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ORIGINAL CONTRIBUTIONS

Bariatric Surgery Outcomes in Patients with Prior Solid Organ Transplantation: an MBSAQIP Analysis

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Abstract

Introduction Obesity is a risk factor for poor patient outcomes after organ transplantation (TXP). While metabolic and bariatric surgery (MBS) is safe and effective in treating severe obesity, the role of MBS in transplant patients continues to evolve.

Methods A retrospective analysis was performed of sleeve gastrectomy (SG) and Roux-en-Y gastric bypass (RYGB) patients in the 2017 Metabolic and Bariatric Surgery Accreditation Quality and Improvement Project (MBSAQIP) database. Propensity and case-control matching, and multivariable logistic regression were performed for 30-day post-operative outcomes.

Results A total of 336 transplant patients were compared with 157,413 patients without transplant. Propensity and case-control matching reveal no significant differences in mortality ($p > 0.2$). However, case-control matching revealed longer operative time (104 min versus 76 min, $p < 0.001$), increased length of stay (2 days versus 1 day, $p < 0.05$), perioperative transfusions (2% versus 0.22%, $p = 0.009$), and leak rates (2.2% versus 0.55%, $p = 0.02$) in the transplant cohort. On multivariable regression analysis, prior transplantation was associated with higher rates of overall (OR 1.6, $p = 0.007$) and bariatric-related morbidity (OR 1.78, $p = 0.004$), leak (OR 3.47, $p = 0.0027$), and surgical site infection (OR 3.32, $p = 0.004$). Prior transplantation did not predict overall ($p = 0.55$) nor bariatric-related mortality ($p = 0.99$).

Conclusion MBS in prior solid organ transplantation patients is overall safe, but is associated with increased operative time and length of stay, as well as higher rates of some post-operative morbidity.

Keywords Bariatric surgery · Solid organ transplantation · MBSAQIP · Perioperative outcomes

Introduction

Obesity is increasingly prevalent after solid organ transplantation, and may negatively impact the transplant population on multiple levels [1–6]. Obesity in transplantation patients may also negatively impact perioperative and long-term outcomes after metabolic and bariatric surgery (MBS) [7–11]. In the systematic review by Sood et al., obesity was associated with a higher odds ratio for biopsy-proven acute rejection, mortality, allograft loss, and the development of diabetes [8]. Patients with a history of solid organ transplantation are routinely considered to be high-risk patients. This risk stratification is compounded by the presence and disease burden of obesity. Given its safety profile and health impact, there is increasing interest in the role of MBS in obese patients with prior organ transplantation. Therefore, the aim of this study is to compare outcomes of the largest North American patient cohort, with and without a history of solid organ transplantation, undergoing metabolic and bariatric surgery.

Material and Methods

Data Source

We performed a retrospective analysis of data from the 2017 Metabolic and Bariatric Surgery Accreditation and Quality Improvement Program (MBSAQIP) Participant Use Files (PUF) database, and compared outcomes between those with and without a history of previous solid organ transplantation.

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The MBSAQIP is responsible for the accreditation of bariatric surgical facilities. Requirements for certification include reporting bariatric surgical outcomes to the MBSAQIP Participant Use Data File (PUF), a Health Insurance Portability and Accountability Act (HIPAA)-compliant data file registry containing prospectively entered, risk-adjusted, clinically rich data using standardized definitions for preoperative, intraoperative, and post-operative variables that are specific to metabolic and bariatric surgical care. Data points are abstracted at participating institutions by certified reviewers who are audited for accuracy of performance. For the first time, the 2017 file included data on previous solid organ transplantation, including a history of heart, lung, liver, renal, pancreas, and bowel transplantation. The database does not give the ability to discern which type of transplant has been performed. This is a de-identified, nationally available, clinical database; therefore, neither institutional review board (IRB) approval nor patient consent was required for our study.

Case Selection and Inclusion Criteria

A patient selection diagram is shown in Fig. 1. Participants included patients who had a primary gastric bypass (RYGB) or sleeve gastrectomy (SG) in 2017, designated by Current Procedural Terminology (CPT) codes 43644, 43645, and 43775. We excluded patients less than 18 years or greater than 80 years old, body mass index (BMI) < 35, any bariatric procedure other than a RYGB or SG, bariatric procedures designated as emergency, open cases, revision/conversion cases, and those with incomplete clinical data. Selected cases were further stratified by a history of solid organ transplantation (TXP). There were 614 TXP patients in the 2017 MBSAQIP database prior to exclusions. 336 were included in our analysis. A total of 278 TXP patients were excluded from analysis for the following reasons: age < 18 or > 80 years old ($n = 1$), BMI < 35 ($n = 136$), having a prior bariatric surgery ($n = 40$), emergency cases ($n = 22$), open surgical approach ($n = 9$), and incomplete data ($n = 70$).

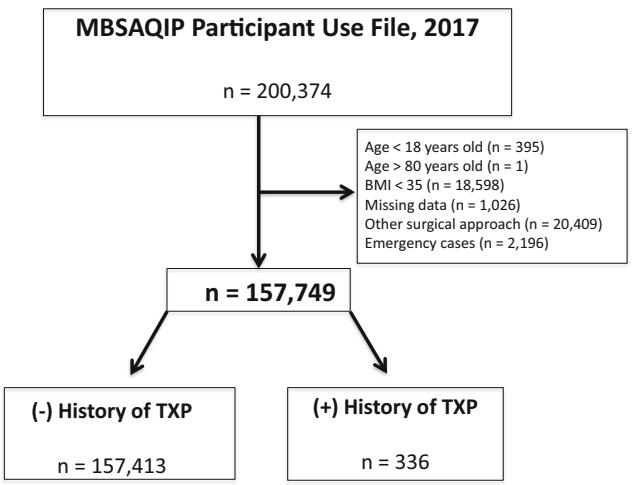

Fig. 1 Patient selection strategy

Data Collection and Statistical Analysis

Descriptive statistics were collected and compared between groups, including demographics, health summary status, preoperative comorbidities, and operative characteristics. Primary outcome measures included 30-day mortality and morbidity. Secondary outcome measures included other 30-day adverse outcomes (reoperation, readmission, and reintervention), post-operative complication, composite complications, operative duration, conversion, and hospital length of stay. Unmatched cohorts were compared by univariate analysis, using Pearson chi-square test for categorical variables and Mann-Whitney *U* test for continuous variables.

A backward method multivariable logistic regression was performed based on those preoperative variables (demographics, health status, comorbidities) that were statistically significant ($p < 0.05$) between cohorts in unmatched analysis. Variables in our regression methodology included, age, BMI, gender, race, American society of anesthesia (ASA) class, operation type, history of myocardial infarction, percutaneous coronary intervention, cardiac surgery, hypertension, hyperlipidemia, diabetes mellitus, smoking, renal insufficiency, dialysis, deep venous thrombosis requiring therapy, pulmonary embolism, inferior vena cava filter, and anticoagulation for presumed or confirmed venous thromboembolism (VTE) and chronic steroids.

Matching

Propensity and case-control matched analyses were performed to account for inter-group biases. For both propensity score and case-control matching, the ratio of transplant recipients to control patients without transplantation was 1:5. For propensity score matching, a logistic regression model was generated on variables significantly different ($p < 0.05$) on univariate analysis between those with and without a history of solid organ transplantation. Matching variables included age, sex, race, BMI, operation type, diabetes mellitus, hypertension, hyperlipidemia, ASA class, steroid use, renal insufficiency, dialysis status, smoking status, history of pulmonary embolism, history of IVC filter preoperatively, history of VTE requiring therapy, and anticoagulation use preoperatively. A propensity score from 0 to 1 was generated from this model and assigned to each subject. A nearest-neighbor variable ratio with propensity scores that fell within a caliper of 0.05 was then used to generate matched cohorts hypothesized to be balanced on potentially confounding baseline characteristics.

For case-control matched analysis, cases and controls were matched based on clinical variables that were significantly different in univariate analysis of the unmatched cohorts. This resulted in matched cohorts with equal distributions of those variables, including age, sex, race, BMI, operation type, diabetes mellitus, hypertension, hyperlipidemia, ASA class, steroid use, renal insufficiency, dialysis status, smoking status, history of pulmonary embolism, history of IVC filter preoperatively, history of VTE requiring therapy, and anticoagulation use preoperatively.

Primary and secondary outcomes were compared with Pearson chi-square test for categorical variables and Mann-Whitney *U* test for continuous variables. Continuous data is expressed as median and interquartile range (IQR) and categorical data is expressed as frequency and percentage. Aggregate complications (Appendix 1 Table 6) were also compared, including aggregate leak, bleeding, renal, cardiovascular and pulmonary complications, venous thromboembolic events, aggregate surgical site infection, and other infection. All statistical analyses were performed with SPSS version 25 (IBM Corporation, Armonk, NY) and SAS version 9.4 (SAS Institute, Cary, NC). A p value of < 0.05 was considered statistically significant.

Results

Demographics of Study Cohorts

Table 1 shows the unmatched patient characteristics of the two cohorts. After exclusions, we identified 336 metabolic and

Table 1 Patient characteristics of unmatched cohorts

	(−) TXP [$n = 157,413$]	(+) TXP [$n = 336$]	p value
Continuous variables, median (IQR)			
Age (years)	44 (35–53)	48 (39–57)	0.040
BMI closest to surgery (kg/m^2)	43.94 (40.15–49.28)	42.53 (39.33–46.18)	0.010
Categorical variables, *n* (%)			
Gender (female)	126,002 (80)	232 (69)	< 0.001
Race (White)	98,528 (63)	175 (52)	< 0.001
Race (Black)	28,607 (18)	76 (23)	0.035
Ethnicity (Hispanic)	19,718 (13)	53 (16)	0.073
ASA class			< 0.001
< 3	34,232 (22)	34 (10)	
> 3	123,181 (78)	302 (90)	
Operation type			< 0.001
Sleeve	114,290 (72)	260 (77)	
Gastric bypass	43,123 (27)	76 (23)	
Surgical approach			0.919
Laparoscopic	144,536 (92)	308 (92)	
Robotic	12,877 (8)	28 (8)	
Preoperative disease prevalence, *n* (%)			
History of MI	1870 (1)	8 (2)	0.044
History of PCI	2814 (2)	15 (4)	< 0.001
History cardiac surgery	1547 (1)	21 (6)	< 0.001
Hypertension	74,576 (47)	229 (68)	< 0.001
Hyperlipidemia	35,554 (23)	132 (39)	< 0.001
Diabetes mellitus	39,710 (25)	131 (39)	< 0.001
COPD	2467 (2)	3 (1)	0.320
OSA	60,224 (38)	114 (34)	0.103
Oxygen dependent	1117 (1)	4 (1)	0.295
Smoker	13,067 (8)	12 (4)	0.002
Renal insufficiency	914 (1)	47 (14)	< 0.001
Dialysis	466 (0.3)	30 (9)	< 0.001
VTE requiring therapy	1783 (1.40)	1013 (1.64)	< 0.001
History of PE	1931 (1)	12 (4)	< 0.001
IVC filter	839 (1)	5 (2)	0.017
Anticoagulation	4451 (3)	23 (7)	< 0.001
Chronic steroids	2755 (2)	144 (43)	< 0.001
Limited ambulation status	2312 (1)	9 (3)	0.066
Independent functional status	155,684 (99)	329 (98)	0.084
History of bariatric surgery	10,834 (7)	26 (8)	0.536

TXP history of solid organ transplantation, *IQR* interquartile range, *kg* kilogram, *ASA* American Society of Anesthesiologist, *MI* myocardial infarction, *PCI* percutaneous coronary intervention, *COPD* chronic obstructive pulmonary disease, *OSA* obstructive sleep apnea, *PE* pulmonary emboli, *IVC* inferior vena cava, *VTE* venous thromboembolism

bariatric surgery cases with a history of prior solid organ transplantation and 157,413 cases without. The transplant cohort had a higher median age (48 years vs. 44 years, $p = 0.04$) and a lower median BMI (42.5 kg/m^2 vs. 43.9 kg/m^2, $p = 0.009$), and was less likely to be female (69% vs. 80%, $p < 0.001$). Surgical approaches were similar between cohorts. The transplant cohort had significantly ($p < 0.05$) higher rates of cardiovascular disease and cardiac risks (history of MI, PCI cardiac surgery, hypertension, hyperlipidemia, and diabetes mellitus), chronic kidney disease, and prior venous thromboembolism. Smoking was more prevalent in the cohort without prior organ transplantation (Table 1).

Outcomes Following Unmatched Cohort Analysis

Outcomes of the unmatched cohorts are detailed in Table 2. There was no mortality difference ($p = 0.17$) between those who had previously undergone TXP and those who had not. Overall morbidity (12% vs. 5%, $p < 0.001$) and bariatric-related morbidity (9% vs. 4%, $p < 0.001$) were both signifi-

Table 2 Outcomes, unmatched cohorts

	(−) TXP [$n = 157,413$]	(+) TXP [$n = 336$]	p value
Operative time, (min)*	74 (53–108)	99 (67–136)	< 0.001
Hospital LOS (days)*	1 (1–2)	2 (1–2)	< 0.001
30-day adverse outcomes and perioperative complications n (%)			
Mortality	130 (0.08)	1 (0.3)	0.170
Death related	77 (0.05)	1 (0.3)	0.410
Overall morbidity	7660 (5)	40 (12)	< 0.001
Overall morbidity related	5781 (4)	29 (9)	< 0.001
Reoperation	1898 (1)	6 (2)	0.330
Reoperation related	1526 (1)	6 (2)	0.130
Readmission	5730 (4)	33 (10)	< 0.001
Readmission related	4511 (3)	25 (7)	< 0.001
Post-op intervention	1838 (1)	8 (2)	0.039
Post-op intervention, related	1591 (1)	8 (2)	0.012
ICU admission	1043 (1)	10 (3)	< 0.001
Follow-up	149,903 (95)	319 (95)	0.800
Transfusion	993 (1)	9 (3)	< 0.001
Acute renal failure	97 (0.06)	2 (0.6)	< 0.001
Progressive renal failure	96 (0.06)	4 (1.19)	< 0.001
CPR	64 (0.04)	0 (0)	0.710
Stroke	20 (0.01)	0 (0)	0.840
Myocardial infarction	36 (0.02)	1 (0.3)	< 0.001
DVT requiring therapy	280 (0.18)	1 (0.3)	0.600
Pulmonary embolism	175 (0.11)	2 (0.6)	0.008
Pneumonia	313 (0.2)	2 (0.6)	0.100
Reintubation	181 (0.11)	0 (0)	0.530
Superficial SSI	679 (0.43)	4 (1.2)	< 0.001
Deep incisional SSI	100 (0.06)	1 (0.3)	0.090
Organ space SSI	354 (0.22)	3 (0.89)	0.030
Post-operative sepsis	153 (0.1)	0 (0)	0.850
Post-operative septic shock	95 (0.06)	0 (0)	0.650
Post-operative UTI	564 (0.37)	1 (0.3)	0.970
C. diff	188 (0.12)	1 (0.3)	0.350
Incisional hernia	109 (0.07)	1 (0.3)	0.110
ED visit w/o admit	10,835 (7)	25 (7)	0.690
Approach converted	252 (0.16)	5 (1.49)	< 0.001
Aggregate complications, n (%)			
Bleeding	687 (0.44)	1 (0.3)	0.670
Leak	747 (0.47)	6 (1.79)	< 0.001
Cardiovascular	160 (0.1)	2 (0.6)	0.005
Pulmonary	724 (0.46)	2 (0.6)	0.710
Renal	209 (0.13)	6 (1.79)	< 0.001
VTE	822 (0.52)	5 (1.49)	0.014
SSI	1103 (0.7)	10 (2.98)	< 0.001
Other infection	1195 (0.76)	4 (1.19)	0.360

TXP history of solid organ transplantation, *LOS* post-operative length of stay, *CPR* cardio-pulmonary resuscitation, *DVT* deep vein thrombosis, *SSI* surgical site infection, *C. diff* Clostridium difficile, *UTI* urinary tract infection, *VTE* venous thromboembolism

*Median (IQR), interquartile range

cantly higher in the transplant cohort. Median operative time and post-operative length of stay were significantly longer in the transplant cohort ($p < 0.05$). All 30-day adverse outcomes were higher in the transplant cohort, including significantly higher rates of readmission ($p < 0.001$), intervention ($p = 0.039$), and unplanned ICU admission ($p < 0.001$). While bleeding was similar between the two cohorts, aggregate leak ($p = 0.0005$) and VTE ($p = 0.014$), as well as aggregate cardiovascular, renal, and infectious complications, were significantly higher in the unmatched transplant cohort (Table 2).

Outcomes Following Multivariate Logistic Regression Analysis

While other variables (history of VTE, chronic steroid use, myocardial infarction, male gender, age, and BMI) conferred a higher mortality risk (Appendix 2 Table 7), we observe that prior solid organ transplantation did not confer a significant overall mortality ($p = 0.55$) or bariatric-related mortality ($p = 0.99$) risk (Table 3). Even though prior organ transplantation did not confer a mortality difference, it was associated with significantly higher overall morbidity (OR 1.60, $p = 0.008$) and morbidity related to bariatric surgery (OR 1.78, $p = 0.004$). Prior organ transplantation also independently impacted readmission (OR 1.90, $p < 0.001$), unplanned ICU admission (OR 2.24, $p = 0.018$), aggregate leak (OR 3.47, $p = 0.003$), and aggregate surgical site infection (OR 3.32, $p < 0.001$) (Table 3). Other variables impacting bariatric-related morbidity are shown in Appendix 2 Table 7.

Outcomes Following Matching

One-to-five propensity matching compared 285 metabolic and bariatric surgery cases with prior solid organ transplantation to 1425 cases without. Cases and controls were statistically similar (Appendix 3 Table 8), except for a higher rate of chronic obstructive lung disease in the cohort without transplantation. Outcomes following propensity matched analysis are detailed in Table 4. Similar to the unmatched cohort analysis, there was no mortality difference between these matched cohorts, but a higher rate of overall morbidity (10% vs. 6%, $p = 0.02$) and bariatric-related morbidity (7% vs. 4%, $p = 0.05$) in the transplant cohort. While leak rate was three-fold higher in the transplant cohort, the difference was not significant ($p = 0.05$) in this matched analysis.

Case-controlled matching compared 182 cases with 910 equally matched controls (Appendix 4 Table 9). Outcomes are shown in Table 5. Similar to unmatched and propensity matched analyses, operative duration ($p < 0.0001$) and hospital length of stay ($p = 0.03$) remained significantly longer in the transplant cohort after case-control matching. There was no mortality difference. Unlike our unmatched and propensity matched analyses, there was no differences in overall and bariatric-related morbidity after case-control matching. Rates of transfusion requirement (2% vs. 0.22%, $p = 0.009$), progressive renal failure (0.55% vs. 0%, $p = 0.025$), and aggregate anastomotic or staple line leak (2.2% vs. 0.55%, $p = 0.025$) remained significantly higher in the transplant cohort, similar to unmatched and propensity matched analyses. All other outcome measures were similar in MBS patients with and without a history of a prior solid organ transplantation (Table 5).

Discussion

Given the potential for poorer outcomes in obese solid organ transplantation patients, there is significant interest in identifying optimal modalities to achieve significant and durable weight loss, including metabolic and bariatric surgery. The literature regarding the safety of MBS in patients with organ transplantation continues to evolve. Current literature

Table 3 Impact of prior transplantation on bariatric outcomes: multivariate regression analysis

History of transplant	Odds ratio	95% confidence interval	*p* value
Overall mortality	1.86	0.24–14.29	0.550
Bariatric-related mortality	< 0.001	0.001–1000	0.990
Overall morbidity	1.60	1.13–2.28	0.008
Bariatric-related morbidity	1.78	1.12–2.64	0.004
Readmission	1.90	1.30–2.78	< 0.001
Bariatric-related readmission	2.20	1.46–3.34	< 0.001
ICU admission	2.24	1.15–4.37	0.018
Aggregate leak	3.47	1.54–7.87	0.003
Aggregate bleeding	0.42	0.06–3.01	0.390
Aggregate VTE	2.42	0.99–5.92	0.050
Aggregate SSI	3.32	1.72–6.41	< 0.001

ICU intensive care unit, *VTE* venous thromboembolism, *SSI* surgical site infection

demonstrates that MBS is overall safe in transplant patients, but is limited to single-center experiences with small sample sizes [1, 2, 12].

Utilizing the 2017 MBSAQIP, we show that MBS in TXP patients with prior solid organ transplantation is overall safe, with an associated low mortality. However, there is an increased rate of overall morbidity and bariatric-related morbidity compared with the general bariatric population. For both propensity and case-control matched analyses, operative duration, post-operative length of stay, and progressive renal failure remained significantly longer and higher in transplant patients. Some outcome differences were noted between our propensity and case-control matched cohorts. While a higher morbidity was noted in the transplant cohort after propensity matched analysis, it did not persist after case-control matched analysis. This was similarly noted for readmission, unplanned ICU admission, aggregate renal complications, and surgical site infection. Across analyses, leak rate remained higher in the transplant cohort. In comparison with propensity matching, case-control matching is often

Table 4 Outcomes following 1:5 propensity score matching

	(−) TXP [$n = 1425$]	(+) TXP [$n = 285$]	p value
Operative time, (min)*	76 (54–108)	100 (67–136)	< 0.001
Hospital LOS (days)*	2 (1–2)	2 (1–2)	< 0.001
30-day outcomes, and perioperative complications n (%)			
Mortality	2 (0.14)	1 (0.35)	0.438
Bariatric-related mortality	1 (0.7)	1 (0.35)	0.387
Overall morbidity	87 (6)	28 (10)	< 0.022
Bariatric-related morbidity	57 (4)	19 (7)	0.046
Reoperation	26 (2)	6 (2)	0.750
Reoperation related	22 (2)	6 (2)	0.495
Readmission	65 (5)	23 (8)	0.014
Readmission related	42 (3)	16 (6)	0.023
Post-op intervention	18 (1)	6 (2)	0.270
Post-op intervention, related	14 (1)	6 (2)	0.108
ICU admission	13 (1)	7 (2)	0.027
Transfusion	13 (1)	6 (2)	0.079
Acute renal failure	2 (0.07)	1 (0.35)	0.206
Progressive renal failure	1 (0.07)	1 (0.35)	0.002
CPR	1 (0.07)	0 (0)	0.655
Stroke	4 (0.28)	0 (0)	0.371
Myocardial infarction	3 (0.21)	1 (0.35)	0.654
DVT requiring therapy	7 (0.49)	3 (1.05)	0.257
Pulmonary embolism	2 (0.14)	1 (0.35)	0.438
Pneumonia	4 (0.28)	2 (0.7)	0.273
Reintubation	2 (0.14)	0 (0)	0.527
Superficial SSI	7 (0.49)	2 (0.7)	0.654
Deep incisional SSI	2 (0.14)	1 (0.35)	0.438
Organ space SSI	8 (0.56)	2 (0.7)	0.740
Post-operative sepsis	3 (0.21)	0 (0)	0.438
Post-operative septic shock	1 (0.07)	0 (0)	0.655
Post-operative UTI	8 (0.56)	1 (0.35)	0.654
C. diff	4 (0.28)	1 (0.35)	0.841
Incisional hernia	2 (0.14)	1 (0.35)	0.438
ED visit w/o admit	108 (8)	20 (7)	0.742
Approach converted	4 (0.28)	3 (1.05)	0.062
Aggregate complications, n (%)			
Bleeding	7 (0.49)	1 (0.35)	0.751
Leak	9 (0.63)	5 (1.75)	0.055
Cardiovascular	9 (0.63)	2 (0.7)	0.892
Pulmonary	11 (0.77)	2 (0.7)	0.901
Renal	2 (0.14)	4 (1.4)	0.001
VTE	11 (0.77)	4 (1.4)	0.297
SSI	11 (0.77)	7 (2.46)	0.001
Other infection	20 (1.4)	4 (1.4)	0.999

TXP history of solid organ transplantation, *LOS* post-operative length of stay, *CPR* cardio-pulmonary resuscitation, *DVT* deep vein thrombosis, *SSI* surgical site infection, *C. diff* Clostridium difficile, *UTI* urinary tract infection, *VTE* venous thromboembolism

*Median interquartile range

Table 5 Outcomes following 1:5 case-control matched analysis

	(−) TXP [$n = 910$]	(+) TXP [$n = 182$]	p value
Operative time, (min)*	76 (53–108)	104 (67–136)	< 0.001
Hospital LOS (days)*	1 (1–2)	2 (1–2)	0.030
30-day outcomes, and perioperative complications n (%)			
Mortality	0 (0)	0 (0)	1.000
Bariatric-related mortality	0 (0)	0 (0)	1.000
Overall morbidity	66 (7)	14 (8)	0.830
Bariatric-related morbidity	46 (5)	9 (5)	0.951
Reoperation	13 (1)	4 (2)	0.444
Reoperation related	8 (1)	4 (2)	0.119
Readmission	46 (5)	12 (7)	0.398
Readmission related	35 (4)	8 (4)	0.728
Post-op intervention	14 (2)	4 (2)	0.524
Post-op intervention, related	13 (1)	4 (2)	0.444
ICU admission	9 (1)	4 (2)	0.170
Follow-up	870 (96)	171 (94)	0.336
Transfusion	2 (0.22)	3 (2)	0.009
Acute renal failure	3 (0.33)	0 (0)	0.438
Progressive renal failure	0 (0)	1 (0.55)	0.025
CPR	0 (0)	0 (0)	1.000
Stroke	1 (0.11)	0 (0)	0.655
Myocardial infarction	0 (0)	0 (0)	1.000
DVT requiring therapy	8 (1)	3 (2)	0.343
Pulmonary embolism	2 (0.22)	1 (0.55)	0.438
Pneumonia	2 (0.22)	0 (0)	0.527
Reintubation	1 (0.11)	0 (0)	0.655
Superficial SSI	2 (0.22)	1 (0.55)	0.438
Deep incisional SSI	2 (0.22)	0 (0)	0.527
Organ space SSI	4 (0.44)	1 (0.55)	0.841
Post-operative sepsis	0 (0)	0 (0)	1.000
Post-operative septic shock	2 (0.22)	0 (0)	0.527
Post-operative UTI	5 (0.55)	0 (0)	0.316
C. diff	4 (0.44)	0 (0)	0.370
Incisional hernia	0 (0)	0 (0)	1.000
ED visit w/o admit	68 (7)	14 (8)	1.000
Approach converted	2 (0.22)	0 (0)	0.527
Aggregate complications, n (%)			
Bleeding	6 (1)	0 (0)	0.272
Leak	5 (0.55)	4 (2.2)	0.025
Cardiovascular	2 (0.22)	0 (0)	0.527
Pulmonary	4 (0.44)	0 (0)	0.370
Renal	3 (0.33)	1 (0.55)	0.654
VTE	9 (1)	4 (2.2)	0.170
SSI	6 (0.66)	3 (1.65)	0.178
Other infection	12 (1.32)	1 (0.55)	0.382

TXP history of solid organ transplantation, *LOS* post-operative length of stay, *CPR* cardio-pulmonary resuscitation, *DVT* deep vein thrombosis, *SSI* surgical site infection, *C. diff* Clostridium difficile, *UTI* urinary tract infection, *VTE* venous thromboembolism

*Median interquartile range

associated with smaller cohorts that are more tightly matched. This was the case in our analyses, and may have accounted for some of the outcome differences noted between our cohort matching techniques.

Transplantation provides a cure for end stage organ failure, but comes with lifelong immunosuppression. This may account for the increased morbidity in the TXP cohort. In our unmatched analysis, transplant patients were more likely to be on chronic steroids and have preoperative renal insufficiency. Previous matched analyses of the 2015–2016 MBSAQIP database have demonstrated that chronic kidney disease (CKD) and corticosteroid to be independent predictors of morbidity following MBS [15, 16]. Patients with CKD were more likely to have increased total morbidity, infectious complications, and hospital length of stay [15]. Interestingly, corticosteroid use was an increased risk factor for anastomotic leak (two- to three-fold) but without an increased risk for overall morbidity [16]. The increased leak rate conferred by steroids is prevalent in other surgical disciplines and throughout the literature. Although we control for both of these variables in our propensity and case-control matching techniques, these factors may still contribute to the increase leak rate and morbidity in the TXP cohort. (Reviewer #1, Comment #1)

Studies on post-transplantation bariatric surgery are limited, with varied outcomes [1, 12–14, 17]. Khoarki et al. reported their experience with 10 patients undergoing sleeve gastrectomy after liver, kidney, or heart transplant. Mortality and morbidity were 0% and 20%, respectively. In addition to significant weight loss and resolution of obesity-related conditions, they reported increased graft preservation in liver transplants, improved ejection fraction in heart transplants, and increased estimated glomerular filtration rate in renal transplants [1]. In a case-control matched analysis, Cohen et al. found that post-transplantation bariatric surgery was protective for allograft failure (HR 0.85) and mortality (HR 0.80) [14]. In another single-center small case series, Elli et al. compared outcomes between 10 post-transplant (kidney, liver, or pancreas) and 490 non-transplant LSG patients. Allograft function at 1 year was excellent with 100% follow-up in the transplant cohort, and there was no reported mortality or morbidity [12]. Transplant specific analyses show that bariatric surgery was also safe after renal [17] and liver transplantation [13], with low morbidity and mortality. Our study corroborates these findings with no difference in mortality; however we found that prior solid organ transplantation increases the risk of 30-day morbidity and anastomotic leak in MBS patients.

While the published literature suggests that bariatric surgery in transplant patients has an acceptable safety profile, larger cohorts are needed to validate reported outcomes. Even though our study cannot draw conclusions about long-term outcomes (past 30 days), our study is the largest matched cohort study reporting on bariatric surgery outcomes post-transplantation. Similar to published literature, we also found that prior solid organ transplantation did not confer a significantly higher overall or bariatric-related mortality risk, compared with the general bariatric population. However, some post-operative complications remained significantly higher in the transplant cohort (transfusion requirement, renal failure, and leak) after adjusting for potential confounding variables.

Our study has several limitations. This is retrospective analysis of a clinical database that is prone to the inherent biases of such analysis. While the largest reported study on this topic, the overall transplant cohort was small and outcomes are limited to 30 days post-operatively. A sample of cases was excluded that may have impacted our outcomes. We were unable to stratify our transplant cohort by the type of solid organ transplantation performed as this variable is not available in the database. Also unavailable was information on non-solid organ transplant patients; therefore, our findings may not be generalizable to all transplant patients. Due to the small sample sizes, we were unable to stratify our analyses by bariatric procedure type (sleeve vs. gastric bypass) and surgical approach (robotic-assisted vs. conventional laparoscopic). These are potential confounders that may have impacted our findings. To limit procedure-type and surgical approach as potential confounders, these variables were equally matched in both our propensity and case-control matched analyses. Additionally, we lack the timeframe between organ transplantation and metabolic and bariatric surgery, which may impact intraoperative findings, operative course, and ultimately outcome. Finally, information regarding specific immunosuppression regimens for the transplant cohort was not available, and may have also biases biased our findings.

Conclusions

Despite the recognized limitations in this matched cohort study of the 2017 MBSAQIP database, we found that metabolic and bariatric surgery is overall safe in carefully selected solid organ transplantation patients compared with the general bariatric patient population, with no significant difference in overall and bariatric-related mortality. However, some complications including anastomotic leak remain higher in prior solid organ transplant patients undergoing metabolic and bariatric surgery. Further studies are needed to determine the optimal timing of metabolic and bariatric surgery in this complex patient cohort.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Ethical Statement All procedures performed in studies involving human participants were in accordance with the ethical standards of the institution and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. For this study utilizing de-identified data from a national database, formal consent is not required.

Consent Statement Inform consent was not required as the study used de-identified data from a nationally available database.

Appendix 1. Composite complication methodology

Table 6 Methodology of aggregate complications. For each aggregate complication, composite variables are outlined

Aggregate variable	Composite variables
Leak	Reoperation with suspected reason: leak
	Readmission with suspected reason: leak
	Intervention with suspected reason: leak
	Drain present over 30 days
	Complication: organ space SSI
Bleeding	Reoperation with suspected reason: bleeding
	Readmission with suspected reason: bleeding
	Intervention with suspected reason: bleeding
Cardiac/CVA	Reoperation with suspected reason: cardiac NOS, CVA, or MI
	Readmission with suspected reason: cardiac NOS, CVA, or MI
	Intervention with suspected reason: cardiac NOS, CVA, or MI
	Complication of CVA
	Complication of MI
Pulmonary	Reoperation with suspected reason: shortness of breath, pneumonia, or other respiratory failure
	Readmission with suspected reason: shortness of breath, pneumonia, or other respiratory failure
	Intervention with suspected reason: shortness of breath, pneumonia, or Other respiratory failure
	Complication: on ventilator > 48 h
	Complication: unplanned intubation
	Complication: pneumonia
Renal	Reoperation with suspected reason: renal insufficiency
	Readmission with suspected reason: renal insufficiency
	Intervention with suspected reason: renal insufficiency
	Complication: progressive renal insufficiency
	Complication: acute renal failure
DVT or PE	Reoperation with suspected reason: vein thrombosis requiring therapy or pulmonary embolism
	Readmission with suspected reason: vein thrombosis requiring therapy or pulmonary embolism
	Intervention with suspected reason: vein thrombosis requiring therapy or pulmonary embolism
	Complication: vein thrombosis requiring therapy
	Complication: pulmonary embolism
	Complication: anticoagulation initiated of presumed/confirmed vein thrombosis/PE
Wound infection	Reoperation with suspected reason: wound infection or other abdominal sepsis
	Readmission with suspected reason: wound infection or other abdominal sepsis
	Intervention with suspected reason: wound infection or other abdominal sepsis
	Complication: Post-op superficial incisional SSI occurrence
	Complication: Post-op deep incisional SSI occurrence
Other infection	Reoperation with suspected reason: infection/fever
	Readmission with suspected reason: infection/fever,
	Intervention with suspected reason: infection/fever
	Complication: post-op sepsis occurrence
	Complication: post-op septic shock occurrence
	Complication: post-op pneumonia occurrence
	Complication: post-op urinary tract infection occurrence
Overall morbidity	Mortality within 30 days
	Need for intervention within 30 days
	Need for readmission within 30 days
	Need for reoperation within 30 days
	Unplanned ICU transfer within 30 days
Aggregate-related reoperation	Any reoperation designated as related to metabolic/bariatric by variable REOP_RELATED_BAR1. To REOP_RELATED_BAR.13
Aggregate-related readmission	Any readmission designated as related to metabolic/bariatric by variable READ_RELATED_BAR1. To READ_RELATED_BAR.11
Aggregate-related intervention	Any intervention designated as related to metabolic/bariatric by variable INVT_RELATED_BAR1. To INTV_RELATED_BAR.5
Bariatric surgery–related morbidity	Death related to bariatric surgery
	Aggregate reoperation related to metabolic/bariatric surgery
	Aggregate readmission related to metabolic/bariatric surgery
	Aggregate intervention related to metabolic/bariatric surgery

Appendix 2. Independent predictors of mortality and morbidity following sleeve and gastric bypass

Table 7 Independent predictors of mortality and morbidity following sleeve and gastric bypass following multivariate regression analysis

Overall mortality	Odds ratio	95% confidence interval	*p* value
VTE	2.53	1.30–4.95	0.006
Chronic steroids	2.39	1.09–5.26	0.030
Myocardial infarction	2.34	1.15–4.78	0.020
Male sex	2.24	1.47–2.99	< 0.001
Anticoagulation for VTE	2.12	1.22–3.68	0.007
Age	1.05	1.04–1.07	< 0.001
BMI	1.05	1.04–1.07	< 0.001
Bariatric-related mortality	Odds ratio	95% confidence interval	*p* value
BMI	1.04	1.00–1.09	0.03
Overall morbidity	Odds ratio	95% confidence interval	*p* value
History of IVC filter	1.74	1.41–2.15	< 0.001
History of dialysis	1.70	1.28–2.28	< 0.001
History of chronic steroids	1.55	1.35–1.78	< 0.001
History of DVT	1.53	1.32–1.77	< 0.001
History of anticoagulation	1.46	1.30–1.64	< 0.001
History of PE	1.42	1.20–1.67	< 0.001
History of MI	1.42	1.20–1.67	< 0.001
History of cardiac disease	1.32	1.10–1.58	0.003
History of renal insufficiency	1.26	1.00–1.59	0.045
ASA > 3	1.15	1.07–1.22	< 0.001
History of smoking	1.13	1.04–1.22	0.004
History of hyperlipidemia	1.12	1.06–1.20	0.002
History of hypertension	1.10	1.04–1.16	0.001
BMI	1.01	1.00–1.01	< 0.00
Age	1.00	1.00–1.01	0.031
Laparoscopic (vs. robotic)	0.90	0.84–0.98	0.017
Male sex	0.88	0.83–0.94	< 0.001
White (vs. Black)	0.77	0.73–0.82	< 0.001
Bariatric-related morbidity	Odds ratio	95% confidence interval	*p* value
History of TXP	1.78	1.12–2.64	0.004
History of DVT	1.69	1.42–2.00	< 0.001
History of IVC filter	1.55	1.21–2.00	< 0.001
History of dialysis	1.54	1.10–2.15	0.012
History of PE	1.53	1.27–1.95	< 0.001
History of MI	1.48	1.22–1.79	< 0.001
History of diabetes	1.45	1.31–1.60	< 0.001
History of chronic steroids	1.36	1.15–1.60	0.003
History of anticoagulation	1.23	1.06–1.41	0.049
ASA > 3	1.17	1.09–1.25	< 0.001
History of hyperlipidemia	1.16	1.09–1.24	< 0.001
History of smoking	1.14	1.04–1.24	0.006
BMI	1.00	1.00–1.01	0.002
Laparoscopic (vs. robotic)	0.90	0.82–0.99	0.267
Male sex	0.82	0.77–0.88	< 0.001

VTE venous thromboembolism, *BMI* body mass index, *IVC* inferior vena cava, *DVT* deep vein thrombosis, *PE* pulmonary emboli, *MI* myocardial infarction, *ASA* American Society of Anesthesiologist, *TXP* history of solid organ transplantation

Appendix 3. Patient characteristics after 1:5 propensity score matching

Table 8 Patient characteristics after propensity score matching

	(−) TXP [$n = 1425$]	(+) TXP [$n = 285$]	p value
Continuous variables, median (IQR)			
Age (years)	48 (38–57)	48 (39–56)	0.832
BMI closest to surgery (kg/m^2)	43.07 (39.4–48.55)	42.57 (39.53–46.59)	0.204
Categorical variables, *n* (%)			
Gender (female)	1048 (74)	207 (73)	0.750
Race (White)	748 (52)	154 (54)	0.634
Race (Black)	305 (21)	62 (22)	0.895
Ethnicity (Hispanic)	247 (17)	45 (16)	0.527
ASA class			0.945
< 3	158 (11)	32 (11)	
> 3	1267 (89)	253 (89)	
Operation type			0.438
Sleeve	1028 (72)	212 (74)	
Gastric bypass	397 (28)	73 (26)	
Surgical approach			0.661
Laparoscopic	1309 (92)	264 (93)	
Robotic	116 (8)	21 (7)	
Preoperative disease prevalence, *n* (%)			
History of MI	28 (2)	6 (2)	0.877
History of PCI	65 (5)	12 (4)	0.794
History cardiac surgery	56 (4)	11 (4)	0.956
Hypertension	922 (65)	185 (65)	0.946
Hyperlipidemia	537 (38)	102 (36)	0.546
Diabetes mellitus	551 (39)	102 (36)	0.591
COPD	58 (4)	3 (1)	*0.012*
OSA	455 (32)	90 (32)	0.908
Oxygen dependent	34 (2)	2 (1)	0.071
Smoker	70 (5)	11 (4)	0.445
Renal insufficiency	108 (8)	20 (7)	0.742
Dialysis	71 (5)	15 (5)	0.843
VTE requiring therapy	42 (3)	9 (3)	0.849
History of PE	43 (3)	9 (3)	0.900
IVC filter	20 (1)	3 (1)	0.639
Anticoagulation	77 (5)	18 (6)	0.539
Chronic steroids	455 (32)	93 (33)	0.817
Limited ambulation status	46 (3)	6 (2)	0.316
Independent functional status	1393 (98)	282 (99)	0.194
History of bariatric surgery	106 (7)	20 (7)	0.804

TXP history of solid organ transplantation, *IQR* interquartile range, *BMI* body mass index, *kg* kilogram, ASA American Society of Anesthesiologist, *MI* myocardial infarction, *PCI* percutaneous coronary intervention, *COPD* chronic obstructive pulmonary disease, *OSA* obstructive sleep apnea, *PE* pulmonary emboli, *IVC* inferior vena cava, *VTE* venous thromboembolism

Appendix 4. Patient characteristics after 1:5 case-control matched analysis

Table 9 Patient characteristics after case-control matching

	(−) TXP [$n = 910$]	(+) TXP [$n = 182$]	p value
Continuous variables, median (IQR)			
Age (years)	45 (36–75)	46 (38–72)	0.45
BMI closest to surgery (kg/m^2)	43.6 (39.6–49)	42.6 (39.6–47)	0.42
Categorical variables, n (%)			
Gender (female)	740 (81)	148 (81)	1
Race (White)	515 (57)	103 (57)	1
Race (Black)	170 (19)	34 (19)	1
Ethnicity (Hispanic)	144 (16)	29 (16)	0.97
ASA class			1
< 3	125 (14)	25 (14)	
> 3	785 (86)	157 (86)	
Operation type			1
Sleeve	640 (70)	128 (70)	
Gastric bypass	270 (30)	54 (30)	
Surgical approach			1
Laparoscopic	833 (92)	168 (92)	
Robotic	77 (8)	14 (8)	
Preoperative disease prevalence			
History of MI	5 (0.55)	1 (0.55)	1
History of PCI	0 (0)	0 (0)	1
History cardiac surgery	5 (0.55)	1 (0.55)	1
Hypertension	490 (54)	98 (54)	1
Hyperlipidemia	245 (27)	49 (27)	1
Diabetes mellitus	250 (27)	50 (27)	1
COPD	25 (3)	3 (2)	0.39
OSA	240 (26)	48 (26)	1
Oxygen dependent	8 (1)	1 (1)	1
Smoker	35 (4)	7 (4)	1
Renal insufficiency	0 (0)	0 (0)	1
Dialysis	0 (0)	0 (0)	1
VTE requiring therapy	0 (0)	0 (0)	1
History of PE	5 (0.55)	1 (0.55)	1
IVC filter	5 (0.55)	1 (0.55)	1
Anticoagulation	5 (0.55)	1 (0.55)	1
Chronic steroids	155 (17)	31 (17)	1
Limited ambulation status	6 (1)	3 (2)	0.18
Independent functional status	898 (99)	182 (100)	0.12
History of bariatric surgery	63 (7)	10 (5)	0.48

TXP history of solid organ transplantation, *IQR* interquartile range, *kg* kilogram, *ASA* American Society of Anesthesiologist, *MI* myocardial infarction, *PCI* percutaneous coronary intervention, *COPD* chronic obstructive pulmonary disease, *OSA* obstructive sleep apnea, *PE* pulmonary emboli, *IVC* inferior vena cava, *VTE* venous thromboembolism

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