Current Obesity Reports (2020) 9:380–389
https://doi.org/10.1007/s13679-020-00389-8

HEALTH SERVICES AND PROGRAMS (R WELBOURN AND C BORG, SECTION EDITORS)

# Outcomes in Bariatric and Metabolic Surgery: an Updated 5-Year Review

A. E. Roth[1] · C. J. Thornley[1] · R. P. Blackstone[2]

Published online: 30 June 2020


## Abstract

**Purpose of Review** Knowledge regarding postoperative outcomes after bariatric and metabolic surgery continues to evolve. This review highlights key findings in outcomes research over the last 5 years related to weight loss, remission of obesity-related disease, reflux, revisional surgery, robotic-assisted surgical platforms, and adolescent populations.

**Recent Findings** Sleeve gastrectomy (SG) and Roux-en-Y gastric bypass (RYGB) produce similar weight loss patterns at 5 years, while duodenal switch (BPD/DS) and related procedures are associated with maximal weight loss overall and optimal resolution of obesity-related comorbidities. Remission of type 2 diabetes mellitus (T2DM) following surgery is more likely in patients who are not insulin dependent prior to surgery. Bariatric and metabolic surgery offers a significant protective effect against coronary artery disease (CAD) and associated interventions in both diabetic and nondiabetic patients, as well as heart failure (HF). Gastroesophageal reflux disease (GERD) and dysphagia following SG are common, and routine endoscopic surveillance for Barrett's esophagus may be of significant utility. Robotic-assisted laparoscopic platforms concur similar outcomes to laparoscopic intervention, with a potential benefit in high BMI patients. Revisional surgery is most commonly performed for weight regain and/or inadequate weight loss following an index procedure, or reflux, and generally characterized by higher postoperative complication rates and longer inpatient lengths of stay (LOS). Surgical intervention in adolescent populations has similar weight loss and postoperative complication profiles to those seen in adult populations, with improved outcomes related to T2DM.

**Summary** Bariatric and metabolic surgery continues to evolve as a treatment for obesity and obesity-related comorbidities. While effective for weight loss and remission of obesity-related disease, SG is associated with high rates of postoperative GERD.

**Keywords** Bariatric surgery · Metabolic surgery · Outcomes · Weight loss · Type 2 diabetes mellitus (T2DM) · Gastroesophageal reflux disease (GERD)

## Introduction

Bariatric and metabolic surgery is a dynamic and ever-evolving field that has established itself as highly effective therapy for obesity and obesity-related comorbid conditions. Over the past several years, clear trends have emerged. The annualized case volumes between 2015 and 2018 indicate an overall growth rate of 21.9% and account for 760,076 total cases (Table 1) [1]. Significant changes in practice patterns during this time period are demonstrated by a number of well-defined shifts in preferred procedures and approaches. Sleeve gastrectomy (SG) continued to be the most common procedure performed in the USA and grew by 30.4%. This accounts for 62% of all primary bariatric procedures and is performed 2.7 times more frequently than Roux-en-Y gastric bypass (RYGB), the next most common procedure performed. Also, during this time period, placement of laparoscopic adjustable gastric bands declined by 65.9%. While the overall case volume remains low, the rate of duodenal switch (BPD/DS) procedures increased by 115.8%. The vast majority of all bariatric and metabolic surgery cases are performed

This article is part of the Topical Collection on *Health Services and Programs*

✉ A. E. Roth
aemerz@gmail.com

1 Department of General Surgery, Banner University Medical Center – Phoenix, University of Arizona, 1441 N 12th Street, 1st floor, Phoenix, AZ 85006, USA

2 Ira A. Fulton Chair in Bariatric Surgery and Metabolic Disorders, Institute for Obesity and Metabolic Disorders, Banner University Medical Center – Phoenix, University of Arizona, 1441 N 12th Street, 1st floor, Phoenix, AZ 85006, USA

**Table 1** Frequencies of primary bariatric procedures in the USA, 2015–2018

| Total bariatric cases by year, *n* (%) | 2015 | 2016 | 2017 | 2018 | % Change from 2015 to 2018 |
|---|---|---|---|---|---|
| Total sleeve gastrectomies | 98,292 (58.5) | 114,251 (61.2) | 125,518 (62.6) | 128,209 (62.6) | + 30.4% |
| Total RYGB | 43,354 (25.8) | 43,792 (23.4) | 45,651 (22.8) | 47,113 (23.0) | + 8.7% |
| Total lap band placements | 4639 (2.8) | 3218 (1.7) | 2143 (1.1) | 1583 (0.8) | − 65.9% |
| Total BPD/DS | 1264 (0.8) | 1588 (0.9) | 2069 (1.0) | 2728 (1.3) | + 115.8% |
| All other cases | 20,544 (12.1) | 23,923 (12.8) | 24,993 (12.5) | 25,204 (12.3) | + 22.7% |
| Total bariatric cases | 168,093 | 186,772 | 200,374 | 204,837 | + 21.9% |

Frequencies of the four most common primary bariatric procedures performed in the USA, 2015–2018. Bariatric procedures are increasingly being performed annually, with an overall increase of 21.9% between 2015 and 2018. Significant changes in practice patterns are highlighted by a 65.9% decrease in the number of laparoscopic band placements, while BPD/DS and sleeve gastrectomies have increased by 115.8% and 30.4% respectively over the given time period [1]. RYGB, Roux-en-Y gastric bypass; BPD/DS, biliopancreatic diversion with duodenal switch

laparoscopically; however, robotic-assisted surgery, natural orifice transluminal endoscopic surgery (NOTES), and additional alternative approaches are starting to gain popularity (Table 2). In 2018, robotic-assisted procedures accounted for approximately 10% of all cases, nearly twice that of 2015 [1].

This review evaluates contemporary data regarding postoperative weight loss patterns and remission of obesity-related comorbid conditions following bariatric and metabolic surgery, as well as outcomes related to revisional surgery, robotic-assisted surgical platforms, and surgical interventions in adolescent populations. Of particular relevance given the increased frequency of sleeve gastrectomy (SG), recent literature related to postoperative gastroesophageal reflux disease (GERD) and Barrett's esophagus is also discussed. Except as specifically discussed in the adolescent portion of this review, all publications and data pertain to adult populations.

## Weight Loss

As sleeve gastrectomy (SG) has grown in popularity alongside Roux-en-Y gastric bypass (RYGB), several authors have sought to elucidate key differences in the medium and long-term outcomes of both procedures. While observed weight loss at 5 years for both laparoscopic SG and RYGB tends to favor RYGB, differences between the two procedures in this regard do not reliably reach statistical significance [2, 3]. Notably, in a recent randomized controlled trial including 217 patients who underwent SG or RYGB, no statistically significant difference in excess BMI loss at 5 years was identified, although data tended to favor RYGB (61.1% for SG, vs. 68.3% for RYGB, $p = 0.22$ after adjustment for multiple comparisons) [2•]. Similarly, a clinical equivalence trial between the two procedures including 240 patients who underwent laparoscopic SG or RYGB failed to demonstrate clinical equivalence between the two procedures. While authors cited a slightly higher mean percentage of excess weight loss (%EWL) following RYGB, they were not able to demonstrate a statistically significant benefit to RYGB over SG at 5 years [3•].

While extended data on weight loss outcomes following SG is still lacking, a recent 12-year prospective observational study evaluating RYGB suggests reasonable durability of 2- and 6-year weight loss patterns associated with this procedure [4•]. Among 418 patients in the surgical arm of the study, mean percent change in body weight was found to be − 35% at 2 years, as compared with − 28.0% at 6 years and − 26.9% at 12 years.

For patients with super morbid obesity (BMI > 50) and/or inadequate weight loss after sleeve gastrectomy in the absence

**Table 2** Frequencies of bariatric procedures by surgical approach in the USA, 2015–2018

| Total bariatric cases by year, *n* (%) | 2015 | 2016 | 2017 | 2018 | % Change from 2015 to 2018 |
|---|---|---|---|---|---|
| Laparoscopic | 155,078 (92.3) | 169,568 (90.8) | 180,328 (89.9) | 180,979 (88.4) | + 16.7% |
| Robotic-assisted | 9866 (5.9) | 12,028 (6.4) | 14,886 (7.4) | 19,335 (9.4) | + 96.0% |
| Open | 1671 (1.0) | 1709 (1.0) | 1575 (0.9) | 1420 (0.7) | − 15.0% |
| Other | 1478 (0.8) | 3467 (1.8) | 3585 (1.8) | 3103 (1.5) | + 109.9% |
| Total bariatric cases | 168,093 | 186,772 | 200,374 | 204,837 | |

Frequencies of bariatric procedures performed in the USA based on operative approach, 2015–2018. The designation of "other" includes natural orifice transluminal endoscopic surgery (NOTES), hand-assisted, and single incision approaches. Most notably, the number of robotic-assisted procedures and "other" procedures has grown by 96.0% and 109.9% respectively [1] of gastroesophageal reflux disease (GERD), biliopancreatic diversion with duodenal switch (BPD/DS) and related procedures remain procedures of choice for maximal weight loss, with %EWL ranging from 70 to 80% at 2 years [5–7].

Beyond the type of operation, long-term weight loss following bariatric and metabolic surgery is significantly predicted by short-term changes in energy intake and dietary distribution postoperatively [8]. Specifically, short-term reductions in energy intake ($p < 0.001$) at 6 months as well as changes in relative proportions of energy from carbohydrates ($p < 0.001$), fat ($p < 0.001$), and protein ($p < 0.05$) were significantly associated with 10-year weight change after bariatric surgery. Men and women with the largest reductions in energy intake at 6 months lost 7.3% and 3.9% more weight, respectively, when compared with study subjects who showed the smallest intake reductions ($p < 0.001$). Greater weight loss was also observed in patients who favored protein and carbohydrates over fat, and in subjects who favored protein over carbohydrates, than in patients who favored the opposite dietary macronutrient compositions ($p < 0.05$) [8].

## Remission of Obesity-Related Disease

The impact of bariatric and metabolic surgery on obesity-related disease is significant, and for many patients, it is the primary driver for surgical intervention [9] (Table 3). With regard to type 2 diabetes mellitus (T2DM) in particular, remission of disease following surgical intervention is significantly more likely among surgically treated patients than among those who receive no therapy or medical therapy alone [10–12]. Although more recent prospective trials and long-term studies question the near-complete remission rates purported by Buchwald's classic 2009 meta-analysis (95.1% for BPD/DS, 80.3% for RYGB, 79.7% for gastroplasty, and 56.7% for adjustable gastric banding), using contemporary criteria for complete remission, resolution of T2DM does occur in many patients following surgical intervention and is reasonably well-sustained at extended follow-up [3, 4, 7, 12]. A recent meta-analysis examining partial and complete remission of T2DM in patients treated with RYGB reported rates of 52.5% at 5 years, however only 27.5% at 5 years [12]. Among patients undergoing laparoscopic RYGB, baseline disease severity and antidiabetic medical requirement are significantly associated with overall long-term outcomes. In the overall diabetic population, remission of T2DM was observed in 75% of patients at 2 years, as compared with 62% of patients at 6 years and 51% of patients at 12 years. Lowest rates of remission were observed in patients with baseline insulin dependence, followed by those who were reliant on oral antidiabetic medication only, followed by those who did not require medication at baseline (16% at 12 years, versus 56% and 73%, respectively) [4•]. Authors attributed this distribution in outcomes to the variability of pancreatic beta cell function at time of surgery, specifically the greater potential for beta cell recovery in patients not yet requiring insulin. These findings are supported by other recent publications, where duration of T2DM less than 8 years at time of surgical intervention was the main predictor of ultimately achieving satisfactory disease control or remission (HgbA1c% < 6) [11].

As compared with RYGB, the impact of SG on T2DM remission is less well-studied; however based on recent published evidence, it does not appear significantly inferior to that seen with RYGB at medium-term follow-up [3, 11]. In a recent prospective clinical equivalence trial, complete or partial remission rates of T2DM at 5 years were observed in 37% of patients who underwent SG, as compared with 45% of patients who underwent RYGB ($p > 0.99$). Similarly, 5-year follow-up results of the STAMPEDE trial found excellent glycemic control (defined as HgbA1C < 6%) of 29% in patients treated with RYGB versus 23% of those treated with SG, without a statistically significant benefit to RYGB observed. Reductions in the rate of insulin use between patients treated with RYGB and SG were also similar (− 35% vs. − 34%, respectively) [11]. With additional long-term data and larger study populations, differences between these two procedures with respect to long-term remission of T2DM may be better understood. BPD/DS is supported in recent literature as the most effective and durable option for treatment of T2DM in surgically treated patients. In their 2015 randomized controlled trial, Mingrone et al. found BPD/DS to be superior to RYGB in sustaining remission of T2DM at 5 years postoperatively—specifically, 53% of patients with baseline T2DM treated with RYGB who experienced remission at 2 years had disease relapse at 5 years, as compared with only 37% of patients treated with BPD/DS [10]. Interestingly, changes in weight were not associated with remission or relapse of T2DM, a finding confirmed by other studies [10, 11]. With regard to cardiovascular disease, bariatric and metabolic surgery has long been associated with improvements in hypertension, hyperlipidemia, and overall cardiovascular health. Particularly in patients with T2DM, several recent publications have highlighted a protective effect of surgical intervention against adverse cardiovascular outcomes. When compared with non-surgically treated controls, surgically treated patients with insulin-dependent T2DM were observed to have significantly higher probability of survival related to non-fatal coronary artery disease at 1-, 5-, and 10-year follow-up (98% vs 89.6%, 92.2% vs 67.6%, and 84% vs 53.1% respectively, log-rank test $p < 0.001$) [13]. Probability of survival for non-fatal peripheral arterial disease (PAD) was also significantly reduced at 5- and 10-year follow-up (90.5% vs 78.8% and 84.0% vs 53.1% respectively, log-rank test $p = 0.007$). Outcomes for non-fatal acute myocardial infarction (AMI), stroke, and heart failure (HF) had little to no statistically significant differences between the study populations over the

**Table 3** Obesity-related diseases and comorbid conditions

| | |
|---|---|
| Cardiovascular disease | Musculoskeletal |
| Hypertension (HTN) | Degenerative arthritis |
| Coronary artery disease (CAD) | Impaired mobility |
| Acute myocardial infarction (AMI)<br>Cerebrovascular event (CVA) | Chronic pain |
| Heart failure (HF) | |
| Cardiac arrhythmias | |
| Metabolic | Reproductive |
| Type 2 diabetes mellitus (T2DM) | Infertility |
| Dyslipidemia (HLD) | Sexual dysfunction |
| Steatohepatitis/Non-alcoholic fatty liver disease (NAFLD) | Polycystic ovarian syndrome (PCOS) (female) |
| Pulmonary | Genitourinary |
| Obstructive sleep apnea (OSA) | Impaired renal function |
| Obesity hypoventilation syndrome (OHS) | Nephrolithiasis |
| Asthma | Stress urinary incontinence |
| Central nervous system | Psychosocial |
| Impaired cognition | Impaired quality of life |
| Headache<br>Pseudotumor cerebri | Depression |

Obesity-related diseases and comorbid conditions which may significantly improve or resolve after bariatric surgery [9]. Recent investigations suggest a particularly strong therapeutic effect with regard to type 2 diabetes mellitus (T2DM), heart failure (HF), and coronary artery disease (CAD)

10 years [13]. These findings were supported in a similar retrospective study, where patients with T2DM who underwent metabolic surgery were significantly less likely to experience a major adverse cardiovascular outcome (MACE) than those managed medically at 8 years (30.8% vs 47.7%, $p < 0.001$; absolute 8-year risk difference 16.9%; adjusted hazard ratio 0.61). In this analysis, all cause-mortality was also positively impacted (10% vs 17.8%; absolute 8-year risk difference 7.8%; adjusted hazard ratio 0.59) [14].

Additional investigation into the long-term risk of cardiovascular events and need for coronary revascularization in patients with and without T2DM suggests bariatric surgery offers a significant protective effect. In a recent propensity-matched retrospective cohort analysis with a median follow-up of over 6 years, bariatric surgery was associated with a significantly reduced rates of myocardial infarct (1.8% vs 10.0%, RR 0.18), coronary catheterization (1.9% vs 8.8%, RR 0.22), percutaneous coronary intervention (0.4% vs 7.8%, RR 0.05), and coronary artery bypass grafting (0.6% vs 2.3%, RR 0.26) [15].

Bariatric and metabolic surgery presents a uniquely efficacious therapy for patients with obesity and HF. The relative safety and efficacy of bariatric and metabolic surgical intervention in patients with severe HF has been well-documented in the literature by several authors in small patient populations. Surgical interventions both decrease hospital readmission rates significantly and improve overall cardiac function [16, 17]. More recent data suggests patients with a history of bariatric surgery subsequently admitted with HF have a nearly 50% reduction in in-hospital mortality and significantly shorter LOS than patients with morbid obesity and no history of bariatric surgery, as well a propensity score-matched patients with no history of bariatric surgery (in-hospital mortality 0.96% vs 1.86%, $p = 0.0013$, and 0.96% vs 1.86%, $p = 0.0011$, respectively; LOS $4.8 \pm 4.4$ versus $5.7 \pm 5.7$ days, $p < .001$, and $4.8 \pm 4.4$ versus $5.4 \pm 6.3$ days, $p < .001$, respectively) [18]. Furthermore, when used as primary prevention, bariatric surgery may significantly reduce the incidence of new HF diagnoses in patients with obesity. As found by a large-scale recent retrospective Swedish cohort study, patients with obesity who undergo RYGB are only half as likely to develop HF as similarly obese patients who undergo intensive lifestyle modification at a median follow-up of 4.1 years (hazard ratio 0.54, 95% CI 0.26–0.82) [19].

Obesity is a well-established risk factor for the development of certain malignancies, including breast, colon, rectum, corpus uteri, esophageal, gallbladder, gastric cardia, renal, liver, meningioma, multiple myeloma, ovary, pancreas, and thyroid [20] (Table 4). Bariatric and metabolic surgery is associated with a reduced risk of subsequent malignancy overall in controlled studies of patients with morbid obesity [21–23]. While bariatric surgery alone does not appear to confer any protective effect against malignancy, weight loss at 1 year following bariatric surgery is significantly associated with reduced risk of any cancer in both adjusted and unadjusted models (hazard ratio 0.897, $p = 0.005$ for every 10% weight loss in adjusted models; hazard ratio 0.876, $p \leq 0.001$ for every 10% weight loss in unadjusted models) [22]. This protective benefit appears to increase as time progresses. At extended follow-up (mean 3.5 years), surgically treated patients with severe obesity had a 33% lower hazard of developing any malignancy when compared to those who did not receive bariatric surgery (hazard ratio 0.67, $p < 0.001$). This effect was more pronounced when analysis was limited to obesity-associated malignancies including postmenopausal breast (hazard ratio 0.58, $p < 0.001$), colon (hazard ratio 0.59, $p = 0.04$), endometrial (hazard ratio 0.50, $p < 0.001$), and pancreatic cancer (hazard ratio 0.46, $p = 0.04$) [23].

## Postoperative Sequelae: Reflux, Barrett's Esophagus, and Feeding Intolerance

A comprehensive summary of common late postoperative complications following bariatric surgical intervention is provided in Tables 5 and 6 [1, 24–30]. Particularly with the increased prevalence of SG as compared with RYGB and other bariatric surgical interventions, postoperative gastroesophageal reflux disease (GERD) is of increasing concern. Recent long-term retrospective data suggests new-onset GERD symptoms occur in 47.8% of patients at an average follow-up of 8.48 years (range 6.1–10.3 years), despite an associated %EWL of 60% [28]. While these authors reported use of a 34-french bougie for all patients examined, which has since been discouraged, these results still merit attention. Along with worsening GERD symptoms, proton-pump inhibitor (PPI) use increased significantly among the study population: 52% of patients were reliant on PPI therapy at the end of the study period, as compared with only 15% preoperatively (relative risk 2.933, $p < 0.0001$). Among the 7 patients included in this study who underwent secondary RYGB for GERD, only 57.1% experienced complete resolution of their symptoms following revisional surgery [28].These findings were duplicated in a similar recent retrospective review, where all patients underwent SG completed with a 48-French bougie [29••]. At an average 58-month follow-up, incidence of GERD symptoms, visual analogue scales (VAS) mean score, and PPI use all increased significantly when compared with preoperative values (68.1% vs 33.6%, $p < 0.0001$; 3 vs 1.8, $p = 0.018$; 57.2% vs 19.1%, $p < 0.0001$). Of even more concern, upward migration of the Z line and biliary-like esophageal reflux was present in 73.6% and 74.5% of patients on upper endoscopy, respectively. While no significant correlations were found between reflux symptoms and endoscopic findings, Barrett's esophagus (BE) was newly diagnosed in 17.2% of patients postoperatively, and a significant increase in the incidence and severity of erosive esophagitis (EE) was observed, up to 59.8% at an average of 66 months postoperatively [29, 31]. Particularly given the poor correlation between visualized esophageal pathology and GERD symptoms, these authors suggest routine endoscopic surveillance of all SG patients may be indicated postoperatively.

In contrast to the above studies, long-term feeding tolerance in patients undergoing RYGB, biliopancreatic diversion (BPD), and duodenal switch (DS) appears fairly robust [32]. In a cross-sectional study of 196 patients who underwent one of these three bariatric procedures, mean food tolerance score (FTS) was 24.6, 24.0, and 23.7 for RYGB, BPD, and DS at mean follow-up of 87.9 months (scale of 1–27, 1 being horrible and 27 perfect). Alimentary satisfaction was observed in 73.3% of patients overall. No significant differences were found between the 3 procedures for FTS, alimentary satisfaction, or frequency of vomiting [32].

**Table 4** Relative risk of obesity-related malignancies in highest body mass index (BMI) patients versus normal BMI

| Cancer site or type | Relative risk (95% CI)* |
|---|---|
| Esophageal adenocarcinoma | 4.8 (3.0–7.7) |
| Gastric cardia | 1.8 (1.3–2.5) |
| Colon and rectum | 1.3 (1.3–1.4) |
| Liver | 1.8 (1.6–2.1) |
| Gallbladder | 1.3 (1.2–1.4) |
| Pancreas | 1.5 (1.2–1.8) |
| Breast (post-menopausal) | 1.1 (1.1–1.2) |
| Corpus uteri | 7.1 (6.3–8.1) |
| Ovarian | 1.1 (1.1–1.2) |
| Renal cell carcinoma | 1.8 (1.7–1.9) |
| Meningioma | 1.5 (1.3–1.8) |
| Thyroid | 1.1 (1.0–1.1) |
| Multiple myeloma | 1.5 (1.2–2.0) |

Compiled by the International Agency for Research on Cancer (IARC), the above values represent the most recent or comprehensive meta-analysis or pooled analysis available at time of the meeting resulting in the cited publication (April 12–15, 2016). Obesity-associated malignancies listed above are those for which sufficient evidence exists to establish an increased risk, defined as the establishment of a preventative relationship between the absence of obesity and the development of malignancy. Normal BMI is defined as 18.5–24.9. Data is pooled from multiple sources so highest BMI is not uniformly defined [20]

## Robotic Surgery

Robotic-assisted surgical platforms are an increasingly utilized adjunct to traditional laparoscopy in bariatric and metabolic interventions worldwide. While surgeon comfort, improved technical dexterity, and greater ease of use in patients with high body mass index (BMI) are purported as selling points of the robotic platform, the majority of outcomes research to date has failed to demonstrate a consistent benefit of robotic-assisted bariatric and metabolic surgery over

**Table 5** Postoperative long-term complications and deleterious effects following bariatric and metabolic surgery

| | Bariatric surgery | SG | RYGB | LAGB | BPD/DS | Key points |
|---|---|---|---|---|---|---|
| Operative vs. nonoperative mortality [24] | HR 2.02 [95% CI, 1.6 to 2.5] | HR 1.60 [95% CI, 1.02 to 2.5] | HR 2.65 [95% CI, 1.6 to 4.5] | HR 2.01 [95% CI, 1.5 to 2.7] | | Operative intervention results in significant reduction in mortality versus nonoperative |
| 30-day mortality rate [1] | 0.11% | 0.08% | 0.12% | 0.06% | 0.29% | Overall 30-day mortality rate is stable and extremely low |
| Suicide [25] | Incidence 2.7/1000 (CI 0.0019–0.0023) | | | | | RYGB has 3× increase rate of suicide versus LAGB |
| Self-harm [25] | Incidence 17/1000 (CI 0.010–0.030) | | | | | Risk of self-harm and suicide is increased following bariatric procedures |
| Bone mineral density levels at femoral neck [26] | Operative group mean difference compared to nonoperative group: − 0.05 g/cm$^2$ (CI, − 0.07 to − 0.02; $p = 0.001$) | | RYGB mean difference compared to nonoperative group: − 0.02 g/cm2 (CI, − 0.05 to 0.01; $p = 0.235$) | | | Malabsorptive and mixed procedures result in greater reduction in BMD versus restrictive procedures |
| Bone mineral density levels at lumbar spine [26] | Operative group mean difference compared to nonoperative group: − 0.01 g/cm2 (CI, − 0.07 to 0.05; $p = 0.661$) | | RYGB mean difference compared to nonoperative group: − 0.04 g/cm2 (95% CI, − 0.08 to 0.00; $p = 0.056$) | | | No significant differences in BMD in lumbar spine regardless of operative versus nonoperative intervention status |
| Fracture [27] | RR 2.3 at osteoporotic and non-osteoporotic sites | | | | | |
| Postoperative GERD [24, 28] | 47.8% | 31.6% | 10.7% | | | Worsening of symptoms occurs in 31.8% of sleeve gastrectomy versus 6.3% of RYGB; $P = 0.006$ |
| Barrett's esophagus [29, 30] | | 17.2% Barrett's metaplasia present in 28% of redo cases related to reflux | | | | |
| Incisional hernia [1] | 0.08% | 0.08% | 0.09% | 0.38% | 0.11% | Overall incisional hernia rate is stable and extremely low |

Postoperative long-term complications and deleterious effects which may occur following bariatric and metabolic surgery. *RYGB* Roux-en-Y gastric bypass, *LAGB* laparoscopic adjustable gastric band, *BPD/DS* biliopancreatic diversion with duodenal switch, *HR* hazard ratio, *CI* confidence interval, *BMD* bone mineral density, *RR* relative risk, *GERD* gastroesophageal reflux disorder

**Table 6** Nutritional deficiencies following bariatric surgery

| | |
|---|---|
| Iron | Occurs in over 30% of all patients who undergo bariatric surgery by 5 years postoperatively. Common with both restrictive and malabsorptive procedures. |
| Vitamin B12 | Occurs in 19–35% of patients who undergo malabsorptive procedures by 5 years postoperatively. |
| Folate | Occurs in 9–39% of patients after both restrictive and malabsorptive procedures. |
| Thiamine | Occurs in up to 49% of patients after both restrictive and malabsorptive procedures, as a result of jejunal bypass or persistent vomiting. |
| Calcium | Occurs in nearly 10% of patients. |
| Vitamin D | Occurs in 25–73% of patients, dependent on duration of follow-up and defining parameters. |
| Vitamins A, E, and K | Actual prevalence of deficiencies unknown, although common in malabsorptive procedures. |
| Vitamin C | Occurs in 10–50% of patients, although rarely clinically significant. |
| Micronutrients | Include magnesium, zinc, copper, and selenium. Actual prevalence of deficiencies unknown, although common in malabsorptive procedures |
| Protein malnutrition | More common in malabsorptive procedures (BPD/DS, 7–21%; RYGB with roux limb > 150 cm, 13%) |

Postoperative nutritional deficiencies which may occur after bariatric surgery. Baseline nutritional deficiencies are often present in bariatric surgical patients prior to surgery and should be assessed and corrected as able prior to surgical intervention. Anemia secondary to iron deficiency and/or B12 or folate deficiency is very common postoperatively, affecting 33–49% of patients within 2 years. 10–12% of obese patients have anemia prior to surgical intervention [27]. *SG* sleeve gastrectomy, *RYGB* Roux-en-Y gastric bypass, *BPD/DS* biliopancreatic diversion with duodenal switch. Malabsorptive procedures include BPD/DS and RYGB. Predominantly restrictive procedures refer to SG and laparoscopic adjustable gastric band (LAGB)

traditional laparoscopy. A recent extensive retrospective review of 77,991 patients who underwent primary RYGB (7.5% robotic-assisted) and 189,503 patients who underwent primary SG (6.8% robotic assisted) found that on the whole, aggregate bleeding complications and transfusion requirements were less in the robotic-assisted cohorts (for example 1.0% vs 0.5%, $p = 0.0005$ for transfusion and 0.8% vs 0.4%, $p = 0.03$ for aggregate bleeding, for RYGB in 1:3 matched patient factor analysis) [33]. Outcomes were otherwise similar for both SG and RYGB, with several exceptions. For RYGB, lower mortality rates ($p = 0.05$) and surgical site infections (SSIs) ($p = 0.0006$) were observed, despite longer operative times using the robotic platform (151.9 min vs 114.6 min, $p < 0.0001$). For SG, a longer length-of-stay (LOS) was observed ($p < 0.0001$) along with higher rates of conversion ($p > 0.0001$), 30-day intervention ($p = 0.01$), operative drain placement ($p < 0.0001$), sepsis ($p = 0.01$), and organ space SSI ($p = 0.0002$) in the robotic-assisted cohort. Despite statistical significance, the majority of these differences were fairly minute, leading study authors to conclude potential benefits of robotic-assisted RYGB and SG found most likely represented a complex interplay between surgeon experience and the surgical platform used [33].

With regard to surgical education, another retrospective review focused on robotic-assisted SG utilizing residents for tissue exposure concluded that while significantly increased cost supply was associated with the robotic platform as compared with its laparoscopic equivalent, preliminary morbidity rates and operative times were similar to historic laparoscopic controls. No differences in operative times between BMI cohorts 50–59 kg/m2 and 30–49 kg/m2 were observed, suggesting a robotic platform may be beneficial in patients with higher BMIs [34].

## Revisional Surgery

As reasons for weight recidivism and other common postoperative sequelae such as GERD become better understood with time, patients who experience these after effects following a primary bariatric surgical intervention frequently present for revisional surgical consideration. Large-scale prospective data in this area is generally lacking. However, in a single-center, retrospective review of 534 patients presenting for revisional evaluation, 64% sought evaluation for weight regain (true of all procedures except BPD/DS), 26% for dysphagia, and 21% for lap band-related complications [35]. Seventy-eight and 88% of patients presenting with band slippage or insufficient weight loss, respectively, were medical tourists, leading study authors to conclude poor follow-up played a substantial role in these postoperative issues. Patients with uncontrolled psychosocial and medical issues were also much more likely to struggle with weight recidivism despite an anatomically successful surgery. Patients who underwent revisional surgery experienced higher rates of postoperative complications than those undergoing primary surgery (41% vs 15%, $p < 0.0001$), most commonly wound infections (24%). Revisional surgeries took on average 0.4 h longer than primary surgeries, and patients remained in the hospital for a median of 2 days longer, both statistically significant differences. Revisional surgery (most commonly RYGB) was successful in assisting weight loss, comparable to that seen in the primary surgery group and significantly more than in patients managed with lifestyle modification alone (%EWL 61.2%, $p < 0.0001$) [35].BPD/DS may present a valuable revisional option for selective patients with super morbid obesity and/or weight regain following SG in the absence of reflux symptoms [5, 36]. A recent expert-consensus paper examining revisional BPD/DS cited a vast majority of experts (96.7%) as supporting this position, specifically for a 2-stage operation. Ninety percent of authors also favored RYGB over BPD/DS for patients with weight regain after SG with associated reflux, and/or enlarged fundus [5]. While BPD/DS remains limited in general applicability by technical difficulty and operative duration, several simplified versions of the procedure such as single-anastomosis duodenoileostomy (SADI) may lead to similar postoperative outcomes with increased ease of completion [6, 36]. Indeed, this concept is well-supported in a recent retrospective cohort study where patients with failed SG underwent SADI or RYGB, primarily based on the absence or presence of reflux symptoms, as well as desire for additional weight loss. Patients who underwent SADI experienced 8.7%, 12.4%, and 19.4% more weight loss compared to those who underwent RYGB at 6, 12, and 24 months postoperatively (all $p < 0.001$), while all patients treated with revisional RYGB for GERD or dysphagia all experienced improvement in these symptoms. Similar rates of complications and nutritional deficiencies were observed in both groups [36].

## Adolescent Bariatric and Metabolic Surgery

Since the hallmark publication by Inge et al. in 2014 examining outcomes from the Teen-Longitudinal Assessment of Bariatric Surgery (Teen-LABS) study which cited similar outcomes and postoperative complication rates in adolescent and adult populations undergoing bariatric and metabolic surgery, several subsequent publications have further delineated specific and significant beneficial effects towards youth-onset T2DM [37, 38]. Indeed, youth-onset T2DM now accounts for a substantial percentage of new pediatric diabetes cases annually and appears to be significantly more aggressive than its adult counterpart. Nearly 50% of teens with T2DM progress to insulin dependence after a median of 11 months, suggesting rapid loss of pancreatic beta-cell function which outpaces that typically seen in adult disease [38•]. In a secondary analysis of the Teen-LABS data released in 2018, in which surgical outcomes related to diabetes were compared with a population of adolescent patients with T2DM managed with lifestyle modification and/or medical therapy, surgical therapy was vastly superior. While patients who underwent metabolic surgery experienced greater weight loss (BMI −29.0% vs + 3.7%) and improvement in HgbA1C (6.8 to 5.5%, vs 6.4 to 7.8%) at 2 years than those managed medically, adolescents in the surgical arm of the study also had a greater than expected improvement in T2DM (95% with HgbA1C < 6.5%) when compared to adult populations, despite similar operations, weight loss, and definitions of disease [38•].

With regard to other obesity-related comorbid conditions, bariatric and metabolic surgery in adolescents is also associated with significant improvements in blood pressure, dyslipidemia, serum inflammatory markers, and abnormal kidney function not seen in medically treated counterparts, as well as functional mobility and musculoskeletal pain [38–40]. Younger adolescent patients appear more likely than older adolescent patients to resolve dyslipidemia, while girls appear more likely than boys to resolve elevated blood pressure [39].

In reflection of these findings, a recent policy statement released by the American Academy of Pediatrics (AAP) advocated for increased access for pediatric patients with severe obesity (defined as BMI ≥ 35 or ≥ 120% of the 95th percentile for age and sex, whichever is lower) to multidisciplinary programs with high-quality pediatric metabolic and bariatric surgical capabilities. While the majority of pediatric patients undergo bariatric surgery as adolescents (defined as age 13 to 18 years), available data does not support a lower age limit for weight-loss surgery in youth. As such, the AAP supports individualized patient-centered care and avoidance of "unsubstantiated lower age limits" when considering surgical referral [41].

## Conclusion

Bariatric and metabolic surgical intervention remains a highly effective therapy for obesity and obesity-related comorbid conditions. While SG and RYGB produce similar weight loss patterns and remission of obesity-related disease at medium-term follow-up, highly prevalent rates of GERD and dysphagia following SG may ultimately limit the long-term success of this procedure. Routine surveillance endoscopy may also be indicated in SG, given high rates of esophagitis and Barrett's esophagus found in these patients postoperatively. When utilized as therapy for T2DM, bariatric and metabolic surgery is most effective in adolescent patients and adult patients who are non-insulin dependent. Surgery is also effective for the prevention of coronary artery disease and related interventions in both diabetic and nondiabetic populations. Robotic-assisted laparoscopic platforms have generally equivalent outcomes to laparoscopic intervention, with a potential benefit in high BMI patients. Revisional surgery is commonly performed for inadequate weight loss or reflux/dysphagia following primary surgery, with outcomes characterized by higher complication rates and longer inpatient LOS. Bariatric and metabolic surgical intervention in adolescent patients with morbid obesity and obesity-related comorbidities is safe and effective, with overall similar outcomes to those seen in adult populations. With regard to youth-onset T2DM in particular, outcomes related to metabolic surgical intervention outpace those seen in adult populations.

## References

Papers of particular interest, published recently, have been highlighted as:
• Of importance
•• Of major importance


1. Metabolic and Bariatric Surgery Accreditation and Quality Improvement Program (2015-2018). *Participant use data file* [Database]. **Retrieved from** https://reports.nsqip.facs.org/acsMbsaqip.
2.• Peterli R, Wolnerhanssen BK, Peters T, et al. Effect of laparoscopic sleeve gastrectomy vs laparoscopic Roux-en-Y gastric bypass on weight loss at 5 years among patients with morbid obesity: the SM-BOSS randomized clinical trial. JAMA 2018:319(3):255–65. **A randomized-controlled trial of 217 patients who underwent RYGB or SG: while weight loss outcomes favored RYGB, no statistically significant differences in excess BMI lost at 5 years were identified between the two procedures.**
3.• Salminen P, Helmio M, Ovaska J, et al. Effect of laparoscopic sleeve gastrectomy vs laparoscopic Roux-en-Y gastric bypass on weight loss at 5 years among patients with morbid obesity: The SLEEVEPASS randomized clinical trial. JAMA 2018;319(3): 241–54. **While postoperative weight loss patterns between SG and RYGB fail to demonstrate clinical equivalence of the two procedures, RYGB is not associated with a statistically significant weight loss benefit at 5 years.**
4.• Adams TD, Davidson LE, Litwin SE, et al. Weight and metabolic outcomes 12 years after gastric bypass. NEJM 2017:377(12):1143–55**. Randomized-controlled trial examining long-term outcomes of patients who undergo RYGB. Initial weight loss and T2DM remission patterns observed at 2 years were reasonably well-sustained at 6 and 12 years, although mild increase in study population mean body weight and decrease in the T2DM remission rate were observed over time. Overall remission of T2DM was best predicted by baseline medication status.**
5. Merz AE, Blackstone RB, Gagner M, Torres AJ, Himpens J, Higa KD, et al. Duodenal switch in revisional bariatric surgery: conclusions from an expert consensus panel. Surg Obes Relat Dis. 2019;15(6):894–9.
6. Balibrea JM, Vilallonga R, Hidalgo M, Ciudin A, González Ó, Caubet E, et al. Mid-term results and responsiveness predictors after two-step single-anastomosis duodeno-ileal bypass with sleeve gastrectomy. Obes Surg. 2017;27(5):1302–8.
7. Buchwald H, Estok R, Fahrbach K, Banel D, Jensen MD, Pories WJ, et al. Weight and type 2 diabetes after bariatric surgery: systematic review and meta-analysis. Am J Med. 2009;122(3):248–56.
8. Kanerva N, Larsson I, Peltonen M, Lindroos AK, Carlsson LM. Changes in total energy intake and macronutrient composition after bariatric surgery predict long-term weight outcome: findings from the Swedish Obese Subjects (SOS) study. Am J Clin Nutr. 2017;106(1):136–45.
9. Wolfe BM, Kvach E, Eckel RH. Treatment of obesity: weight loss and bariatric surgery. Circ Res. 2016;118(11):1844–55.
10. Mingrone G, Panunzi S, De Gaetano A, et al. Bariatric-metabolic surgery versus conventional medical treatment in obese patients with type 2 diabetes: 5 year follow-up of an open-label, single-centre, randomized controlled trial. Lancet. 2015;386(9997):964–73.
11. Schauer PR, Bhatt DL, Kirwan JP, Wolski K, Aminian A, Brethauer SA, et al. Bariatric surgery versus intensive medical therapy for diabetes – 5-year outcomes. NEJM. 2017;376(7):641–51.
12. Khorgami Z, Shoar S, Saber AA, Howard CA, Danaei G, Sclabas GM. Outcomes of bariatric surgery versus medical management for type 2 diabetes mellitus: a meta-analysis of randomized controlled trials. Obes Surg. 2019;29(3):964–74.
13. Alkharaiji M, Anyanwagu U, Donnelly R, Idris I. Effect of bariatric surgery on cardiovascular events and metabolic outcomes in obese patients with insulin-treated type 2 diabetes: a retrospective cohort study. Obes Surg. 2019;29(10):3154–64.
14. Aminiam A, Zajichek A, Arterburn DE, et al. Association of metabolic surgery with major adverse cardiovascular outcomes in patients with type 2 diabetes and obesity. JAMA. 2019 Sep;2 **Epub ahead of print**.
15. Michaels AD, Mehaffey JH, Hawkins RB, Kern JA, Schirmer BD, Hallowell PT. Bariatric surgery reduces long-term rates of cardiac events and need for coronary revascularization: a propensity-matched analysis. Surg Endosc. 2019 Aug;2 **Epub ahead of print**.
16. Ramani GV, McCloskey C, Ramanathan RC, Mathier MA. Safety and efficacy of bariatric surgery in morbidly obese patients with severe systolic heart failure. Clin Cardiol. 2008;31(11):516–20.
17. McCloskey CA, Ramani GV, Mathier MA, et al. Bariatric surgery improves cardiac function in morbidly obese patients with severe cardiomyopathy. Surg Obes Relat Dis. 2007;3(5):503–7.
18. Aleassa EM, Khorgami Z, Kindel TL, Tu C, Tang WHW, Schauer PR, et al. Impact of bariatric surgery on heart failure mortality. Surg Obes Relat Dis. 2019;15(7):1189–96.
19. Sundström J, Bruze G, Ottosson J, Marcus C, Näslund I, Neovius M. Weight loss and heart failure: a nationwide study of gastric bypass surgery versus intensive lifestyle treatment. Circulation. 2017;135(17):1577–85.
20. Lauby-Secretan B, Scoccianti C, Loomis D, Grosse Y, Bianchini F, Straif K, et al. Body fatness and cancer – viewpoint of the IARC Working Group. NEJM. 2016;375:794–8.
21. Casagrande DS, Rosa DD, Umpierre D, Sarmento RA, Rodrigues CG, Schaan BD. Incidence of cancer following bariatric surgery: systemic review and meta-analysis. Obes Surg. 2014;24(9):1499–509.
22. Schauer DP, Feigelson HS, Koebnick C, Caan B, Weinmann S, Leonard AC, et al. Association between weight loss and the risk of cancer after bariatric surgery. Obesity. 2017;25(Suppl 2):S52–7.
23. Schauer DP, Feigelson HS, Koebnick C, Caan B, Weinmann S, Leonard AC, et al. Bariatric surgery and the risk of cancer in a large multicenter cohort. Ann Surg. 2019;269(1):95–101.
24. Arterburn D, Gupta A. Comparing the outcomes of sleeve gastrectomy and Roux-en-Y gastric bypass for severe obesity. JAMA. 2018;319(3):235–7.
25. Castaneda D, Popov VB, Wander P, Thompson CC. Risk of suicide and self-harm is increased after bariatric surgery – a systematic review and meta-analysis. Obes Surg. 2019;29(1):322–33.
26. Ko BJ, Myung SK, Cho KH, Park YG, Kim SG, Kim do H, Kim SM. Relationship between bariatric surgery and bone mineral density: a meta-analysis. Obes Surg 2016;26(7):1414–1421.
27. Lupoli R, Lembo E, Saldalamacchia G, Kesia Avola C, Angrisani L, Capaldo B. Bariatric surgery and long-term nutritional issues. World J Diabetes. 2017;8(11):464–74.

28. Mandeville Y, Van Looveren R, Vancoillie PJ, et al. Moderating the enthusiasm of sleeve gastrectomy: up to fifty percent of reflux symptoms after ten years in a consecutive series of one hundred laparoscopic sleeve gastrectomies. Obes Surg. 2017;27(7):1797–803.
29.•• Genco A, Soricelli E, Casella G, et al. Gastroesophageal reflux disease and Barrett's esophagus after laparoscopic sleeve gastrectomy: a possible, underestimated long-term complication. Surg Obes Relat Dis 2017;13(4):568–74. **Retrospective study evaluating GERD symptoms, PPI use, and endoscopic findings in patients who underwent SG at an average of 58 months following surgery. While reflux symptoms and PPI use were present in a majority of patients, significantly increased rates of erosive esophagitis and Barrett's esophagitis were also identified, with no significant correlation with reflux symptoms.**
30. Ebrahimi R, Kermansaravi M, Khalaj A, Eghbali F, Mousavi A, Pazouki A. Gastro-intestinal tract cancers following bariatric surgery: a narrative review. Obes Surg. 2019;29(8):2678–94.
31. Soricelli E, Casella G, Baglio G, Maselli R, Ernesti I, Genco A. Lack of correlation between gastroesophageal reflux disease symptoms and esophageal lesions after sleeve gastrectomy. Surg Obes Relat Dis. 2018;14(6):751–6.
32. Cano-Valderrama O, Sánchez-Pernaute A, Rubio-Herrera MA, Domínguez-Serrano I, Torres-García AJ. Long-term food tolerance after bariatric surgery: comparison of three different surgical techniques. Obes Surg. 2017;27(11):2868–72.
33. Acevedo E Jr, Mazzei M, Zhao H, Lu X, Soans R, Edwards MA. Outcomes in conventional laparoscopic versus robotic-assisted primary bariatric surgery: a retrospective, case-controlled study of the MBSAQIP database. Surg Endosc. 2019 Jun;17 **Epub ahead of print**.
34. Ecker BL, Maduka R, Ramdon A, Dempsey DT, Dumon KR, Williams NN. Resident education in robotic-assisted vertical sleeve gastrectomy: outcomes and cost-analysis of 411 consecutive cases. Surg Obes Relat Dis. 2016;12(2):313–20.
35. Fulton C, Sheppard C, Birch D, Karmali S, de Gara C. A comparison of revisional and primary bariatric surgery. Can J Surg. 2017;60(3):205–11.
36. Dijkhorst PJ, Boerboom AB, Janssen IM, et al. Failed sleeve gastrectomy: single anastomosis duodenoileal bypass or Roux-en-Y gastric bypass? A multicenter cohort study. Obes Surg. 2018;28(12):3834–42.
37. Inge TH, Zeller MH, Jenkins TM, Helmrath M, Brandt ML, Michalsky MP, et al. Perioperative outcomes of adolescents undergoing bariatric surgery: the Teen-Longitudinal Assessment of Bariatric Surgery (Teen-LABS) study. JAMA Pediatr. 2014;168(1):47–53.
38.• Inge TH, Laffel LM, Jenkins TM, et al. Comparison of surgical and medical therapy for type 2 diabetes in severely obese adolescents. JAMA Pediatr 2018;172(5):452–60. **Subanalysis of the Teen-LABS study demonstrating robust efficacy of bariatric and metabolic surgical intervention in treating youth-onset T2DM in severely obese adolescents, with improved outcomes compared to adult populations.**
39. Michalsky MP, Inge TH, Jenkins TM, et al. Cardiovascular risk factors after adolescent bariatric surgery. Pediatrics 2018;141(2). pii:e20172485.
40. Ryder JR, Edwards NM, Gupta R, Khoury J, Jenkins TM, Bout-Tabaku S, et al. Changes in functional mobility and musculoskeletal pain after bariaric surgery in teens with severe obesity: Teen-Longitudinal Assessment of Bariatric Surgery (LABS) study. JAMA Pediatr. 2016;170(9):871–7.
41. Armstrong SC, Bolling CF, Michalsky MP, Reichard KW. Pediatric metabolic and bariatric surgery: evidence, barriers, and best practices. Pediatrics 2019;144(6): pii: e20193223.