and location of the operating surgeon and assistants based on use of split-leg extenders (Skytron, Grand Rapids, MI, USA). The manner in which the authors perform this procedure at their institution is detailed here.

A 1:1 mixture of 0.25% marcaine and 1% lidocaine with epinephrine is used to pre-infiltrate all incision sites. The first incision is made at the left anterior axillary line just subcostally. A 5-mm Optiview port (Ethicon Endosurgery, Cincinnati, OH) with a 0° laparoscope inserted is used to enter the abdomen under direct vision. The abdomen is insufflated with carbon dioxide gas to a pressure of 12–18 mm Hg. Once adequate insufflation has been obtained, a 5-mm 45° angled scope is inserted into the abdomen. Exploratory laparoscopy is then performed. The visualized portions of the stomach, spleen, colon, small intestine, liver, and gallbladder are all assessed. At this point, a 5-mm port is placed above and to the left of the umbilicus. Additional 5-mm and 15-mm ports are placed in the right upper quadrant (Fig. 4). Using abdominal graspers, the omentum is retracted cephalad and the ligament of Treitz is identified. The small bowel is measured 50 cm distal to the ligament of Treitz and the small bowel is transected with a laparoscopic linear stapler (Echelon 60 mm length, 2.5 mm thickness; Ethicon Endosurgery). Then 100 cm of small bowel is measured distal to

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**Fig. 4.** Port site placement for the LRNY.
this and a side-to-side functional end-to-side jejunojejunostomy is created. Using an ultrasonic dissector, an enterotomy is made in the Roux limb as well as in the distal portion of the biliopancreatic limb. The linear stapler is used again to create the enteroenterostomy by placing each end of the stapler in the corresponding enterotomies. Once the stapler is fired, the common opening is closed using a running 2-0 Surgidac suture with an endoscopic suturing device (EndoStitch, 10 mm; Covidien, Mansfield, MA). A triple-staple technique may also be used to create this anastomosis. To perform this technique, enterotomies are made as previously described using the ultrasonic dissector. A linear stapler is used to create a long enterenterostomy. The common enterotomy is then closed transversely with the linear stapler. The mesenteric defect between the anastomosis is closed using a running 2-0 Surgidac suture with an endoscopic suturing device (EndoStitch, 10 mm). The omentum is split just to the left of midline to allow for a tension-free path of the Roux limb up to the pouch to create an antecolic, antegastric gastrojejunostomy.

The Nathanson liver retractor (Cook Medical, Bloomington, IN) is inserted through a subxiphoid stab wound to retract the left lateral lobe of the liver (see Fig. 4). The gastrohepatic ligament is opened in an avascular plane. A linear stapler with bovine pericardial reinforcement strips (Peri-strips; Synovis Surgical Innovations, St. Paul, MN) is fired into the lesser curve of the stomach 5 cm distal to the gastroesophageal junction. Prior to this point all tubes are removed from the stomach. A linear stapler (Echelon 60 mm length, 3.8 mm thickness) is fired perpendicularly into the lesser curve of the stomach at this same point. The transection is completed up to the angle of His using an articulating linear stapler with bovine pericardial reinforcement strips (Peri-strips). A gastrotomy is created into the distal end of the pouch through the unreinforced staple line. The OrVil (EEA OrVil 21 mm Device; Covidien) tube is pulled out through this gastrotomy and the 15-mm port site. Once the stem of the anvil is visualized, the strings holding the tube are cut and the tube is removed, leaving the anvil in place. A Lembert suture is placed on either side of the anvil stem to purse-string the stomach.

Next, the Roux limb is identified. It is brought up to the upper abdomen. Care is taken to make sure that the mesentery is not twisted. An enterotomy is made in the proximal Roux limb. The EEA stapler is introduced through the 15-mm port site. It is deeply intubated into the Roux limb and brought up to the pouch. The anvil and the stapler are married and fired. The stapler is removed and inspected for two complete donuts of tissue. The anastomosis is visualized through the opening in the Roux limb, and active sites of bleeding are assessed. The proximal portion of the Roux limb is excised using a linear stapler. The mesentery is divided with the ultrasonic dissector. Lembert sutures are used to reinforce the corners of the gastrojejunostomy. A bowel clamp is placed proximally on the Roux limb, and an intraoperative gastroscopy is performed to visualize portions of the esophagus, pouch, anastomosis, and Roux limb for evidence of bleeding. The upper abdomen is filled with water to submerge the gastric pouch and anastomosis simultaneously for an air leak test. The air and the gastroscope are withdrawn once the anastomosis has been adequately assessed. The irrigation fluid is suctioned from the abdomen, and a Jackson Pratt drain is placed in the left upper quadrant. The drain is pulled out through the 5-mm left upper quadrant port site and secured to the skin using a 3-0 nylon suture. The Roux remnant is placed in a laparoscopic specimen retrieval bag (Endopouch, 10 mm; Ethicon Endosurgery) and pulled out through the 15-mm port site. The Nathanson liver retractor and upper abdominal ports are removed under direct vision. Bleeding from the port sites is assessed. The abdomen is desufflated. A 0-Vicryl suture is used to close the 15-mm port site fascial defect. The skin incisions are closed with 4-0 Monocryl suture and the skin covered with Dermabond.
Laparoscopic Roux-en-Y Linear-Stapled Technique

The LRNY linear-stapled technique is performed in a similar fashion to the previously described transoral stapled technique, with the exception of the creation of the gastrojejunostomy. The jejunojejunostomy and gastric pouch are created in a similar fashion. In this technique a 2-layer anastomosis is then created between the pouch and the Roux limb. The outer layer is a running 2-0 Surgidac suture using the endoscopic suturing device. The inner layer is a partial firing of a linear stapler (Echelon 60 mm length, 3.5 mm thickness). The gastroscope is passed through the common enterotomy. The common enterotomy is closed over the top of the gastroscope using a running 2-0 Polysorb suture. A second layering of 2-0 Surgidac is then performed over the anastomosis in a Lembert fashion. Once both layers are complete, a bowel clamp is placed proximally on the Roux limb and an intraoperative gastroscopy is performed. The esophagus, pouch, and proximal Roux limb are visualized. An underwater air leak test is performed at this point. The air and the gastroscope are withdrawn. The irrigation fluid is suctioned from the abdomen. The anastomosis is circumferentially wrapped with omentum, and held in place using 2-0 Surgidac suture.

ANALYZING THE CURRENT TECHNIQUES OF THE LAPAROSCOPIC ROUX-EN-Y GASTRIC BYPASS

It is widely apparent that the art or technique of creation of the gastrojejunostomy is one of the most challenging steps during the LRNY. As a result, multiple different techniques for creating the gastrojejunostomy have been used by bariatric surgeons to facilitate this step, as previously discussed. Countless studies and series have reported that the main complications using a circular stapler for the gastrojejunostomy are anastomotic leaks and strictures.\(^35\) Historical data for the open RNY for morbid obesity indicate that the hand-sewn technique has lower stricture and leak rates in comparison with the circular-stapled technique.\(^36\) The LRNY data mimic the historical data with the open RNY with regard to the techniques in creating the gastrojejunostomy and the stomal stenosis rates (Table 1). Leak rates have been reported from 0% to 3% in multiple large LRNY series using the various techniques for creating the gastrojejunostomy. A 0% leak rate after 1000 LRNY procedures using either

| Table 1: Comparison of published data for the incidence of gastrojejunostomy stenosis |
|---------------------------------------------|-----------------|-----------------|-----------------|
| Authors, Year                              | No. of Patients | Technique       | Stenosis Number (Percentage) |
| Wittgrove et al\(^{31}\) 2000               | 500             | CS              | 8 (1.6%)          |
| Matthews et al\(^{37}\) 2000                | 48              | CS              | 13 (27.1%)        |
| Champion et al\(^{38}\) 1999               | 63              | LS              | 4 (6.3%)          |
| Schauer et al\(^{23}\) 2000                 | 275             | LS              | 13 (4.7%)         |
| Higa et al\(^{39}\) 2001                    | 1500            | HS              | 73 (4.9%)         |
| Wittgrove et al\(^{40}\) 2002               | 1000            | CS              | 40 (4.0%)         |
| DeMaria et al\(^{41}\) 2002                 | 281             | LS              | 18 (6.6%)         |
| Gonzalez et al\(^{42}\) 2003                | 108 (87/13/8)   | HS/CS/LS        | 3 (3%)/4 (31%)/0 (0%) |
| Carrodeguas et al\(^{43}\) 2006             | 1291            | LS              | 94 (7.3%)         |
| Leyba et al\(^{44}\) 2008                    | 80 (40/40)      | CS/LS           | 7 (17.5%)/1 (2.5%) |
| Kravetz et al\(^{45}\) 2011                 | 222 (123/99)    | HS/LS           | 5 (4.1%)/10 (10.1%) |

Abbreviations: CS, circular stapled; HS, hand sewn; LS, linear stapled.
hand-sewn or circular-stapled techniques for the gastrojejunostomy has been reported.39,46

As we approach a second decade in the era of LRNY, the circular-stapled anastomosis technique originally described by Wittgrove and Clark24 is still the most commonly used technique for creation of the gastrojejunostomy. As modern technology continues to evolve so does the surgical technology, affording better devices to assist in difficult problems faced with older devices. The original and early use of the circular stapler by surgeons was with a 21-mm circular stapler to create the gastrojejunostomy. Since then the 25-mm circular stapler has been developed. Some surgeons have adopted use of the 25-mm stapler secondary to decreased rates of stomal stenosis at the gastrojejunostomy. Despite skepticism from some surgeons to change their approach from the 21-mm to the 25-mm circular stapler in creating the gastrojejunostomy, published data would suggest that the use of 25-mm circular stapler shows a decrease in stomal stenosis rates when compared with those of the 21-mm circular stapler, with no effect on long-term weight loss (Table 2). Higher potential for esophageal injury23,32 contributes to the skepticism in passing a larger-diameter transoral anvil, but this has not been demonstrated. Some reports have shown this potential in passing a 21-mm anvil transorally. However, Wittgrove and Clark published a series of more than 1400 patients using the pull-wire technique of passing a 21-mm anvil for a circular-stapled anastomosis. This technique was evaluated with intraoperative upper endoscopy and water-soluble upper gastrointestinal series (UGI) on postoperative day 1, with no demonstration of esophageal injuries.53

A transgastric technique of anvil placement to avoid the transoral route has been described, and has been reported to decrease the incidence of wound infections and operative times.54,55 Although the circular-stapled technique remains the popular choice among surgeons for creating the gastrojejunostomy, complications specifically reported for the circular-stapled technique include stapler malfunction and increased wound infection rate at the extended abdominal port site where the contaminated stapler is withdrawn from the abdomen.23

TABLE 2
Comparison of published data for the incidence of gastrojejunostomy stenosis with 21-mm and 25-mm circular stapler

<table>
<thead>
<tr>
<th>Authors, Year</th>
<th>No. of Patients</th>
<th>Circular Stapler Size (mm)</th>
<th>Stenosis Number (Percentage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nguyen et al,47 2003</td>
<td>185 (114/71)</td>
<td>25/21</td>
<td>10 (8.8%)/19 (26.8%)</td>
</tr>
<tr>
<td>Gould et al,48 2006</td>
<td>226 (81/145)</td>
<td>25/21</td>
<td>5 (6.2%)/23 (15.9%)</td>
</tr>
<tr>
<td>Fisher et al,49 2007</td>
<td>200 (100/100)</td>
<td>25/21</td>
<td>7 (7%)/17 (17%)</td>
</tr>
<tr>
<td>Suggs et al,50 2007</td>
<td>438 (374/64)</td>
<td>25/21</td>
<td>11 (2.9%)/6 (9.4%)</td>
</tr>
<tr>
<td>Alasfar et al,51 2009</td>
<td>126</td>
<td>21</td>
<td>29 (23%)</td>
</tr>
<tr>
<td>Dolce et al,52 2009</td>
<td>159</td>
<td>21</td>
<td>15 (9.4%)</td>
</tr>
</tbody>
</table>
of LRNY in 1993, it has now become the preferred method and procedure of choice for morbid obesity over its open counterpart. This adoption is mostly attributable to the decreased complication profile with respect to wound infection and incisional hernia rates. Other published data demonstrated further advantages of the laparoscopic approach with regard to less postoperative pain, decreased operative blood loss, shorter in patient hospital stay, lower pulmonary complications, and an overall better quality of life.\textsuperscript{32–34} All surgical procedures include a list of potential complications, and the LRNY procedure is no exception.

**Intestinal Leaks**

Intestinal leaks can be fatal, and are likely related to the learning curve associated with advanced surgical techniques required to perform the procedure. Wittgrove and Clark reported 11 leaks in their first 500 patients; 9 (3.0\%) leaks occurred in the first 300 cases, with only 2 (1.0\%) leaks in the final 200 cases.\textsuperscript{56} Leaks can occur at the gastrojejunostomy, jejunojejunostomy, the bypassed stomach staple line, or the gastric pouch staple line. Leak rates as high as 6.9\% have been reported.\textsuperscript{42} Abdominal pain and peritonitis are not readily found in this group of patients. Clinical findings are nonspecific and can also represent an acute myocardial infarction or pulmonary embolus. It is imperative that if a high index of suspicion exists of an intestinal leak then the appropriate tests be expeditiously performed to guide to the appropriate therapy. Failure to act quickly could result in the rapid demise of the patient. Diagnosing intestinal leaks are usually made clinically, by UGI or computed tomography (CT). Greater than 50\% of leaks can be missed by the UGI but CT is more reliable.\textsuperscript{56} Subjective symptoms of a leak include the patient’s feeling of “impending doom,” left shoulder pain, back pain, pelvic pressure or pain, tenesmus, or worsening abdominal pain. Objective signs are often late and include tachycardia, fever, tachypnea, oliguria, fluid sequestration, hypotension, hypoxia, or shock. Treatment often depends on the clinical situation present. If the leak is well contained and the patient is hemodynamically stable, the patient can be treated conservatively with nothing by mouth, percutaneous drainage, intravenous antibiotics, and intravenous nutrition. If the leak is not well contained and the patient is hemodynamically stable, laparoscopic exploration is warranted. If the patient is hemodynamically compromised, open exploration should be performed. During exploration, whether open or laparoscopic, there are 3 principles that must be addressed at the time of exploration: repair of the leak, drain placement, and placement of a gastrostomy tube in the bypassed stomach.

**Pulmonary Embolism**

Multiple series of LRNY procedures have shown that the rates of pulmonary embolism (PE) are less than 1\%.\textsuperscript{57} Despite the low incidence of PE, all precautions should be undertaken for the prevention of a fatal PE. Obesity itself is a risk factor for the development of DVT and PE. The combination of increased intra-abdominal pressure and a baseline hypercoagulable state places the patient at high risk of DVT and PE. Prevention of DVT includes the use of preoperative heparin or low molecular weight heparin, as well as intraoperative sequential compression devices.

**Death**

The risk of death associated with the LRNY is reported in most series to be less than 1\%. Historical data reported from the open RNY experience shows that the two most significant postoperative events that cause mortality are intestinal leak and PE. For this reason a high index of suspicion must be maintained to prevent this from occurring.
**Cholelithiasis**

Rapid weight loss is associated with the formation of gallstones as a result of the increased concentration of cholesterol in the bile. The concentrated bile leads to the formation of sludge with cholesterol crystals that serve as the nidus for gallstone formation. The best treatment is prevention. Sugerman and colleagues\textsuperscript{58} showed that 32% of patients form gallstones after the open RNY. The risk of gallstone formation can be reduced with the addition of prophylactic ursodiol for the first 6 months postoperatively, thus reducing the risk to just 2%.\textsuperscript{58}

**Stomal Stenosis**

Much debate has taken place regarding the complication of stomal stenosis and its causes. Stomal stenosis, or stricture, is usually at the constructed gastrojejunostomy and not the jejunojejunostomy. As previously discussed, there are multiple techniques used by surgeons to create the gastrojejunostomy, which include a hand-sewn technique, linear-stapled technique, and circular-stapled technique. Gonzalez and colleagues\textsuperscript{42} published an analysis of the 3 techniques and showed that the hand-sewn technique resulted in a lower postoperative stricture rate. There are subtle differences within the same technique that can also contribute to increased incidence of stomal stenosis, such as the size of circular stapler used (21 mm or 25 mm). Stricture at the gastrojejunostomy site has been reported to occur at as high a rate as 6.6%. The reason for which stomal stenosis occurs is not well understood. Symptoms include dysphagia, nausea/vomiting, or odynophagia. Diagnosis and treatment are usually well tolerated by patients, and consists of upper endoscopy with balloon dilatation. Endoscopic balloon dilatation is usually successful after the first attempt, although multiple dilatations may be necessary to relieve the symptoms associated with stomal stenosis or stricture.

**Internal Hernia**

Internal hernia is another potential complication after the LRNY procedure, and is reported in less than 2% of cases.\textsuperscript{41} The RNY has 3 potential sites of small intestine herniation: at the jejunojejunalostomy, at the area between the Roux limb mesentery and the transverse colon mesentery (Petersen defect), and at the transverse colon mesentery. The mesocolic defect is created only if the Roux limb is brought retrocolic. This diagnosis can be very difficult to make. The symptoms associated with an internal hernia are vague and most commonly include periumbilical or left-sided crampy abdominal pain. Multiple episodes may occur with only transient symptoms. Patients may also present with a small-bowel obstruction. The diagnostic tests of choice include a UGI series or a CT of the abdomen with oral and intravenous contrast. Unfortunately, both of these tests will likely be normal if performed after symptoms have subsided. Treatment is laparoscopic reduction and closure of the hernia defect. Rarely is open exploration needed unless there is necrotic bowel or loss of domain due to dilated small-bowel loops.

**Marginal Ulcers**

Marginal ulcers can occur early or late, and are located on the jejunal side of the gastrojejunostomy anastomosis. The rate of ulceration is less than 2%.\textsuperscript{41} Diagnosis is based on strong clinical suspicion and an upper endoscopy. Treatment is antacid therapy using proton-pump inhibitors. *Helicobacter pylori* infection should also be identified and treated. Use of tobacco and nonsteroidal anti-inflammatory drugs also contributes to ulcer formation, and should be discontinued. If treatment should
fail, a UGI should be performed to rule out a gastrogastric fistula with regurgitation of acid from the excluded stomach. If a gastrogastric fistula is discovered, surgical ablation of the gastrogastric fistula may be required.

**Bypassed Stomach Dilatation**

Acute dilatation of the bypassed stomach can occur as a result of obstruction at the jejunojejunostomy, or may occur spontaneously. Interruption of the nerves of Laterjet resulting in a loss of vagal innervation can also result in dilatation. This complication can still be seen in patients despite the preservation of these nerves. Diagnosis can be made either clinically or radiographically. Signs and symptoms include hiccups, bloating, tympani, tachycardia, and cardiopulmonary compromise. A plain abdominal radiograph may show a large gastric bubble or air-fluid level. If the stomach is fluid-filled without air, the radiograph may not be helpful. Treatment involves needle decompression of the excluded stomach under fluoroscopy. If the problem recurs, percutaneous placement of a gastrostomy tube may be necessary. If these fail or the patient becomes hemodynamically unstable, placement of a gastrostomy tube in the operating room will be necessary.

**Wound Complications**

One of the advantages of the laparoscopic approach is the significant decrease in wound complications, including hernias and surgical site infections, in comparison with the open RNY. The rate of trocar site hernia is less than 1%, and wound infection rates are less than 8%. Diagnosis is made in most instances by physical examination. If the problem arises before any significant weight loss, a CT scan of the abdomen will be required, as the patient’s body habitus may obscure the diagnosis. Treatment of simple wound infections or cellulitis includes antibiotic therapy, and incision and drainage of any fluid collections. Asymptomatic hernias may be postponed until the patient’s weight has stabilized to increase the success of the repair. Obviously if the hernia is incarcerated, strangulated, or symptomatic, immediate repair is necessary.

**Inadequate Weight Loss**

Inadequate weight loss may be a problem after gastric bypass surgery. Wittgrove and Clark reported that 15% of their patients failed to lose more than 50% of their excess weight after the LRNY. These data correlate well with what is known from the open literature. The solution to this problem is not easy and potentially adds more risk for the patient. Two mechanical causes of inadequate weight loss are gastrogastric fistula and dilated stoma. Diagnosis of these can be made with a UGI series or esophagogastroduodenoscopy. Another cause of inadequate weight loss is noncompliance with dietary recommendations. Patients can “eat through” an RNY if they have a daily intake composed of high fat and carbohydrate foods or drinks. Treatment for a gastrogastric fistula is surgical. In most cases the reexploration can be performed laparoscopically because of the minimal adhesions left from the initial LRNY. Surgical treatment for a dilated stoma has been met with a high failure rate and a higher risk of leak for the patient. The noncompliant patient with inadequate weight loss should be treated with dietetic interventions to help the patient attain more weight loss. The added risk of a second procedure for these patients is not justified if the patient’s compliance is the issue. For those compliant patients who are dissatisfied with their weight loss, conversion to a malabsorptive procedure should only be done if serious comorbidities remain, as the risk of malnutrition is high.
**Dumping Syndrome**

Gastric dumping is seen in 70% to 76% of RNY patients. These patients report symptoms of abdominal pain and cramping, nausea, diarrhea, lightheadedness, flushing, tachycardia, and syncope. These side effects are seen as a beneficial side effect of surgical alteration of the gastrointestinal physiology by some patients, by contributing to decreasing the consumption of energy-dense foods and beverages and ultimately encouraging weight loss. Recently, the etiology of dumping syndrome has been elucidated. It was once thought to be caused by the hyperosmolarity of intestinal contents accompanied by increased fluid in the intestinal lumen resulting in intestinal distention, decreased intravascular volume, and hypotension. Recent data suggest that the release of gut peptides, as a result of food bypassing the stomach and entering the small intestines, is responsible for dumping symptoms due to the fact that the symptoms can be countered with a somatostatin analogue. Dumping symptoms decrease with severity and frequency with time, and most symptoms are well controlled by dietary and nutritional changes. Dietary modifications found to improve symptoms include eating small frequent meals and avoiding ingestion of foods with concentrated simple sugars, while increasing intake of foods containing complex carbohydrates high in fiber and protein. Fifty milligrams of octreotide 30 minutes before meals may also decrease symptoms if dietary changes are ineffective. Reactive hypoglycemia may cause late dumping, and can be managed with nutritional guidance and alterations or by simply eating small snacks.

**Hyperinsulinemic Hypoglycemia**

The phenomenon of severe hyperinsulinemic hypoglycemia after RNY is extremely rare. Also termed nesidioblastosis, this condition is characterized by inappropriately elevated insulin concentrations and neuroglycopenia. Service and colleagues described nesidioblastosis, a pathologic hyperplasia of pancreatic β cells, as a non-insulinoma pancreatogenous hypoglycemia, which is far less common than insulinoma as a cause of hyperinsulinemic hypoglycemia. This rare condition of postprandial neuroglycopenic, hyperinsulinemic, hypoglycemia, and pancreatic nesidioblastosis has been described only in small series of patients.

The mechanisms underlying this disorder are unclear. One theory is that an intestinal hormone glucagon-like peptide 1 (GLP-1) mediates expansion of pancreatic β cells. Others would argue that postprandial hypoglycemia after malabsorptive bariatric surgery is attributable to a combination of gastric dumping and inappropriately increased insulin secretion, either as a failure to adaptively decrease insulin secretion after malabsorptive bariatric surgery or as an acquired phenomenon.

Several different treatment strategies are available, ranging from conservative medical therapies and diet modification to those of radical surgical treatments. If debilitating nesidioblastosis occurs, it will likely require another major operation. The result of that second operation could be permanent insulin-dependent diabetes if the entire pancreas is removed or failure to control the attacks of hypoglycemia if some pancreas is left in place. Recommendations for pancreatic resection for nesidioblastosis require approximately 80% to 90% of pancreatic tissue to be removed. As previously stated, pancreatic resection comes with its own host of problems. Despite the reported morbidity of 20% to 40% and mortality of 1% to 5%, and the risk of developing lifelong diabetes mellitus after pancreatic resection for nesidioblastosis, it can be life saving. Z’graggen and colleagues concluded in a small study of 12 patients that the majority of patients with severe postprandial hypoglycemia after gastric bypass, who are unresponsive to diet modifications, can be controlled by...
simple laparoscopic restoration of gastric restriction with surgical placement of a silastic ring as a first-line surgical treatment before consideration for pancreatic resection.

NUTRITIONAL COMPLICATIONS OF THE ROUX-EN-Y GASTRIC BYPASS

Although routinely performed, the LRNY necessitates the knowledge of potential long-term nutritional metabolic complications and their treatments. The RNY combines the two mechanisms of restriction and malabsorption which, in turn, promote effective long-term weight loss and improvement of obesity-associated medical conditions. This intervention is fraught with alterations of digestive physiology, leading to nutritional and metabolic complications.

Routine laboratory studies looking for vitamin and mineral deficiencies in the post-operative gastric bypass patient should be performed and monitored on a regular basis. The deficits most frequently observed after the RNY are deficiencies concerning proteins, iron, calcium, vitamin B12, and vitamin D. Iron deficiency is common after RNY and presents primarily as microcytic anemia. Various studies have shown an incidence ranging from 20% to 49% of patients. The reduced intake and common intolerance of iron-rich foods such as red meat may contribute to the deficiency. Coupled with the alterations seen in the changes of digestive physiology of the bypassed stomach contributing to the malabsorption of dietary iron, this makes the etiology of iron deficiency in these patients multifactorial. Oral iron supplementation given as ferrous sulfate, 300 mg 3 times daily, is usually adequate treatment when anemia is identified. Iron supplements are sometimes poorly tolerated because of constipation and dyspepsia, which may fail to correct the underlying anemia. In rare instances patients may require intravenous iron infusions for correction.

While these patients require lifelong multivitamin supplementation, iron supplementation is also recommended for all RNY patients. Commercially available daily standard multivitamins with iron are not adequate for this population of patients secondary to the small amount of elemental iron contained within. Two randomized double-blind studies have demonstrated that supplementing with 320 mg of ferrous sulfate twice daily prevented iron deficiency anemia.

Playing a vital role in neurologic function and DNA synthesis, vitamin B12 absorption begins in the stomach where pepsin and hydrochloric acid cleave it from dietary intake. Normal vitamin metabolism is altered secondary to the surgical alterations of the gastrointestinal anatomy in the RNY. In the duodenum vitamin B12 normally binds to intrinsic factor released from the stomach, and is absorbed in the terminal ileum. Vitamin B12 deficiency occurs in 26% to 70% of gastric bypass patients. Even though clinically symptomatic B12 deficiency is rare, the ability to maintain adequate serum levels without supplementation is difficult. While multiple forms of supplementation are available including sublingual and nasal sprays, some clinicians recommend intramuscular injections. However, several studies have shown that a 300- to 500-μg dose of oral vitamin B12 supplementation may be sufficient if tolerated.

Folic acid deficiency rarely causes anemia following the RNY. Essential for reactions of carbon transfer and playing an important role in DNA synthesis, folic acid must not be ignored as a potential cause of anemia in the RNY patient. The study of 1067 patients by Mallory and Macgregor demonstrated that only 1% of RNY patients developed folate deficiency. Folic acid deficiency has been reported to affect as many as 9% to 18% of RNY patients at different points in follow-up. Although folate can be absorbed throughout the entire length of the small intestine, folate absorption occurs primarily in the upper one-third of the small intestine.
The principal cause of folate deficiency appears to be a decreased consumption from dietary sources, which are easily corrected with vitamin supplementation. Most daily multivitamin tablets contain between 400 and 500 μg of folate. Folate deficiency should be avoided with a daily multivitamin, although additional folate supplementation (1 mg/d) should correct deficiencies and is essential for women who become pregnant after RNY, preventing neural tube defects in infants.

Fat-soluble vitamin deficiencies may also occur after RNY, but more commonly occur after the biliopancreatic diversion procedure secondary to the delayed interaction of dietary fats with bile salts and pancreatic enzymes from the duodenum. Vitamin D and calcium deficiencies are less likely because they are absorbed preferentially in the jejunum and ileum. Complications related to this deficiency are clinically seen as osteomalacia, and have been reported in several studies after RNY procedures. Moderate to severe vitamin D deficiency can cause significant muscle aches and fatigue, and is common in the overall population. Daily supplementation of 400 IU of vitamin D and 1500 mg of elemental calcium is adequate for replacement. Vitamin A deficiency has also been seen after RNY procedures, clinically recognized as night blindness. Halverson reported vitamin A deficiency in as many as 10% of gastric bypass patients. Oral supplemental therapy is occasionally needed for correction.

Thiamine or vitamin B1 is found in a wide variety of foods at low concentrations, and was the first of the water-soluble vitamins to be described. It is not often evaluated; nevertheless, deficiency in this vitamin can occur after malabsorptive procedures such as the RNY as a result of bypass of the jejunum, where thiamine is primarily absorbed. Vitamin B1 deficiency can also be seen as a result of impaired nutritional intake or frequent emesis. Early recognition is essential to initiate appropriate supplementation and to avoid potential complications resulting in neurologic deficits. Neurologic deficits have been reported as soon as 1 to 3 months after surgery. Patients with active neurologic symptoms should be started on parenteral supplementation for 1 to 2 weeks with thiamine (100 mg/d). An oral preparation of (10 mg/d)

<table>
<thead>
<tr>
<th>Nutritional Deficiency</th>
<th>Primary Treatment</th>
<th>Secondary Treatment</th>
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<tr>
<td>Vitamin B1 (thiamine)</td>
<td>Parenteral thiamine (100 mg/d) for 7–14 d</td>
<td>Oral preparation of thiamine (10 mg/d)</td>
</tr>
<tr>
<td>Vitamin B12 (cobalamin)</td>
<td>Oral crystalline B12, 350 μg/d</td>
<td>1000–2000 μg/2–3 mo intramuscular</td>
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<tr>
<td>Folic acid</td>
<td>Oral folate, 400 mg/d (included in multivitamin)</td>
<td>Oral folate, 1000 mg/d</td>
</tr>
<tr>
<td>Vitamin A</td>
<td>Oral vitamin A, 5000–10,000 IU/d</td>
<td>Oral vitamin A, 50,000 IU/d</td>
</tr>
<tr>
<td>Iron</td>
<td>Ferrous sulfate 300 mg 2–3 times/d, taken with vitamin C</td>
<td>Parenteral iron administration</td>
</tr>
<tr>
<td>Protein malnutrition</td>
<td>Enteral protein supplements</td>
<td>Enteral or parenteral nutrition; reversal of surgical procedure</td>
</tr>
<tr>
<td>Calcium/vitamin D</td>
<td>Calcium citrate, 1200–2000 mg, oral vitamin D, 50,000 IU/d</td>
<td>Calcitriol oral vitamin D, 1000 IU/d</td>
</tr>
</tbody>
</table>

can be used following parenteral supplementation until neurologic symptoms resolve.\textsuperscript{116–118} Severe thiamine deficiency typically occurs in patients after bariatric surgery, who develop intractable vomiting due to stomal stenosis. It is important that unrelenting vomiting be evaluated and resolved aggressively to prevent this complication.

The anatomic changes imposed by bariatric or malabsorptive surgery increase the risk for various vitamin and mineral deficiencies that occur as soon as the first year after surgery.\textsuperscript{59,97,119–124} Malabsorptive procedures can be associated with micronutrient and macronutrient deficiencies, and require lifelong supplementation and monitoring.\textsuperscript{125,126} Patients with existing osteoporosis and heavy menstruation who undergo bariatric surgery are at increased risk, and prophylactic supplementation should be considered.\textsuperscript{119,127–129} Proper screening and supplementation of deficiencies with a multivitamin-mineral, iron, vitamin B12, or calcium with vitamin D is routinely conducted. Best-practice guidelines recently published recommend a daily multivitamin and calcium supplementation with added vitamin D for all weight-loss surgery patients.\textsuperscript{130} Table 3 highlights the list of common nutritional deficiencies and treatment plans seen in the RNY patient.

**SUMMARY**

Morbid obesity has become a pandemic problem of this century, and has accelerated to the forefront of leading causes of preventable death. The trend for bariatric surgery has followed this trend because it has proved to be a valid treatment strategy for reduction and elimination of obesity-related diseases and long-term sustainable weight loss. Over the past 60 years bariatric surgery has embraced surgical innovation, which has refined techniques to offer multiple unique and effective surgical treatment options. As in most fields of surgery, the minimally invasive or laparoscopic techniques have replaced the open procedures. Despite the need for advanced technical skills to achieve success and assure adequate patient safety, bariatric surgery has been no exception to a new generation of minimally invasive surgical techniques. Published data of case series, improvements in surgical technology, surgical training, and surgeon preference are all factors that play a critical role in the small intricacies and variations of the procedure. The largest variable in technical aspects of the LRNY is the creation and size of the gastrojejunostomy. These factors contribute to the lack of a single universal way in which the LRNY is performed. Regardless of the variations in technique, over the past 20 years the LRNY has remained the gold standard for the surgical treatment of clinically severe or morbid obesity, with relatively low morbidity and mortality.

**REFERENCES**

29. DeMaria EJ, Schweitzer MA, Kellum JM, et al. Hand-assisted laparoscopic gastric bypass does not improve outcome and increases costs when compared


