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Outcomes in conventional laparoscopic versus robotic-assisted primary bariatric surgery: a retrospective, case–controlled study of the MBSAQIP database

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Abstract

Introduction Robotic-assisted bariatric surgery is increasingly performed. There remains controversy about the overall benefit of robotic-assisted (RBS) compared to conventional laparoscopic (LBS) bariatric surgery. In this study, we used a large national risk-stratified bariatric clinical database to compare outcomes between robotic and laparoscopic gastric bypass (RNYGB) and sleeve gastrectomy (SG).

Methods A retrospective analysis of the 2015 and 2016 Metabolic and Bariatric Surgery Accreditation and Quality Improvement Program (MBSAQIP) Participant Use Data File (PUF) was performed. Primary robotic and laparoscopic RYNGB and SG were analyzed. Descriptive analysis was performed of the unmatched cohorts, followed by 1:3 case-controlled matching. Cases and controls were matched by patient demographics and pre-operative comorbidities, and peri-operative outcomes compared.

Results 77,991 Roux-en-Y gastric bypass (RnYGB) (7.5% robotic-assisted) and 189,503 SG (6.8% robotic-assisted) cases were identified. Operative length was significantly higher in both the robotic-assisted RnYGB and SG cohorts ($p < 0.0001$). Outcomes were similar between the robotic-assisted and laparoscopic RnYGB cohorts, except a lower mortality rate ($p = 0.05$), transfusion requirement ($p = 0.005$), aggregate bleeding ($p = 0.04$), and surgical site infections (SSI) ($p = 0.006$) in the robotic-assisted cohort. Outcomes were also similar between robotic-assisted and laparoscopic SG, except for a longer length of stay ($p < 0.0001$) and higher rates of conversion ($p < 0.0001$), 30-day intervention ($p = 0.01$), operative drain present ($p < 0.0001$), sepsis ($p = 0.01$), and organ space SSI ($p = 0.0002$) in the robotic cohort. Bleeding was lower in the robotic SG cohort and mortality was similar.

Conclusion Both robotic-assisted and laparoscopic RnYGB and SG are overall very safe. Robotic-assisted gastric bypass is associated with a lower mortality and morbidity; however, a clear benefit for robotic-assisted SG compared to laparoscopic SG was not seen. Given the longer operative and hospital duration, robotic SG is not cost-effective.

Keywords Primary bariatric surgery · Robotic-assisted · Conventional laparoscopic

Obesity is a worldwide epidemic. According to the World Health Organization (WHO), in 2016 more than 1.9 billion adults were overweight and over 650 million were classified as obese globally [1]. Obesity is a preventable disease that is caused by excessive caloric intake, fat accumulation, and fat dysregulation, and is associated with considerable deleterious downstream effects. It has been found to significantly increase the risk of chronic diseases, such as obstructive sleep apnea, diabetes, cardiovascular disease, hypertension, and even some cancers [2]. In 1967, Edward E. Mason introduced the concept of surgical gastric restriction for the treatment of morbid obesity [3]. Since then, techniques in bariatric surgery have been refined and many studies report

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successes in sustaining weight loss and resolution of, or improvement in comorbid conditions [4–8]. In fact, in 2014 the National Institutes of Health (NIH) held a consensus panel to review evidence regarding its safety and efficacy in treating obesity. They concluded that there is sufficient evidence to support metabolic and bariatric surgery for the treatment of obesity and type 2 diabetes mellitus (T2DM) [8].

Surgical approaches to weight loss continue to evolve. Technologies such as laparoscopic and robotic-assisted surgical systems have revolutionized metabolic and bariatric surgery to the point where many of these operations can be performed in an outpatient setting, or require a relatively short hospital length of stay (HLOS). Many studies have compared laparoscopic (LBS) and robotic-assisted (RBS) metabolic and bariatric surgery with varied results [4, 9–20]. Baily et al. performed a systematic review and economic analysis that compared laparoscopic and robotic-assisted Roux-en-Y gastric bypasses, and found that complication rates, operative outcomes, and HLOS did not differ significantly between the two surgical approaches [9]. In a more recent systematic review and meta-analysis, Li et al. found that there were no significant differences between conventional laparoscopic (LBS) and robotic-assisted (RBS) metabolic and bariatric surgery in overall post-operative complications, major complications, readmission, conversion, or mortality [10]. They also noted that robotic-assisted cases were associated with longer operative time and HLOS when compared to laparoscopic procedures, in contrast to findings by Bailey et al. [9]. Although this most recent systematic review and meta-analysis included 34 observational studies, only 27,997 patients were included in the meta-analysis. In fact, many of the studies evaluating laparoscopic and robotic-assisted bariatric surgery have been limited by small numbers and have reported mix results. Here, we present one of the largest retrospective case-control studies of the Metabolic and Bariatric Surgery Accreditation and Quality Improvement Program (MBSAQIP) Participant User Files (PUF) database comparing peri-operative outcomes between conventional laparoscopic and robotic-assisted primary Roux-en-Y gastric bypass (RnYGB) and sleeve gastrectomy (SG) cases.

Materials and methods

Data source and case selection

We performed a retrospective analysis of the 2015 and 2016 Metabolic and Bariatric Surgery Accreditation and Quality Improvement Program Participant Use File (MBSAQIP PUF) for this study comparing primary robotic-assisted and conventional laparoscopic metabolic and bariatric surgery. The MBSAQIP PUF is the largest bariatric-specific clinical database. It collects prospective risk-adjusted data based on standardized definitions. Data are collected by trained clinical nurse reviewers at each bariatric center and audited similar to the National Surgical Quality Improvement Program (NSQIP). De-identified data are reported on patient characteristics, operative details, and intra-operative and peri-operative outcomes. An Institutional Review Board (IRB) approval was not required as the study utilized only de-identified data from a nationally available clinical database.

There are 355,675 bariatric cases in combined 2015 and 2016 MBSAQIP PUF. We selected primary gastric bypass and sleeve gastrectomy cases by Current Procedural Terminology (CPT) codes 43644, 43645, and 43775. Inclusion and exclusion criteria are detailed in Fig. 1. Cases stratified by revision/conversion variable were first excluded. Open metabolic and bariatric procedures (CPT codes 43845, 43663, 43846, and 43847) were also excluded. Cases were then selected by variable "Surgical_Approach," limiting selection to only conventional laparoscopic and robotic-assisted cases. Cases with missing data were additionally excluded from analysis.

Case–control matching

In order to control for variables that may influence outcomes comparing the conventional laparoscopic and robotic-assisted cohorts, cases and controls were matched by patient demographics (age, gender, race/ethnicity, and body mass index (BMI) closest to surgery), functional status (ASA classification, limited ambulation status, partial functional dependence, and total functional dependence), and pre-existing comorbid conditions (hypertension requiring medication, hyperlipidemia, myocardial infarction, renal insufficiency, chronic renal disease requiring dialysis, vein thrombosis requiring therapy, history of pulmonary emboli, diabetes mellitus, current smoking within 1-year, obstructive sleep apnea, chronic obstructive lung disease, oxygen dependence, and steroid/immunosuppressant use). An initial 1:3 case–control matching was performed with the above covariates for both sleeve gastrectomy and gastric bypass cases independently. In order to account for surgeon experience as a possible confounder, a second procedure-specific 1:3 case–control match analysis was performed, controlling for operative duration and conversion, as these variables may correlate with surgeon experience—a variable that is missing from the MBSAQIP PUF database. In addition to the patient demographics and pre-operative comorbidities included in the first matched analysis, operative duration and conversion rate were included as matching covariates in the second procedure-specific case–control match analysis.

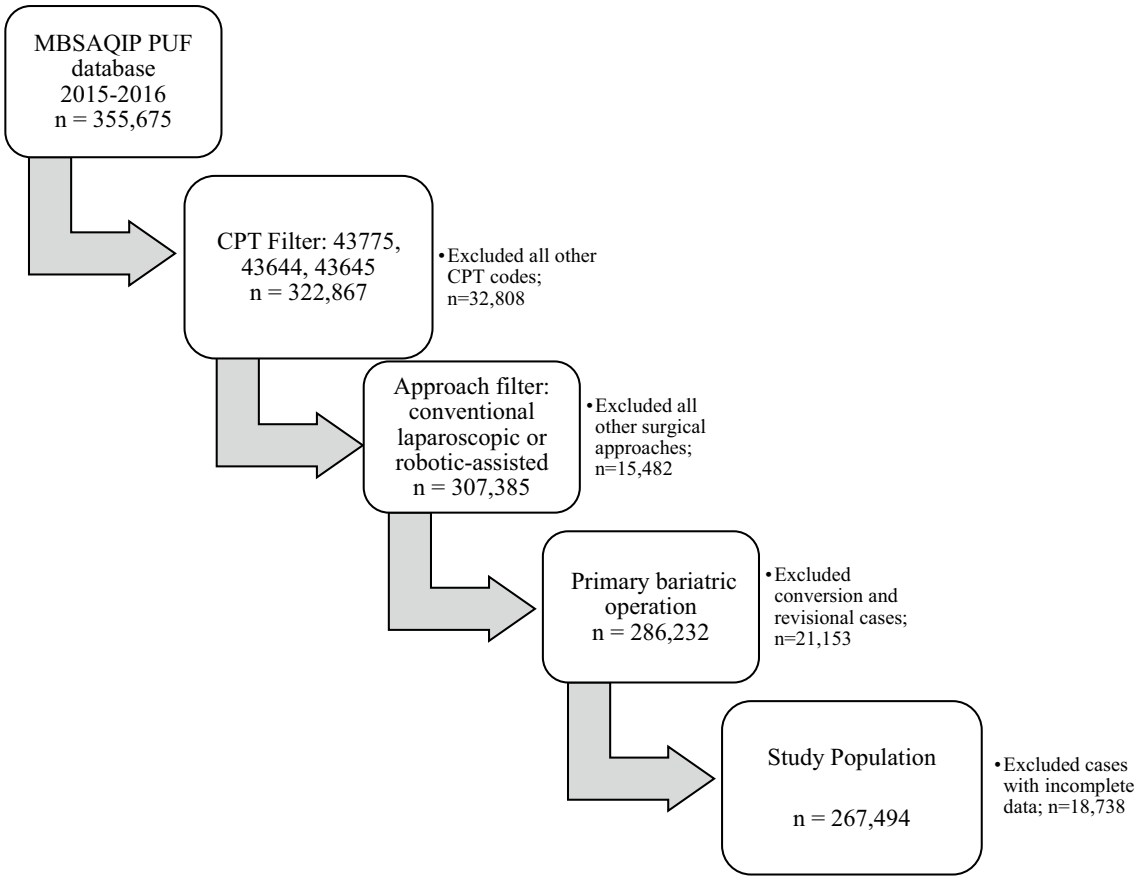

Fig. 1 Case selection flow diagram. Flow diagram outlining case inclusion and exclusion criteria. *MBSAQIP PUF* Metabolic and Bariatric Surgery Accreditation and Quality Improvement Project Participant Use Data File, *CPT* CPT

Outcome measures

Thirty-one primary outcome variables were assessed, including operative length, HLOS, conversion rate, discharge status, 30-day ICU admission, reoperation, readmission, intervention or mortality, drain present at 30-days, death likely related to bariatric surgery, renal failure, progressive renal insufficiency, cardiopulmonary resuscitation (CPR), coma > 24 h, stroke, myocardial infarction (MI), venous thrombosis requiring therapy, pulmonary emboli (PE), anticoagulation for presumed/confirmed vein thrombosis/PE, transfusion, pneumonia, unplanned intubation, on ventilator > 48 h, urinary tract infection (UTI), sepsis, septic shock, superficial surgical site infection (SSI), deep SSI, and organ space SSI. Seven aggregate complications were also assessed, including aggregate leak, bleeding, renal, cardiovascular and pulmonary complications, venous thromboembolic events, and surgical site infections. These composite complications methodology has been previously reported by Berger et al. [21] and are based on variables in the Related File of the MBSAQIP PUF. For example, aggregate leak is defined by 30-day reoperation, readmission or intervention with the suspected reason being a "leak", the presence of a drain at 30-days, and organ space SSI. Outcome measures were analyzed and reported for gastric bypass and sleeve gastrectomy unmatched and matched patient cohorts.

Statistical analysis

Univariate analysis of patient demographics and comorbid conditions was performed using Pearson's Chi squared test for categorical variables (gender, race, ASA class, preoperative comorbidities) and an independent sample *t* test and Mann–Whitney test for normally and non-normally distributed continuous variables (age, weight, and BMI), respectively. Univariate analysis of primary and aggregate outcomes was also performed using Pearson's Chi squared test for categorical variables (conversion rate, 30-day outcomes, and aggregate complication rates) and an independent sample *t* test and Mann–Whitney test for normally and skewed distributed continuous variables (operative length, HLOS), respectively. Categorical variables were reported as frequency and percentage, and continuous variables as mean (± standard deviation). A similar statistical analysis

was performed for all matched cohorts. All statistical analysis was performed with SPSS version 25 (IBM Corporation, Armonk, NY) or SAS version 9.4 (SAS Institute, Cary, NC). A p-value < 0.05 was considered statistically significant.

Results

Of the 355,675 cases in the 2015 and 2016 MBSAQIP PUF database, 77,991 Roux-en-Y gastric bypass (RnYGB) (7.5% robotic-assisted) and 189,503 sleeve gastrectomy (SG) (6.8% robotic-assisted) cases were identified. Descriptive statistics for unmatched RnYGB and SG cases are detailed in Table 1. For the entire unmatched RnYGB cohort, the mean age and BMI were 45.3 years and 46.3 kg/m^2, respectively. The unmatched robotic-assisted RnYGB cohort was older (46.5 years vs. 45.2 years, $p < 0.0001$) with a lower BMI (46 kg/m^2 vs 46.4 kg/m^2, $p = 0.007$). The robotic-assisted RnYGB cohort had a higher prevalence of numerous pre-operative comorbid conditions, including myocardial infarction, hypertension, hyperlipidemia, renal insufficiency, impaired ambulation, obstructive sleep apnea (OSA), and chronic obstructive lung disease (COPD). The mean age and BMI were 44.4 years and 45.2 kg/m^2 for all sleeve gastrectomy cases. The unmatched robotic-assisted SG cohort had a higher BMI (45.5 kg/m^2 vs. 45.2 kg/m^2, $p < 0.0001$), but were similar in age. This cohort also had a lower proportion of males (20% vs. 21.1%, $p = 0.002$) and a higher proportion of Non-Hispanic Black patients (20.1% vs. 18.3%, $p < 0.0001$). Pre-operative comorbid conditions were mostly similar between the robotic-assisted and conventional laparoscopic sleeve gastrectomy cohorts.

30-day outcomes and peri-operative complications in the unmatched RnYGB and SG cohorts are outlined in Table 2. For both RnYGB and SG, operative length and conversion rate were significantly higher in the robotic-assisted cohort. Post-operative length of stay was significantly higher in the robotic-assisted sleeve gastrectomy cohort (1.8 days vs. 1.6 days, $p < 0.0001$), but were similar between the robotic and laparoscopic gastric bypass cohorts ($p = 1.0$). For gastric bypass, all outcome measures were lower in the robotic-assisted cohort, except for a higher rate of readmission (6.6% vs. 5.6%, $p = 0.004$). The rate of transfusion, superficial SSI, and aggregate wound infection were higher in the conventional laparoscopic cohort. All other outcome measures were similar between the gastric bypass cohorts. In contrast, 30-day readmission (3.6% vs. 3.2%, $p = 0.02$), intervention 1.3% vs. 0.09%, $p = 0.0002$ and the present of an operative drain (0.5% vs. 0.2%, $p > 0.0001$) were significantly higher in the robotic-assisted sleeve gastrectomy cohort. Ventilator requirement > 48 h (0.1% vs. 0.05%, $p = 0.0008$), sepsis (0.1% vs. 0.08%, $p = 0.02$), organ space SSI (0.3% vs 0.2%, $p < 0.0001$), aggregate leak (0.4% vs. 0.2%, $p = 0.003$), and aggregate pulmonary complications (0.5% vs. 0.3%, $p = 0.04$) were also higher in this cohort of patients. All other outcome measures were similar between the robotic and laparoscopic SG cohorts.

Roux-en-Y gastric bypass and sleeve gastrectomy robotic-assisted and conventional laparoscopic cases were then matched on demographics and pre-operative comorbid conditions. Descriptive statistics of the 1:3 matched cohorts are detailed in Table 3, including 12,688 Roux-en-Y gastric bypass (3172 robotic-assisted and 9516 conventional laparoscopic) and 35,956 sleeve gastrectomy (8989 robotic-assisted and 26,967 conventional laparoscopic) cases. Compared to RnYGB, there was a higher prevalence of male (16.2% vs. 14.3%), Black (18.6% vs. 12.5%), and Hispanic (9.6% vs. 7.2%) patients in the SG cohort. Demographics (age, gender, pre-operative weight, and BMI), ASA and pre-operative comorbidities were similar between matched robotic-assisted and conventional laparoscopic cohorts, for both Roux-en-Y gastric bypass and sleeve gastrectomy cases.

Outcomes for matched robotic-assisted and conventional laparoscopic Roux-en-Y gastric bypass and sleeve gastrectomy cases are reported in Table 4. For RnYGB cases, operative length (151.9 min vs. 114.6 min, $p < 0.0001$) and 30-day readmission (6.6% vs. 5.6%, $p = 0.03$) were significantly higher in the robotic-assisted cohort, while transfusion (1.0 vs. 0.5%, $p = 0.0005$), aggregate bleeding (0.8% vs. 0.4%, $p = 0.03$), and aggregate wound infection (1.5% vs. 0.8%, $p = 0.006$) were significantly higher in the conventional laparoscopic cohort. There was no mortality difference (0.1% vs. 0%, $p = 0.05$). Post-operative length of stay and all other 30-day, non-aggregate and aggregate complications were similar between the robotic-assisted and conventional laparoscopic gastric bypass cohorts. For sleeve gastrectomy cases, operative length (99.2 min vs. 71.6 min, $p < 0.0001$), post-operative length of stay (1.7 days vs. 1.6 days, $p < 0.0001$), conversion rate (0.6% vs 0.04%, $p < 0.0001$), 30-day intervention (1.1% vs 0.8%, $p = 0.009$), operative drain present at 30-days (0.6% vs 0.1%, $p < 0.0001$), sepsis (0.1% vs 0.05%, $p = 0.01$), and organ space SSI (0.3% vs 0.1%, $p = 0.0002$) were significantly higher in the robotic-assisted cohort. Acute renal failure (0.09 vs 0.02%, $p = 0.03$) was significantly higher in the conventional laparoscopic cohort. All other outcome measures were statistically similar between the robotic-assisted and conventional laparoscopic sleeve cohorts.

The second 1:3 case–control match analysis was performed, which included operative length and conversion rate (surrogates for surgeon experience) as matching covariates. 7576 Roux-en-Y gastric bypass (1894 robotic-assisted and 5682 conventional laparoscopic) and 25,164 sleeve gastrectomy (6291 robotic-assisted and 18,873 conventional laparoscopic) cases were identified. Outcomes were compared and are detailed in Table 5. For Roux-en-Y gastric

Table 1 Descriptive statistics in unmatched Roux-en-Y gastric bypass and sleeve gastrectomy cohorts

	Roux-en- Y gastric bypass				Sleeve gastrectomy			
	All [n = 77,991]	RGB [n = 5817]	LGB [n = 72,174]	P-value	All [n = 189,503]	RSG [n = 12,912]	LSG [n = 176,591]	*p*-value
Continuous variables, mean ± SD								
Age (years)	45.3 ± 11.9	46.5 ± 12.0	45.2 ± 1.9	**< 0.0001**	44.4 ± 12.0	44.5 ± 12.1	44.35 ± 12.0	0.4
Pre-operative weight (lbs)	284.5 ± 59.8	283.8 ± 59.5	284.5 ± 59.8	0.4	278.2 ± 59.4	280.1 ± 60.3	278.0 ± 59.3	**< 0.0001**
Pre-operative BMI	46.3 ± 8.2	46.0 ± 8.2	46.4 ± 8.2	**0.007**	45.2 ± 8.0	45.5 ± 8.2	45.2 ± 8.0	**< 0.0001**
Categorical variables, *N* (%)								
ASA class								
1	163 (0.2)	30 (0.5)	133 (0.2)	**< 0.0001**	724 (0.4)	42 (0.3)	682 (0.4)	**< 0.0001**
2	13,438 (17.2)	1002 (17.2)	12,436 (17.2)		48,014 (25.3)	3036 (23.5)	44,978 (25.5)	
3	60,927 (78.1)	4561 (78.4)	56,366 (78.1)		134,533 (71.0)	9403 (72.8)	125,130 (70.9)	
4	3458 (4.4)	224 (3.9)	3234 (4.5)		6220 (3.3)	431 (3.3)	5789 (3.3)	
5	5 (0.01)	0	5 (0.01)		12 (0.01)	–	12 (0.01)	
Gender								
Male	15,691 (20.1)	1180 (20.3)	14,511 (20.1)	0.7	39,852 (21.0)	2,579 (20.0)	37,273 (21.1)	**0.002**
Female	62,300 (79.88)	4637 (79.7)	57,663 (79.9)	0.7	149,651 (79.0)	10,333 (80.0)	139,318 (78.9)	**0.002**
Race								
Non-Hispanic White	52,145 (66.9)	4071 (70.0)	48,071 (66.6)	**< 0.0001**	120,250 (63.5)	8273 (64.1)	111,977 (63.4)	0.1
Non-Hispanic Black	10,586 (13.6)	891 (15.3)	9695 (13.4)	**< 0.0001**	34,856 (18.4)	2592 (20.1)	32,264 (18.3)	**<0.0001**
Hispanic	9587 (12.3)	571 (9.8)	9016 (12.5)	**< 0.0001**	23,340 (12.3)	1426 (11.0)	21,914 (12.4)	**<0.0001**
Pre-operative comorbidities, *N* (%)								
History of MI	1,284 (1.7)	97 (1.7)	1,187 (1.6)	**< 0.0001**	2,298 (1.2)	158 (1.2)	2,140 (1.2)	0.9
Hypertension requiring medication	41,644 (53.4)	3337 (57.4)	38,307 (53.1)	**< 0.0001**	89,404 (47.2)	6160 (47.7)	83,244 (47.1)	0.2
Hyperlipidemia	23,014 (29.5)	1884 (32.4)	21,130 (29.3)	**< 0.0001**	42,946 (22.7)	2952 (22.9)	39,994 (22.7)	0.6
Renal insufficiency	510 (0.7)	54 (0.9)	456 (0.6)	**0.007**	1,228 (0.7)	96 (0.7)	1,132 (0.6)	0.2
Dialysis	128 (0.2)	12 (0.2)	116 (0.2)	0.4	592 (0.3)	45 (0.6)	547 (0.3)	0.4
DVT requiring therapy	1440 (1.9)	91 (1.6)	1349 (1.9)	0.09	2797 (1.48)	204 (1.6)	2593 (1.5)	0.3
History of PE	974 (1.3)	70 (1.2)	904 (1.3)	0.7	2,070 (1.1)	146 (1.1)	1924 (1.09)	0.7
Limited ambulation status	1634 (2.1)	185 (3.2)	1449 (2.0)	**< 0.0001**	3108 (1.6)	344 (2.7)	2764 (1.6)	**< 0.0001**
Partial functional dependence	609 (0.8)	64 (1.1)	545 (0.8)	**0.004**	1206 (0.6)	88 (0.7)	1118 (0.6)	0.5

Table 1 (continued)

	Roux-en- Y gastric bypass				Sleeve gastrectomy			
	All [n = 77,991]	RGB [n = 5817]	LGB [n = 72,174]	P-value	All [n = 189,503]	RSG [n = 12,912]	LSG [n = 176,591]	*p*-value
Total functional dependence	175 (0.2)	15 (0.3)	160 (0.2)	0.6	753 (0.4)	33 (0.3)	720 (0.4)	**0.008**
Diabetes mellitus	27,515 (35.3)	2205 (37.9)	25,310 (35.1)	**< 0.0001**	43,755 (23.1)	3071 (23.8)	40,684 (23.0)	**0.05**
Chronic steroid	1122 (1.4)	94 (1.6)	1028 (1.4)	0.2	3289 (1.7)	209 (1.6)	3080 (1.7)	0.3
Smoking	6702 (8.6)	495 (8.5)	6207 (8.6)	0.8	16,947 (8.9)	1175 (9.1)	15,772 (8.9)	0.5
OSA	33,791 (43.3)	2592 (44.6)	31,199 (43.2)	**0.05**	67,811 (35.8)	4775 (37.0)	63,036 (35.7)	**0.003**
COPD	1608 (2.1)	181 (3.1)	1,427 (2.0)	**< 0.0001**	3193 (1.7)	212 (1.6)	2981 (1.7)	0.7
Oxygen-dependent	694 (0.9)	51 (0.9)	643 (0.9)	0.9	1168 (0.6)	61 (0.5)	1107 (0.6)	**0.03**

Bold values represent descriptive statistics and outcome variables that were significantly different between the study cohorts

RGB robotic-assisted gastric bypass, *LGB* conventional laparoscopic gastric bypass, *RSG* robotic-assisted sleeve gastrectomy, *LSG c*onventional laparoscopic sleeve gastrectomy, *SD* standard deviation, *lbs* pounds, *BMI* body mass index, *ASA* American Society of Anesthesiologist, *MI* myocardial infarction, *DVT* deep venous thrombosis, *PE* pulmonary emboli, *OSA* obstructive sleeve apnea, *COPD* chronic obstructive pulmonary disease

bypass cases, 30-day readmission (7.2% vs. 5.7%, $p = 0.02$) remained significantly higher in the robotic-assisted cohort, while aggregate SSI (1.5% vs. 0.6%, $p = 0.003$) remained higher in the conventional laparoscopic cohort. In this analysis, post-operative length of stay, mortality, transfusion, and all other aggregate complications remained lower in the robotic-assisted gastric bypass cohort, but the differences were not statistically significant. Renal and VTE complications remained higher in the robotic-assisted cohort, but the differences were also not statistically significant. For sleeve gastrectomy cases, post-operative length of stay and all 30-day outcomes were similar after controlling for operation length and conversion as surrogates for surgeon experience. Drain present at 30-days (0.6% vs. 0.1%, $p < 0.0001$) and post-operative sepsis (0.1% vs. 0.05%, $p = 0.01$) remained higher in the robotic-assisted sleeve gastrectomy group. Intervention and aggregate bleeding, which were previously significantly higher in the conventional laparoscopic cohort, were now similar between these cohorts. Post-operative transfusion requirement, which was previous non-significantly higher in the laparoscopic cohort, was now significantly higher in this cohort (0.5% vs. 0.2%, $p = 0.01$). All other outcome measures were similar between cohorts.

Discussion

Approaches to metabolic and bariatric surgery continue to evolve. Over the last decade, robotic-assisted Roux-en-Y gastric bypass and sleeve gastrectomy are increasingly performed with varied results [4, 9–20]. Recent meta-analyses comparing RBS and LBS have reported no significant differences between major and minor complications, 30-day reoperation, or readmission rates; however, they are limited by the small sample size and heterogeneity of the studies included in the meta-analysis [9, 10]. In the review by Bailey et al., the authors concluded that the "review found the evidence insufficient to show a difference in complications, operative outcomes, or length of stay between robotic-assisted and laparoscopic gastric bypass [9]. In contrast, Li et al. reported a significant difference in post-operative length of stay (HLOS) and operative time for the robotic cohort, but no statistical difference in complications or readmission rates [10]. In a recent multivariate regression analysis of the 2015 MBSAQIP PUF database comparing robotic-assisted and laparoscopic sleeve gastrectomy ($n = 75{,}079$), Alizadeh et al. found that 30-day reoperation, intervention, and readmission rates were higher in the robotic cohort [11].

Here, we attempted to add to the published evidence by comparing metabolic and bariatric surgery outcomes performed with conventional laparoscopic and robotic-assisted approaches. Our study represents the largest 1:3 case–control matched analysis of the MBSAQIP PUF database comparing these two surgical platforms.

Roux-en-Y gastric bypass: robotic-assisted versus conventional laparoscopic

In our 1:3 case–control matched analysis of gastric bypass cases, we found that operative duration was significantly

Table 2 Outcomes in unmatched Roux-en-Y gastric bypass and sleeve gastrectomy cohorts

	Roux-en-Y gastric bypass				Sleeve gastrectomy			
	All [$n=77{,}991$]	RGB [$n=5817$]	LGB [$n=72{,}174$]	*p*-Value	All [$n=189{,}503$]	RSG [$n=12{,}912$]	LSG [$n=176{,}591$]	*p*-Value
Operative length in minutes (mean ± SD)	119.6 ± 54.1	154 ± 63.1	116.8 ± 52.3	**< 0.0001**	74.3 ± 37.2	100.6 ± 44.1	72.3 ± 36	**< 0.0001**
Length of stay in days (mean ± SD)	2.1 ± 2.0	2.1 ± 2.0	2.1 ± 2.0	1.0	1.6 ± 1.5	1.8 ± 1.7	1.6 ± 1.5	**< 0.0001**
Conversion, *n* (%)	212 (0.3)	26 (0.5)	186 (0.3)	**0.008**	179 (0.1)	64 (0.5)	115 (0.1)	**< 0.0001**
30-day outcomes and peri-operative complications, N (%)								
ICU admission	915 (1.2)	65 (1.1)	850 (1.2)	0.7	991 (0.5)	73 (0.6)	918 (0.5)	0.5
Reoperation	1776 (2.3)	149 (2.6)	1627 (2.3)	0.1	1628 (0.9)	113 (0.9)	1515 (0.9)	0.8
Readmission	4766 (6.1)	406 (7.0)	4360 (6.0)	**0.004**	6078 (3.2)	460 (3.6)	5618 (3.2)	**0.02**
Intervention	2004 (2.6)	171 (2.9)	1833 (2.5)	0.06	1821 (1.0)	164 (1.3)	1657 (0.9)	**0.0002**
Mortality	119 (0.2)	6 (0.1)	113 (0.2)	0.3	140 (0.07)	8 (0.06)	132 (0.07)	0.6
Related mortality	59 (0.08)	3 (0.05)	56 (0.08)	1.0	66 (0.03)	3 (0.02)	63 (0.04)	0.6
Operative drain present	510 (0.7)	15 (0.3)	495 (0.7)	**< 0.0001**	396 (0.2)	63 (0.5)	333 (0.2)	**< 0.0001**
Renal failure	103 (0.1)	6 (0.1)	97 (0.1)	0.5	108 (0.06)	6 (0.05)	102 (0.06)	0.6
Progressive renal insufficiency	81 (0.1)	5 (0.09)	76 (0.1)	0.7	107 (0.06)	5 (0.04)	102 (0.06)	0.4
CPR	45 (0.06)	3 (0.05)	42 (0.06)	0.8	59 (0.03)	3 (0.02)	56 (0.03)	0.6
Coma > 24 h	1 (0.001)	–	1 (0.00)	0.8	7 (0.004)	–	7 (0.004)	0.5
Stroke/CVA	3 (0.004)	–	3 (0.00)	0.6	23 (0.01)	2 (0.02)	21 (0.01)	0.7
MI	42 (0.05)	2 (0.03)	40 (0.06)	0.5	54 (0.03)	4 (0.03)	50 (0.03)	0.9
DVT	135 (0.2)	6 (0.1)	129 (0.2)	0.2	330 (0.2)	24 (0.2)	306 (0.2)	0.7
Pulmonary embolism	117 (0.2)	8 (0.1)	109 (0.2)	0.8	172 (0.1)	13 (0.1)	159 (0.09)	0.7
Anticoagulation for DVT/PE	341 (0.4)	26 (0.5)	315 (0.4)	0.9	823 (0.4)	57 (0.4)	766 (0.4)	0.9
Transfusion	859 (1.1)	36 (0.6)	823 (1.1)	**0.0002**	931 (0.5)	50 (0.4)	881 (0.5)	0.08
Post-operative pneumonia	327 (0.4)	20 (0.3)	307 (0.4)	0.4	256 (0.1)	21 (0.2)	235 (0.1)	0.4
On ventilator > 48 h	130 (0.2)	6 (0.1)	127 (0.2)	0.2	98 (0.05)	15 (0.1)	83 (0.05)	**0.0008**
Unplanned intubation	213 (0.3)	13 (0.2)	200 (0.3)	0.5	223 (0.1)	20 (0.2)	203 (0.1)	0.2
Post-operative UTI	386 (0.5)	22 (0.4)	364 (0.5)	0.2	548 (0.3)	36 (0.3)	512 (0.3)	0.8
Post-operative sepsis	149 (0.2)	10 (0.2)	139 (0.2)	0.7	153 (0.08)	18 (0.1)	135 (0.08)	**0.02**
Post-operative septic shock	92 (0.1)	4 (0.07)	88 (0.1)	0.3	59 (0.03)	5 (0.04)	54 (0.03)	0.6
Superficial SSI	720 (0.9)	17 (0.3)	703 (1.0)	**< 0.0001**	430 (0.2)	23 (0.2)	407 (0.2)	0.2
Deep SSI	118 (0.2)	6 (0.1)	112 (0.2)	0.3	45 (0.02)	2 (0.02)	43 (0.02)	0.5
Organ space SSI	266 (0.3)	23 (0.4)	243 (0.3)	0.5	302 (0.2)	40 (0.3)	262 (0.2)	**< 0.0001**

Table 2 (continued)

	Roux-en-Y gastric bypass				Sleeve gastrectomy			
	All [$n=77{,}991$]	RGB [$n=5817$]	LGB [$n=72{,}174$]	p-Value	All [$n=189{,}503$]	RSG [$n=12{,}912$]	LSG [$n=176{,}591$]	p-Value
Aggregate complications, *N* (%)								
Leak	268 (0.3)	22 (0.4)	246 (0.3)	0.6	466 (0.3)	48 (0.4)	418 (0.2)	**0.003**
Bleeding	676 (0.9)	40 (0.7)	636 (0.9)	0.1	507 (0.3)	29 (0.2)	478 (0.3)	0.3
Renal complications	197 (0.3)	14 (0.2)	183 (0.3)	0.9	236 (0.1)	11 (0.09)	225 (0.1)	0.2
Venous thromboembolic events	486 (0.7)	38 (0.7)	448 (0.6)	0.8	1135 (0.6)	81 (0.6)	1054 (0.6)	0.7
Cardiovascular complications	77 (0.1)	6 (0.1)	71 (0.1)	0.9	150 (0.08)	7 (0.05)	143 (0.08)	0.3
Pulmonary complications	662 (0.9)	43 (0.7)	619 (0.9)	0.3	668 (0.4)	59 (0.5)	609 (0.3)	**0.04**
Wound infection	1226 (1.6)	55 (1.0)	1171 (1.6)	**< 0.0001**	868 (0.5)	72 (0.6)	796 (0.5)	0.08

Bold values represent descriptive statistics and outcome variables that were significantly different between the study cohorts

RGB robotic-assisted gastric bypass, *LGB* laparoscopic gastric bypass, *RSG* robotic-assisted sleeve gastrectomy, *LSG* laparoscopic sleeve gastrectomy, *SD* standard deviation, *ICU* intensive care unit, *ICU* intensive care unit, *CPR* cardiopulmonary arrest, *CVA* cerebrovascular accident, *MI* myocardial infarction, *DVT* deep venous thrombosis, *PE* pulmonary emboli, *UTI* urinary tract infection, *SSI* surgical site infection

longer with the robotic-assisted surgical approach ($p<0.0001$), which is consistent with the findings by Li et al. and others [4, 10, 11, 13, 15, 16]. We also found a significantly higher rate of 30-day readmission in the robotic-assisted gastric bypass cohort ($p=0.03$). This is consistent with a large (n = 137,455) retrospective propensity-matched cohort analysis of the Bariatric Outcomes Longitudinal Database (BOLD), where Celio et al. found longer operative time, 30-day reoperation, and 30-day readmission in the robotic-assisted RnYGB cohort [18]. However, after the authors controlled for operative time, 30-day readmission was no longer significant, which is inconsistent with our findings. In our study, we have found that 30-day readmission remained significantly higher in the robotic-assisted cohort, even when controlling for operative time and conversion rate as surrogates for surgeon experience ($p=0.02$). Post-operative length of stay between the two surgical approaches has also been a point of contention in the literature. In our study, HLOS was similar between the two surgical approaches for gastric bypass before ($p=0.2$) and after ($p=0.08$) controlling for operative time and conversion rate. Studies have found both shorter HLOS [13, 19] and longer HLOS [16] in robotic-assisted RnYGB cohorts, while others have reported no difference [14, 15]. While our study represents a large 1:3 case–control cohort analysis comparing surgical approaches between Roux-en-Y gastric bypass ($n=12{,}688$), and will likely add value to the discussion, the reasons for differences in readmission rates between these two surgical approaches remain unclear and in need of further study.

In our case–control matched analysis of robotic and laparoscopic gastric bypass, we found significantly lower rates of mortality ($p=0.05$), transfusion ($p=0.005$), superficial SSI ($p=0.0003$), aggregate bleeding ($p=0.04$), and aggregate wound infection ($p=0.006$) in the robotic cohort. After controlling for operative time and conversion rate, however, only superficial SSI ($p=0.0002$) and aggregate wound infection ($p=0.003$) remained lower in the robotic-assisted cohort. Regarding 30-day mortality, others have reported no significant difference between these surgical approaches [4, 9, 10, 12, 14–19], which is consistent with our study once we account for operative length and conversion rate. A lower rate of SSI following robotic-assisted compared to conventional laparoscopic gastric bypass has not been previously reported [9, 10, 12–14, 16, 19]. Similar to our findings, Sebastian et al. analyzed the same data set with propensity-score matching and reported higher rates of bleeding following laparoscopic gastric bypass before and after adjusting for operative time and conversion rate [19]. However, once conversion rate and operative length is accounted for in our case–control study, we have shown no difference in transfusion rate between the two surgical approaches ($p=0.1$). This trend toward higher transfusion rate with conventional laparoscopic compared to robotic-assisted RnYGB remains unclear. Possible mechanism may include a higher rate of stapled

Table 3 Descriptive statistics after 1:3 case–control matching in Roux-en-Y gastric bypass and sleeve gastrectomy cohorts

	Roux-en-Y gastric bypass [$n=12{,}688$]			Sleeve gastrectomy [$n=35{,}956$]		
	RGB [$n=3172$]	LGB [$n=9516$]	*p*-Value	RSG [$n=8989$]	LSG [$n=26{,}967$]	*p*-Value
Continuous variables, mean ± SD						
Age (years)	44.1 ± 11.6	44.12 ± 11.5	1.0	43.0 ± 11.7	43.0 ± 11.6	0.7
Pre-operative weight	283.3 ± 58.7	284 ± 60.2	0.6	278.3 ± 58.9	278.0 ± 59.1	0.7
Pre-operative BMI	46.2 ± 7.7	46.49 ± 8.0	0.09	45.3 ± 7.6	45.4 ± 7.6	0.8
Categorical variables, *N* (%)						
ASA class						
1	1 (0.03)	3 (0.03)	1.0	6 (0.07)	18 (0.07)	1.0
2	495 (15.6)	1485 (15.6)		2210 (24.6)	6630 (24.6)	
3	2641 (83.3)	7923 (83.3)		6675 (74.3)	20,025 (74.3)	
4	35 (1.1)	105 (1.1)		98 (1.1)	294 (1.1)	
Gender						
Male	452 (14.3)	1,356 (14.3)	1.0	1458 (16.2)	4374 (16.2)	1.0
Female	2720 (85.8)	8160 (85.8)		7531 (83.8)	22,593 (83.8)	
Race						
Non-Hispanic White	2464 (77.7)	7389 (77.7)	1.0	6155 (68.5)	18,465 (68.5)	1.0
Non-Hispanic Black	396 (12.5)	1188 (12.5)		1671 (18.6)	5013 (18.6)	
Hispanic	227 (7.2)	681 (7.2)		860 (9.6)	2,580 (9.6)	
Pre-operative comorbidities, *N* (%)						
History of MI	6 (0.2)	18 (0.2)	1.0	11 (0.1)	33 (0.1)	1.0
Hypertension requiring medication	1575 (49.7)	4725 (49.7)	1.0	3815 (42.4)	11,445 (42.4)	1.0
Hyperlipidemia	710 (22.4)	2130 (22.4)	1.0	1448 (16.1)	4344 (16.1)	1.0
Renal insufficiency	1 (0.03)	3 (0.03)	1.0	–	–	–
Vein thrombosis requiring therapy	–	–	–	5 (0.06)	15 (0.06)	1.0
History of PE	1 (0.03)	3 (0.03)	1.0	4 (0.04)	12 (0.04)	1.0
Limited ambulation status	2 (0.06)	6 (0.06)	1.0	12 (0.1)	36 (0.1)	1.0
Diabetes mellitus	831 (26.2)	2493 (26.2)	1.0	1391 (15.5)	4173 (15.5)	1.0
Steroid/immunosuppressant use	1 (0.03)	3 (0.03)	1.0	537 (6.0)	1,611 (6.0)	1.0
Current smoker within 1-year	133 (4.2)	399 (4.2)	1.0	21 (0.2)	63 (0.2)	1.0
Obstructive sleep apnea	1,239 (39.1)	3,717 (39.1)	1.0	2,845 (31.7)	8,535 (31.7)	1.0
Chronic obstructive pulmonary disease	2 (0.06)	6 (0.06)	1.0	10 (0.1)	30 (0.1)	1.0

RGB robotic gastric bypass, *LGB* conventional laparoscopic gastric bypass, *SD* standard deviation, *lbs* pounds, *BMI* body mass index, *ASA* American Society of Anesthesiologist, *MI* myocardial infarction, *PE* pulmonary emboli

anastomosis with conventional laparoscopic compared to a higher rate of hand-sewn anastomosis with the robotic-assisted approach. Surgeons may also be more aggressive in suture hemostasis with the robotic-assisted approach due to easier ergonomics and improved visualization with the robotic platform. These patient level data points are not available in this database, and are worthy of future studies. However, even with a significantly higher operative duration, overall complications were less with the robotic-assisted approach for gastric bypass. In our second matched analysis, controlling for operation duration and conversion, there was much less outcome differences between robotic-assisted gastric bypass and conventional laparoscopic gastric bypass, with similar mortality and morbidity rates.

Sleeve gastrectomy: robotic-assisted versus conventional laparoscopic

In our matched analysis of over 35,000 sleeve gastrectomy cases, we found that robotic-assisted SG was associated with significantly longer operative duration ($p<0.0001$) and post-operative length of stay ($p<0.0001$). These findings are consistent with Sebastian et al. and their analysis of the two surgical approaches in SG, as well as a systematic review and meta-analysis [19, 20]. Most perioperative outcomes were similar between robotic-assisted and laparoscopic sleeve gastrectomy cohorts. Some outcomes were more common in the robotic-assisted group, including 30-day intervention ($p=0.01$), drain present at 30-day ($p<0.0001$), sepsis ($p=0.01$) and organ space SSI

Table 4 Outcomes after 1:3 case–control matching in Roux-en-Y gastric bypass and sleeve gastrectomy cohorts

	Roux-en-Y Gastric Bypass [$n=12{,}688$]			Sleeve Gastrectomy [$n=35{,}956$]		
	RGB [$n=3172$]	LGB [$n=9516$]	*p*-Value	RSG [$n=8989$]	LSG [$n=26{,}967$]	*p*-Value
Operative length, minutes (mean ± SD)	151.9 ± 62.3	114.6 ± 50.3	**< 0.0001**	99.2 ± 43.6	71.7 ± 35.0	**< 0.0001**
Length of stay, days (mean ± SD)	2.0 ± 1.4	2.0 ± 2.3	0.2	1.7 ± 1.8	1.6 ± 1.2	**< 0.0001**
Outcomes, *N* (%)						
Conversion	13 (0.4)	23 (0.2)	0.1	50 (0.6)	12 (0.04)	**< 0.0001**
Unplanned admission to ICU	30 (1.0)	79 (0.8)	0.5	37 (0.4)	102 (0.4)	0.7
Reoperation	77 (2.4)	215 (2.3)	0.6	68 (0.8)	202 (0.8)	0.9
Readmission	209 (6.6)	528 (5.6)	**0.03**	272 (3.03)	778 (2.9)	0.5
Intervention	84 (2.7)	212 (2.2)	0.2	100 (1.1)	219 (0.8)	**0.01**
Mortality	–	12 (0.1)	**0.05**	3 (0.03)	18 (0.07)	0.3
Drain present at 30 days	9 (0.3)	38 (0.4)	0.4	54 (0.6)	32 (0.1)	**< 0.0001**
Renal failure	2 (0.06)	3 (0.03)	0.4	–	9 (0.03)	
Progressive renal insufficiency	2 (0.06)	3 (0.03)	0.4	–	–	–
CPR	–	3 (0.03)	0.3	1 (0.01)	4 (0.01)	0.8
Stroke/CVA	–	–	–	–	1 (0.0004)	1.0
MI	–	1 (0.01)	0.6	1 (0.01)	3 (0.01)	1.0
Post-operative vein thrombosis requiring therapy	3 (0.09)	17 (0.2)	0.3	17 (0.2)	31 (0.1)	0.09
Pulmonary embolism	5 (0.2)	10 (0.1)	0.5	7 (0.08)	20 (0.07)	0.9
Anticoagulation for DVT/PE	13 (0.4)	34 (0.4)	0.7	33 (0.4)	103 (0.4)	0.8
Transfusion	15 (0.5)	96 (1.0)	**0.005**	28 (0.3)	122 (0.5)	0.07
Post-operative pneumonia	6 (0.2)	29 (0.3)	0.3	9 (0.1)	27 (0.1)	1.0
On ventilator > 48 h	5 (0.2)	12 (0.1)	0.7	6 (0.07)	14 (0.05)	0.6
Unplanned intubation	2 (0.06)	18 (0.2)	0.1	10 (0.1)	17 (0.06)	0.2
Post-operative UTI	12 (0.4)	43 (0.5)	0.6	27 (0.3)	72 (0.3)	0.6
Post-operative sepsis	4 (0.1)	13 (0.1)	0.9	12 (0.1)	14 (0.05)	**0.01**
Post-operative septic shock	1 (0.03)	8 (0.08)	0.3	4 (0.04)	5 (0.02)	0.2
Superficial SSI	8 (0.3)	83 (0.9)	**0.0003**	14 (0.2)	59 (0.2)	0.3
Deep SSI	4 (0.1)	16 (0.2)	0.6	2 (0.02)	6 (0.02)	1.0
Organ space SSI	9 (0.3)	29 (0.3)	0.9	27 (0.3)	32 (0.1)	**0.0002**
Aggregate complications, *N* (%)						
Leak	9 (0.3)	28 (0.3)	0.9	28 (0.3)	58 (0.2)	0.1
Bleeding	13 (0.4)	73 (0.8)	**0.04**	11 (0.1)	62 (0.2)	**0.05**
Renal complications	5 (0.2)	7 (0.07)	0.2	2 (0.02)	25 (0.09)	**0.03**
Venous thromboembolic events	20 (0.6)	47 (0.5)	0.4	43 (0.5)	143 (0.5)	0.6
Cardiovascular complications	2 (0.06)	8 (0.08)	0.7	4 (0.04)	16 (0.06)	0.6
Pulmonary complications	15 (0.5)	69 (0.7)	0.1	29 (0.3)	65 (0.2)	0.2
Wound infection	26 (0.8)	139 (1.5)	**0.006**	44 (0.5)	111 (0.4)	0.3

Bold values represent descriptive statistics and outcome variables that were significantly different between the study cohorts

RGB robotic-assisted gastric bypass, *LGB* conventional laparoscopic gastric bypass, *RSG* robotic-assisted sleeve gastrectomy, *LSG* conventional laparoscopic sleeve gastrectomy, *SD* standard deviation, *ICU* intensive care unit, *CPR* cardiopulmonary arrest, *CVA* cerebrovascular accident, *MI* myocardial infarction, *DVT* deep venous thrombosis, *PE* pulmonary emboli, *UTI* urinary tract infection, *SSI* surgical site infection

($p=0.0002$). While we did not find higher rates of readmission and reoperation in our robotic-assisted sleeve gastrectomy cohort, as did Alizadeh et al. [11], we similarly found a higher rate of organ space SSI ($p=0.0002$). While leak rate was higher in our robotic-assisted cohort, the difference was not statistically significant ($p=0.1$), which is similar to other published reports [10, 19, 20], and in contrast to the significantly higher leak rate noted in the study by Alizadeh et al. [11].

Similar to analysis of our gastric bypass cases, we found a lower rate of transfusion ($p=0.07$) and aggregate bleeding complications ($p=0.05$) in our robotic-assisted sleeve gastrectomy cohort. Aggregate renal complications were also noted to be 4.5-fold lower in robotic cohort of

Table 5 Outcomes after 1:3 case–control matching in Roux-en-Y gastric bypass and sleeve gastrectomy cohorts, stratified by operative length and conversion rate

	Roux-en-Y gastric bypass [$n=7576$]			Sleeve gastrectomy [$n=25{,}164$]		
	RGB [$n=1894$]	LGB [$n=5682$]	*p*-Value	RSG [$n=6291$]	LSG [$n=18{,}873$]	*p*-Value
Operative length, minutes (mean ± SD)	146.6 ± 59.7	139.1 ± 49.2	1.0	95.6 ± 42.4	90.12 ± 38.3	1.0
Length of Stay in days (mean ± SD)	2.0 ± 1.4	2.1 ± 2.8	0.08	1.7 ± 1.7	1.7 ± 1.4	0.6
Outcome, *N* (%)						
Unplanned ICU admission	21 (1.1)	44 (0.8)	0.2	21 (0.3)	83 (0.4)	0.3
Reoperation	51 (2.7)	113 (2.0)	0.07	49 (0.8)	153 (0.8)	0.8
Readmission	137 (7.2)	325 (5.7)	**0.02**	185 (2.9)	569 (3.01)	0.8
Intervention	55 (2.9)	149 (2.6)	0.5	66 (1.1)	174 (0.92)	0.4
Mortality	–	8 (0.1)	0.1	3 (0.05)	9 (0.05)	1.0
Related mortality	–	3 (0.05)	–	2 (0.03)	5 (0.03)	0.7
Drain present at 30 days	7 (0.4)	22 (0.4)	0.9	40 (0.6)	22 (0.1)	**< 0.0001**
Acute renal failure	1 (0.05)	2 (0.04)	0.7		7 (0.04)	0.1
Progressive renal insufficiency	1 (0.05)	2 (0.04)	0.7	1 (0.02)	8 (0.04)	0.3
CPR	–	2 (0.04)	0.4	–	4 (0.02)	0.2
Stroke/CVA	–	1 (0.02)	0.6	1 (0.02)	–	0.08
Intra-operative or post-operative MI	–	–	–	–	2 (0.01)	0.4
Post-operative vein thrombosis requiring therapy	1 (0.05)	7 (0.1)	0.4	12 (0.2)	37 (0.2)	0.9
Pulmonary embolism	2 (0.1)	2 (0.04)	0.2	5 (0.08)	22 (0.1)	0.4
Anticoagulation for presumed DVT/PE	7 (0.4)	13 (0.2)	0.2	24 (0.4)	71 (0.4)	1.0
Transfusion	8 (0.4)	42 (0.7)	0.1	15 (0.2)	93 (0.5)	**0.01**
Post-operative pneumonia	5 (0.3)	16 (0.3)	0.9	5 (0.08)	28 (0.2)	0.2
On ventilator > 48 h	3 (0.2)	4 (0.07)	0.3	3 (0.05)	7 (0.04)	0.7
Unplanned intubation	2 (0.1)	11 (0.2)	0.4	5 (0.08)	16 (0.08)	0.9
Post-operative UTI	10 (0.5)	34 (0.6)	0.7	20 (0.3)	64 (0.3)	0.8
Post-operative sepsis	2 (0.1)	10 (0.2)	0.5	10 (0.1)	10 (0.05)	**0.01**
Post-operative septic shock	–	4 (0.07)	0.2	3 (0.05)	7 (0.04)	0.7
Superficial SSI	3 (0.2)	60 (1.1)	**0.0002**	9 (0.1)	43 (0.2)	0.2
Deep SSI	3 (0.2)	9 (0.2)	1.0	1 (0.02)	4 (0.02)	0.8
Organ space SSI	3 (0.2)	12 (0.2)	0.7	18 (0.3)	31 (0.2)	0.06
Nerve injury	1 (0.05)	–	0.08	–	–	–
Aggregate complications, *N* (%)						
Anastomotic leak	5 (0.3)	20 (0.4)	0.6	19 (0.3)	38 (0.2)	0.1
Bleeding	8 (0.4)	37 (0.7)	0.3	10 (0.2)	44 (0.2)	0.3
Renal failure	3 (0.2)	4 (0.07)	0.3	1 (0.02)	15 (0.08)	0.08
Venous thromboembolic complications	11 (0.6)	18 (0.3)	0.1	28 (0.5)	102 (0.5)	0.4
Cardiovascular complications	1 (0.05)	4 (0.07)	0.8	1 (0.02)	10 (0.05)	0.2
Pulmonary complications	10 (0.5)	37 (0.7)	0.6	15 (0.2)	55 (0.3)	0.5
Wound infection	12 (0.6)	86 (1.5)	**0.003**	28 (0.5)	87 (0.5)	0.9

Bold values represent descriptive statistics and outcome variables that were significantly different between the study cohorts

RGB robotic-assisted gastric bypass, *LGB* conventional laparoscopic gastric bypass, *RSG* robotic-assisted sleeve gastrectomy, *LSG* conventional laparoscopic sleeve gastrectomy, *SD* standard deviation, *ICU* intensive care unit, *CPR* cardiopulmonary arrest, *CVA* cerebrovascular accident, *MI* myocardial infarction, *DVT* deep venous thrombosis, *PE* pulmonary emboli, *UTI* urinary tract infection, *SSI* surgical site infection

patients. The reported higher rates of bleeding complications with laparoscopic compared to robotic-assisted sleeve gastrectomy remain elusive and require further study. After controlling for operative length and conversion rate in our subsequent 1:3 case–control matched analysis, most outcomes did not change. However, the rate of intra-operative or post-operative transfusion became significantly higher ($p=0.01$) in the conventional laparoscopic sleeve gastrectomy cohort, which is different from findings in previous studies [10, 11, 19, 20].

Readmissions, re-interventions, operative duration and post-operative HLOS directly contribute to healthcare costs [22]. Many of the studies comparing the cost of conventional laparoscopic versus robotic-assisted surgery do not account for the large initial investment, consumables per procedures, annual maintenance, and other reusable equipment that comprise a substantial portion of the total operating costs of robotic platforms [9, 10, 23]. Because of the growing emphasis on healthcare costs, it is imperative that bariatric surgeons continue to find new and innovative ways to reduce costs associated with the utilization of differently surgical platforms for bariatric surgery without effecting patient outcomes. From our matched analysis, it would appear that even though robotic-assisted RnYGB takes longer, it is associated with better outcomes when compared to the conventional laparoscopic approach, including a lower overall mortality rate, less bleeding complications, and similar leak rates. In contrast, robotic-assisted sleeve gastrectomy is associated with a higher rate of infectious complications (sepsis and organ space SSI). For both gastric bypass and sleeve gastrectomy, the robotic platform seems to be protective of aggregate bleeding complications and transfusion requirements, but more so for gastric bypass cases. These findings remained, though less significant, after controlling for operation length and conversion as surrogate variables for surgeon experience. This suggest that the potential benefits of robotic-assisted metabolic and bariatric surgery noted in this study most likely represents an interplay between the surgical platform and surgeon experience.

There are several limitations to our study. First, this study was limited to peri-operative outcomes data only. Stratified outcomes on weight loss, long-term complications, and surgical impact on comorbid conditions could not be assessed. Second, this dataset does not provide relevant surgeon and surgical technique variables that may impact peri-operative outcomes. Surgeon experience or case volume has been shown to have a considerable effect on outcomes [14, 16] and is a variable that is missing from the data set. We attempted to control for this potential confounder by including operative length and conversion rate as matching covariates. There are limitations to using operation length and conversion as surrogate variables for surgeon experience, as there are other patient variables and intra-operative variables that may impact operative length and the likelihood of conversion. A more accurate representation of surgeon experience is needed in the MBSAQIP database to account for this possible confounder. The data also lack information on surgical technique variables between the two cohorts that could have also impacted outcomes. The portion of anastomosis created with a purely hand-sewn, stapled, or a combination of techniques is unknown. With the introduction of the robotic stapler, it is unclear how surgeon's anastomotic technique on the robotic platform may have changed and impacted outcomes. It is possible that higher rates of organ space SSI and post-operative sepsis seen in SG using the robotic-assisted surgical approach represent surgeon's early learning curve or changes in technique as technology evolves. There is likely significant intra-operative variation in technique between the two surgical approaches that is not accounted for in the database, and limits a true assessment on outcomes between laparoscopic and robotic-assisted Roux-en-Y gastric bypass and sleeve gastrectomy. As robotic platforms become more common, it is important to continue to critically assess these surgeon and surgical technique variables and their impact on outcomes. Lastly, even though this is the largest bariatric clinical database available, this is a retrospective analysis and is therefore vulnerable to biases associated with retrospective analysis of clinical databases. While we had a large volume of clinical data to analyze, there were missing data points. Data entry is limited by the timeliness and completeness of data entry by bariatric Clinical Nurse Reviewers. Given the missing data points, this is currently not a 100% capture of relevant clinical data and limits any analysis utilizing this database.

This study represents the largest case–control matched analyses of the MBSAQIP PUF database comparing these two surgical approaches for gastric bypass and sleeve gastrectomy. Both platforms are overall very safe. The robotic-assisted platform is associated with longer operative duration. In spite of the longer operative time, we conclude that the robotic-assisted approach is safe and may provide some advantage for primary Roux-en-Y gastric bypass, as it is associated with less complication compared to the conventional laparoscopic approach. In contrast, the benefits of robotic-assisted sleeve gastrectomy remain unclear. Our analysis suggest that it is likely less cost-effective due to longer operative duration, post-operative length stay, and 30-days intervention. It may also be less safe due to higher rates of post-operative sepsis and drains present at 30-days, and a tendency toward a higher leak rate. The robotic platform seems to be protective of bleeding complications for both gastric bypass and sleeve gastrectomy, but may mitigate post-operative bleeding complications more in gastric bypass compared to sleeve gastrectomy cases and subsequently impact peri-operative mortality and morbidity. Further studies are warranted to better understand the cost-effectiveness and safety of these surgical platforms, while addressing some of the limitations of this dataset. Surgeons need to remain safety- and cost-conscious when deciding which platform to use in performing primary metabolic and bariatric surgery.

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Compliance with ethical standards

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