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A superior approach? The role of robotic sleeve gastrectomy in patients with super super obesity using the 2019–2022 MBSAQIP database

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Abstract

Background Laparoscopic sleeve gastrectomy (LSG) in patients with BMI ≥ 60 presents technical challenges, that might be overcome by robotic surgery, but its effectiveness has not been rigorously evaluated. We compared the 30-day outcomes of LSG and robotic sleeve gastrectomy (RSG) in patients with BMI < 60 versus ≥ 60 and between LSG and RSG in patients with BMI ≥ 60.

Methods Patients aged 18–65 years who underwent sleeve gastrectomy were included using the 2019–2022 MBSAQIP database. We performed a Propensity Score Matching analysis, with 21 preoperative characteristics. We compared 30-day postoperative outcomes for patients with BMI < 60 versus ≥ 60 using either a laparoscopic (Analysis 1) or robotic approach (Analysis 2) and compared LSG versus RSG in patients with BMI ≥ 60 (Analysis 3).

Results 297,250 patients underwent LSG and 81,008 RSG. Propensity-matched¸ outcomes in analysis 1 (13,503 matched cases), showed that patients with BMI ≥ 60 had higher rates of mortality (0.1% vs. 0.0%, $p = 0.014$), staple line leak (0.3% vs. 0.2%, $p = 0.035$), postoperative bleeding (0.2% vs 0.1%, $p = 0.028$), readmissions (3.5% vs. 2.4%, $p < 0.001$), and interventions (0.7% vs. 0.5%, $p = 0.028$) when compared to patients with BMI < 60. In analysis 2 (4350 matched cases), patients with BMI ≥ 60 demonstrated longer operative times, length of stay, and higher rates of unplanned ICU when compared to patients with BMI < 60. In analysis 3 (4370 matched cases), patients who underwent RSG had fewer readmissions (2.9% vs. 3.7%, $p = 0.037$), staple line leaks (0.1% vs. 0.3%, $p = 0.029$), and postoperative bleeding (0.1% vs. 0.3%, $p = 0.045$), compared to LSG. Conversely, a longer operative time (92.74 ± 38.65 vs. 71.69 ± 37.45 min, $p < 0.001$) was reported.

Conclusion LSG patients with BMI ≥ 60 have higher rates of complications compared to patients with a BMI < 60. Moreover, some outcomes may be improved with the robotic approach in patients with BMI ≥ 60. These results underscore the importance of considering a robotic approach in this super super obese population.

Keywords Bariatric surgery · Sleeve gastrectomy · Minimally invasive surgery · Robotic surgery

Obesity has become a global health concern with an expected global rise from 14 to 24% of the population by 2035, as projected by the World Obesity Federation [1]. This alarming trend has intensified the demand for efficacious weight loss interventions, particularly bariatric procedures [2, 3]. With over 270,000 bariatric surgeries performed annually in the USA, sleeve gastrectomy (SG) stands out as one of the most popular bariatric surgery due to its safety and effectiveness in promoting weight loss and resolving obesity-related comorbidities [4–7].

The rise of minimally invasive surgery has established laparoscopic SG as a highly preferred technique, improving operative outcomes and lowering morbidity and mortality

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in the short and long term [8–10]. Following the pioneering robotic bariatric procedure in 2000, the adoption of robotic platforms is steadily on the rise, driven by technological advancements [11–13]. Robotic surgery brings a host of technical enhancements to the table, including precise tissue manipulation, improved three-dimensional imaging, and enhanced autonomy for the surgeon through self-assisting exposure capabilities [14]. Studies have demonstrated controversial results on robotics, some showing that bariatric robotic surgeries are associated with lower mortality and postoperative bleeding rates [15, 16]. On the other hand, Li et al., in a systematic review reported longer operative times and higher hospital costs compared to the laparoscopic approach [17].

Patients with super-super obesity, defined as those with a body mass index (BMI) ≥ 60 kg/m^2, pose significant technical challenges during bariatric surgery. Despite the considerable number of patients with BMI ≥ 60 kg/m^2, there is a scarcity of research on this particular patient population [18]. Robotic surgery presents a significant advantage with its improved dexterity and enhanced precision which could be a compelling option for this high-risk population to overcome the technical challenges [19].

We aim to compare the 30-day postoperative outcomes and bariatric-specific complications for patients with BMI < 60 versus ≥ 60 who underwent laparoscopic sleeve gastrectomy (LSG) or robotic sleeve gastrectomy (RSG) and to compare LSG versus RSG in patients with a BMI ≥ 60 through a comprehensive analysis of the 2019–2022 MBSAQIP database.

Materials and methods

Study population

Patients who underwent either RSG or LSG within the MBSAQIP data registry from January 1, 2019 to December 31, 2022 were included in this study. Patients who underwent primary SG were identified within the 2020 and 2021 MBSAQIP participant use file (PUF) using the Current Procedural Terminology codes 43775.

Exclusion criteria included patients younger than 18 years old and older than 65 years old. Also, patients who had other approaches besides conventional laparoscopic and robotic-assisted such as hand-assisted, open, single incision, and natural orifice transluminal endoscopic surgery were excluded. Additionally, 30-day re-admission, re-operation, and intervention data were extracted from separate files by matching the unique case identification numbers. MBSAQIP data are de-identified and contain no personal health information, and consequently, data were publicly available in an anonymous manner. Existing de-identified datasets as MBSAQIP by federal regulations do not constitute strictly Human Subjects Research; therefore, the Institutional Review Board (IRB) of The Johns Hopkins Hospital approved the study under exempt status.

Data sources

The 2019, 2020, 2021, and 2022 MBSAQIP participant use files (PUF) were used for the study. The MBSAQIP-PUF is one of the largest bariatric-specific clinical data sets. There were 817,099 bariatric cases from approximately 924 MBSAQIP participating sites performed from January 1, 2019 to December 31, 2022 across the USA 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 trained reviewers.

Propensity score matching (PSM)

To overcome potential biases from the different distributions of covariates among patients who underwent LSG or RSG, a propensity score analysis was performed for each surgical approach. The PSM included 21 preoperative characteristics and comorbidities. 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 [20].

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

Surgical outcomes

Eighteen postoperative outcomes within the first 30 days of operation were assessed. These included mortality, cardiac complications (cardiac arrest or myocardial infarction), pulmonary complications (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, emergency visits, venous thromboembolism (VTE—including deep venous thrombosis or pulmonary embolism), wound disruption, incisional hernia, surgical site infection (SSI), non-home discharge, operative time, 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 staple line leak, postoperative bleeding, stricture, gastrointestinal perforation, and gallstone disease.

Statistical analysis

Univariate analyses were performed using either the Pearson $\times$ 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 29.0, IBM Corp., Armonk, NY).

Results

Patient demographic characteristics

A total of 378,258 patients met the inclusion criteria. 297,250 and 81,008 were included for LSG (78.6%) and RSG (21.4%), respectively. In analysis 1, patients who underwent LSG with BMI < 60 (n = 283,723) were compared to patients with BMI ≥ 60 (n = 13,527), whereas in analysis 2, patients who underwent RSG with BMI < 60 (n = 76,636) were compared to patients with BMI ≥ 60 (n = 4372). In the analysis, 3 patients with BMI ≥ 60 who underwent LSG (n = 13,527) were compared to patients who underwent RSG (n = 4372). Propensity score matching analysis was performed to adjust for preoperative characteristics and comorbidities. Statistically significant variables before propensity score matching in analyses 1, 2, and 3 are displayed in Tables 1, 2, and 3.

In all three analyses, a 1:1 PSM analysis was performed. In Analysis 1; 13,503 patients were obtained. There were no statistically significant differences in preoperative patient variables after PSM. All the standardized differences were ≤ 0.10. The highest standardized mean difference after matching was found in dependent functional status with a value of d = 0.012 (Table 1). In Analysis 2, 4350 patients were obtained. There were no statistically significant differences in preoperative patient variables after PSM. All the standardized differences were ≤ 0.10. The highest standardized mean difference after matching was found in white ethnicity with a value of d = 0.030 (Table 2). In Analysis 3, 4370 patients were obtained. There were no statistically significant differences in preoperative patient variables after PSM. All the standardized differences were ≤ 0.10. The highest standardized mean difference after matching was found in sleep apnea with a value of d = 0.034 (Table 3).

Outcomes of matched cohorts

After propensity matching in analysis 1, patients with BMI ≥ 60 showed higher rates of mortality (0.1% vs. 0.0%, p = 0.014), staple line leak (0.3% vs. 0.2%, p = 0.035), and postoperative bleeding (0.2% vs 0.1%, p = 0.028), when compared to patients with BMI < 60. Similarly, longer operative times (72.22 ± 37.54 min vs. 66.38 ± 32.92 min, P < 0.001), length of stay (1.45 ± 1.25 days vs. 1.31 ± 1.14 days, p < 0.001), and higher rates of renal complications (0.3% vs. 0.2%, p = 0.045), non-home discharge (30.1% vs. 27.8%, P < 0.001), readmissions (3.5% vs. 2.4%, P < 0.001), interventions (0.7% vs. 0.5%, p = 0.028), and unplanned ICU admissions (1.1% vs. 0.5%, p < 0.001) were found in patients with BMI > 60 (Table 4).

In analysis 2, patients with BMI ≥ 60 demonstrated longer operative times (92.73 ± 38.67 min vs. 86.72 ± 35.47 min, p < 0.001), length of stay (1.46 ± 1.79 days vs 1.30 ± 0.87 days, p < 0.001), and higher rates of unplanned ICU admissions (0.9% vs 0.5%, p = 0.015) when compared to patients with BMI < 60. Other 30-day outcomes such as mortality, staple line leak, postoperative bleeding, readmissions, and interventions were comparable between these groups (Table 5).

In analysis 3, patients who underwent RSG reported fewer readmissions (2.9% vs. 3.7%, p = 0.037), staple line

Table 1 Laparoscopic sleeve gastrectomy in BMI < 60 versus ≥ 60

	All cohort (before match)			Match cohort (adjusting for preoperative characteristics)			
	BMI < 60 (283,723)	BMI ≥ 60 (*n* = 13,527)	*p**	BMI < 60 (*n* = 13,503)	BMI ≥ 60 (*n* = 13,503)	*p**	*d**
Characteristics[a]							
Age, years	42.59 ± 11.23	39.73 ± 10.49	**< 0.001**	39.79 ± 10.92	39.73 ± 10.49	**< 0.001**	– 0.006
Sex (female)	231,450 (81.6%)	9562 (70.7%)	**< 0.001**	9627 (71.3%)	9553 (70.7%)	0.321	– 0.012
ASA 1 and 2	61,807 (21.8%)	824 (6.1%)	**< 0.001**	862 (6.4%)	824 (6.1%)	0.339	– 0.012
ASA 3	213,348 (75.2%)	10,785 (79.7%)	**< 0.001**	10,762 (79.7%)	10,784 (79.9%)	0.739	0.004
ASA 4 and 5	7434 (2.6%)	1869 (13.8%)	**< 0.001**	1826 (13.5%)	1846 (13.7%)	0.723	0.004
White	152,078 (53.6%)	6994 (51.7%)	**< 0.001**	6939 (51.4%)	6983 (51.7%)	0.592	0.007
Black	120,162 (42.4%)	6139 (45.4%)	**< 0.001**	6144 (45.5%)	6128 (45.4%)	0.845	−0.002
Hispanic	74,996 (26.4%)	2894 (21.4%)	**< 0.001**	2871 (21.3%)	2892 (21.4%)	0.755	0.004
History of myocardial infarction	2515 (0.9%)	124 (0.9%)	0.714	132 (1.0%)	124 (0.9%)	0.615	−0.006
Previous cardiac stent	3324 (1.2%)	127 (0.9%)	**0.014**	128 (0.9%)	127 (0.9%)	0.950	−0.001
Previous cardiac surgery	2207 (0.8%)	95 (0.7%)	0.327	89 (0.7%)	95 (0.7%)	0.657	0.005
Diabetes mellitus	57,528 (20.3%)	3439 (25.4%)	**< 0.001**	3432 (25.4%)	3427 (25.4%)	0.944	−0.001
Hypertension	116,641 (41.1%)	7181 (53.1%)	**< 0.001**	7138 (52.9%)	7160 (53.0%)	0.789	0.003
Hyperlipidemia	56,064 (19.8%)	2276 (16.8%)	**< 0.001**	2338 (17.3%)	2269 (16.8%)	0.264	−0.014
History of deep venous thrombosis	4198 (1.5%)	375 (2.8%)	**< 0.001**	365 (2.7%)	366 (2.7%)	0.970	0.000
History of pulmonary embolism	3129 (1.1%)	383 (2.8%)	**< 0.001**	360 (2.7%)	374 (2.8%)	0.600	0.006
Therapeutic anticoagulation	6983 (2.5%)	694 (5.1%)	**< 0.001**	693 (5.1%)	683 (5.1%)	0.782	−0.003
COPD	2466 (0.9%)	285 (2.1%)	**< 0.001**	287 (2.1%)	280 (2.1%)	0.766	−0.004
Current smoker	20,826 (7.3%)	1164 (8.6%)	**< 0.001**	1135 (8.4%)	1162 (8.6%)	0.556	0.007
Renal Insufficiency	1375 (0.5%)	95 (0.7%)	**< 0.001**	100 (0.7%)	94 (0.7%)	0.666	– 0.005
Dialysis	942 (0.3%)	37 (0.3%)	0.246	49 (0.4%)	37 (0.3%)	0.195	−0.017
Sleep apnea	95,002 (33.5%)	7275 (53.8%)	**< 0.001**	7177 (53.2%)	7251 (53.7%)	0.367	0.011
GERD	70,753 (24.9%)	3196 (23.6%)	**< 0.001**	3177 (23.5%)	3194 (23.7%)	0.807	0.003
Steroid/immunosuppressive use	5810 (2.0%)	299 (2.2%)	0.193	292 (2.2%)	295 (2.2%)	0.900	0.002
Functional status (non-dependent)	282,291 (99.5%)	13,194 (97.5%)	**< 0.001**	13,213 (97.9%)	13,187 (97.7%)	0.285	0.012

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

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

[a]Continuous data are shown as the mean ± standard deviation and categoric data as number (%), *d* = standardized mean difference

leaks (0.1% vs. 0.3%, $p = 0.029$), and postoperative bleeding (0.1% vs. 0.3%, $p = 0.045$), compared to LSG. Conversely, a longer operative time (92.74 ± 38.65 min vs. 71.69 ± 37.45 min, $p < 0.001$) was found for RSG compared to LSG (Table 6).

Disclosures

Alba Zevallos, Jorge Cornejo, Jennifer Brown, Joaquin Sarmiento, Fatemeh Shojaeian, Farzad Mokhtari-Esbuie, Christina Li and Raul Sebastian have no conflicts of interest or financial ties to disclose. Alisa Coker accepts honoraria for teaching, speaking, and consulting for Intuitive Surgical. Gina Adrales reports an unrelated disclosure of honoraria for consulting for Caresyntax, Inc and Ethicon Johnson and Johnson Advisory Board.

Discussion

The current 2019–2022 MBSAQIP database analysis is the first study comparing 30-day postoperative outcomes and bariatric-specific complications between patients with BMI < 60 versus ≥ 60 using either a laparoscopic or robotic approach and between LSG and RSG in patients with BMI ≥ 60. Our study revealed that patients with BMI ≥ 60 undergoing LSG are at higher risk of

Table 2 Robotic sleeve gastrectomy in BMI < 60 versus BMI ≥ 60

	All cohort (before match)			Match cohort (adjusting for preoperative characteristics)			
	BMI < 60 (*n* = 76,636)	BMI ≥ 60 (*n* = 4372)	*p**	BMI < 60 (*n* = 4350)	BMI ≥ 60 (*n* = 4350)	*p**	*d**
Characteristics[a]							
Age, years	42.75 ± 11.40	39.95 ± 10.50	**< 0.001**	40.10 ± 11.04	39.98 ± 10.48	**< 0.001**	− 0.012
Sex (female)	62,821 (82.0%)	3187 (72.9%)	**< 0.001**	3152 (72.5%)	3176 (73.0%)	0.563	0.012
ASA 1 and 2	15,004 (19.6%)	216 (4.9%)	**< 0.001**	245 (5.6%)	216 (5.0%)	0.165	− 0.031
ASA 3	58,884 (76.8%)	3388 (77.5%)	0.316	3356 (77.1%)	3387 (77.9%)	0.426	0.017
ASA 4 and 5	2626 (3.4%)	763 (17.5%)	**< 0.001**	745 (17.1%)	742 (17.1%)	0.932	− 0.002
White	41,385 (54.0%)	2247 (51.4%)	**< 0.001**	2169 (49.9%)	2234 (51.4%)	0.163	0.030
Black	31,123 (40.6%)	1,889 (43.2%)	**< 0.001**	1924 (44.2%)	1881 (43.2%)	0.353	− 0.020
Hispanic	19,608 (25.6%)	953 (21.8%)	**< 0.001**	932 (21.4%)	950 (21.8%)	0.639	0.010
History of myocardial infarction	719 (0.9%)	37 (0.8%)	0.539	40 (0.9%)	37 (0.9%)	0.731	− 0.008
Previous cardiac stent	911 (1.2%)	50 (1.1%)	0.789	48 (1.1%)	50 (1.1%)	0.839	0.004
Previous cardiac surgery	551 (0.7%)	23 (0.5%)	0.139	24 (0.6%)	23 (0.5%)	0.884	− 0.003
Diabetes mellitus	16,194 (21.1%)	1205 (27.6%)	**< 0.001**	1224 (28.1%)	1198 (27.5%)	0.534	− 0.013
Hypertension	32,895 (42.9%)	2365 (54.1%)	**< 0.001**	2328 (53.5%)	2345 (53.9%)	0.715	0.008
Hyperlipidemia	16,457 (21.5%)	795 (18.2%)	**< 0.001**	814 (18.7%)	793 (18.2%)	0.562	− 0.013
History of deep venous thrombosis	1164 (1.5%)	112 (2.6%)	**< 0.001**	118 (2.7%)	108 (2.5%)	0.500	− 0.015
History of pulmonary embolism	927 (1.2%)	125 (2.9%)	**< 0.001**	132 (3.0%)	122 (2.8%)	0.524	− 0.014
Therapeutic anticoagulation	1981 (2.6%)	228 (5.2%)	**< 0.001**	219 (5.0%)	224 (5.1%)	0.807	0.005
COPD	911 (1.2%)	115 (2.6%)	**< 0.001**	106 (2.4%)	113 (2.6%)	0.632	0.010
Current smoker	5176 (6.8%)	344 (7.9%)	**0.004**	340 (7.8%)	343 (7.9%)	0.905	0.003
Renal insufficiency	431 (0.6%)	21 (0.5%)	0.479	20 (0.5%)	21 (0.5%)	0.876	0.003
Dialysis	362 (0.5%)	13 (0.3%)	0.097	15 (0.3%)	13 (0.3%)	0.705	− 0.008
Sleep apnea	26,784 (34.9%)	2361 (54.0%)	**< 0.001**	2302 (52.9%)	2339 (53.8%)	0.427	0.017
GERD	20,629 (26.9%)	1088 (24.9%)	**0.003**	1088 (25.0%)	1080 (24.8%)	0.843	− 0.004
Steroid/immunosuppressive use	1854 (2.4%)	83 (1.9%)	**0.028**	76 (1.7%)	82 (1.9%)	0.630	0.010
Functional status (non-dependent)	76,305 (99.6%)	4277 (97.8%)	**< 0.001**	4262 (98.0%)	4262 (98.0%)	1.000	0.000

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

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

[a]Continuous data are shown as the mean ± standard deviation and categoric data as number (%), *d* = standardized mean difference

perioperative complications and 30-day mortality compared with patients with BMI < 60, a risk that is not associated with RSG. Moreover, when we sub-analyzed only patients with BMI ≥ 60, we found that patients who underwent RSG had lower rates of perioperative complications in terms of readmissions, staple line leaks, and postoperative bleeding compared to LSG.

In our Analysis 1, comparing patients with BMI < 60 vs BMI ≥ 60, who underwent LSG, other authors reported similar results to our study regarding mortality (0.0% vs. 0.1%; $p = 0.014$). Nasser et al. in a large cohort study reported a significantly higher mortality rate in the super-super obese group at 0.18%, compared to super obese (0.08%) and patients with morbid obesity (0.04%) [21]. Furthermore, patients with BMI ≥ 60 who underwent LSG showed higher rates of staple line leak (0.3% vs. 0.2%, $p = 0.035$), and postoperative bleeding (0.3% vs. 0.2%, $p = 0.028$) compared to patients with BMI < 60, leading to a significant increase in readmissions (3.5% vs. 2.4%, $p < 0.001$), interventions (0.7% vs. 0.5%, $p = 0.028$), and unplanned ICU admissions (1.1% vs. 0.5%, $p < 0.001$).

LSG in patients with super super obesity poses significant challenges due to the increased abdominal wall thickness, and visceral fat [22–24]. We hypothesize that there is a higher risk of staple line leak and bleeding due to the hindering of appropriate exposure to the operative field, making mobilization and visualization difficult. Consistent with this hypothesis, Gaillard et al. found that visceral obesity > 85 cm^2/m^2 increases the risk for staple line leak rates by five-fold [23], whereas Han et al. in a small population study reported that a visceral fat area > 100 cm^2 increases the risk

Table 3 Laparoscopic versus robotic sleeve gastrectomy in patients with BMI ≥ 60

	All cohort (before match)			Match cohort (adjusting for preoperative characteristics)			
	Laparoscopic approach (n = 13,527)	Robotic approach (n = 4372)	p*	Laparoscopic approach (n = 4370)	Robotic approach (n = 4370)	p*	d*
Characteristics[a]							
Age, years	39.73 ± 10.49	39.95 ± 10.50	0.858	39.78 ± 10.51	39.93 ± 10.49	0.935	0.015
BMI (kg/m^2)	66.19 ± 6.22	66.39 ± 6.30	0.337	66.35 ± 6.28	66.39 ± 6.28	0.802	0.006
Sex (female)	9562 (70.7%)	3187 (72.9%)	**0.005**	3261 (74.6%)	3185 (72.9%)	0.065	− 0.039
ASA 1 and 2	824 (6.1%)	216 (4.9%)	**0.005**	221 (5.1%)	216 (4.9%)	0.806	− 0.005
ASA 3	10,785 (79.7%)	3388 (77.5%)	**0.002**	3410 (78.0%)	3388 (77.5%)	0.571	− 0.012
ASA 4 and 5	1869 (13.8%)	763 (17.5%)	**< 0.001**	734 (16.8%)	761 (17.4%)	0.443	0.016
White	6994 (51.7%)	2247 (51.4%)	0.722	2271 (52.0%)	2247 (51.4%)	0.607	− 0.011
Black	6139 (45.4%)	1889 (43.2%)	**0.012**	1865 (42.7%)	1888 (43.2%)	0.619	0.011
Hispanic	2894 (21.4%)	953 (21.8%)	0.572	959 (21.9%)	952 (21.8%)	0.856	− 0.004
History of myocardial infarction	124 (0.9%)	37 (0.8%)	**0.668**	40 (0.9%)	37 (0.8%)	0.731	− 0.007
Previous cardiac stent	127 (0.9%)	50 (1.1%)	0.234	46 (1.1%)	49 (1.1%)	0.757	0.006
Previous cardiac surgery	95 (0.7%)	23 (0.5%)	0.211	20 (0.5%)	23 (0.5%)	0.647	0.009
Diabetes mellitus	3439 (25.4%)	1205 (27.6%)	**0.005**	1155 (26.4%)	1204 (27.6%)	0.238	0.025
Hypertension	7181 (53.1%)	2365 (54.1%)	0.246	2319 (53.1%)	2363 (54.1%)	0.345	0.020
Hyperlipidemia	2276 (16.8%)	795 (18.2%)	**0.038**	733 (16.8%)	793 (18.1%)	0.091	0.036
History of deep venous thrombosis	375 (2.8%)	112 (2.6%)	0.457	114 (2.6%)	112 (2.6%)	0.893	− 0.003
History of pulmonary embolism	383 (2.8%)	125 (2.9%)	0.924	122 (2.8%)	125 (2.9%)	0.846	0.004
Therapeutic anticoagulation	694 (5.1%)	228 (5.2%)	0.826	223 (5.1%)	227 (5.2%)	0.846	0.004
COPD	285 (2.1%)	115 (2.6%)	**0.042**	98 (2.2%)	114 (2.6%)	0.266	0.023
Current smoker	1164 (8.6%)	344 (7.9%)	0.127	351 (8.0%)	344 (7.9%)	0.782	− 0.006
Renal insufficiency	95 (0.7%)	21 (0.5%)	0.112	21 (0.5%)	21 (0.5%)	1.000	0.000
Dialysis	37 (0.3%)	12 (0.3%)	0.795	11 (0.3%)	13 (0.3%)	0.683	0.008
Sleep apnea	7275 (53.8%)	2361 (54.0%)	0.798	2286 (52.3%)	2360 (54.0%)	0.113	0.034
GERD	3196 (23.6%)	1088 (24.9%)	0.090	1078 (24.7%)	1087 (24.9%)	0.824	0.005
Steroid/immunosuppressive use	299 (2.2%)	83 (1.9%)	0.215	80 (1.8%)	83 (1.9%)	0.813	0.005
Functional status (non- dependent)	13,194 (97.5%)	4277 (97.8%)	0.277	4263 (97.6%)	4275 (97.8%)	0.393	− 0.019

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

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

[a]Continuous data are shown as the mean ± standard deviation and categoric data as number (%), d = standardized mean difference

by sixfold of early postoperative complications including bleeding [24].

On the other hand, in Analysis 2, comparing patients with BMI < 60 versus ≥ 60 who underwent RSG, our study did not find statistical differences in mortality, staple line leak, postoperative bleeding, readmissions, and interventions. However, we found significant differences regarding unplanned ICU admissions (0.9% vs 0.5%, $p = 0.015$), longer operative times (92.73 ± 38.67 min vs. 86.72 ± 35.47 min, $p < 0.001$), and length of stay (1.46 ± 1.79 days vs. 1.30 ± 0.87 days, $p < 0.001$) in patients with BMI ≥ 60. RSG may be a better alternative in patients with super super obesity. However, with either approach, patients with BMI ≥ 60 have a higher rate of complications.

Finally, in Analysis 3, when comparing LSG versus RSG in patients with BMI ≥ 60, patients who underwent RSG had fewer readmissions (2.9% vs. 3.7%, $p = 0.037$), staple line leaks (0.1% vs. 0.3%, $p = 0.029$), and postoperative bleeding (0.1% vs. 0.3%, $p = 0.045$), compared to LSG. These findings might be attributed to the surgeons' experience and the unique properties of the robotic platform which provides a three-dimensional image, filters out tremors, improves precision, and facilitates delicate movements in limited spaces, thereby minimizing tissue damage. Moreover, the utilization of robotic-controlled surgical staplers featuring Smartfire or Fire-fly technology offers surgeons improved engagement and compression control before and during stapling [25, 26]. Conversely, the operative time was significantly increased

Table 4 30-Day outcomes of laparoscopic sleeve gastrectomy in BMI < 60 versus ≥ 60

	BMI < 60 (*n* = 13,503)	BMI ≥ 60 (*n* = 13,503)	*p**
30-day outcomes			
Mortality	6 (0.0%)	18 (0.1%)	**0.014**
Cardiac complications	9 (0.1%)	16 (0.1%)	0.161
Pulmonary complications	9 (0.1%)	13 (0.1%)	0.394
Renal complications	24 (0.2%)	40 (0.3%)	**0.045**
Unplanned ICU admission	72 (0.5%)	150 (1.1%)	**< 0.001**
Blood transfusion	75 (0.6%)	69 (0.5%)	0.616
Readmissions	320 (2.4%)	479 (3.5%)	**< 0.001**
Reoperations	94 (0.7%)	112 (0.8%)	0.208
Interventions	72 (0.5%)	89 (0.7%)	**0.028**
Emergency visits	1089 (8.1%)	1130 (8.4%)	0.364
Venous thromboembolism	41 (0.3%)	46 (0.3%)	0.591
Surgical site infection	3 (0.0%)	6 (0.0%)	0.317
Incisional hernia	1 (0.0%)	5 (0.0%)	0.102
Wound disruption	4 (0.0%)	4 (0.0%)	1.000
Sepsis or septic shock	1 (0.0%)	0 (0.0%)	0.317
Non-home discharge	32 (0.2%)	82 (0.6%)	**< 0.001**
Postoperative-LOS (days)	1.31 ± 1.14	1.45 ± 1.25	**< 0.001**
Operative time (min)	66.38 ± 32.92	72.22 ± 37.54	**< 0.001**
Bariatric-specific complications			
Staple line leak	21 (0.2%)	37 (0.3%)	**0.035**
Postoperative bleeding	9 (0.1%)	21 (0.2%)	**0.028**
Stricture/stomal obstruction	2 (0.0%)	1 (0.0%)	0.564
Intestinal obstruction	0 (0.0%)	1 (0.0%)	0.317
Internal hernia	1 (0.0%)	1 (0.0%)	1.000
Gastrointestinal perforation	4 (0.0%)	4 (0.0%)	1.000
Anastomotic ulcer	0 (0.0%)	2 (0.0%)	0.157
Gallstone disease	18 (0.1%)	21 (0.2%)	0.631

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

in the RSG group (92.74 ± 38.65 min vs. 71.69 ± 37.45 min, $p < 0.001$). Our operative time findings are similar to other studies. Scarritt et al. examined outcomes over four years in robotic bariatric surgery, and showed similar results, highlighting that although operative time remained significantly longer with the robotic approach, postoperative outcomes improved as the robotic platform's utilization increased [27]. Therefore, we suggest the use of the robotic platform for a sleeve gastrectomy in patients with super super obesity.

The MBSAQIP is the most comprehensive resource for analyzing the field of bariatric surgery. Nevertheless, there are some limitations of the dataset to consider. First, some relevant variables are not recorded in this database such as visceral fat and abdominal wall thickness. Second, the robotic stapler and featured technology (Smartfire or Firefly) are not reported. Third, the surgeon's experience in the robotic field is not reported. Fourth, our study exclusively captures 30-day postoperative data; thus, determining long-term outcomes is beyond the scope of this study. Despite these limitations, our study provides an analysis of one of the largest samples from a national bariatric-specific database.

We conclude that LSG patients with a BMI ≥ 60 have a higher rate of mortality, staple line leaks, postoperative bleeding, and readmissions compared to patients with a BMI < 60. Moreover, patients who underwent RSG with BMI ≥ 60 have lower rates of readmissions, staple line leaks, and postoperative bleeding compared to RSG. These results validate the importance of considering the robotic approach in this super-super obese population.

Table 5 30-Day outcomes of robotic sleeve gastrectomy in BMI < 60 versus ≥ 60

	BMI < 60 (*n* = 4350)	BMI ≥ 60 (*n* = 4350)	*p**
30-day outcomes			
Mortality	2 (0.0%)	6 (0.1%)	0.157
Cardiac complications	2 (0.0%)	6 (0.1%)	0.157
Pulmonary complications	4 (0.1%)	9 (0.2%)	0.165
Renal complications	9 (0.2%)	17 (0.4%)	0.116
Unplanned ICU admission	21 (0.5%)	40 (0.9%)	**0.015**
Blood transfusion	26 (0.6%)	23 (0.5%)	0.667
Readmissions	131 (3.0%)	128 (2.9%)	0.850
Reoperations	37 (0.9%)	41 (0.9%)	0.649
Interventions	27 (0.6%)	27 (0.6%)	1.000
Emergency visits	325 (7.5%)	365 (8.4%)	0.113
Venous thromboembolism	20 (0.5%)	15 (0.3%)	0.397
Surgical site infection	1 (0.0%)	1 (0.0%)	1.000
Incisional hernia	1 (0.0%)	1 (0.0%)	1.000
Wound disruption	1 (0.0%)	2 (0.0%)	0.564
Sepsis or septic shock	1 (0.0%)	0 (0.0%)	0.317
Non-home discharge	4 (0.1%)	31 (0.7%)	**< 0.001**
Postoperative-LOS (days)	1.30 ± 0.87	1.46 ± 1.79	**< 0.001**
Operative time (min)	86.72 ± 35.47	92.73 ± 38.67	**< 0.001**
Bariatric-specific complications			
Staple line leak	5 (0.1%)	4 (0.1%)	0.739
Postoperative bleeding	3 (0.1%)	4 (0.1%)	0.705
Stricture/stomal obstruction	2 (0.0%)	0 (0.0%)	0.157
Intestinal obstruction	–	–	–
Internal hernia	0 (0.0%)	1 (0.0%)	0.317
Gastrointestinal perforation	2 (0.0%)	2 (0.0%)	1.000
Anastomotic ulcer	–	–	–
Gallstone disease	2 (0.0%)	3 (0.1%)	0.655

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

Table 6 30-Day outcomes of laparoscopic versus robotic sleeve gastrectomy in patients with BMI ≥ 60

	Laparoscopic approach ($n=4370$)	Robotic approach ($n=4{,}370$)	p*
30-day outcomes			
Mortality	8 (0.2)	6 (0.1)	0.593
Cardiac complications	4 (0.1)	6 (0.1)	0.527
Pulmonary complications	2 (0.0)	9 (0.2)	0.424
Renal complications	14 (0.3)	17 (0.4)	0.589
Unplanned ICU admission	51 (1.2)	39 (0.9)	0.204
Blood transfusion	29 (0.7)	23 (0.5)	0.404
Readmissions	163 (3.7)	128 (2.9)	**0.037**
Reoperations	44 (1.0)	41 (0.9)	0.744
Interventions	32 (0.7)	27 (0.6)	0.514
Emergency visits	381 (8.7)	366 (8.4)	0.566
Venous thromboembolism	18 (0.4)	15 (0.3)	0.601
Surgical site infection	2 (0.0)	0 (0.0)	0.157
Incisional hernia	4 (0.1)	1 (0.0)	0.180
Wound disruption	1 (0.0)	2 (0.0)	0.564
Sepsis or septic shock	–	–	–
Non-home discharge	23 (0.5)	31 (0.7)	0.275
Postoperative-LOS (days)	1.47 ± 1.18	1.46 ± 1.79	0.731
Operative time (min)	71.69 ± 37.45	92.74 ± 38.65	**< 0.001**
Bariatric-specific complications			
Staple line leak	13 (0.3)	4 (0.1)	**0.029**
Postoperative bleeding	12 (0.3)	4 (0.1)	**0.045**
Stricture/stomal obstruction	–	–	–
Intestinal obstruction	–	–	–
Internal hernia	1 (0.0)	1 (0.0)	1.000
Gastrointestinal perforation	1 (0.0)	2 (0.0)	0.564
Anastomotic ulcer	–	–	–
Gallstone disease	9 (0.2)	3 (0.1)	0.083

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

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