Journal of the Endocrine Society, 2024, **8**, 1–9
https://doi.org/10.1210/jendso/bvae027
Advance access publication 14 March 2024
Clinical Research Article

Cardiometabolic Improvements After Metabolic Surgery and Related Presurgery Factors

Lei Wang,[1] Michael T. O'Brien,[2] Xinmeng Zhang,[3] You Chen,[4] Wayne J. English,[5] Brandon Williams,[5] Matthew Spann,[5] Vance Albaugh,[6] Xiao-Ou Shu,[1] Charles R. Flynn,[5] and Danxia Yu[1]

[1]Division of Epidemiology, Department of Medicine, Vanderbilt University Medical Center, Nashville, TN 37203, USA
[2]School of Medicine, Vanderbilt University, Nashville, TN 37203, USA
[3]Department of Computer Science, Vanderbilt University, Nashville, TN 37203, USA
[4]Department of Biomedical Informatics, Vanderbilt University Medical Center, Nashville, TN 37203, USA
[5]Department of Surgery, Vanderbilt University Medical Center, Nashville, TN 37203, USA
[6]Metamor Institute, Pennington Biomedical Research Center, Baton Rouge, LA 70808, USA

Correspondence: Danxia Yu, PhD, Division of Epidemiology, Vanderbilt University Medical Center, 2525 West End Ave, Nashville, TN 37203, USA. Email: danxia.yu@vumc.org.

Abstract

Context: Metabolic surgery remains the most effective and durable treatment for severe obesity and related metabolic diseases.

Objective: We examined cardiometabolic improvements after metabolic surgery and associated presurgery demographic and clinical factors in a large multiracial cohort.

Methods: Included were 7804 patients (20-79 years) undergoing first-time metabolic surgery at Vanderbilt University Medical Center from 1999 to 2022. Pre- and 1-year postsurgery cardiometabolic profiles were extracted from medical records, including body mass index (BMI), blood pressure, blood lipids, glucose, and hemoglobin A1c. The 10-year atherosclerotic cardiovascular disease (ASCVD) risk was estimated per American College of Cardiology/American Heart Association equations. Pre- to postsurgery cardiometabolic profiles were compared by paired t-test, and associated factors were identified by multivariable linear and logistic regression.

Results: Among 7804 patients, most were women and White, while 1618 were men and 1271 were Black; median age and BMI were 45 years [interquartile range (IQR): 37-53] and 46.4 kg/m^2 (IQR: 42.1-52.4). At 1-year postsurgery, patients showed significant decreases in systolic blood pressure (10.5 [95% confidence interval: 10.1, 10.9] mmHg), total cholesterol (13.5 [10.3, 16.7] mg/dL), glucose (13.6 [12.9, 14.4] mg/dL), hemoglobin A1c (1.13% [1.06, 1.20]), and 10-year ASCVD risk (absolute reduction: 1.58% [1.22, 1.94]; relative reduction: 34.4% [29.4, 39.3]); all $P < .0001$. Older, male, or Black patients showed less reduction in 10-year ASCVD risk and lower odds of diabetes/hypertension/dyslipidemia remission than younger, female, or White patients. Patients with a history of diabetes, hypertension, dyslipidemia, or cardiovascular disease showed less cardiometabolic improvements than those without. Results were similar with or without further adjusting for weight loss and largely sustained at 2-year postsurgery.

Conclusion: Metabolic surgery results in significant cardiometabolic improvements, particularly among younger, female, or White patients and those without comorbidities.

Key Words: metabolic surgery, metabolic health, cardiovascular disease risk, electronic health records, cohort analysis, multiracial population

Abbreviations: ASCVD, atherosclerotic cardiovascular disease; BMI, body mass index; CI, confidence interval; CVD, cardiovascular disease; DBP, diastolic blood pressure; EHR, electronic health records; HbA1c, hemoglobin A1c; HDL, high-density lipoprotein; IQR, interquartile range; LDL, low-density lipoprotein; OR, odds ratio; PP, pulse pressure; QES, Quality, Efficacy, and Safety; RYGB, Roux-en-Y gastric bypass; SBP, systolic blood pressure; TC, total cholesterol; TG, triglycerides; SG, sleeve gastrectomy; VUMC, Vanderbilt University Medical Center.

Obesity is a continuing and growing health concern globally, with the United States being in the top tier among all countries in terms of obesity prevalence. In 2017-2018, 42.4% of US adults had obesity [body mass index (BMI) ≥ 30 kg/m^2], and 9.2% had severe obesity (BMI ≥ 40 kg/m^2) [1], while, alarmingly, these rates are predicted to increase to 51% and 11%, respectively, by 2030 [2]. In addition, across racial/ethnic groups and geographic regions in the United States, non-Hispanic Black adults and the South had the highest prevalence of obesity and severe obesity, highlighting the need for more research among these populations [3].

Obesity, especially severe obesity, is strongly associated with cardiometabolic disorders [4], including diabetes, hypertension, dyslipidemia, and cardiovascular disease (CVD) [5]. Metabolic surgery is currently the most effective treatment for severe obesity and related comorbidities. On average, the percentage of total weight loss 1 year after surgery was 31.9% for Roux-en-Y gastric bypass (RYGB) and 30.5% for sleeve gastrectomy (SG), estimated by a recent meta-analysis including >11 000 patients [6]. Additionally, studies have reported that 1 year after surgery, metabolic surgery decreased hemoglobin A1c (HbA1c) by 1.8% to 3.5% [7], total

Received: 12 December 2023. **Editorial Decision:** 7 February 2024. **Corrected and Typeset:** 14 March 2024

cholesterol (TC) by 5.2 to 69.9 mg/dL, low-density lipoprotein (LDL) by 7.9 to 45.2 mg/dL, and triglycerides (TG) by 44.6 to 70.6 mg/dL [8] and was associated with a remission rate of 33% to 90% for diabetes [7], 43% to 83% for hypertension [9], and 16% to 80% for dyslipidemia [10], as well as a relative reduction of CVD risk scores ranging from 19% to 54% [11]. However, while studies have generally shown that metabolic surgery significantly improves cardiometabolic health, treatment effects varied across different studies and populations and with different procedure types. Some studies suggested certain patient characteristics (eg, age) and comorbidities (eg, diabetes duration, poor glycemic control, and antidiabetic/antihypertensive medications) are associated with treatment effects [12, 13]. However, studies examining presurgery factors predictive of multifaceted postsurgery cardiometabolic improvements are still limited, and data from Black/African American patients are notably lacking.

This study aimed to systemically evaluate cardiometabolic improvements after metabolic surgery, including blood pressure; blood lipids; glucose; HbA1c; predicted 10-year atherosclerotic cardiovascular disease (ASCVD) risk; and remissions of diabetes, hypertension, and dyslipidemia based on a large multiracial patient cohort from a single academic medical center and examine associated presurgery demographic and clinical factors. Identifying presurgery factors related to postsurgery cardiometabolic health may help determine which patients are most likely to experience certain cardiometabolic improvements vs those who would likely benefit from further intervention or a higher level of management and care after surgery.

Materials and Methods

Study Population and Data

This cohort consisted of 7804 patients aged 20 to 79 who underwent their first metabolic surgery at Vanderbilt University Medical Center (VUMC) from January 1999 to July 2022. Data were collected from the Vanderbilt Metabolic and Bariatric Surgery Quality, Efficacy, and Safety (QES) database, containing demographics, surgery information, and clinical outcomes before and 1 to 120 months after surgery. QES was further linked with electronic health records (EHR) to obtain extra data from all VUMC clinics up to 10 years before and after surgery. The following categories of data were used: (1) demographics and lifestyles (ie, age, sex, race, zip code, and smoking status); (2) surgery variables (ie, date of surgery and procedure type); (3) clinical outcomes [ie, body weight, systolic blood pressure (SBP), diastolic blood pressure (DBP), pulse pressure (PP), TC, LDL cholesterol, high-density lipoprotein (HDL) cholesterol, TG, glucose, and HbA1c]; (4) disease diagnosis, ie, diabetes [International Classification of Disease (ICD)-9: 250; ICD-10-CM: E10-E11], hypertension (ICD-9: 401-405; ICD-10-CM: I10-I16), dyslipidemia (ICD-9: 272; ICD-10-CM: E78), coronary heart disease (ICD-9: 410-414; ICD-10-CM: I20-I25), and stroke (ICD-9: 430-438; ICD-10-CM: I60-I69); and (5) medications. The study was reviewed and approved by the VUMC institutional review board, and written informed consent for this study was waived.

Outcomes

The primary outcomes included body weight, SBP, DBP, PP, TC, LDL, HDL, TG, glucose, HbA1c, and predicted 10-year ASCVD risk before and 1 year after surgery. Two 6-month time windows were defined, ie, 6 months to 1 week before surgery for presurgery measures and 9 to 15 months after surgery for 1-year measures. We used the median value of all measurements during the 6-month time window after excluding outliers defined as measurements that fell below Q1−1.5 interquartile range (IQR) or above Q3 + 1.5 IQR. The 10-year ASCVD risk was calculated per the American College of Cardiology/American Heart Association pooled cohort equations among patients without a diagnosis of CVD before surgery and within 15 months after surgery, including age, sex (men/women), race (White or other/Black), current smoking (yes/no), diabetes status (yes/no), pharmaceutical treatment for hypertension, SBP, TC, and HDL.

The secondary outcomes were remission of diabetes, hypertension, and dyslipidemia at 1-year postsurgery. Diseases status was defined by diagnosis code, pharmaceutical treatment [14-16] (for diabetes: biguanides, sulfonylureas, dipeptidyl peptidase 4 inhibitors, thiazolidinedione, sodium-glucose cotransporter inhibitors, meglitinide, and α-glucosidase inhibitors, and insulin; for hypertension: thiazide-type diuretics, calcium channel blockers, angiotensin-converting enzyme inhibitors, and angiotensin II receptor blockers; for dyslipidemia: statin), and lab tests (diabetes: glucose ≥200 mg/dL or HbA1c ≥ 6.5%; hypertension: SBP ≥140 mmHg or DBP ≥90 mmHg; dyslipidemia: TC ≥240 mg/dL or LDL ≥160 mg/dL or TG ≥200 mg/dL or HDL < 40 mg/dL for men/ < 50 mg/dL for women). Remission of diseases was defined by no diagnosis, no medication use, and normal lab test results (median values) during 9 to 15 months after surgery.

Using the same methods and data from 21 to 27 months after surgery, we also evaluated cardiometabolic profiles and disease status at 2-year postsurgery as an exploratory analysis.

Statistical Analyses

Patient characteristics were summarized as median and IQR for continuous variables and frequency and percentage for categorical variables. Paired t-tests were used to compare continuous outcomes post- vs presurgery among patients who had both pre- and postsurgery values; results were presented as absolute reduction [95% confidence interval (CI) and relative reduction (95% CI)]. Two-sample t-tests were used to compare absolute reductions of continuous outcomes across patient subgroups [ie, age (≤45 vs > 45 years), sex (men vs women), race (Black vs White), procedure (SG vs RYGB), and presurgery status (yes vs no) of diabetes, hypertension, dyslipidemia, and CVD]. Linear regression was used to identify demographic and clinical factors associated with cardiometabolic improvements, adjusting for the corresponding presurgery value (body weight/SBP/LDL/HDL/TG/glucose/HbA1c/10-year ASCVD risk), age, sex, race, procedure type, surgery year, and history of diabetes, hypertension, dyslipidemia, and CVD (model 1); amount of weight loss was further adjusted in model 2. Logistic regression was used to identify factors associated with the remission of diabetes, hypertension, or dyslipidemia with the same covariates listed previously. Two-sided $P < .05$ was considered statistically significant. All analyses were performed in SAS (version 9.4; SAS Institute, Cary, NC, USA).

Results

Patient Characteristics

Of 7804 included patients from 1999 to 2022, the majority were women (79.3%) and White (81.3%), while 20.7%

Table 1. Baseline characteristics of study patients who underwent metabolic and bariatric surgery at the Vanderbilt University Medical Center (n = 7804)

	Median (25th, 75th percentile)/n (%)
Age, year	45 (37, 53)
Sex	
Women	6186 (79.3)
Men	1618 (20.7)
Race/ethnicity	
White	6341 (81.3)
Black	1271 (16.3)
Other	192 (2.4)
Body mass index, kg/m^2	46.4 (42.1, 52.4)
Procedure	
RYGB	5272 (67.6)
SG	2103 (26.9)
AGB	429 (5.5)
Surgery year	
1999-2005	1224 (15.7)
2006-2010	1407 (18.0)
2011-2015	1787 (22.9)
2016-2022	3386 (43.4)
Current smoker	373 (4.8)
History of diabetes	3378 (43.3)
Macrovascular complications	564 (16.7)
Microvascular complications	731 (21.6)
Use of insulin	909 (11.7)
History of hypertension	6018 (77.1)
History of dyslipidemia	3729 (47.8)
History of cardiovascular disease	823 (10.6)
History of using antiobesity medications[a]	1214 (15.6)

Abbreviations: AGB, adjustable gastric banding; RYGB, Roux-en-Y gastric bypass; SG, sleeve gastrectomy.
[a]Antiobesity medications: orlistat, phentermine-topiramate, naltrexone-bupropion, setmelanotide, phentermine, benzphetamine, diethylpropion, phendimetrazine, dulaglutide, exenatide, semaglutide, liraglutide, lixisenatide.

(n = 1618) were men and 16.3% (n = 1271) were Black/African American (Table 1). The median age was 45 years (IQR: 37-53), and the median BMI was 46.4 kg/m^2 (IQR: 42.1-52.4); 67.6% of patients underwent RYGB and 26.9% had SG. The prevalence of cardiometabolic diseases was high before surgery, with 43.3%, 77.1%, 47.8%, and 10.6% of patients having a history of diabetes, hypertension, dyslipidemia, or CVD, respectively. Among patients without a history of CVD, the median estimated 10-year ASCVD risk was 2.43% (IQR: 1.04%-5.53%) before surgery (Table 2). Patient characteristics by age, sex, race, and procedure type are shown in Supplementary Tables 1-4 [17]. Most SG operations were performed after 2011, and 24.4% of SG recipients were Black patients, higher than that among RYGB recipients (13.5%). In general, RYGB patients had higher BMI (median: 47.2 vs 45.2 kg/m^2) and higher prevalence of diabetes (46.4% vs 36.1%), hypertension (78.7% vs 73.1%), and dyslipidemia (50.0% vs 40.0%) than SG patients before surgery.

Cardiometabolic Health Improvements at 1-year Postsurgery

Substantial improvements in cardiometabolic health were observed after surgery (Table 2). Specifically, at 1-year postsurgery, patients had significantly reduced body weight (41.9 [95% CI: 41.5, 42.3] kg), SBP (10.5 [10.1, 10.9] mmHg), DBP (4.9 [4.6, 5.3] mmHg), PP (5.5 [5.2, 5.9] mmHg), TC (13.5 [10.3, 16.7] mg/dL), LDL (10.3 [7.5, 13.2] mg/dL), TG (66.7 [60.2, 73.2] mg/dL), glucose (13.6 [12.9, 14.4] mg/dL), and HbA1c (1.13 [1.06, 1.20] %), while increased HDL (9.9 [8.9, 10.9] mg/dL). Meanwhile, the 10-year ASCVD risk was reduced by 34.4% (95% CI: 29.4, 39.3%). All pre- to 1-year postsurgery cardiometabolic improvements showed $P < .0001$. In addition, among patients with a history of diabetes (n = 3378), hypertension (n = 6018), or dyslipidemia (n = 3729) before surgery, 31.7%, 35.6%, and 49.6%, respectively, had remission at 1-year postsurgery. Furthermore, cardiometabolic improvements were sustained to 2-year postsurgery (Supplementary Table S5 [17]). The numbers of patients with missing outcomes at presurgery, 1-year, and 2-year postsurgery are presented in Supplementary Table S6 [17].

Demographic and Clinical Factors Associated With Postsurgery Cardiometabolic Improvements

From the mutually adjusted linear model (Table 3), we found that older age, male sex, and Black race were associated with less reduction in body weight, SBP, and 10-year ASCVD risk (all $P < .05$); specifically, per 5 years increase in age, men, and Black patients showed ~14% to 17% less reduction in 10-year ASCVD risk than younger, women, or White patients (Table 3 and Fig. 1). Men also showed less improvement in glucose (-2.47 [95% CI: -3.74, -1.21] mg/dL) and HDL (3.25 [0.88, 5.62] mg/dL) but greater improvement in TG (10.56 [2.51, 18.61] mg/dL) than women. In addition, Black patients showed greater improvement in HDL (-3.29 [-6.03, -0.56] mg/dL) and TG (14.21 [4.37, 24.05] mg/dL) than White patients.

Patients who underwent SG had less reduction in body weight (-5.55 [-6.23, -4.88] kg), SBP (-1.90 [-2.75, -1.06] mmHg), LDL (-11.64 [-18.30, -4.98] mg/dL), and 10-year ASCVD risk (-11.72 [-24.88, 1.45] %) than patients who underwent RYGB (all $P < .05$ except that ASCVD risk $P = .08$; Table 3). Compared to those without a history of diabetes, hypertension, dyslipidemia, or CVD, patients with these diseases showed less metabolic improvements, although their estimated 10-year ASCVD risk reduction was comparable. For example, patients with diabetes had less improvement in body weight (−3.23 [−3.81, −2.65] kg), SBP (−1.12 [−1.87, −0.38] mmHg), HDL (2.92 [0.83, 5.01] mg/dL), TG (−8.62 [−16.02, −1.22] mg/dL), and glucose (−4.15 [−5.28, −3.01] mg/dL) than those without diabetes; patients with hypertension showed less reduction in SBP (−5.48 [−6.45, −4.50] mmHg) than those without; patients with dyslipidemia had less reduction in LDL (−10.57 [−17.09, −4.04] mg/dL) and glucose (−1.98 [−3.09, −0.87] mg/dL) than those without; patients with prior CVD had less reduction in TG (−9.76 [−18.46, −1.06] mg/dL) and glucose (−2.39 [−3.96, −0.82] mg/dL) than those without. Most associations were only slightly changed and still significant after further adjusting for weight loss (model 2 in Table 3). All the pre- vs postsurgery cardiometabolic changes in patient subgroups by age, sex,

Table 2. Comparison of cardiometabolic profiles between pre- and 1-year postsurgery

	Presurgery[a]		1-year postsurgery		Difference (95% CI)		
	Number of patients	Median (IQR)	Number of patients	Median (IQR)	Pairs	Absolute reduction[b]	Relative reduction[c], %
Body weight (kg)	7550	130.9 (115.6, 150.5)	5547	89.8 (77.1, 105.6)	5504	41.9 (41.5, 42.3)	31.0 (30.8, 31.3)
SBP (mmHg)	7197	134.0 (126.0, 143.0)	5201	123.0 (113.5, 133.5)	4916	10.5 (10.1, 10.9)	7.3 (7.0, 7.6)
DBP (mmHg)	7201	79.0 (72.0, 86.0)	5217	74.0 (67.0, 81.0)	4936	4.9 (4.6, 5.3)	5.3 (4.9, 5.7)
PP (mmHg)	7190	54.0 (48.0, 62.0)	5196	48.5 (42.0, 57.0)	4908	5.5 (5.2, 5.9)	7.8 (7.2, 8.5)
TC (mg/dL)	1099	183.0 (159.5, 208.0)	1050	165.8 (144.0, 188.0)	464	13.5 (10.3, 16.7)	5.5 (3.7, 7.3)
LDL (mg/dL)	1083	100.0 (80.5, 122.0)	1035	87.0 (70.0, 107.0)	457	10.3 (7.5, 13.2)	4.3 (0.8, 7.7)
HDL (mg/dL)	1095	46.0 (39.0, 55.0)	1046	56.0 (47.0, 66.0)	467	−9.9 (−10.9, −8.9)	−24.4 (−26.9, −21.9)
TG (mg/dL)	1069	149.0 (106.0, 213.0)	1002	89.0 (66.0, 118.0)	427	66.7 (60.2, 73.2)	33.3 (30.4, 36.2)
Glucose (mg/dL)	6218	99.5 (91.0, 115.0)	4234	90.0 (84.5, 98.0)	3573	13.6 (12.9, 14.4)	9.9 (9.3, 10.6)
HbA1c (%)	1681	6.50 (5.80, 7.50)	1108	5.53 (5.20, 6.10)	747	1.13 (1.06, 1.20)	14.9 (14.1, 15.8)
10-year ASCVD risk (%)	1214	2.43 (1.04, 5.53)	789	1.63 (0.53, 4.70)	284	1.58 (1.22, 1.94)	34.4 (29.4, 39.3)

Abbreviations: ASCVD, atherosclerotic cardiovascular disease; CI, confidence interval; DBP, diastolic blood pressure; HDL, high-density lipoprotein; IQR, interquartile range; LDL, low-density lipoprotein; PP, pulse pressure; SBP, systolic blood pressure; TC, total cholesterol; TG, triglycerides.
[a]Among patients who had at least 1 postsurgery value during follow-up period.
[b]Absolute reduction = presurgery—1-year postsurgery. All $P < .0001$.
[c]Relative reduction = (presurgery—1-year postsurgery)/presurgery * 100. All $P < .0001$.

race, procedure, and history of comorbidities are illustrated in Supplementary Fig. S1-S8 [17], respectively.

From the mutually adjusted logistic model among patients with a history of diabetes, hypertension, or dyslipidemia (Table 4), we found that older patients or men were less likely to have remission of those diseases [odds ratio (OR) ranged from 0.71 to 0.89 per 5-year increase in age and 0.51 to 0.68 for men vs women]. Black patients were less likely to have remission of hypertension (OR [95% CI]: 0.55 [0.47, 0.64]) than White patients, while SG patients were more likely to have remission of diabetes (OR [95% CI]: 1.46 [1.16, 1.83]) than RYGB patients. Patients accompanied with other cardiometabolic diseases had lower odds of achieving remission of diabetes, hypertension, or dyslipidemia compared to those without comorbidities (OR ranged from 0.38 to 0.82). Most associations were similar with or without adjusting for weight loss (model 2 in Table 4). Furthermore, we also observed significant associations of older age, male sex, Black race, and history of comorbidities with less cardiometabolic improvements and lower odds of disease remission at 2-year postsurgery (Supplementary Tables S7 and S8[17]), with similar or larger effect sizes but wider 95% CIs than the 1-year associations, which may be due to decreased sample size during postsurgery follow-up and should be interpreted with caution.

Discussion

In this large cohort of patients who underwent metabolic surgery, we observed significant and comprehensive cardiometabolic improvements 1 year after the surgery, including reductions in the estimated 10-year ASCVD risk (on average: 34.4% relative reduction), SBP (10.5 mmHg), DBP (4.9 mmHg), PP (5.5 mmHg), TC (13.5 mg/dL), LDL (10.3 mg/dL), TG (66.7 mg/dL), glucose (13.6 mg/dL), and HbA1c (1.13%); an increase in HDL (9.9 mg/dL); and 32% to 50% remission rates of diabetes, hypertension, and dyslipidemia. In addition, we identified patient demographic and presurgery clinical factors independently associated with greater improvements in cardiometabolic health, including younger age, female sex, White race, and no history of cardiometabolic diseases.

Accumulated evidence from clinical trials and observational studies has revealed that metabolic surgery results in long-term weight loss and improvements in CVD risk factors. For example, a meta-analysis of 29 studies including >11 000 patients estimated 31.9% and 30.5% total weight loss for RYGB and SG patients 1 year after surgery [6], similar to our findings (RYGB: 33.4%, SG: 28.3%). The magnitudes of cardiometabolic improvements after surgery, however, appear heterogeneous among reported studies depending on the study design, patient characteristics (eg, age, sex, race, BMI, comorbidities), and definition of disease remission (eg, threshold of HbA1c ranging from 6.0-7.0% and/or no medication). For example, clinical trials have shown a 1.8% to 3.5% reduction in HbA1c and 25% to 100%, 31% to 84%, and 16% to 80% remission rates of diabetes, hypertension, and dyslipidemia at 1 year after RYGB or SG [7, 10]; cohort studies also showed significant but varied reduction in HbA1c (0.3–2.7%), SBP (7.2-15.1 mmHg), and TG (46.5-152.5 mg/dL) [18-20] and the remission rates ranged from 37% to 74% for diabetes [21-25], 28% to 58% for hypertension [26-28], and 31% to 63% for dyslipidemia [26, 27, 29]. Our findings were largely consistent with previous cohort studies, except that the diabetes remission rate was slightly lower in our study (32%), which may be due to our strict definition of disease remission (no diagnosis, no medication, and normal lab test results). Furthermore, a growing number of recent studies have also estimated potential CVD risk reduction to evaluate the overall cardiometabolic benefit of metabolic surgery. Three cohort studies conducted in the United States, using the same American College of Cardiology/American Heart Association equation as our study, reported a 27% to 55% reduction in predicted 10-year ASCVD risk at 1-year postsurgery among RYGB patients and a 27% to 36% reduction among SG patients [30-32]. Our results (~35% among all

Table 3. Presurgery factors associated with cardiometabolic improvements at 1-year postsurgery

Reduction of outcomes	Model	n [a]	β coefficient (95% CI) [b]							
			Age (per 5 years)	Sex (Men vs Women)	Race (Black vs White)	Procedure (SG vs RYGB)	Diabetes (Yes vs No)	Hypertension (Yes vs No)	Dyslipidemia (Yes vs No)	CVD (Yes vs No)
Body weight (kg)	M1[c]	5504	**−0.67 (−0.81, −0.52)***	**−2.52 (−3.31, −1.74)***	**−5.74 (−6.49, −4.99)***	**−5.55 (−6.23, −4.88)***	**−3.23 (−3.81, −2.65)***	0.05 (−0.66, 0.77)	**−0.68 (−1.29, −0.08)^**	−0.03 (−0.92, 0.86)
SBP (mmHg)	M1	4916	**−0.57 (−0.75, −0.40)***	**−2.67 (−3.57, −1.78)***	**−5.42 (−6.39, −4.46)***	**−1.90 (−2.75, −1.06)***	**−1.12 (−1.87, −0.38)***	**−5.48 (−6.45, −4.50)***	−0.04 (−0.82, 0.74)	−0.95 (−2.08, 0.19)
	M2[d]	4824	**−0.45 (−0.63, −0.27)***	**−3.25 (−4.18, −2.33)***	**−5.10 (−6.07, −4.12)***	**−1.37 (−2.23, −0.50)***	**−0.92 (−1.67, −0.17)^**	**−5.50 (−6.47, −4.52)***	0.22 (−0.57, 1.00)	−0.96 (−2.10, 0.17)
LDL (mg/dL)	M1	457	−0.75 (−2.03, 0.53)	1.49 (−3.70, 6.68)	4.52 (−1.93, 10.97)	**−11.64 (−18.30, −4.98)***	−2.06 (−7.12, 2.99)	−0.13 (−6.36, 6.36)	**−10.57 (−17.09, −4.04)***	2.44 (−3.21, 8.08)
	M2	445	−0.63 (−1.95, 0.70)	1.11 (−4.21, 6.43)	5.07 (−1.49, 11.63)	**−12.15 (−18.87, −5.43)***	−2.02 (−7.19, 3.15)	−0.15 (−6.77, 6.47)	**−10.10 (−16.78, −3.41)***	2.15 (−3.58, 7.88)
HDL (mg/dL)	M1	467	**0.58 (0.02, 1.13)^**	**3.25 (0.88, 5.62)^**	**−3.29 (−6.03, −0.56)^**	1.28 (−1.57, 4.14)	**2.92 (0.83, 5.01)^**	−1.45 (−4.24, 1.33)	−0.16 (−3.20, 2.88)	0.98 (−1.40, 3.37)
	M2	456	0.51 (−0.06, 1.08)	**3.06 (0.64, 5.48)^**	**−3.85 (−6.62, −1.08)^**	1.30 (−1.58, 4.18)	**3.23 (1.10, 5.36)***	−1.12 (−3.95, 1.71)	−0.48 (−3.59, 2.62)	1.09 (−1.31, 3.49)
TG (mg/dL)	M1	427	−0.56 (−2.49, 1.36)	**10.56 (2.51, 18.61)^**	**14.21 (4.37, 24.05)***	−9.20 (−19.29, 0.88)	**−8.62 (−16.02, −1.22)^**	−5.11 (−14.85, 4.64)	−6.39 (−16.22, 3.43)	**−9.76 (−18.46, −1.06)^**
	M2	415	−0.24 (−2.22, 1.73)	**9.64 (1.45, 17.84)^**	**15.09 (5.14, 25.04)***	−8.92 (−19.06, 1.21)	**−7.70 (−15.24, −0.16)^**	−6.22 (−16.13, 3.69)	−6.28 (−16.32, 3.76)	**−10.74 (−19.55, −1.92)^**
Glucose (mg/dL)	M1	3573	**−0.63 (−0.88, −0.38)***	**−2.47 (−3.74, −1.21)***	0.03 (−1.32, 1.38)	0.57 (−0.61, 1.76)	**−4.15 (−5.28, −3.01)***	−0.51 (−1.82, 0.79)	**−1.98 (−3.09, −0.87)***	**−2.39 (−3.96, −0.82)***
	M2	3473	**−0.50 (−0.77, −0.24)***	**−3.06 (−4.39, −1.73)***	0.41 (−0.97, 1.80)	1.21 (−0.01, 2.43)	**−3.91 (−5.06, −2.75)***	−0.71 (−2.03, 0.61)	**−1.64 (−2.77, −0.50)***	**−2.54 (−4.12, −0.95)***
HbA1c (%)	M1	747	**−0.04 (−0.07, −0.02)***	0.05 (−0.06, 0.15)	−0.10 (−0.22, 0.01)	−0.04 (−0.17, 0.09)	−0.11 (−0.27, 0.06)	0.08 (−0.08, 0.24)	−0.09 (−0.21, 0.03)	−0.07 (−0.19, 0.04)
	M2	722	**−0.03 (−0.05, −0.003)^**	−0.01 (−0.12, 0.10)	−0.08 (−0.20, 0.03)	0.05 (−0.09, 0.18)	−0.08 (−0.24, 0.08)	0.05 (−0.11, 0.21)	−0.07 (−0.19, 0.05)	−0.07 (−0.19, 0.04)
10-year ASCVD relative risk (%)	M1	284	**−13.69 (−17.01, −10.36)***	**−13.93 (−26.73, −1.12)***	**−17.34 (−31.76, −2.91)^**	−11.72 (−24.88, 1.45)	−7.91 (−18.28, 2.46)	11.87 (−1.07, 24.81)	3.15 (−9.33, 15.63)	/
	M2	280	**−13.26 (−16.18, −10.34)***	**−16.79 (−26.81, −6.76)***	**−15.03 (−26.55, −3.50)^**	−10.20 (−20.88, 0.48)	−7.16 (−16.01, 1.69)	8.69 (−3.27, 20.66)	3.11 (−8.24, 14.46)	/

Abbreviations: ASCVD, atherosclerotic cardiovascular disease; CI, confidence interval; CVD, cardiovascular disease; HbA1c, hemoglobin A1c; HDL, high-density lipoprotein; LDL, low-density lipoprotein; M1, model 1; M2, model 2; RYGB, Roux-en-Y gastric bypass; SBP, systolic blood pressure; SG, sleeve gastrectomy; TC, total cholesterol; TG, triglycerides.

[a]n indicates the number of patients used in each analysis.

[b]β coefficients (95% CI) from multivariate linear regression models; the reference groups were women, White, RYGB, and those without comorbidities; bold β (95% CI) with mark ^ indicated $P < .05$, and bold β (95% CI) with mark * indicated $P < .005$.

[c]Model 1 adjusted for presurgery values (weight/SBP/LDL/HDL/TG/glucose/HbA1c/10-year ASCVD risk), age at surgery, sex, race, procedure type, surgery year, status of diabetes, hypertension, dyslipidemia, and cardiovascular disease.

[d]Model 2 adjusted for covariates in model 1 and weight loss.

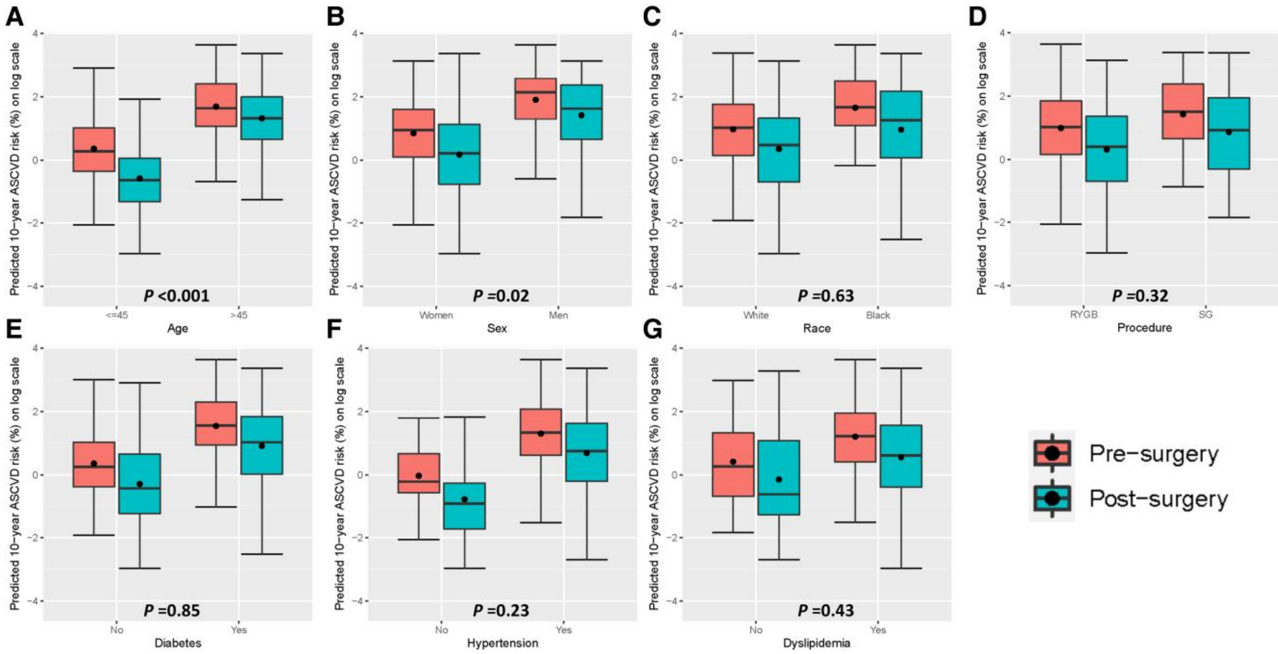

Figure 1. Predicted 10-year ASCVD risk (%) before and 1 year after surgery in metabolic surgery patient subgroups. The 10-year ASCVD risk (%) was calculated per American College of Cardiology/American Heart Association pooled cohort equations among patients without a diagnosis of cardiovascular disease and presented on a log scale. Patient subgroups were defined by age (A), sex (B), race (C), procedure type (D), history of diabetes (E), hypertension (F), and dyslipidemia (G). The *P*-values were for comparisons of 10-year ASCVD risk reduction between subgroups.

Abbreviation: ASCVD, atherosclerotic cardiovascular disease.

patients, 37% for RYGB, and 26% for SG) align with those findings but are on the lower end. This may partly be due to our strict definition of diabetes remission, as discussed previously. In addition, the definition and rates of cigarette smoking were different among studies [30, 31], which may also affect the ASCVD risk calculation. Nevertheless, despite the varied magnitude of cardiometabolic improvements and ASCVD risk reduction among reported studies, the cardiometabolic benefits of metabolic surgery are substantial and clinically meaningful.

At the same time, varied cardiometabolic benefits highlight the importance of examining associated presurgery factors. In the United States, ~252 000 metabolic procedures are performed each year, the majority (>70%) among women and White patients, with a mean age of 44 [33]. Our study found that younger age, women, and White patients generally showed greater cardiometabolic improvements, including a greater reduction in body weight, blood pressure, blood lipids, glucose, and/or 10-year ASCVD risk and a higher likelihood of remission of diabetes, hypertension, and/or dyslipidemia than older, male, and Black patients, respectively. Previous studies have linked younger age at surgery with greater weight loss and higher remission rates of diabetes and hypertension [12, 34-36], consistent with our findings. However, previous results on the potential effect modification by sex or race have been inconsistent. For example, women were found to have greater weight loss and ASCVD risk reduction but lower or similar remission rates of diabetes, hypertension, or dyslipidemia than men [12, 21, 35, 37, 38]; White patients had greater weight loss but less ASCVD risk reduction than Black patients [34, 36, 37]. In contrast, our study showed 21% to 49% lower odds of diabetes, hypertension, or dyslipidemia remission among men and 15% to 17% less ASCVD risk reduction among Black patients than their counterparts, with or without adjustment for weight loss. The discrepancies may be due to different surgery types, eg, exclusive RYGB patients in Hatoum et al's study [12] and small sample size of Black patients in prior studies, eg, n = 170 in Hinerman et al's study [37] vs n = 1271 in ours. Nevertheless, sex, race, procedure type, and other clinical factors were mutually adjusted in our regression model, and, in a further analysis stratified by procedure type, we found consistent results that Black patients showed less ASCVD risk reduction than White patients with either RYGB or SG. To gain a better understanding of the potential sex and race differences in cardiometabolic outcomes after metabolic surgery, studies with a large sample size of diverse patient populations, particularly men and Black patients, are still needed.

In addition, many studies have compared RYGB with SG for weight loss and metabolic improvements. They have generally shown greater weight loss among RYGB than SG patients [34, 36, 39], which aligns with our finding; however, whether and to what extent metabolic improvements may differ by procedure type remain debatable. Most but not all observational studies have found higher rates of diabetes remission with RYGB than SG, while a meta-analysis conducted in 2019 with 4089 patients showed that the diabetes remission rate did not differ between RYGB and SG at 1 to 5 years after surgery [40]. A recent systematic review also showed a comparable effect on diabetes remission between RYGB and SG [41]. Our study found no difference in glucose or HbA1c reduction between RYGB and SG but a higher probability of diabetes remission after SG than RYGB (OR [95% CI]: 1.59 [1.21-2.08]). The mechanisms for diabetes remission or improvement after metabolic surgery remain not fully understood, with one explanation involving decreased energy intake resulting in substantial weight loss and improved glucose sensitivity. However, this does not explain

Table 4. Presurgery factors associated with remissions of metabolic diseases at 1-year postsurgery

Remission of diseases	Model	n[a]	Odds ratio (95% CI)[b] Age (per 5 years)	Sex (Men vs Women)	Race (Black vs White)	Procedure (SG vs RYGB)	Diabetes (Yes vs No)	Hypertension (Yes vs No)	Dyslipidemia (Yes vs No)	CVD (Yes vs No)
Diabetes	M1[c]	2737	**0.89 (0.85, 0.93)**	**0.61 (0.48, 0.77)**	0.87 (0.69, 1.11)	**1.46 (1.16, 1.83)**	—	**0.64 (0.48, 0.84)**	**0.74 (0.61, 0.91)**	**0.73 (0.55, 0.96)**
	M2[d]	2059	**0.89 (0.84, 0.94)**	**0.63 (0.47, 0.85)**	0.93 (0.71, 1.23)	**1.59 (1.21, 2.08)**	—	**0.66 (0.48, 0.91)**	**0.77 (0.61, 0.97)**	**0.68 (0.49, 0.94)**
Hypertension	M1	5623	**0.83 (0.81, 0.86)**	**0.63 (0.54, 0.73)**	**0.55 (0.47, 0.64)**	1.01 (0.88, 1.17)	**0.70 (0.62, 0.79)**	—	**0.79 (0.70, 0.90)**	**0.64 (0.52, 0.79)**
	M2	4102	**0.82 (0.79, 0.85)**	**0.51 (0.42, 0.63)**	**0.58 (0.48, 0.71)**	1.03 (0.86, 1.23)	**0.69 (0.59, 0.80)**	—	**0.82 (0.70, 0.96)**	**0.53 (0.41, 0.69)**
Dyslipidemia	M1	1339	**0.71 (0.66, 0.77)**	0.79 (0.59, 1.08)	0.90 (0.62, 1.31)	0.92 (0.61, 1.36)	**0.38 (0.29, 0.50)**	0.68 (0.45, 1.03)	—	**0.44 (0.32, 0.62)**
	M2	1018	**0.72 (0.66, 0.78)**	**0.68 (0.48, 0.97)**	0.76 (0.50, 1.16)	1.04 (0.67, 1.61)	**0.44 (0.32, 0.60)**	0.76 (0.49, 1.18)	—	**0.47 (0.31, 0.69)**

Abbreviations: CI, confidence interval; CVD, cardiovascular disease; M1, model 1; M2, model 2; RYGB, Roux-en-Y gastric bypass; SG, vertical sleeve gastrectomy.
[a]n indicates the number of patients used in each analysis.
[b]Odds ratios (95% CI) were obtained from multivariate logistic regression models; the reference groups were younger age, women, White, RYGB, and those without comorbidities; bold OR (95% CI) indicated $P < .05$.
[c]Model 1 adjusted for presurgery biomarkers related to diseases (glucose/systolic blood pressure/low-density lipoprotein), age at surgery, sex, race, procedure type, surgery year, and presurgery status of other comorbidities.
[d]Model 2 adjusted for covariates in model 1 and weight loss at 1-year postsurgery.

the drastic improvement in glucose control immediately following surgery and similar results with or without adjustment for weight loss in our study. Furthermore, in a sensitivity analysis, we additionally adjusted for diabetes severity before surgery, including diabetes duration, use of insulin, and macrovascular and microvascular diabetes complications, and still found higher odds of diabetes remission in SG than RYGB patients (OR [95%CI]: 1.55 [1.16, 2.06]). In terms of hypertension and dyslipidemia remission, studies have reported higher rates among RYGB than SG patients 5 years after surgery [9, 10]. Meanwhile, our study found greater reductions in SBP and LDL among RYGB than SG patients but similar remission rates of hypertension and dyslipidemia between procedures 1 to 2 years after surgery. It is possible that the results appear different from linear regression of biomarkers or logistic regression of disease outcomes. Regarding predicted 10-year ASCVD risk, RYGB patients in our study showed greater, although nonsignificant, relative reduction (10.2%) than SG patients, which was also reported in previous studies [30, 31]. As RYGB has declined while SG has increased and become the dominant procedure [33], examining the short- and long-term effects on cardiometabolic health by procedure type remains an important research and clinical topic.

Finally, we observed that patients with a history of cardiometabolic diseases before surgery showed less improvement than those without a disease history, particularly when comparing diabetes vs no diabetes. Consistent with our findings, in a study of 1837 patients, Guerreiro et al [35] found that patients with diabetes had less weight loss than those without diabetes at years 1, 2, and 3 after surgery, as did those with hypertension at year 1. Moreover, several studies have identified less severe diabetes (ie, shorter diabetes duration/better glucose control/no insulin use) or hypertension (ie, less antihypertensive drug use), no CVD history, and no use of antihyperlipidemic medication with better chances of remissions of diabetes [12, 13, 21, 42-45] and hypertension [12], suggesting metabolic surgery may be best performed before the onset or progression of obesity-related comorbidities.

Our study has several notable strengths. First, it is a multiracial cohort with >7800 patients who underwent metabolic surgery at a single academic medical center, utilizing both the bariatric QES database and EHR to improve data completeness and quality. The diverse population and comprehensive information enable us to examine the effect of metabolic surgery on cardiometabolic health in a real-world clinical setting. Second, we evaluated multifaceted cardiometabolic improvements after surgery, including body weight, blood pressure, blood lipids, glucose, predicted 10-year ASCVD risk, and remissions of comorbidities, and identified multiple independently associated demographic and clinical factors, which may help inform patients who may experience greater improvements and who may require extra health management after surgery. Third, our results are similar with or without further adjustment for weight loss, indicating postsurgery cardiometabolic improvements are largely independent of weight loss and calling for more research on underlying mechanisms. Several limitations in this study are also worth noting. First, despite the integration of QES with EHR, the sample sizes for some cardiometabolic measures (eg, blood lipids and the 10-year ASCVD risk, which requires lipids data in its calculation) were much smaller than other measures (eg, blood pressure and glucose). However, a post hoc power analysis showed that only 32 or 14 patients were able to detect a

1.58% 10-year ASCVD risk absolute reduction (SD: 3.08%) or 34.4% relative reduction (SD: 42.7%) with 80% power and a type I error of 0.05. The sample sizes decreased further at 2-year postsurgery, causing wider confidence intervals, although we still observed significant improvements and similar associations as those at 1-year postsurgery. Studies with large sample sizes investigating long-term cardiometabolic health after metabolic surgery are still needed, particularly the overall measure like 10-year ASCVD risk. Second, given the observational, retrospective nature of our study design, our results could be affected by measurement errors and confounding bias from unmeasured or poorly measured variables. For example, we did not adjust for socioeconomic status (eg, education and income) or lifestyle (eg, smoking) in the regression models due to substantial missing values. However, in a sensitivity analysis, we adjusted for neighborhood deprivation index (a measure of socioeconomic status derived from zip codes) and smoking status among those with available data and found similar results. Given the significant impact of social determinants and lifestyle on health, future studies capturing the information are needed to further reveal the factors that may affect cardiometabolic health after metabolic surgery. In addition, considering the potential influence of different surgeons, antiobesity medication use, and the COVID-19 pandemic, we did sensitivity analyses by additionally adjusting for surgeons or antiobesity medication use in the model or only including patients with surgery before 2020 (n = 6297), and all results remained similar.

In conclusion, our study demonstrated that patients who underwent metabolic surgery had significant improvements in cardiometabolic health, including reductions in blood pressure, blood lipids, glucose, HbA1c, and estimated 10-year ASCVD risk, and remissions of diabetes, hypertension, and dyslipidemia. Younger age group, women, White patients, and those without comorbidities generally showed greater cardiometabolic improvements than older patients, men, Black patients, and those with existing cardiometabolic disease(s).

Funding

This analysis is supported by Grant R01DK126721 from the National Institute of Diabetes and Digestive and Kidney Diseases of the National Institutes of Health.

Author Contributions

L.W. and D.Y. designed the study. X.Z., Y.C., W.J.E., B.W., V.L.A., and C.R.F. collected the data. L.W. and M.T.O. cleaned and analyzed data. L.W. drafted the manuscript. All authors contributed to writing and revising the paper and approved the final version of the manuscript.

Disclosures

All the authors declare that they have no conflict of interest.

Data Availability

Restrictions apply to the availability of some or all data generated or analyzed during this study to preserve patient confidentiality or because they were used under license. The corresponding author will on request detail the restrictions and any conditions under which access to some data may be provided.

References

1. Hales CM, Carroll MD, Fryar CD, Ogden CL. Prevalence of obesity and severe obesity among adults: united States, 2017-2018. *NCHS Data Brief*. 2020;2(360):1-8.
2. Finkelstein EA, Khavjou OA, Thompson H, *et al*. Obesity and severe obesity forecasts through 2030. *Am J Prev Med*. 2012;42(6):563-570.
3. Ward ZJ, Bleich SN, Cradock AL, *et al*. Projected U.S. State-level prevalence of adult obesity and severe obesity. *N Engl J Med*. 2019;381(25):2440-2450.
4. Twig G, Reichman B, Afek A, *et al*. Severe obesity and cardiometabolic comorbidities: a nationwide study of 2.8 million adolescents. *Int J Obes (Lond)*. 2019;43(7):1391-1399.
5. Ortega FB, Lavie CJ, Blair SN. Obesity and cardiovascular disease. *Circ Res*. 2016;118(11):1752-1770.
6. Van Rijswijk AS, van Olst N, Schats W, van der Peet DL, van de Laar AW. What is weight loss after bariatric surgery expressed in percentage total weight loss (%TWL)? A systematic review. *Obes Surg*. 2021;31(8):3833-3847.
7. Arterburn DE, Telem DA, Kushner RF, Courcoulas AP. Benefits and risks of bariatric surgery in adults: a review. *JAMA*. 2020;324(9):879-887.
8. Heffron SP, Parikh A, Volodarskiy A, *et al*. Changes in lipid profile of obese patients following contemporary bariatric surgery: a meta-analysis. *Am J Med*. 2016;129(9):952-959.
9. Climent E, Goday A, Pedro-Botet J, *et al*. Laparoscopic roux-en-Y gastric bypass versus laparoscopic sleeve gastrectomy for 5-year hypertension remission in obese patients: a systematic review and meta-analysis. *J Hypertens*. 2020;38(2):185-195.
10. Lee Y, Doumouras AG, Yu J, *et al*. Laparoscopic sleeve gastrectomy versus laparoscopic roux-en-Y gastric bypass: a systematic review and meta-analysis of weight loss. Comorbidities, and biochemical outcomes from randomized controlled trials. *Ann Surg*. 2021;273(1):66-74.
11. English WJ, Spann MD, Aher CV, Williams DB. Cardiovascular risk reduction following metabolic and bariatric surgery. *Ann Transl Med*. 2020;8(S1):S12.
12. Hatoum IJ, Blackstone R, Hunter TD, *et al*. Clinical factors associated with remission of obesity-related comorbidities after bariatric surgery. *JAMA Surg*. 2016;151(2):130-137.
13. Aminian A, Brethauer SA, Andalib A, *et al*. Individualized metabolic surgery score: procedure selection based on diabetes severity. *Ann Surg*. 2017;266(4):650-657.
14. Khalil H, Zeltser R. *Antihypertensive Medications. StatPearls [Internet]*. StatPearls Publishing; 2022.
15. Pappan N, Rehman A. *Dyslipidemia. StatPearls [Internet]*. StatPearls Publishing; 2023.
16. Ganesan K, Rana MBM, Sultan S. *Oral Hypoglycemic Medications. StatPearls [Internet]*. StatPearls Publishing; 2022.
17. Wang L, O'Brien MT, Zhang X, *et al*. Supplementary material for "Cardiometabolic Improvements After Metabolic Surgery and Related Pre-surgery Factors." Deposited Dec 07, 2023. https://github.com/LeiWang212/JCEM_LW/blob/main/Supplementary%20Materials_1.15.pdf
18. Barzin M, Motamedi MAK, Serahati S, *et al*. Comparison of the effect of gastric bypass and sleeve gastrectomy on metabolic syndrome and its components in a cohort: tehran obesity treatment study (TOTS). *Obes Surg*. 2017;27(7):1697-1704.
19. Lee WJ, Chong K, Aung L, Chen SC, Ser KH, Lee YC. Metabolic surgery for diabetes treatment: sleeve gastrectomy or gastric bypass? *World J Surg*. 2017;41(1):216-223.
20. Benaiges D, Goday A, Ramon JM, Hernandez E, Pera M, Cano JF. Laparoscopic sleeve gastrectomy and laparoscopic gastric bypass are equally effective for reduction of cardiovascular risk in severely obese patients at one year of follow-up. *Surg Obes Related Dis*. 2011;7(5):575-580.
21. Madsen LR, Baggesen LM, Richelsen B, Thomsen RW. Effect of roux-en-Y gastric bypass surgery on diabetes remission and

complications in individuals with type 2 diabetes: a danish population-based matched cohort study. *Diabetologia*. 2019;62(4): 611-620.
22. Courcoulas AP, King WC, Belle SH, *et al*. Seven-Year weight trajectories and health outcomes in the longitudinal assessment of bariatric surgery (LABS) study. *JAMA Surg*. 2018;153(5):427-434.
23. Arterburn DE, Bogart A, Sherwood NE, *et al*. A multisite study of long-term remission and relapse of type 2 diabetes mellitus following gastric bypass. *Obes Surg*. 2013;23(1):93-102.
24. Dicker D, Yahalom R, Comaneshter DS, Vinker S. Long-Term outcomes of three types of bariatric surgery on obesity and type 2 diabetes control and remission. *Obes Surg*. 2016;26(8): 1814-1820.
25. McTigue KM, Wellman R, Nauman E, *et al*. Comparing the 5-year diabetes outcomes of sleeve gastrectomy and gastric bypass: the national patient-centered clinical research network (PCORNet) bariatric study. *JAMA Surg*. 2020;155(5):e200087.
26. Maiz C, Alvarado J, Quezada N, Salinas J, Funke R, Boza C. Bariatric surgery in 1119 patients with preoperative body mass index< 35 (kg/m(2)): results at 1 year. *Surg Obes Relat Dis*. 2015;11(5):1127-1132.
27. Carlin AM, Zeni TM, English WJ, *et al*. The comparative effectiveness of sleeve gastrectomy, gastric bypass, and adjustable gastric banding procedures for the treatment of morbid obesity. *Ann Surg*. 2013;257(5):791-797.
28. Fisher DP, Liu L, Arterburn D, *et al*. Remission and relapse of hypertension after bariatric surgery: a retrospective study on long-term outcomes. *Ann Surg Open*. 2022;3(2):e158.
29. Coleman KJ, Basu A, Barton LJ, *et al*. Remission and relapse of dyslipidemia after vertical sleeve gastrectomy vs roux-en-Y gastric bypass in a racially and ethnically diverse population. *JAMA Netw Open*. 2022;5(9):e2233843.
30. Basu A, Barton LJ, Fischer H, *et al*. Comparative effectiveness of gastric bypass and sleeve gastrectomy on predicted 10-year risk of cardiovascular disease 5 years after surgery. *Surg Obes Relat Dis*. 2022;18(6):716-726.
31. Raygor V, Garcia L, Maron DJ, Morton JM. The comparative effect of roux-en-Y gastric bypass and sleeve gastrectomy on 10-year and lifetime atherosclerotic cardiovascular disease risk. *Obes Surg*. 2019;29(10):3111-3117.
32. Blanco DG, Funes DR, Giambartolomei G, Lo Menzo E, Szomstein S, Rosenthal RJ. High cardiovascular risk patients benefit more from bariatric surgery than low cardiovascular risk patients. *Surg Endosc*. 2019;33(5):1626-1631.
33. Campos GM, Khoraki J, Browning MG, Pessoa BM, Mazzini GS, Wolfe L. Changes in utilization of bariatric surgery in the United States from 1993 to 2016. *Ann Surg*. 2020;271(2):201-209.
34. Arterburn D, Wellman R, Emiliano A, *et al*. Comparative effectiveness and safety of bariatric procedures for weight loss: a PCORnet cohort study. *Ann Intern Med*. 2018;169(11):741-750.
35. Guerreiro V, Neves JS, Salazar D, *et al*. Long-Term weight loss and metabolic syndrome remission after bariatric surgery: the effect of sex, age, metabolic parameters and surgical technique—a 4-year follow-up study. *Obes Facts*. 2019;12(6):639-652.
36. Masrur M, Bustos R, Sanchez-Johnsen L, *et al*. Factors associated with weight loss after metabolic surgery in a multiethnic sample of 1012 patients. *Obes Surg*. 2020;30(3):975-981.
37. Hinerman AS, El Khoudary SR, Wahed AS, Courcoulas AP, Barinas-Mitchell EJM, King WC. Predictors of change in cardiovascular disease risk and events following gastric bypass: a 7-year prospective multicenter study. *Surg Obes Relat Dis*. 2021;17(5): 910-918.
38. Mousapour P, Tasdighi E, Khalaj A, *et al*. Sex disparity in laparoscopic bariatric surgery outcomes: a matched-pair cohort analysis. *Sci Rep*. 2021;11(1):12809.
39. Maciejewski ML, Arterburn DE, Van Scoyoc L, *et al*. Bariatric surgery and long-term durability of weight loss. *JAMA Surg*. 2016; 151(11):1046-1055.
40. Park CH, Nam SJ, Choi HS, *et al*. Comparative efficacy of bariatric surgery in the treatment of morbid obesity and diabetes Mellitus: a systematic review and network meta-analysis. *Obes Surg*. 2019;29(7):2180-2190.
41. Balasubaramaniam V, Pouwels S. Remission of type 2 diabetes Mellitus (T2DM) after sleeve gastrectomy (SG), one-anastomosis gastric bypass (OAGB), and roux-en-Y gastric bypass (RYGB): a systematic review. *Medicina (Kaunas)*. 2023;59(5):985.
42. Salman AA, Salman MA, Marie MA, *et al*. Factors associated with resolution of type-2 diabetes mellitus after sleeve gastrectomy in obese adults. *Sci Rep*. 2021;11(1):6002.
43. Wang GF, Yan YX, Xu N, *et al*. Predictive factors of type 2 diabetes mellitus remission following bariatric surgery: a meta-analysis. *Obes Surg*. 2015;25(2):199-208.
44. Still CD, Wood GC, Benotti P, *et al*. Preoperative prediction of type 2 diabetes remission after roux-en-Y gastric bypass surgery: a retrospective cohort study. *Lancet Diabetes Endocrinol*. 2014;2(1):38-45.
45. Shen SC, Wang W, Tam KW, *et al*. Validating risk prediction models of diabetes remission after sleeve gastrectomy. *Obes Surg*. 2019;29(1):221-229.