



Robot-assisted versus laparoscopic Roux-en-Y gastric bypass and sleeve gastrectomy: a propensity score-matched comparative analysis using the 2015–2016 MBSAQIP database

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Abstract

Background Robotic-assisted bariatric surgery is part of the armamentarium in many bariatric centers. However, limited data correlate the robotic benefits to with clinical outcomes. This study compares 30-day outcomes between robotic-assisted and laparoscopic procedures for Roux-en-Y gastric bypass (RYGB) and sleeve gastrectomy (SG).

Methods Using the 2015–2016 Metabolic and Bariatric Surgery Accreditation and Quality Improvement Program (MBSAQIP) database, patients between 18- and 65-year-old were included. To adjust for potential confounders, 1:1 propensity-score matching (PSM) was performed using 22 preoperative characteristics. Second PSM analysis was performed adding operative time and conversion rate.

Results 269,923 patients underwent SG ($n = 190,494$) or RYGB ($n = 79,429$). The operative time was significantly longer in the Robotic-assisted compared to laparoscopic approach either for SG (102.58 ± 46 vs. 73.38 ± 36 ; $P < 0.001$) or for RYGB (158.29 ± 65 vs. 120.17 ± 56 ; $P < 0.001$). In the SG cohort (12,877 matched cases), the robotic approach showed significant reduction of postoperative bleeding (0.16% vs. 0.43%; $P < 0.001$) and strictures (0.19% vs. 0.33%; $P = 0.04$) with similar results in the other 30-day outcomes in both analyses. Similarly, for the RYGB cohort (5780 matched cases), the robotic approach showed significantly fewer requirements for blood transfusions (0.64% vs. 1.16%; $P = 0.004$) with no statistically different results for the other's outcomes. Conversely, when adding operative time and conversion rate to the PSM analysis, the robotic platform showed significantly shorter length of stay (2.12 ± 1.9 vs. 2.30 ± 3.1 days; $P < 0.001$), reduction of anastomotic leak (0.52% vs. 0.92%; $P = 0.01$), renal complications (0.16% vs. 0.38%; $P = 0.004$), and venous thromboembolism (0.24% vs. 0.52%; $P = 0.02$).

Conclusions Our findings show that postoperative bleeding and blood transfusion are significantly reduced with the robotic platform, and after correcting for all factors including operative time, the robotic-assisted approach is associated with better postoperative outcomes especially for RYGB.

Keywords Bariatric surgery · Robotic bariatric surgery · Robotic sleeve gastrectomy · Robotic gastric bypass · Minimally invasive surgery

Obesity has reached epidemic proportions in the USA. In 1996, 16.7% of the adult population was considered obese [1], while in 2015–2016, that number has more than doubled

to 39.8% of adults in the United States [2]. Among different treatment options, bariatric surgery has emerged as the therapeutic mode of highest efficiency of sustainable weight loss and with high resolution of comorbidities. Unsurprisingly, in 2016, there were an estimated 216,000 bariatric procedures performed in the US [3] with low incidents of morbidity and mortality. One of the reasons for the reduction in complications is the shift away from open surgery to a minimally invasive surgery. Laparoscopic surgery has quickly become the primary approach in an era of minimally invasive surgery and is the gold standard for all bariatric surgeries, since it

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was first used for gastric bypass by Wittgrove et al. in 1993 [4]. Compared to open surgery, laparoscopic surgery yields reduced overall complications and significantly faster recovery [5–9].

Laparoscopic surgery is not exempt from limitations—for example: lost degrees of freedom in a small space; limited rotational motion; reduced depth perception; 2D video system; spatial disorientation; decreased haptic feedback; significant ergonomic difficulties; and interference of the natural coupling of surgeon's eyes and hands by the interposition of an independently moving video camera [10]. These limitations have led to an increase in the adoption of new forms of minimally invasive surgery such as robotic surgery. Robotic surgery was introduced to overcome these drawbacks of laparoscopic surgery with endowrist technology improving the rotational motion, 3-dimensional visualization, tremor filtration, motion scaling and surgeon-controlled camera, all of which increases precision, and operative dexterity [10–12]. In addition, the improvement of the ergonomic position of the head and body at the robotic console provides exceptional comfort to the surgeon to perform several and longer operations [10] and may even confer ambidexterity to surgeons [13]. Finally, robotic surgery has a shorter learning curve demonstrated in sleeve gastrectomy (SG) and Roux-en-Y gastric bypass surgery (RYGB) [14–16].

Despite the advances in technology for robotic surgery, it has some disadvantages such as extended operative time and high cost [17–19]. Furthermore, despite recent increase in popularity of utilizing the robot for bariatric procedures, most current studies are single-institution and do not show a clear advantage between robotic and laparoscopic surgery [20–25]. The objective of this study was to use the Metabolic and Bariatric Surgery Accreditation and Quality Improvement Program (MBSAQIP) database to investigate the impact of the robotic approach on the Roux-en-Y gastric bypass and sleeve gastrectomy by describing the short-term 30-day outcomes of robotic vs. laparoscopic approach.

Methods

Study population

All patients within the MBSAQIP data registry who underwent either a SG or RYGB between January 1, 2015 and December 31, 2016 were included in this study. Patients undergoing primary robotic-assisted and conventional laparoscopic approach for RYGB and SG were identified within the 2015 and 2016 MBSAQIP participant use file (PUF) using the Current Procedural Terminology codes 43644 and 43755. To reflect a similar patient population, inclusion criteria were restricted to patients between 18 and 65 years old.

Exclusion criteria included patients who underwent other approaches besides conventional laparoscopic or robotic-assisted such as laparoscopic-assisted, hand-assisted, open, single incision, and natural orifice transluminal endoscopic surgery. Also, cases with missing data were eliminated. Additionally, 30-day re-admission, re-operation, and intervention data were extracted from the separate file by matching the unique case identification numbers, respectively. MBSAQIP data are de-identified and contain no personal health information, and consequently data were publically available in anonymous manner. Existing de-identified datasets as MBSAQIP by federal regulations do not constitute strictly a Human Subjects Research; therefore, the Institutional Review Board (IRB) of the Johns Hopkins University approved the study under exempt status.

Data sources

The 2015 and 2016 MBSAQIP participant use file (PUF) were used for the study. The MBSAQIP-PUF is one of the largest bariatric-specific clinical data sets. There were 355,675 bariatric cases from approximately 791 MBSAQIP-participating sites performed between January 1, 2015 and December 31, 2016 across the United States and Canada. The MBSAQIP-PUF is a bariatric surgery-specific clinical data set, which contains nearly 200 variables including preoperative patient characteristics, procedure details, as well as details on complications, reoperations, readmissions, or interventions within 30 days in both the inpatient and outpatient setting.

The MBSAQIP-PUF does not identify hospitals or individual healthcare providers. The data registry collects prospective, risk-adjusted information based on previously standardized definitions for preoperative, intraoperative, and postoperative variables specific to bariatric surgery. Data are collected and audited at each center by reviewers trained in collecting and auditing similar to the National Surgical Quality Improvement Program.

Propensity score matching (PSM)

To overcome biases from the different distribution of covariates among patients in the robotic and laparoscopic approach groups, a two-consecutive propensity score analysis was performed in each operation (RYGB and SG). One included the preoperative characteristics and comorbidities. The other contained operative time and conversion rate in addition to preoperative characteristics and comorbidities.

In each PSM analysis, we obtained a 1:1 nearest-neighbor matching with no replacement. To exclude bad matches, we imposed a caliper of 0.2 of the standard deviation of the logit of the propensity score. Propensity score analysis and matching were performed with the PS matching program

that performs all analyses in R through the SPSS R-Plugin (SPSS R Essentials) and utilizes newly written R code as described by Thoemmes [26].

The preoperative characteristics and comorbidities which were matched include age, sex, Body Mass Index (BMI), history of diabetes, hypertension requiring medications, myocardial infarction, cardiac stent, cardiac surgery, smoker status, chronic obstructive pulmonary disease, GERD, hyperlipidemia, sleep apnea, use of therapeutic anticoagulation, use of a mobility device, chronic corticosteroid/immunosuppressive therapy, renal insufficiency, dialysis dependent, pulmonary embolism, DVT, ASA score, and functional status. After matching, we examined the balance of all observed covariates using absolute standardized mean differences that are the absolute value of the difference in means between groups.

Surgical Outcomes

Twenty-five postoperative outcomes within the first 30 days of operation were assessed. These included mortality, cardiac (cardiac arrest or myocardial infarction), pulmonary (pneumonia, unplanned intubation or mechanical ventilation for more than 48 h), renal complications (renal failure or dialysis requirement), sepsis (sepsis or septic shock), unplanned ICU, blood transfusions, re-admissions, re-operations, interventions, Venous Thromboembolism (VTE—including deep venous thrombosis or pulmonary embolism), wound disruption, incisional hernia and Surgical site Infection (SSI), operative time, conversion rate and length of hospital stay. In addition, we obtained eight composite outcomes that were coded in the suspected causes for re-operation, interventions and re-admission files in the MBSAQIP data set. These composite outcomes were anastomotic/staple-line leak, stricture, internal hernia, postoperative bleeding, gallstone disease, intestinal obstruction, anastomotic ulcer, and gastrointestinal perforation.

Finally, we obtained the operative times between the robotic approach and the laparoscopic group in specific subpopulations including patients with BMI < 50, BMI 50–59, BMI ≥ 60, history of previous bariatric or foregut surgery alone, history of previous bariatric or foregut surgery within the patients with BMI ≥ 50.

Statistical analysis

Univariate analyses were performed using either the Pearson χ^2 test (or Fisher's exact test for rare events) for categorical variables. Independent sample t-test was used for normally distributed continuous variables and Mann–Whitney test for skewed continuous variables. The results were reported as the frequency and percentage for categorical variables and mean (\pm standard deviation) for continuous variables. After

PSM analyses, matched pair cohort was assessed using the paired McNemar test for categorical variables, paired *t* test for continuous variables normally distributed or Wilcoxon signed-rank sum test for non-normally distributed continuous variables. Any *P* value < 0.05 was considered statistically significant. All analyses were performed with computer software (IBM SPSS Statistics, Version 25.0, IBM Corp., Armonk, NY).

Results

Patient demographic characteristics

A total of 269,923 patients met inclusion criteria; 190,494 patients underwent minimally invasive SG, of which 177,617 (93.24%) patients underwent conventional laparoscopic surgery while 12,877 (6.76%) patients underwent robotic-assisted approach. On the other hand, 79,429 patients underwent minimally invasive RYGB, of which 73,649 (92.72%) patients underwent conventional laparoscopic surgery while 5780 (7.28%) patients underwent robotic-assisted approach.

Propensity score matching analysis was performed to adjust for preoperative characteristics and comorbidities (analysis 1) for the SG. Before propensity score matching, patients who underwent robotic-assisted approach were significantly more likely to be female ($P=0.002$), diabetic ($P=0.03$), have a higher BMI ($P<0.001$), Sleep Apnea ($P=0.01$), were more likely to have an American Society of Anesthesiologist (ASA) class of 3 ($P<0.001$), have to use a mobility device ($P<0.001$), and were less likely to have a history of previous bariatric or foregut surgery ($P<0.001$). After propensity matching (analysis 1), 25,754 patients remained with matching method of 1:1. There were no statistically significant differences in preoperative patient variables after propensity matching except for sleep apnea ($P=0.01$) which was more frequent in the robotic-assisted approach patients. More importantly, all the standardized mean differences were ≤ 0.10 . The highest standardized mean difference after matching of analysis 1 was found in the history of hyperlipidemia with a value of $d=0.022$. Additional preoperative patient variables before and after matching either for analysis 1 and 2 are described in Table 1.

In the same fashion, analysis 1 was performed for the RYGB, before propensity score matching patients who underwent robotic-assisted approach were significantly more likely to be older ($P<0.001$), diabetic ($P=0.01$), Hypertensive requiring medications ($P<0.001$), have GERD ($P<0.001$), COPD ($P<0.001$), hyperlipidemia ($P=0.003$), renal failure ($P=0.03$), lower BMI ($P<0.001$), have to use a mobility device ($P<0.001$), have a history of previous bariatric or foregut surgery ($P=0.002$), and were less likely to have an American Society of Anesthesiologist (ASA)

Table 1 Comparison of laparoscopic and robotic-assisted approach for sleeve gastrectomy for all cohort (before match) and after propensity matching for analysis 1 and 2

Characteristics ^a	All cohort (Before match)				Match cohort for analysis 1 (Adjusting for preoperative characteristics)				Match cohort for analysis 2 (Adjusting for preoperative characteristics, operative time and conversion rate)			
	Laparoscopic (n = 177,617)	Robotic- assisted (n = 12,877)	P*	d	Laparoscopic (n = 12,877)	Robotic- assisted (n = 12,877)	P*	d	Laparoscopic (n = 12,877)	Robotic- assisted (n = 12,877)	P*	d
Age, years	43.48 ± 10.97	43.61 ± 10.96	0.23	43.65 ± 11.03	43.61 ± 10.96	43.61 ± 10.96	0.74	0.003	43.52 ± 10.98	43.61 ± 10.96	0.53	0.008
Sex (female)	141,433 (79.63)	10,397 (80.74)	0.002	10,490 (81.46)	10,397 (80.74)	10,397 (80.74)	0.12	-0.005	10,507 (81.60)	10,397 (80.74)	0.08	0.022
Body Mass Index, kg/m ²	45.07 ± 8.01	45.39 ± 8.20	<0.001	45.36 ± 8.14	45.39 ± 8.20	45.39 ± 8.20	0.92	0.013	45.47 ± 8.33	45.39 ± 8.20	0.08	-0.010
ASA 1 or 2	47,368 (26.67)	3176 (24.66)	<0.001	3234 (25.11)	3176 (24.66)	3176 (24.66)	0.31	0.008	3021 (23.46)	3176 (24.66)	0.02	0.028
ASA 3	125,006 (70.38)	9395 (72.26)	<0.001	9251 (71.84)	9395 (72.26)	9395 (72.26)	0.38	0.005	9496 (73.74)	9395 (72.26)	0.01	-0.033
ASA 4 or 5	5243 (2.95)	396 (3.08)	0.43	392 (3.04)	396 (3.08)	396 (3.08)	0.91	-0.003	360 (2.80)	396 (3.08)	0.18	0.016
History of myocardial infarction	1865 (1.05)	141 (1.09)	0.63	122 (0.95)	141 (1.09)	141 (1.09)	0.27	0.001	150 (1.16)	141 (1.09)	0.60	-0.007
Previous cardiac stent	2941 (1.66)	252 (1.96)	0.01	223 (1.73)	252 (1.96)	252 (1.96)	0.13	0.007	246 (1.91)	252 (1.96)	0.79	0.003
Previous cardiac surgery	1741 (0.98)	111 (0.86)	0.19	106 (0.82)	111 (0.86)	111 (0.86)	0.78	0.020	109 (0.85)	111 (0.86)	0.89	0.002
Diabetes mellitus	38,519 (21.69)	2899 (22.51)	0.03	2844 (22.09)	2899 (22.51)	2899 (22.51)	0.40	0.001	2963 (23.01)	2899 (22.51)	0.34	-0.012
Hypertension	80,631 (45.40)	5940 (46.13)	0.11	5972 (46.38)	5940 (46.13)	5940 (46.13)	0.69	0.003	5934 (46.08)	5940 (46.13)	0.94	0.001
Hyperlipidemia	37,203 (20.95)	2734 (21.23)	0.44	2644 (20.53)	2734 (21.23)	2734 (21.23)	0.17	0.022	2727 (21.18)	2734 (21.23)	0.92	0.001
Mobility device use	2469 (1.40)	321 (2.50)	<0.001	315 (2.45)	321 (2.50)	321 (2.50)	0.60	0.018	386 (3.00)	321 (2.49)	0.01	-0.032
Deep venous throm- bosis	2460 (1.39)	191 (1.48)	0.36	182 (1.41)	191 (1.48)	191 (1.48)	0.67	0.005	188 (1.46)	191 (1.48)	0.88	0.002
Pulmonary embolism	1855 (1.04)	140 (1.09)	0.65	130 (1.01)	140 (1.09)	140 (1.09)	0.58	0.006	143 (1.11)	140 (1.09)	0.86	-0.002
Therapeutic antico- agulation	3643 (2.05)	257 (2.00)	0.67	243 (1.89)	257 (2.00)	257 (2.00)	0.60	-0.001	240 (1.86)	257 (2.00)	0.44	0.009
COPD	2603 (1.47)	176 (1.37)	0.37	159 (1.23)	176 (1.37)	176 (1.37)	0.37	0.017	179 (1.39)	176 (1.37)	0.87	-0.002
Current smoker	16,120 (9.08)	1194 (9.27)	0.45	1203 (9.34)	1194 (9.27)	1194 (9.27)	0.86	0.010	1237 (9.61)	1194 (9.27)	0.36	-0.012
Renal failure	976 (0.55)	71 (0.55)	0.98	65 (0.50)	71 (0.55)	71 (0.55)	0.67	-0.004	61 (0.47)	71 (0.55)	0.38	0.010
Dialysis	529 (0.30)	44 (0.34)	0.38	37 (0.29)	44 (0.34)	44 (0.34)	0.51	-0.011	41 (0.32)	44 (0.34)	0.74	0.004
Sleep apnea	61,234 (34.48)	4595 (35.68)	0.01	4389 (34.08)	4595 (35.68)	4595 (35.68)	0.01	-0.004	4653 (36.13)	4595 (35.68)	0.45	-0.009
GERD	49,762 (28.02)	3770 (29.28)	0.002	3739 (29.04)	3770 (29.28)	3770 (29.28)	0.66	0.020	3837 (29.80)	3770 (29.28)	0.36	-0.011
Steroids/immunosup- pressive use	3060 (1.72)	203 (1.58)	0.27	201 (1.56)	203 (1.58)	203 (1.58)	0.96	0.001	195 (1.51)	203 (1.58)	0.69	0.005
Previous bariatric or foregut surgery	11,296 (6.36)	680 (5.28)	<0.001	697 (5.41)	680 (5.28)	680 (5.28)	0.54	-0.003	555 (4.31)	680 (5.28)	<0.001	0.043

Table 1 (continued)

All cohort (Before match)	Match cohort for analysis 1 (Adjusting for preoperative characteristics)		Match cohort for analysis 2 (Adjusting for preoperative characteristics, operative time and conversion rate)				
	Robotic-assisted (n = 12,877)	P* 0.14	Laparoscopic (n = 12,877)	Robotic-assisted (n = 12,877)	Laparoscopic (n = 12,877)	P* 0.95	d 0.001
Functional status (non-dependent)	12,767 (99.15)	0.14	12,782 (99.26)	12,767 (99.15)	12,766 (99.14)	0.95	0.001

Bold values represent significant differences defined as $P < 0.05$

ASA American Society of Anesthesiologists, COPD chronic obstructive pulmonary disease, GERD gastroesophageal reflux disease

^aContinuous data are shown as the mean \pm standard deviation and categorical data as number (%), d = standardized mean difference

class of 4 or 5 ($P < 0.001$) and history of myocardial infarction ($P = 0.01$). After 1:1 propensity matching (analysis 1); 11,558 patients were obtained. There were no statistically significant differences in preoperative patient variables after propensity matching and all the standardized differences were ≤ 0.10 . The highest standardized mean difference after matching of analysis 1 was found in renal failure $d = 0.032$. All the preoperative patient variables before and after matching either for analysis 1 and 2 are displayed in Table 2.

Outcomes of matched cohorts (analysis 1 and 2)

After propensity matching in analysis 1 (adjusting for preoperative characteristics and comorbidities), patients who underwent Robotic-assisted SG had a significantly longer operative time compared to the laparoscopic approach (102.58 ± 46 vs. 73.38 ± 36 min; $P < 0.001$). Similarly, the operative time was longer for Robotic-assisted RYGB compared to laparoscopic approach (158.29 ± 65 vs. 120.17 ± 56 min; $P < 0.001$). The conversion rates were higher for the robotic-assisted approach than the laparoscopic surgery either for SG (0.53% vs. 0.12%; $P < 0.001$) and for RYGB (0.57% vs. 0.26%; $P = 0.01$).

In terms of 30-day postoperative outcomes in the analysis 1, the robotic-assisted SG was associated with a significant reduction of postoperative bleeding (0.16% vs. 0.43%; $P < 0.001$) and stricture formation (0.19% vs. 0.33% $P = 0.04$). The postoperative length of stay was significantly longer with the robotic approach. The remainder of outcomes: mortality, reoperation, readmission, and interventions were comparable between the robotic platform and the conventional laparoscopic approach (Table 3).

On the other hand, the outcomes for the RYGB in the analysis 1 revealed a significant reduction of blood transfusions in favor of the robotic platform (0.64% vs. 1.16%; $P = 0.004$), with no other significant differences in 30-day outcomes including the postoperative length of stay (Table 4).

Analysis 2 (adjusting for preoperative characteristic, comorbidities, conversion rate, and operative time) was created to eliminate the bias of the longer operative time and conversion rate. After this adjustment, the mean difference in operative time was now within 2 min between the Robotic-assisted and Laparoscopic SG groups (102.58 ± 46 vs. 100.55 ± 47 min, $P < 0.001$) and within 3 min between the Robotic-assisted and Laparoscopic RYGB groups (158.31 ± 65 vs. 155.49 ± 68 min, $P = 0.02$). Also, after the Analysis 2, the differences of conversion rates between the robotic-assisted and laparoscopic approach were reduced for SG (0.53% vs. 0.33%; $P = 0.01$) and for RYGB (0.57% vs. 0.52%; $P = 0.71$).

Table 2 Comparison of laparoscopic and robotic-assisted approach for gastric bypass for all cohort (before match) and after propensity matching for analysis 1 and 2

Characteristics ^a	All cohort (before match)			Match cohort for analysis 1 (Adjusting for preoperative characteristics)			Match cohort for analysis 2 (Adjusting for preoperative characteristics, operative time and conversion rate)		
	Laparoscopic (n = 73,649)	Robotic-assisted (n = 5,780)	P*	Laparoscopic (n = 5779)	Robotic-assisted (n = 5779)	P*	Laparoscopic (n = 5780)	Robotic-assisted (n = 5780)	P*
	<i>d</i>	<i>d</i>	<i>d</i>	<i>d</i>	<i>d</i>	<i>d</i>	<i>d</i>	<i>d</i>	<i>d</i>
Age, years	44.34 ± 10.9	45.14 ± 10.8	<0.001	45.13 ± 10.8	45.14 ± 10.8	0.01	45.13 ± 10.86	45.14 ± 10.82	0.96
Sex (female)	59,714 (81.08)	4700 (81.31)	0.66	4767 (82.49)	4699 (81.31)	0.10	4732 (81.87)	4700 (81.31)	0.44
Body Mass Index, kg/m ²	46.08 ± 8.3	45.47 ± 8.2	<0.001	45.47 ± 7.9	45.47 ± 8.2	0.66	45.17 ± 7.84	45.47 ± 8.23	0.04
ASA 1 or 2	13,589 (18.45)	1120 (19.38)	0.08	1128 (19.52)	1120 (19.38)	0.87	1184 (20.48)	1120 (19.38)	0.14
ASA 3	56,881 (77.23)	4470 (77.34)	0.86	4452 (77.04)	4469 (77.33)	0.72	4430 (76.64)	4470 (77.34)	0.38
ASA 4 or 5	3179 (4.32)	190 (3.29)	<0.001	199 (3.44)	190 (3.29)	0.68	166 (2.87)	190 (3.29)	0.20
History of myocardial infarction	1064 (1.44)	70 (1.21)	0.01	55 (0.95)	70 (1.21)	0.21	67 (1.16)	70 (1.21)	0.80
Previous cardiac stent	1567 (2.13)	140 (2.42)	0.14	134 (2.32)	140 (2.42)	0.76	147 (2.54)	140 (2.42)	0.68
Previous cardiac surgery	676 (0.92)	55 (0.95)	0.80	60 (1.04)	54 (0.93)	0.63	53 (0.92)	54 (0.95)	0.85
Diabetes mellitus	24,135 (32.77)	1998 (34.57)	0.01	1961 (33.93)	1998 (34.57)	0.45	2002 (34.64)	1998 (34.57)	0.94
Hypertension	37,386 (50.76)	3111 (53.82)	<0.001	3087 (53.42)	3110 (53.82)	0.66	3141 (54.34)	3111 (53.82)	0.58
Hyperlipidemia	20,029 (27.20)	1677 (29.01)	0.003	1630 (28.21)	1677 (29.02)	0.31	1662 (28.75)	1677 (29.01)	0.76
Mobility device use	1338 (1.82)	161 (2.79)	<0.001	148 (2.56)	160 (2.77)	0.52	171 (2.96)	161 (2.79)	0.58
Deep venous thrombosis	1322 (1.80)	89 (1.54)	0.16	94 (1.63)	89 (1.54)	0.77	75 (1.30)	89 (1.54)	0.27
Pulmonary embolism	919 (1.25)	66 (1.14)	0.48	66 (1.14)	66 (1.14)	1.00	59 (1.02)	66 (1.14)	0.53
Therapeutic anticoagulation	1673 (2.27)	147 (2.54)	0.18	147 (2.54)	147 (2.54)	1.00	149 (2.58)	147 (2.54)	0.91
COPD	1287 (1.75)	146 (2.53)	<0.001	146 (2.53)	145 (2.51)	1.00	148 (2.56)	146 (2.53)	0.91
Current smoker	6381 (8.66)	497 (8.60)	0.87	501 (8.67)	497 (8.60)	0.92	486 (8.41)	497 (8.60)	0.71
Renal failure	395 (0.54)	44 (0.76)	0.03	27 (0.47)	43 (0.74)	0.07	40 (0.69)	44 (0.76)	0.66
Dialysis	122 (0.17)	12 (0.21)	0.45	9 (0.16)	11 (0.19)	0.82	10 (0.17)	12 (0.21)	0.67
Sleep apnea	30,306 (41.15)	2401 (41.54)	0.56	2351 (40.68)	2401 (41.55)	0.35	2363 (40.88)	2401 (41.54)	0.47
GERD	28,033 (38.06)	2391 (41.37)	<0.001	2447 (42.34)	2390 (41.36)	0.29	2404 (41.59)	2391 (41.36)	0.81
Steroids/immunosuppressive use	1057 (1.44)	98 (1.7)	0.11	94 (1.63)	98 (1.70)	0.83	83 (1.44)	98 (1.70)	0.26
Previous bariatric or foregut surgery	6604 (8.97)	587 (10.16)	0.002	589 (10.19)	587 (10.16)	0.96	568 (9.83)	587 (10.16)	0.56

Table 2 (continued)

All cohort (before match)	Match cohort for analysis 1 (Adjusting for preoperative characteristics)		Match cohort for analysis 2 (Adjusting for preoperative characteristics, operative time and conversion rate)						
	Robotic-assisted (n = 5,780)	P* 0.14	Laparoscopic (n = 5779)	Robotic-assisted (n = 5779)	P* 0.79	Laparoscopic (n = 5780)	Robotic-assisted (n = 5780)	P* 0.79	d
Functional status (non-dependent)	5715 (98.88)	0.14	5718 (98.94)	5714 (98.88)	0.79	5718 (98.93)	5715 (98.88)	0.79	-0.005

Bold values represent significant differences defined as $P < 0.05$

ASA American Society of Anesthesiologists, COPD chronic obstructive pulmonary disease, GERD gastroesophageal reflux disease

^aContinuous data are shown as the mean \pm standard deviation and categorical data as number (%). *d* = standardized mean difference

In the Analysis 2, the 30-day outcomes for SG were similar as showed in analysis 1 when comparing robotic platform vs. laparoscopic approach as displayed in Table 3.

In contrast, for the RYGB, the Analysis 2 revealed that patients who underwent robotic-assisted RYGB had a significantly shorter length of hospital stay (2.12 ± 1.9 vs. 2.30 ± 3.1 days; $P < 0.001$). Furthermore, there was a significant reduction of anastomotic leaks (0.52% vs. 0.92%; $P = 0.01$), VTE, (0.24% vs. 0.52%; $P = 0.02$), renal complications, (0.16% vs. 0.38%; $P = 0.004$), and blood transfusions (0.64% vs. 1.30%; $P < 0.001$) with the robotic platform compared to the laparoscopic approach (Table 4).

Finally, to investigate the influence of each approach with regard to prolonged operative time in high-risk subpopulations, a table was created to compare univariate analysis of operative times between the robotic approach and the laparoscopic group in specific subpopulations including patients with BMI < 50 , BMI 50–59, BMI ≥ 60 , history of previous bariatric or foregut surgery alone, history of previous bariatric or foregut surgery within the patients with BMI ≥ 50 . In all the groups, the robotic platform had longer operative times than the laparoscopic approach ($P < 0.001$) as shown in Table 5.

Discussion

The first report of robotic-assisted bariatric surgery was published by Cadiere et al. to perform an adjustable gastric banding in 1999 [27]. Subsequently, Horgan and collaborators performed the first robot-assisted gastric bypass in 2000 [28]. Moreover, the first robotic sleeve gastrectomy was conducted as part of biliopancreatic diversion with duodenal switch in 2000 by Sudan et al. [29]. However, in this minimally invasive surgery era, only a few retrospective comparative studies have demonstrated clear advantages of robotic surgery with respect to laparoscopic surgery [20–25]. Although there is limited evidence, it is likely that the benefit of robotics can be shown with complex operations such as RYGB. Recently, a meta-analysis by Li et al. in 2016 has shown similar outcomes of robotic vs. laparoscopic bariatric surgery thus confirming the safety and feasibility of robotic surgery. In this meta-analysis, the incidence of anastomotic leak was lower with the robotic approach [30]. However, this meta-analysis included studies from single institutions or with a small number of patients. Extensive scale data on this subject are necessary to further explore the findings of these prior authors.

Our analysis of the 2015–2016 MBSAQIP database is one of the largest retrospective studies that establishes the benefits of robotic surgery in the bariatric field. This study revealed that after adjusting for operative times and the conversion rates, the platform of robotic-assisted surgery is

Table 3 30-Day outcomes of laparoscopic and robotic-assisted sleeve gastrectomy for analysis 1 and 2

	Analysis 1 (Adjusting for preoperative characteristics)			Analysis 2 (Adjusting for preoperative characteristics, operative time and conversion rate)		
	Laparoscopic (n = 12,877)	Robotic-assisted (n = 12,877)	P*	Laparoscopic (n = 12,877)	Robotic-assisted (n = 12,877)	P*
30-Day outcomes^a						
Mortality	10 (0.08)	8 (0.06)	0.82	11 (0.09)	8 (0.06)	0.65
Cardiac complications	10 (0.08)	4 (0.03)	0.18	9 (0.07)	4 (0.03)	0.27
Pulmonary complications	20 (0.16)	18 (0.14)	0.87	14 (0.11)	18 (0.14)	0.60
Renal complications	20 (0.16)	9 (0.07)	0.06	16 (0.12)	9 (0.07)	0.23
Unplanned ICU admission	58 (0.45)	72 (0.56)	0.25	82 (0.64)	72 (0.56)	0.47
Blood transfusions	68 (0.53)	52 (0.40)	0.17	65 (0.50)	52 (0.40)	0.27
Readmissions	438 (3.4)	457 (3.55)	0.54	467 (3.63)	457 (3.55)	0.76
Reoperations	111 (0.86)	128 (0.99)	0.30	131 (1.02)	128 (0.99)	0.90
Interventions	140 (1.09)	173 (1.34)	0.07	142 (1.10)	173 (1.34)	0.09
Venous thromboembolism	31 (0.24)	37 (0.29)	0.54	41 (0.32)	37 (0.29)	0.73
Surgical site infection	1 (0.01)	3 (0.02)	0.25	4 (0.03)	3 (0.02)	1.00
Incisional hernia	9 (0.07)	10 (0.08)	1.00	9 (0.07)	10 (0.08)	1.00
Wound disruption	5 (0.04)	4 (0.03)	1.00	7 (0.05)	4 (0.03)	0.55
Sepsis or septic shock	0.01(1)	1 (0.01)	1.00	2 (0.02)	1 (0.01)	1.00
Postoperative-LOS	1.65 ± 1.58	1.75 ± 1.78	<0.001	1.76 ± 1.60	1.75 ± 1.78	0.04
Bariatric-specific complications						
Anastomotic/staple line leak	64 (0.50)	56 (0.43)	0.52	70 (0.54)	56 (0.43)	0.25
Postoperative bleeding	56 (0.43)	20 (0.16)	<0.001	50 (0.39)	20 (0.16)	0.001
Stricture/stomal obstruction	43 (0.33)	25 (0.19)	0.04	47 (0.36)	25 (0.19)	0.01
Intestinal obstruction	16 (0.12)	12 (0.09)	0.57	24 (0.19)	12 (0.09)	0.07
Internal hernia	9 (0.07)	7 (0.05)	0.80	9 (0.07)	7 (0.05)	0.80
Gastrointestinal perforation	12 (0.09)	6 (0.05)	0.24	16 (0.12)	6 (0.05)	0.052
Anastomotic ulcer	7 (0.05)	2 (0.02)	0.18	7 (0.05)	2 (0.02)	0.18
Gallstone disease	19 (0.15)	11 (0.09)	0.20	15 (0.12)	11 (0.09)	0.56

ICU intensive care unit, LOS length of stay

Bold values represent significant differences defined as * $P < 0.05$

^aContinuous data are shown as the mean ± standard deviation and categorical data as number (%)

favorable with respect to the 30-day postoperative outcomes for the RYGB and confirms the non-inferiority in postoperative outcomes for the SG.

We performed two consecutive analyses comparing robotic-assisted vs. laparoscopic approach of two of the most common bariatric operations in the US, the SG and RYGB. Our first analysis, adjusting only for comorbidities and preoperative characteristics, showed that there was no difference in postoperative complications between robotic and laparoscopic surgery groups. If anything, a significant advantage was seen in a reduction of blood transfusion or postoperative bleeding associated with the robotic platform for SG and RYGB.

However, a notable difference in operative times was found between robotic-assisted and laparoscopic approach in either SG or RYGB. There was a significantly longer

operative time associated with the robotic platform. These operative time differences were remarkably wide and longer operative time by itself is well recognized as an independent risk factor for more postoperative complications in the general surgery [31–33] and in the bariatric surgery literature [34, 35]. To address this, we conducted a second PSM analysis adjusting for operative times and conversion rates in order to evaluate the robotic technique by itself independent to the prolonged operative time. In our analysis, the robotic-assisted vs. the laparoscopic approach's mean operative times for the RYGB were 158 min and 120 min, respectively. For the sleeve gastrectomy, the robotic approach's mean operative time was 103 min while the laparoscopic approach had a mean approach time of 73 min. In a recent meta-analysis in 2017, mean operative time ranged from 84 to 138 min for the laparoscopic SG and from 96 to 148 min

Table 4 30-Day outcomes of laparoscopic and robotic-assisted RYGB for analysis 1 and 2

	Analysis 1 (Adjusting for preoperative characteristics)			Analysis 2 (Adjusting for preoperative characteristics, operative time and conversion rate)		
	Laparoscopic (n = 5779)	Robotic-assisted (n = 5779)	P*	Laparoscopic (n = 5780)	Robotic-assisted (n = 5780)	P*
30-Day outcomes^a						
Mortality	9 (0.16)	7 (0.12)	0.80	7 (0.12)	7 (0.12)	1.00
Cardiac complications	7 (0.12)	4 (0.07)	0.55	4 (0.07)	4 (0.07)	1.00
Pulmonary complications	14 (0.24)	11 (0.19)	0.69	19 (0.33)	11 (0.19)	0.20
Renal complications	14 (0.24)	9 (0.16)	0.41	22 (0.38)	9 (0.16)	0.03
Unplanned ICU admission	66 (1.14)	63 (1.09)	0.86	87 (1.51)	63 (1.09)	0.06
Blood transfusions	67 (1.16)	37 (0.64)	0.004	75 (1.30)	37 (0.64)	<0.001
Readmissions	363 (6.28)	414 (7.16)	0.06	386 (6.68)	414 (7.16)	0.32
Reoperations	146 (2.53)	153 (2.65)	0.72	159 (2.75)	153 (2.65)	0.77
Interventions	172 (2.98)	178 (3.08)	0.79	176 (3.04)	178 (3.08)	0.96
Venous thromboembolism	17 (0.29)	14 (0.24)	0.72	30 (0.52)	14 (0.24)	0.02
Surgical site infection	1 (0.02)	2 (0.03)	0.50	2 (0.03)	2 (0.03)	1.00
Incisional hernia	7 (0.12)	6 (0.10)	1.00	11 (0.19)	6 (0.10)	0.33
Wound disruption	5 (0.09)	8 (0.14)	0.58	4 (0.07)	8 (0.14)	0.39
Sepsis or septic shock	1 (0.02)	1 (0.02)	1.00	1 (0.02)	1 (0.002)	1.00
Postoperative-LOS	2.17 ± 2.4	2.12 ± 1.9	0.29	2.30 ± 3.1	2.12 ± 1.9	<0.001
Bariatric-specific complications						
Anastomotic/staple line leak	43 (0.74)	30 (0.52)	0.16	53 (0.92)	30 (0.52)	0.02
Postoperative bleeding	50 (0.87)	44 (0.76)	0.60	49 (0.85)	44 (0.76)	0.60
Stricture/stomal obstruction	35 (0.61)	31 (0.54)	0.71	39 (0.67)	31 (0.54)	0.34
Intestinal obstruction	38 (0.66)	42 (0.73)	0.74	50 (0.87)	42 (0.73)	0.47
Internal hernia	4 (0.07)	5 (0.09)	1.00	7 (0.12)	5 (0.09)	0.77
Gastrointestinal perforation	7 (0.12)	5 (0.09)	0.77	4 (0.07)	5 (0.09)	1.00
Anastomotic ulcer	16 (0.28)	21 (0.36)	0.51	23 (0.40)	21 (0.36)	0.88
Gallstone disease	10 (0.17)	6 (0.10)	0.45	7 (0.12)	6 (0.10)	1.00

Bold values represent significant differences defined as $P < 0.05$

ICU intensive care unit, LOS length of stay

^aContinuous data are shown as the mean ± standard deviation and categorical data as number (%)

for the robotic-assisted SG [36]. Furthermore, Celio *et al.* reported a surgical time of 150 vs. 112 min for robotic-assisted vs. laparoscopic RYGB, respectively [37]. The reasons for the prolonged operative time in robotic surgery are generally attributed to the docking time and a lack of efficiency of the operating room team, unfamiliarity of the robotic instruments, or a lack of a strategic plan with respect to step by step of the surgery with the robots.

Our study revealed a significant reduction in anastomotic leaks when using a robotic approach vs. laparoscopic approach (0.5 vs. 0.9%) for RYGB, after adjusting for operative times and conversion rates. This anastomotic leak reduction with the robotic approach in our study is consistent with previous reports in the literature. Buchs *et al.* demonstrated an incidence of 0.3% for robotically hand-sewn anastomoses vs. 3.6% with the laparoscopic

stapled anastomoses [22]. Moreover, Hagen *et al.* revealed a lower rate of anastomotic leak with the robotic platform than the laparoscopic approach (0 vs. 4%), leading to a cost reduction [24]. However, a study using a similar statistical model presents contrasting results. Celio *et al.* reported a higher rate of anastomotic leak for the robotic (1.5%) vs. laparoscopic (0.5%) approach in surgeries performed between 2007 and 2012 [37]. Our improved leak rate finding for more recent data may represent an improvement in surgeon experience and robotic platform technology over time. The FDA approved the *EndoWrist* linear stapler for the *da Vinci Si* and *Xi* Surgical Systems in the United States in 2012. However, the MBSAQIP does not report data of the specific anastomosis technique (circular, linear, robotic *EndoWrist* stapler or hand-sewn technique). Therefore, even though a robotic linear stapler was

Table 5 Comparative operative times between laparoscopic and robotic-assisted approach in different high-risk subpopulations

	Operative time (min)					
	Sleeve gastrectomy			RYGB		
	Laparoscopic (<i>n</i> = 177,617) Mean ± SD	Robotic-assisted (<i>n</i> = 12,877) Mean ± SD	<i>P</i> *	Laparoscopic (<i>n</i> = 73,649) Mean ± SD	Robotic-assisted (<i>n</i> = 5780) Mean ± SD	<i>P</i> *
Subpopulation						
BMI < 50	73.04 ± 37	101.48 ± 45	<0.001	119.31 ± 55	155.01 ± 65	<0.001
BMI 50–59	76.49 ± 39	104.87 ± 47	<0.001	120.36 ± 55	163.97 ± 66	<0.001
BMI > 60	80.14 ± 41	110.73 ± 51	<0.001	122.39 ± 58	171.59 ± 70	<0.001
Previous bariatric or foregut surgery alone	100.18 ± 47	141.82 ± 65	<0.001	152.68 ± 72	192.55 ± 70	<0.001
BMI > 50 and previous bariatric or foregut surgery	103.89 ± 52	144.46 ± 81	<0.001	153.23 ± 71	198.84 ± 72	<0.001

BMI Body Mass Index in kg m²

Operative times are shown as the mean ± standard deviation (SD)

Bold values represent significant differences between operative times, defined as **P* < 0.05 found in *t* test or Mann Whitney test

available during the time of this study, we cannot determine the anastomotic technique that was most commonly used with the robotic-assisted approach and its influence on the outcomes. Similarly, the use of the Robotic “*Firefly*” Fluorescence Imaging for the da Vinci® Xi™ Surgical System to evaluate the perfusion of anastomosis is not a variable of the MBSAQIP database.

On the other hand, there was no decrease seen with respect to staple-line leaks with the robotic platform for the SG, and there was a significant decrease of the 30-day stricture formation (0.19% vs. 0.36%) in the robotic platform before and after adjusting for the operative time and conversion rate. To date, only two other studies have reported rates of stricture formation and have found no statistically significant differences between robotic and laparoscopic SG [38, 39]. Our results, although in favor for the robotic platform, should be taken with caution in this particular uncommon complication as we could not adjust for factors such as bougie size for calibration of the sleeve, over-sewing of the staple line, use of sealing material and type of stapler (such as robotic *EndoWrist* Stapler). However, the reduction of stricture with the robotic-assisted SG may be result of the improved three-dimensional visualization, precise movement and better ergonomics conferring technical advantages both in tissue dissection and manipulation improving the orientation to keep a safe distance between the incisura angularis and the edge where the staples are applied. Furthermore, in case of staple line over-sewing, the robotic technology may allow a symmetric and meticulous suturing of the staple line involving only necessary amount of the gastric wall.

The most conclusive results in our study were the fact that the robotic platform is associated with a significant reduction of blood transfusion requirement and postoperative bleeding for RYGB and SG, respectively, pre- and post-adjustment of operative time. This may be due to the high precision of robotic movements and fine manipulation of tissues in a magnified 3-dimensional operating field leading to less intraoperative and postoperative bleeding. The advantage with respect to blood transfusion requirements and postoperative bleeding has also been demonstrated in robotic studies examining both colorectal [40] and bariatric outcomes [41, 42].

Venous thromboembolism is one of the most life-threatening complications of bariatric surgery. There is a directly proportional relationship between operative time and venous thromboembolism reported in the bariatric surgery literature [43]. However, other studies have reported a similar incidence of VTE between robotic-assisted and laparoscopic approach even with significantly longer operative times conferred by robotic surgery [21, 30]. In our study, after adjusting for operative times and conversion rates, the incidence of VTE was lower with the robotic platform for RYGB, and this could be explained by having less tissue damage which can lead to a reduced pro-coagulant inflammatory response. However, this benefit was not seen for the robotic-assisted SG. Furthermore, the incidence of postoperative renal failure was reduced in patients with the robotic-assisted RYGB after adjustment of operative time and conversion rate, which may be related to a reduced incidence of postoperative or intraoperative bleeding associated with robotic surgery.

The postoperative length of stay was shorter with robotic-assisted RYGB after operative adjustment. This could be an effect of less tissue damage with the robotic technology minimizing postoperative pain and decreasing the postoperative ileus leading to a faster recovery. This shorter length of stay is consistent with previous publications in the robotic bariatric surgery [20, 21].

Since our outcomes with the robotic platform were directly influenced by the operative time specifically in RYGB, we decided to analyze the operative time in different subpopulations. There are different proposed high-risk subpopulations of prolonged operative time such as patients with high BMI or with the presence of adhesions due to previous bariatric or foregut surgeries. One of the proposed advantages of robotic surgery in patients with high BMI is to decrease the “torque effect” and technical limitations of a thick abdominal wall in this subpopulation. Ayloo et al. showed that in superobese patients ($\text{BMI} \geq 50$), robotic-assisted surgery has better outcomes than laparoscopic surgery with a mean operative time of 129 min for robotic approach vs. 143 min for laparoscopic surgery in sleeve gastrectomy patients [39]. In another study, Elli et al. showed a better approach with respect to adhesiolysis using the robotic platform in patients with previous surgeries such as liver transplantation [44]. Our results show that the operative time is directly proportional to BMI; consequently, high BMI is related to prolonged operative times in both robotic and laparoscopic approach with the tendency for longer operative times with the robotic platform for either RYGB and SG. In patients with previous surgeries, the operative time is longer than patients with high BMI in both robotic and laparoscopic approaches. Moreover, the super obese patients ($\text{BMI} \geq 50$) with a history of previous surgeries were the subpopulation that required the longest operative times in our study for either in robotic or laparoscopic approach. In all subgroups, the operative time was always longer with robotic-assisted than the laparoscopic approach in both SG and RYGB. Therefore, our analysis of the operative time suggests that the robotic approach does not guarantee a reduction of operative time in these subpopulations of patients with high BMI or with a history of previous surgeries in both SG or RYGB.

One of the most relevant criticisms of robotic surgery besides the operative time is the cost [18]. Unfortunately, MBSQIP does not collect cost data; therefore, a cost analysis and an evaluation of the utilization of resources were not possible in this study.

Despite this extensive analysis, our retrospective study has several limitations. First, some relevant variables are not recorded in this database such as docking time, anesthesia time, and the anastomotic techniques were not reported. Second, other relevant data are the surgeon’s experience in the robotic field that is not quantified in the MBSQIP database. Third, the volume of patients in the robotic institution is not

provided, and consequently we cannot explore the relationship between operative time and high-volume established robotic bariatric centers. Fourth, the data only reported robotic-assisted approach, but do not mention if there was a total robotic surgery or partially assisted. Fifth, the dataset is heavily skewed towards patients undergoing laparoscopic vs. robotic surgery. Lastly, our dataset only spans 2 years and outcomes with longer follow-up periods are necessary. To address some of these limitations, we chose inclusion and exclusion criteria that would allow comparison of the most common and relevant factors to allow differentiation between the two techniques, and we performed propensity score matching to address the skewed nature of the data. Despite these limitations, our study provides analysis of one of the largest samples from a national bariatric-specific database.

In conclusion, despite bariatric surgery being a complex minimally invasive operation, it is considered a safe treatment to morbid obesity, and has become more so as surgeons gain more experience.

As robotic platforms continue to become more commonly seen within modern-day operating rooms, the debate over the appropriate utilization of robotic surgery in regards to cost and outcomes also becomes more common. Utilization of the robot only makes sense if there is evidence of improved outcomes, especially if these instruments require substantial financial investment, personnel training and resource management. Our study’s purpose is to determine whether robotic utilization will confer advantages on patient outcomes, and the results are cautiously optimistic. Our findings show that after correcting for all factors including operative time, the robotic-assisted approach is associated with better postoperative outcomes compared to laparoscopic surgery, including shorter length of stay and lower risk for anastomotic leak, blood transfusion, VTE, and renal complication especially for RYGB. Robotic SG may also have a lower risk of postoperative bleeding and stricture formation. However, analyzing high-risk patient subpopulations did not find shorter operative times for robotic surgery compared to laparoscopic approach.

As robotic surgery becomes more commonly utilized in bariatric surgery, further surgeon experience coupled with iterative advancements in the robotic platforms may show improvements in later studies. Operative time is expected to reduce with advances in the technology and specific institutional strategies for creating dedicated robotic operating room teams to improve efficiency. Propensity score matching was needed to make up for the vast differences in the smaller number of robotically performed cases, and statistically significant findings need to also be interpreted from the perspective of clinical relevance. Definitively, our data should be validated by future well-designed prospective randomized control studies to investigate short and long-term

outcomes and correlate the reduction of weight-associated comorbidities with the robotic platform.

Compliance with ethical standards

Disclosures Raul Sebastian, Melanie H. Howell, Kai-Hua Chang, Gina Adrales, Thomas Magnuson, Michael Schweitzer and Hien Nguyen have no conflicts of interest or financial ties to disclose.

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