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Review

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Gastric bypass: evolution toward mini-invasive techniques and long-term results

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Abstract

Since its inception and eventual use by Mason and Ito to treat obesity in 1966, the Roux-en-Y gastric bypass has proven to be an effective procedure for achieving durable weight loss and improving obesity-related comorbidities. Over time, the technique and its complication profile have evolved, including modifications such as lengthening the Roux and biliopancreatic limbs and altering the preferred path of the Roux limb. Due to its longstanding use, a substantial body of research has accumulated regarding the gastric bypass and its outcomes. Long-term follow-up demonstrates durable weight loss in most patients, extending up to twenty years postoperatively. Comorbidity resolution has been extensively studied, showing significant improvements in diabetes mellitus, hypertension, dyslipidemia, and other obesity-related conditions. Although the incidence of complications has decreased since the procedure's inception, they have not been entirely eliminated.

Keywords: Gastric bypass, long-term, complications, history, outcomes

INTRODUCTION

The Roux-en-Y gastric bypass (RYGB) was first used as a weight loss procedure in 1966, when Edward Mason and Chikashi Ito adapted gastrointestinal anatomy for the treatment of duodenal ulcers[1]. The original surgical configuration is shown in Figure 1. RYGB quickly became the gold standard for obesity treatment, largely due to the seminal paper by Pories *et al.*, which demonstrated significant improvements

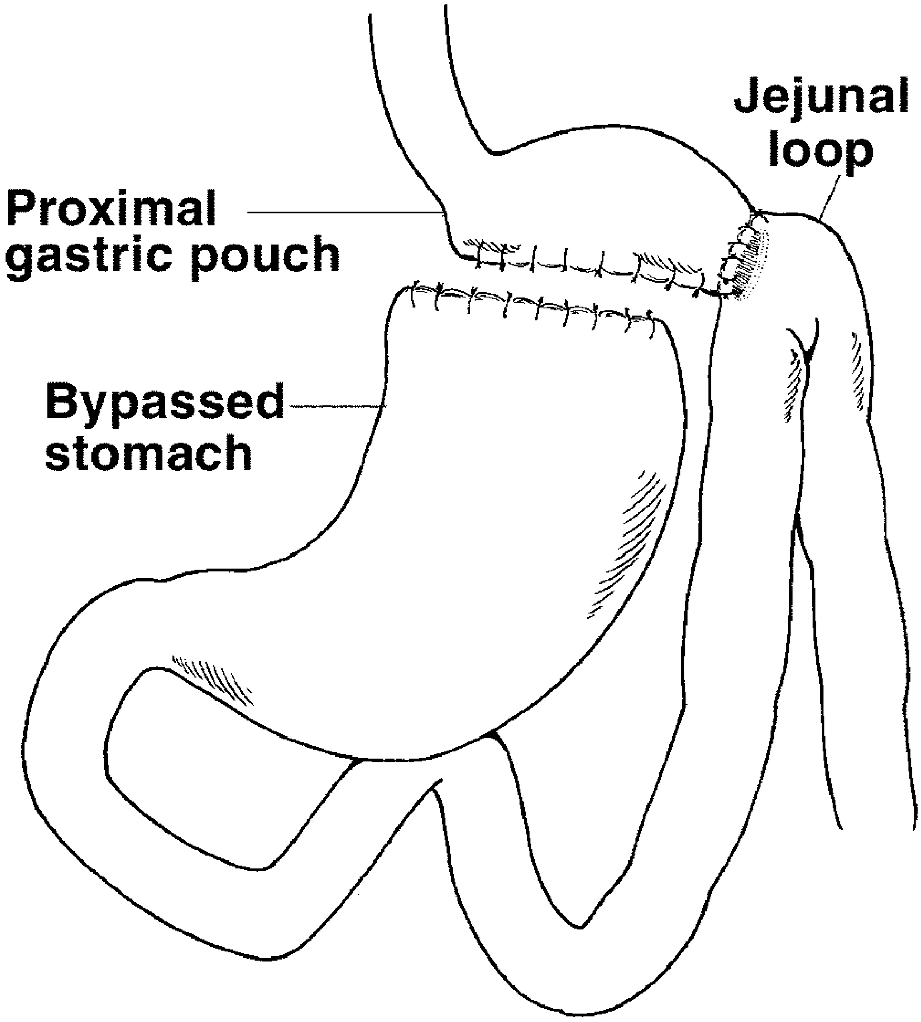

Figure 1. Mason Gastric Bypass with loop of jejunum. (From Dietel M. A synopsis of the development of bariatric operations. *Obes Surg* 2007;17:708 with permission).

in diabetes mellitus (DM) among patients who had undergone the procedure[2]. In 1991, the National Institutes of Health issued guidelines for the use of gastrointestinal surgeries, especially RYGB, to treat severe obesity. These recommendations were adopted by both surgeons and healthcare payors[3]. Since then, it is estimated that more than one million patients have undergone RYGB for obesity treatment[4]. The high volume of procedures has resulted in a substantial body of patient data, enabling a better understanding of both treatment outcomes and the procedure's risk profile. Reflecting this evolving knowledge, the American Society for Metabolic and Bariatric Surgeons (ASMBS) and the International Federation for Surgery for the Surgery of Obesity and Metabolic Disorders (IFSO) released updated guidelines for metabolic and bariatric surgery in November 2022[5]. These new recommendations lowered the minimum body mass index (BMI) threshold for surgery eligibility, influenced by improved insights into the pathophysiology and treatment of obesity as well as surgical risks. Given RYGB's central role in bariatric surgery, understanding its origins, iterations, and evolution is essential. This historical perspective also helps trace the procedure's transformation from large open surgeries to minimally invasive approaches.

THE RYGB OVER TIME

Initial history of the RYGB

The earliest known record of surgical treatment for obesity dates back to the 10th century and involves the Jewish physician Hasday Ibn Shaprut. He is said to have sewn shut the mouth of King Sancho I of León - known as "Sancho the Fat" - who reportedly weighed approximately 240 kg. Sancho had lost his kingdom in 957 CE due to his severe obesity. By restricting his intake to clear liquid diets and implementing a rigorous exercise regimen, Hasday facilitated a weight loss of more than 100 kg, ultimately enabling King Sancho to reclaim his throne[6].

The next notable reference to surgical weight loss is from Dr. Viktor Henrickson of Sweden in 1952. Recognizing that patients often lost weight following bowel resections, he surgically removed 105 cm of small bowel from an obese female who had failed other weight loss programs. While the patient achieved only modest weight loss, she reported an improved quality of life. However, due to the irreversible nature of the procedure, it did not gain popularity[7,8].

Modern bariatric surgery gained traction with research investigating micronutrient absorption in the gastrointestinal tract. In 1954, Kremen experimented on the impact of varying lengths of small bowel resection on nutrient uptake in dogs. He found that resecting the distal 50% of the small bowel significantly reduced fat absorption and led to weight loss[9]. This study is often credited as the inception of the jejunoileal bypass. Although Kremen's publication is the first on record, Dr. Richard Varco reportedly performed the first of such procedures on a human in 1953 but did not publish the case[10]. In 1955, Friedman reported notable improvements in blood sugar levels among three patients with diabetes who underwent subtotal gastrectomy for peptic ulcer disease. This is considered the first documented observation of metabolic changes resulting from gastric surgery[11].

Building on Kremen's data, Payne *et al.* published a 1963 case series involving 10 patients with severe obesity who underwent jejunoileal bypass. The inclusion criteria included individuals who were at least 125 pounds overweight, had failed all other weight loss methods, and had a life-threatening comorbidity[12]. Although the procedure was initially designed to be reversible, instances of weight regain in some patients led to its adoption as a long-term solution[8].

Subsequently, in 1964, Varco and Buchwald published multiple reports on ileal bypasses, starting with rabbit models and progressing to the first human subject in 1963. Their goal was to improve serum cholesterol levels in patients with a familial predisposition and clinical signs of atherosclerotic disease[13]. Initially, the authors stated, "to date there have been no untoward aftereffects of the operation…no evidence of malnutrition or inadequate carbohydrate and protein absorption," but later that year, they reported vitamin B12 deficiencies in their patients[14]. They also noted that no sustained weight loss occurred among these patients - none of whom were obese - as the procedure was intended to prevent further cardiovascular events rather than to treat obesity[15].

By 1971, the jejunoileal bypass was recognized for inducing weight loss and resolving hyperlipidemia. However, it was also associated with severe comorbidities, including electrolyte imbalances, vitamin and mineral deficiencies, diarrhea, bloating, kidney stones, steatohepatitis, liver failure, diffuse rashes, and psychosocial complications. These comorbidities were believed to be secondary to short bowel syndrome and bacterial overgrowth[10]. The procedure carried a mortality rate of 10%[8].

Due to the unacceptable morbidity associated with the jejunoileal bypass, efforts began to find alternative methods for obesity treatment. In 1967, Mason and Ito described the first gastric bypass. Their concept was based on observations that patients undergoing subtotal gastrectomy for peptic ulcer disease also experienced postoperative weight loss. Their procedure represented the first to combine restrictive and malabsorptive elements for the treatment of obesity and its comorbidities[8]. Mason's approach involved a retrocolic loop gastrojejunostomy[1]. The procedure went as follows: first, the stomach was divided horizontally at the upper 10%, preserving the fundus. The ligament of Treitz was then divided, and a short loop of jejunum was brought up retrocolically to create a 1.2 cm gastrojejunostomy - essentially a modification of the Billroth II reconstruction[16]. In their follow-up reports, Mason and colleagues noted concerns regarding marginal ulceration and dumping syndrome in some postoperative patients[17].

The gastric bypass procedure gained further support in 1977, when Alden conducted a comparative study involving 100 patients undergoing gastric bypass and 100 receiving jejunoileal bypass. Unlike the original Mason technique, Alden's variation involved stapling - but not dividing - the stomach. The anastomosis was antecolic, and a smaller gastric pouch was created by dissecting along the greater curvature. The gastrojejunostomy stoma was fashioned using a 2 cm stapling device. These modifications aimed to simplify the surgery, as Mason's original procedure was considered technically demanding and time-consuming. Alden's study found comparable weight loss between the two groups, but the gastric bypass group experienced fewer long-term postoperative complications[18]. However, the technique of pouch stapling without division eventually fell out of favor due to staple line failure and subsequent weight regain[19].

In 1977, Griffen introduced a further modification to the gastric bypass. In response to issues such as bilious vomiting associated with the Mason bypass, difficulty in keeping the gastrojejunostomy below the mesocolon, and tension at the anastomotic site leading to leaks, Griffen implemented a Roux-en-Y configuration. Originally developed by Swiss surgeon Dr. Cesar Roux in 1892 for gastric outlet obstruction[20], this configuration improved surgical outcomes. Griffen's prospective study compared gastric bypass to jejunoileal bypass in 59 patients. His technique used a 10% pouch, consistent with Mason's design, and a retrocolic gastrojejunostomy to a 30 cm Roux limb. The gastric bypass group experienced significantly fewer complications[16]. Around the same time, Pories independently developed a similar Roux procedure known as the Greenville gastric bypass, with the difference of gastric stapling without division[21]. Their Roux limb was between 30 and 60 cm. Long-term follow-up revealed that 83% of patients experienced sustained remission of type 2 diabetes mellitus[8].

Later in 1977, further evolution occurred with a study by Alder and Terry, which demonstrated a correlation between smaller pouch size and sustained weight loss[22]. They found that a pouch volume of less than 30 mL decreased postoperative dilation, consistent with predictions based on the law of Laplace[19].

In 1983, Torres *et al*. introduced the next major refinement. They created a 25 to 35 mL pouch based on the lesser curvature of the stomach rather than the greater curvature. This technique preserved blood flow to the gastrojejunostomy and utilized a more muscular portion of the stomach to prevent postoperative pouch dilation[23]. Additionally, they employed a longer Roux limb to enhance malabsorption, Figure 2[24].

Adjunct procedures to the gastric bypass were introduced by Salmon in 1988, combining vertical-banded gastroplasty with a distal gastric bypass[25]. The vertical-banded gastroplasty itself was first developed by Mason in 1980[26]. The distal bypass is often credited to Scopinaro, who pioneered the biliopancreatic diversion in 1979, creating a 50 cm common channel[27]. Variations using restricted pouches have also been implemented, including those utilizing a silastic band surrounding the pouch[28].

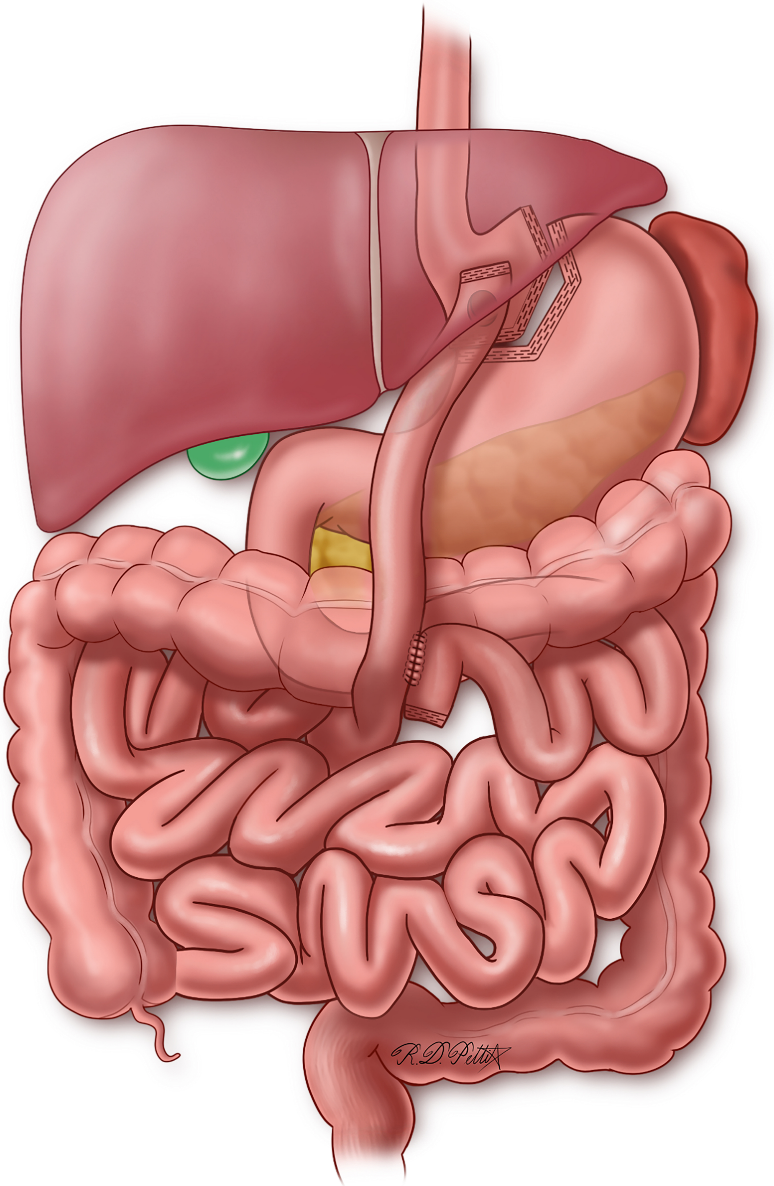

Figure 2. Artistic rendition of modern RYGB. (From RD Pettit, medical illustrator, D.D. Eisenhower Army Medical Center). RYGB: Roux-en-Y gastric bypass.

The term “extended bypass” is somewhat loosely defined but generally refers to procedures involving a shortened common channel resulting from a distal jejunojejunostomy. Sugerman replicated Scopinaro’s original 50 cm common channel in 1997 for use in distal gastric bypass among patients with extreme obesity. He reported severe malnutrition in all five patients and two deaths. Concluding that this morbidity rate was unacceptable, he subsequently revised the procedure to use a 150 cm common channel[29].

Introduction of laparoscopy and the onset of minimally invasive RYGB

The first laparoscopic gastric bypass was reported by Wittgrove, Clark, and Tremblay in 1993. Wittgrove published a case series of five patients in which[30]. he used a 75 cm retrocolic Roux limb to minimize anastomotic tension and ensure the shortest route, along with a 15 mL pouch based on the lesser curvature. The gastrojejunostomies measured 1.2 cm in diameter. He noted that the early laparoscopic approach was limited by the reach of available instruments. In his review of the first 75 laparoscopic gastric bypass patients, he observed resolution of diabetes in 22 out of 24 patients, along with complete resolution of GERD. Compared to open surgery, the laparoscopic approach significantly reduced hospital stay, recovery time, and improved cosmetic outcomes.

Originally, gastrostomy tubes were routinely placed into the remnant stomach to enable feeding in case of a leak and to help separate the pouch from the gastric remnant. However, in 2000, Wood challenged this practice. In a retrospective review of over 1,000 RYGB cases, he found that only 1.6% of patients might have had different outcomes with a gastrostomy tube, suggesting the routine use of gastrostomy tubes was likely unnecessary[31].

As more surgeons became proficient in laparoscopic techniques and transitioned to laparoscopic RYGB, there was an effort to maintain the integrity of the open procedure. Higa published his version of laparoscopic RYGB, using a retrocolic Roux limb (100-150 cm, depending on patient BMI) and a hand-sewn gastrojejunostomy. He believed this better preserved the open approach, citing a high leak rate with stapled gastrojejunostomy during laparoscopy. Wittgrove had reported a 4% leak rate for this anastomosis. Notably, Wittgrove also observed an increased incidence of internal hernias following the adoption of laparoscopy, likely due to reduced intra-abdominal adhesions. His group addressed this by securing the Roux limb to the transverse mesocolon using nonabsorbable sutures[32].

The shift to an almost entirely laparoscopic RYGB occurred in the early 2000s. In 2001, Nguyen *et al.* published a randomized controlled trial involving 155 patients, comparing laparoscopic and open gastric bypass. The laparoscopic group showed shorter hospital stays, fewer wound complications, faster return to normal activities, and less postoperative pain. Rates of anastomotic leak and weight loss were comparable between the two groups[33].

As previously observed by Higa, the transition to laparoscopy was accompanied by a rise in internal hernias. Escalona, in a 2007 prospective study of 754 patients, compared retrocolic and antecolic Roux limb configurations. The retrocolic group had higher rates of internal hernia and a greater need for exploratory laparotomy due to small bowel obstruction[34]. These findings were reinforced by a 2015 meta-analysis by Al Harakeh, which demonstrated higher rates of bowel obstruction and internal hernia in retrocolic compared to antecolic Roux limbs[35].

Robotic innovations in RYGB

The first robotic bariatric procedure, marking the next evolution in bariatric surgery, was done by Cadiere in Italy in 1998, involving a laparoscopic adjustable gastric band[36]. Subsequently, robot-assisted RYGB was introduced, where the robot was used to assist in the gastrojejunostomy of seven gastric bypass procedures[37]. The first fully robotic RYGB was completed by Dr. Mohr in 2005, using a 100 to 150 cm antecolic Roux limb[38]. This was a significant achievement, as RYGB at that time was considered a multi-quadrant surgery, typically requiring either repositioning of the robotic system or conversion to a standard laparoscopic approach. Notably, Mohr's robotic approach reduced operative time by 40 min. These early pioneers of robotic surgery highlighted the improved ease of tissue dissection in confined anatomical spaces compared to laparoscopic or even open RYGB.

As the robotic platform has continued to evolve and gain prominence as a primary modality for gastric bypass surgery, increasing attention has been paid to its effectiveness relative to traditional methods. Although surgeons frequently report improved instrument articulation, these benefits are often offset by higher operational costs. However, as robotic systems become more widespread, associated overhead costs are expected to decline, as demonstrated by Read *et al.* in 2024[39]. While robotic surgery has yet to become less expensive than laparoscopic surgery, cost parity is anticipated in the near future. Senatore *et al.* reported cost equivalence in the context of revisional surgeries[40].

The comparison of outcomes between laparoscopic and robotic approaches remains a topic of interest. A meta-analysis by Bertoni *et al.*, published in 2021, compared laparoscopic and robotic revisional gastric bypass surgeries and found no significant differences in postoperative complications, conversion rates to open surgery, length of hospital stay, or operative time[41]. The authors also noted that earlier reports of increased complication rates associated with robotic surgery are no longer supported by more recent data. Further evidence was provided by Coker *et al.* in a 2023 study comparing outcomes from two time periods (2015-2016 *vs.* 2019-2020)[42]. While operative times remained consistent across both intervals, the later period showed a reduction in postoperative bleeding, stomal strictures, and marginal ulcer formation. These improvements were attributed to overcoming the learning curve and improved technology.

LONG-TERM RESULTS

Weight loss

Because of its long history of use, RYGB is supported by a substantial body of long-term outcome data, including studies with 15- and 20-year follow-ups. However, comparing these studies is challenging because they often use different criteria for defining successful long-term weight loss and employ various limb lengths in surgical technique. Several metrics are commonly used to report weight loss outcomes: (1) Percent excess weight loss (%EWL), which calculates the percentage of weight lost based on a patient's excess weight above their ideal body weight. A potential confounder here is the method used to determine ideal body weight; (2) Percent excess BMI loss (%EBMIL), which typically uses an ideal BMI of 25 kg/m^2 as the benchmark; (3) Percent total body weight loss (%TWL), which represents the proportion of a patient's total body weight lost. While these metrics can be used to compare studies that employ the same measurement method, comparisons between studies using different metrics often require cautious extrapolation. Generally, an RYGB is considered successful if it results in at least 50% EWL or 50% EBMIL, as these typically reflect similar degrees of weight loss. For %TWL, defining a universal success threshold is more complex, as it varies depending on the individual patient's baseline weight. Surgical technique is another source of variability in RYGB outcomes. Although the overall procedure and anatomical result are generally consistent, surgeons around the world use different limb lengths. An ASMBS literature review found no consensus on standard lengths for the alimentary (Roux) limb and biliopancreatic limbs, with international surgeons tending to use longer segments for both[43].

Numerous single-institution studies have reported long-term outcomes of RYGB. A common challenge in these studies is declining patient follow-up over time. For instance, a study involving 294 eligible patients reported 10-year follow-up data for 134 patients, showing a mean %EWL of 58.9%. Notably, patients with preoperative BMIs below 50 kg/m^2 lost more weight than those with higher BMIs[44]. Another institution followed 1,402 patients, with 10-year follow-up data available for 191 patients, showing a %EWL of about

58%[45]. Among 92 patients followed up to 12 years, the %EWL averaged 53%. A study from New York, NY, highlighted the difficulty of long-term follow-up[46]: of 486 eligible patients at 15 years post-op, only 92 (18.9%) had available data, with a mean %TWL of 28.0% ± 13.0%. Additionally, 55 patients had surpassed 20 years post-surgery, but data were available for only 12 (21.8%), with a mean %TWL of 24.3% ± 16.9%.

Several multicenter studies were completed prior to the widespread use of the Metabolic Bariatric Surgery Accreditation and Quality Improvement Program (MBSAQIP) database. One such study, the Longitudinal Assessment of Bariatric Surgery (LABS), published 7-year follow-up data in 2017[47]. The LABS Consortium, comprising 10 U.S. hospitals throughout the country to account for any regional differences, included 1,738 RYGB patients and found an average total weight loss of 28.4%, with only modest weight regain (approximately 3.9%) between years 3-7. Moreover, 75% of participants maintained at least a 20% reduction in total body weight. Another earlier database, the Bariatric Outcomes Longitudinal Database (BOLD), also contributed long-term data prior to MBSAQIP[48].

International data mirror trends seen in U.S. studies. A Swedish single-institution study with an average follow-up of 11 years (range 7-17 years) reported a 63.3% EBMIL[49], although the use of self-reported weights may have introduced bias. An Italian study followed 105 patients for 15 years, with 97 patients still participating at the final assessment[50]. At 15 years, the average %EWL was 58.6% and %TWL was 26.8%. During the first five years, patients with starting BMIs below 50 kg/m^2 had significantly better outcomes, but this difference was no longer statistically significant beyond five years. These findings suggest that patients with a starting BMI over 50 kg/m^2 may experience less favorable long-term weight loss following RYGB compared to those with lower initial BMIs.

Diabetes mellitus

In a seminal 1995 publication, Dr. Pories demonstrated the superiority of RYGB over medical treatments in treating adult-onset DM. Of 165 patients with non-insulin-dependent diabetes mellitus, 146 (88.5%) maintained normal fasting blood glucose levels an average of 7.5 years after undergoing gastric bypass surgery[2]. The Swedish obese subjects (SOS) Study further supported the long-term effectiveness of gastric bypass in managing type 2 diabetes. Sjöström *et al*. reported a 72% remission at 2 years following surgery (primarily vertical banded gastroplasty, with some gastric bypass procedures) and a 36% remission at 10 years. Additionally, the study demonstrated a lower incidence of new-onset diabetes over a 10-year period in the surgical group compared to patients managed medically[51].

Other large single-institution studies have yielded comparable results. One study involving 367 diabetic patients found that 18% achieved complete diabetes remission - defined as a hemoglobin A1C (HbA1C) level < 6% - 8 years after RYGB[45]. Furthermore, 46% of patients experienced at least some improvement in blood glucose control at the 8-year follow-up. Another single-institution study with a 10-year follow-up of 32 diabetic RYGB patients reported a diabetes remission rate of 59.4% at 10 years[46].

A randomized controlled trial comparing bariatric surgery [including RYGB, sleeve gastrectomy (SG), and adjustable gastric banding] with medical and lifestyle management found surgery to be significantly more effective in achieving glucose control and diabetes remission over a follow-up period of up to 12 years[52]. At 12 years, the remission rate was 12.7% in the surgery group compared to 0% in the medically managed group.

Risk factors for failure to achieve diabetes remission after gastric bypass have also been examined. *Hage et al.* found that a longer preoperative duration of diabetes, preoperative insulin use, higher preoperative HbA1C, and more preoperative diabetes medications were all associated with a lower likelihood of remission. In their cohort of 686 patients, 39.1% achieved a sustained cure of type 2 diabetes - defined as HbA1C < 6% for at least five years - at follow-up periods ranging from 5 to 14 years post-surgery[53].

Lastly, meta-analyses continue to affirm the efficacy of gastric bypass in treating diabetes. Yu *et al*. reported an initial remission rate of 63.0% across 17 eligible studies, with a pooled long-term relapse rate of 30.0%[54]. Another meta-analysis of randomized controlled trials comparing gastric bypass to medical therapy showed relative risks for remission of 18.01 at 1 year, 29.58 at 3 years, and 16.92 at 5 years[55]. Overall, substantial evidence supports the long-term success of gastric bypass in the treatment of type 2 diabetes mellitus.

Hypertension

Hypertension is another well-known obesity-related comorbidity that significantly contributes to patient morbidity. Individuals with obesity are three times more likely to develop hypertension than those without obesity[56]. Several studies have reported a hypertension incidence of > 50% in patients seeking RYGB[44,42,57]. The SOS Study reported an odds ratio of 1.68 for 10-year hypertension remission in RYGB patients compared to medically treated patients[51]. A 10-year follow-up study of over 300 RYGB patients found a hypertension remission rate of 46%[44]. Similarly, in a cohort of 217 hypertensive patients who underwent RYGB, 13 out of 31 patients (41.9%) achieved remission at the 10-year follow-up[46]. Another study involving patients at least 10 years post-RYGB found a 34.1% remission rate (44/129 patients)[58]. However, long-term outcomes vary considerably. For example, one study involving 53 RYGB patients with baseline hypertension had a remission rate of only 5% at 10 years[45].

Dyslipidemia

Dyslipidemia increases the risk of cardiovascular disease and its complications. According to the National Health and Nutrition Examination Survey (NHANES), individuals with obesity have an adjusted odds ratio (AOR) of 2.2 for developing dyslipidemia[56]. The risk of dyslipidemia rises with increasing BMI. Fortunately, substantial evidence supports the efficacy of RYGB in improving lipid profiles.

Several retrospective studies have shown long-term improvements or resolution of dyslipidemia in RYGB patients. In one study, 10 years after surgery, 8 out of 13 patients with baseline dyslipidemia (61.5%) experienced resolution, while the remaining 5 (38.5%) showed improvement[46]. Another study involving 47 patients with 10-year follow-up data reported dyslipidemia resolution in 23% and improvement in an additional 19%[45]. In a cohort of 134 RYGB patients followed for 10 years, Obeid *et al*. reported a 46% dyslipidemia rate[44]. However, results across studies remain inconsistent. For example, a separate study with an average follow-up of 7 years in 52 patients showed a remission rate of only 24%[57].

The SLEEVEPASS study, a randomized clinical trial comparing SG to RYGB with 5 years of follow-up, found that RYGB patients were more likely to discontinue all dyslipidemia medications (60% *vs*. 47%). However, the overall difference between the two surgeries in terms of dyslipidemia outcomes was not statistically significant[59]. In contrast, the SM-BOSS study, another randomized clinical trial with a 5-year follow-up, showed significantly higher dyslipidemia resolution in RYGB patients (62.3%) compared to SG patients (42.6%)[60].

The ASMBS released a scientific statement concluding that RYGB can lead to complete resolution of dyslipidemia in some patients and reduce the need for lipid-lowering medications in many others[61]. The malabsorptive component of RYGB helps improve lipid metabolism and mitigate the harmful effects of dyslipidemia.

COMPLICATIONS: CHANGES OVER TIME

Mortality

Initial reports of RYGB mortality were significantly higher than those seen in more recent studies. Pories *et al*. reported a perioperative mortality rate of 1.5% in their first cohort of 608 RYGB patients (9/608)[2]. Of these deaths, five were attributed to sepsis, likely due to an anastomotic leak, three were caused by pulmonary embolism (PE), and one had an unknown cause. This perioperative mortality rate of 1.5% persisted through the early 2000s. In a single-institution study of 3,073 patients during the transition from largely open to laparoscopic RYGB, the mortality rate remained at 1.5%. Identified independent risk factors for mortality included intestinal leak, higher body weight, hypertension, and surgical approach (revisional RYGB > open RYGB > laparoscopic RYGB)[62]. Over time, perioperative mortality associated with RYGB has markedly improved. In the LABS study, the 30-day mortality rate was notably low, with only 3 deaths among 1,738 patients (0.17%)[47]. During a 7-year follow-up period, 59 deaths were reported. Similarly, the BOLD study, which included over 180,000 patients, reported an overall mortality rate of just 0.13% and a 30-day mortality rate of 0.09%[48]. In many single-center studies conducted in the new millennium, perioperative deaths have become increasingly rare[44,45]. The SOS Study showed a long-term reduction in overall mortality following RYGB, with an adjusted hazard ratio of 0.71 (95%CI: 0.54-0.92; $P = 0.01$)[63]. This finding was further supported by a meta-analysis of randomized controlled trials, which reported a 41% reduction in all-cause mortality of 41% following bariatric surgery, including RYGB (hazard ratio: 0.59; 95%CI: 0.52-0.67; $P < 0.01$)[64]. Table 1 shows the estimated incidence of RYGB complications.

Several studies have identified risk factors for mortality associated with RYGB. These include increasing age (especially over 65), male sex, higher BMI, pulmonary hypertension, congestive heart failure, and liver disease[65,66]. A study analyzing more than 16,000 Medicare patients who underwent bariatric surgery, not limited to RYGB, found a one-year mortality rate of 4.8% for those aged over 65, compared to 1.7% for those under 65[65].

Leak

An anastomotic leak remains the most feared complication following RYGB. Leaks can occur at several sites, including the gastrojejunostomy, gastric pouch staple line, excluded stomach staple line, Roux limb staple line, and jejunojejunostomy, with the gastrojejunostomy being the most common site[67]. Some studies have reported a high mortality risk associated with leaks. For example, in a cohort of 3,000 patients, one study found a leak incidence of 3.2% (102 patients), with a leak-associated mortality rate of 16.7%[62].

In the era of open RYGB, reported anastomotic leak rates ranged from 0% to 5.6%[62,68]. With the introduction of laparoscopic techniques, the risk initially increased. De Maria *et al*. reported a leak rate of 5.1% among their first 281 patients undergoing laparoscopic RYGB. Notably, the rate decreased to 1.8% in the final 164 patients in their series, highlighting a learning curve associated with laparoscopic RYGB[69]. More recent literature reports lower leak rates, likely reflecting improvements in surgical techniques over time. Identified risk factors for anastomotic leaks include advanced age, male sex, higher BMI, the presence of multiple preoperative comorbidities, and revisional RYGB procedures[70]. Advances in technology and operative techniques have contributed to the reduction in leak rates. These improvements include appropriate staple sizing, the use of fibrin sealants, intraoperative leak testing, avoidance of anastomosis under tension, and prevention of ischemia at the anastomotic site[71,72].

Table 1. Sites of absorption for macro- and micronutrients, symptoms of deficiency, normal laboratory reference values, and incidence of deficiency following RYGB

Nutrient	Major site of absorption	Deficiency symptoms	Normal laboratory levels[107]	Incidence of deficiency post-RYGB[83-87]
Iron	Duodenum	Microcytic anemia, fatigue, pallor, glossitis, koilonychia	Serum iron: 60-170 μg/dL Ferritin: 20-335 μg/L	3%-38%
Vitamin B12	Ileum	Megaloblastic anemia, fatigue, glossitis, paresthesias, ataxia	200-900 ng/mL	3%-29%
Thiamine	Jejunum	Wet beriberi (cardiac insufficiency) Dry beriberi (neuritis and neuropathy) Wernicke-Korsakoff Syndrome (nystagmus, ataxia, mental status changes)	2.5-7.5 μg/dL	0%-5%
Zinc	Duodenum	Rash, acne, hair loss, change in taste, immune deficiency	60-130 μg/dL	4%-20%
Calcium	Duodenum	Muscle cramps, tetany, neuromuscular hyperexcitability, osteomalacia, osteoporosis	9.0-10.5 mg/dL	0%-20%
Vitamin D	Ileum	Osteomalacia, secondary hyperparathyroidism	25-OH Vitamin D: 25-40 ng/mL	29%-83%
Vitamin A	Ileum	Vision changes, endophthalmitis, poor wound healing	Plasma retinol: 20-80 μg/dL	0%-1%
Protein	Ileum	Organ dysfunction (particularly liver and pancreas), edema	Albumin: 3.5-5.0 g/dL	0%-8.9%
Folate	Throughout the small intestine, mostly the jejunum	Megaloblastic anemia, glossitis, changes in skin pigmentation	2-20 ng/mL	0%-4%

RYGB: Roux-en-Y gastric bypass.

As a result of these developments, more recent studies report significantly lower leak rates. For example, among 486 patients operated on between 2001 and 2007, only 2 (0.4%) required reoperation for a leak[46]. In another study of 1,402 RYGB patients operated on between 2001 and 2015, only 3 (0.2%) experienced an anastomotic leak[45]. Similarly, the SM-BOSS trial, which included 110 RYGB patients operated on between 2007 and 2011, reported only 1 leak (0.9%)[60].

Bleeding

Despite improvements in surgical techniques and technology, bleeding remains a potential complication in RYGB patients. The author recalls that their first RYGB as a bariatric surgery fellow in 2014 was complicated by gastrointestinal bleeding on postoperative day 1, requiring a blood transfusion. Fortunately, the patient recovered fully without the need for additional interventions. A study of 2,639 patients who underwent laparoscopic RYGB between 1999 and 2020 reported clinically significant bleeding in 72 patients (2.7%). Of these, 52 cases (72%) were due to gastrointestinal/intraluminal bleeding, while 20 (28%) were classified as extraluminal bleeding[73]. Another large-scale study using data from the Metabolic and Bariatric Surgery Accreditation and Quality Improvement Program (MBSAQIP) analyzed 43,280 laparoscopic RYGB patients and identified postoperative bleeding in 652 cases (1.51%). The specific location of bleeding in these cases was not reported[74].

While some instances of postoperative bleeding necessitate reoperation, many can be managed conservatively with supportive care, such as blood transfusion and critical care. Odovic *et al.* reported that only 31.9% of their patients with postoperative bleeding required reoperation - specifically, 35% of those with intraluminal bleeding and 25% of those with extraluminal bleeding[73]. In some cases, however, intraluminal bleeding does require surgical intervention. One study found that 5 out of 486 RYGB patients (1.0%) required reoperation for gastrointestinal bleeding within the first 30 days post-surgery[46].

Identified risk factors for postoperative bleeding after laparoscopic RYGB include a history of renal insufficiency, preoperative therapeutic anticoagulation, and revisional surgery[74]. Additional risk factors include arterial hypertension, chronic liver disease, and chronic obstructive pulmonary disease[75].

VTE

Deep vein thrombosis (DVT) and PE are serious but relatively rare complications following RYGB. Despite their infrequency, these events significantly increase mortality risk, with some studies suggesting an AOR for mortality as high as 11.6 in RYGB patients who develop venous thromboembolism (VTE)[76]. Among the various causes of early postoperative mortality, PE is the most common[77]. In a single-institution study employing both mechanical and chemical prophylaxis, the incidence of VTE was 0.2%, with no cases of PE, while bleeding complications occurred in 1.6% of patients[78]. A large study involving over half a million patients who underwent either SG or RYGB reported a VTE incidence of 0.55%[76].

Over the course of RYGB practice, several risk factors for postoperative VTE have been identified. These include prior VTE events, older age, male sex, history of congestive heart failure, paraplegia, dyspnea at rest, race, operative time exceeding 3 h, and higher BMI[79,80,81]. While some of these factors are modifiable, many are not. Moreover, the risk of VTE remains inherent even with laparoscopic approaches.

Initially, no formal consensus existed regarding VTE prophylaxis in patients undergoing RYGB. Currently, however, ASMBS has issued a position statement on perioperative VTE prophylaxis in bariatric surgery[82]. Mechanical prophylaxis is recommended for all RYGB patients, while chemical prophylaxis - typically with unfractionated or low-molecular-weight heparin - is indicated in most cases. Extended chemoprophylaxis after discharge should be considered for patients with elevated VTE risk. Although inferior vena cava (IVC) filters were previously used more frequently in RYGB patients, their use is now discouraged due to a higher rate of complications compared to the risk of VTE itself[82].

Malnutrition

Although often underrecognized, patients preparing for RYGB are at risk of malnutrition. In one study involving 169 preoperative RYGB patients, 4% had anemia, 5% iron deficiency, 74% vitamin D deficiency, and 12% vitamin B12 deficiency. Additionally, hyperparathyroidism was observed in 22% of patients[83]. It is important to conduct a thorough nutritional assessment and address both macro- and micronutrient deficiencies before surgery.

Given that RYGB is a hypoabsorptive procedure, the risk of malnutrition increases with the lengthening of the alimentary (Roux) limb lengths. A study examining various Roux limb lengths found that lengths greater than 250 cm were associated with increased deficiencies in vitamin A, D, B12, calcium, and iron. Extended limb lengths also raised the risk of zinc and selenium deficiencies[84]. Table 2 presents the reported incidence ranges of nutritional complications in RYGB patients.

Postoperative nutritional deficiencies in RYGB patients can often be corrected through oral supplementation of specific vitamins and minerals. Notably, oral supplementation has been shown to significantly improve vitamin D and B12 levels. In the same study of 169 preoperative patients, 74% had vitamin D deficiency, which decreased to 56% postoperatively with the use of a daily multivitamin, even without additional vitamin D or calcium supplementation[83]. Another study involving 427 RYGB patients reported that oral supplementation corrected vitamin D and B12 deficiencies in over 80% of cases and anemia improved in more than 60% of patients with the addition of oral iron[85]. A long-term follow-up study of 490 RYGB patients over 12 years compared outcomes between those who adhered to

Table 2. Reported incidence range of RYGB complications (combined from cited studies)

Complication	Reported incidence
Early postoperative (< 30 days) mortality	0%-1.5%
Anastomotic leak	0%-5.6%
Postoperative bleeding	0%-2.7%
Venous thromboembolism	0.12%-3.8%
Marginal ulceration	0.6%-25%
Internal herniation	4%-17% without defect closure 0%-7% with defect closure
Need for revisional surgery	2.8%-10.3%

RYGB: Roux-en-Y gastric bypass.

supplementation regimens and those who did not. Among these patients, 74% were compliant. The recommended regimen included an over-the-counter multivitamin twice daily, daily calcium with vitamin D, and periodic vitamin B12 injections. This protocol reduced the incidence of vitamin D deficiency from 78% to 52%. Deficiencies in folate, vitamin B12, and vitamin B6 without supplementation were 34%, 52%, and 52%, respectively. With supplementation, these rates dropped to 11%, 29%, and 17%[86]. While oral supplementation may not entirely eliminate the risk of nutritional deficiencies after surgery, it is essential that patients follow the current clinical practice guidelines. Without supplementation, the likelihood of significant nutrient deficiencies remains high[87].

Marginal ulcers

Marginal ulcers (MUs), also referred to as anastomotic or ischemic ulcers, are defined as ulcerations occurring at or near the gastrojejunostomy site following RYGB[88]. They typically present with epigastric pain, which may be accompanied by dysphagia or nausea and vomiting[89]. A systematic review reported the incidence of Mus to range from 0.6% to 25%[90]. In a study involving 166 RYGB patients followed for up to 12 years, 6% developed MUs[52]. These ulcers can manifest early, within the first postoperative month, or later. Csendes *et al*. found that most MUs in their study developed within the first month after surgery, followed by additional cases occurring within the first two years postoperatively[91]. Similarly, Kothari *et al*. reported that 6 patients (0.4%) developed MUs within the first 30 days, while 50 patients (3.6%) developed them during the subsequent 10 years of follow-up[45].

Several risk factors have been identified for MU development, including pouch size and orientation, mucosal ischemia, gastro-gastric fistula, foreign body reactions, *Helicobacter pylori* infection, tobacco use, and the use of nonsteroidal anti-inflammatory drugs (NSAIDs)[70]. Endoscopy is the diagnostic modality of choice for identifying MUs and can also aid in detecting contributory factors, such as retained suture material or *H. pylori* infection through biopsy[88]. Initial treatment of MUs is medical. High-dose proton pump inhibitors (PPIs) are typically effective in resolving these ulcers[92]. Addressing modifiable risk factors is also essential - for example, smoking cessation and NSAID avoidance. In rare cases, revisional surgery may be required.

Internal hernias

An internal hernia refers to the protrusion of the intestine through a defect within the abdominal cavity[70]. In RYGB, there are two or three potential sites where internal hernias can occur. In the antecolic, antegastric RYGB, the most common modern technique, the intestines may herniate through either the jejunojejunostomy mesenteric defect (located between the biliopancreatic limb and the common channel) or Petersen's space (also known as the retro-Roux mesenteric space), which lies between the mesentery of the Roux limb and that of the transverse colon[93]. In retrocolic, retrogastric RYGB, a third potential defect is created through the mesentery of the transverse colon. There was initial debate over whether these mesenteric defects should be closed. The reported incidence of internal hernias ranges from 4%-17% when the defects are left open, compared to 0%-7% when they are closed[94,95]. In the SLEEVEPASS study, no mesenteric defects were closed, and the Roux limb was brought up in an antecolic/antegastric configuration. Internal hernias developed in 17 of 119 patients (14.3%) during the study period[59]. Similarly, in the SM-BOSS study, 9 patients (8.2%) developed internal hernias following antecolic/antegastric RYGB; some participating surgeons closed mesenteric defects, while others did not[60]. In a long-term follow-up of up to 15 years, McClelland *et al.* reported that 26 of 486 patients (5.3%) developed internal hernias requiring operative intervention[46].

Diagnosis of internal herniation requires a high index of suspicion, as presenting symptoms are often nonspecific and variable. Abdominal pain is the most common symptom and may be localized or diffuse. A thorough clinical history and review of computed tomography (CT) imaging are essential[93]. The mesenteric "swirl sign" on CT has the highest diagnostic accuracy, with a reported sensitivity of 78%-100% and specificity of 80%-90%[96]. When internal herniation is suspected, patients should be promptly taken to the operating room for systematic exploration of the entire small intestine and all mesenteric defects. Notably, one study reported a recurrence rate of 14% following surgical intervention for internal hernia[97].

Cholelithiasis

Gallstone formation is a recognized risk following bariatric surgery. This is hypothesized to result from rapid weight loss, which leads to fat mobilization and increased levels of cholesterol and triglycerides. These changes can disrupt the balance of bile components, promoting gallstone crystallization. Additional contributing factors may include decreased cholecystokinin levels, which can impair gallbladder function[98,99]. In early practice of bariatric surgery, concomitant cholecystectomy was routinely performed. However, this approach has often been associated with a higher risk of postoperative complications[100]. An alternative strategy involves administering ursodeoxycholic acid (UDCA) to patients after metabolic surgery. UDCA has been shown to reduce the risk of gallstone formation[101] and is now selectively recommended by the ASMBS for patients with a high risk of biliary complications[102].

Need for revisions

There are multiple reasons why a patient may require revision following RYGB, as previously noted. These include postoperative complications, insufficient weight loss, or inadequate resolution of comorbidities. In a study of 281 RYGB patients with at least 10 years of follow-up, 8 patients (2.8%) underwent revisional surgery, all due to weight regain rather than other complications[58]. Another study, which followed 486 RYGB patients for at least 15 years, reported that 50 patients (10.3%) underwent revisional surgery, most commonly for internal hernias[46]. It is important to note that the complications discussed earlier are more frequently observed in revisional surgery compared to primary RYGB.

While most surgeons consider various surgical techniques, including minimally invasive techniques, for RYGB revisions, endoscopic revision represents the least invasive option that can effectively treat complications or suboptimal weight loss. In one study, 70 patients who had regained over 40% of their excess weight underwent endoscopic reduction of the gastrojejunostomy to a target diameter of 5-9 mm using suturing techniques. These patients achieved an average of 18.5% of EWL at one year post-procedure. However, gradual weight regain was observed over the following five years[103]. Endoscopic revisions can also address complications beyond weight gain. A systematic review of six studies showed that endoscopic sutured gastrojejunostomy reduction significantly reduced symptoms of dumping syndrome in RYGB patients, as evidenced by lower Sigstad scores[104]. When compared to surgical revisions, a retrospective study demonstrated that endoscopic revisions yielded similar outcomes with fewer complications. In that study, patients received argon beam coagulation to the anastomosis before endoscopic suturing to reduce the gastrojejunostomy size[105]. However, the long-term durability of endoscopic RYGB revisions remains uncertain. In a study of 27 patients who underwent endoscopic suturing for gastrojejunostomy reduction, follow-up upper endoscopy at 3 and 12 months revealed that while most repairs remained intact at 3 months, the majority had failed by 12 months. This deterioration was associated with subsequent weight regain[106]. Thus, despite their minimally invasive nature, endoscopic revisions may be associated with limited long-term effectiveness and a higher risk of recurrence compared to the effect of the original RYGB.

LIMITATIONS

Although there is substantial research on RYGB, studies specifically examining more modern techniques, such as robotic surgeries, remain limited. As time progresses, the accumulation of long-term data on these minimally invasive techniques will facilitate a more comprehensive evaluation of whether their outcomes match the consistently excellent results of traditional laparoscopic methods. Additionally, considerable variability in the technical aspects of minimally invasive RYGB procedures, such as gastric pouch construction, anastomotic techniques for the gastrojejunostomy and jejunojejunostomy, and the lengths of the biliopancreatic and Roux limbs, makes direct comparisons between studies challenging.

CONCLUSION

The RYGB has a long and distinguished history in the treatment of obesity and its associated comorbidities. Its current form, which is predominantly performed laparoscopically, may increasingly be replaced by robotic RYGB in the near future. RYGB remains the gold standard against which all other obesity treatments are measured. It continues to demonstrate durable weight loss and high rates of resolution of diabetes mellitus, hypertension, and dyslipidemia. Over time, advancements in technique have contributed to a reduction in the incidence of complications. Future research should include enhancing existing databases, such as the MBSAQIP, by incorporating additional variables like alimentary limb length and gastric pouch construction techniques. These comprehensive, long-term databases enable ongoing evaluation of outcomes and complications beyond the 20-year mark. Ideally, randomized controlled trials comparing different minimally invasive RYGB techniques should be conducted to assess their cost-effectiveness, clinical outcomes, and safety profiles. While surgical innovations will continue to emerge, RYGB is expected to remain a foundational bariatric procedure for the foreseeable future.

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Completed research for the article, wrote large segments, and reviewed the article prior to submission: Brockmeyer JR, Coffin EM

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