Nutrition, Metabolism & Cardiovascular Diseases (2019) **29**, 518–526

Available online at www.sciencedirect.com

Nutrition, Metabolism & Cardiovascular Diseases

journal homepage: www.elsevier.com/locate/nmcd

Comparative effectiveness of gastric bypass versus gastric banding on acute care use for cardiovascular disease in adults with obesity

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Received 3 September 2018; received in revised form 24 January 2019; accepted 4 February 2019
Handling Editor: F. Galletti
Available online 14 February 2019

KEYWORDS
Bariatric surgery;
Gastric bypass;
Gastric banding;
Cardiovascular disease

Abstract *Background and aims:* Gastric bypass is known to have larger effects on weight and metabolism than gastric banding. However, scarce data exist as to whether the differences are translated into differential risks of cardiovascular disease (CVD)-related morbidities. The objective was to examine whether adults with obesity and CVD who underwent gastric bypass have a lower rate of acute care use (emergency department [ED] visit or unplanned hospitalization) for CVD than those with gastric banding.
Methods and results: We performed a comparative effectiveness study of gastric bypass versus banding among adults with obesity and CVD who underwent either surgery, using population-based [ED] and inpatient samples in California, Florida, and Nebraska from 2005 through 2011. The primary outcome was acute care use for CVD during a two-year postoperative period. We constructed negative binomial regression models to compare the event rate during sequential 6-month periods, using gastric banding group as the reference. We identified 11,229 adults with obesity and CVD who underwent gastric bypass and 3896 adults who had gastric banding. Patients with gastric bypass had significantly lower rate of the outcome compared to those with banding in the 7–12 months postoperative period (adjusted rate ratio [aRR] 0.77; 95% confidence interval [CI], 0.61–0.98; $P = 0.03$). The significant reduction in the rate persisted during 13–18 months (aRR 0.71; 95% CI, 0.57–0.90; $P = 0.005$) and 19–24 months (aRR 0.66; 95% CI, 0.52–0.82; $P < 0.001$) after bariatric surgery.
Conclusion: In this population-based comparative effectiveness study of adults with obesity and CVD, the rate of acute care use for CVD was lower after gastric bypass compared to gastric banding.

List of abbreviations: CAD, coronary artery disease; CI, confidence interval; CVD, cardiovascular disease; ED, emergency department; HCUP, Healthcare Cost and Utilization Project; HF, heart failure; ICD-9-CM, International Classification of Diseases, Ninth Revision, Clinical Modification; PS, propensity score; RR, rate ratio; SEDD, State Emergency Department Databases; SID, State Inpatient Databases; VTE, venous thromboembolism.

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https://doi.org/10.1016/j.numecd.2019.02.001
0939-4753/

Introduction

Cardiovascular disease (CVD) is the leading cause of death and the largest public health problem in the U.S., affecting approximately one-third (92 million) of American adults [1]. The burden of healthcare utilization for CVD is substantial, accounting for 4.4 million emergency department (ED) visits and 5.8 million hospitalizations in 2010 alone [1]. The estimated direct and indirect costs of CVD were $316 billion in 2012 [1]. In parallel, the nation has also experienced an obesity epidemic – 35% of men and 40% of women are obese [2]. Patients with obesity often have multiple cardiovascular comorbidities given that obesity is an established risk factor for various CVDs (e.g., coronary artery disease [CAD], heart failure [HF], hypertension, dysrhythmia, and venous thromboembolism [VTE]) [1].

Bariatric surgery is the most effective method to achieve substantial and sustained weight loss [3]. Several types of bariatric surgery are available – e.g., Roux-en-Y gastric bypass and adjustable gastric banding [4]. Gastric bypass procedures allow for bypassing of the greater portion of the stomach and duodenum. By contrast, gastric banding is a solely restrictive procedure that creates a gastric pouch of ~30 ml. Studies have reported that these procedures have different effect on weight reduction – gastric bypass with ~70% excess weight loss and gastric banding with ~35% [5]. Emerging evidence has also shown that gastric bypass results in a greater improvement in metabolism and CVD risk factors than banding [5]. However, to date, there have been no efforts to examine the differential effects of these two bariatric surgery procedures on CVD-related morbidities.

To address the knowledge gap, we designed a comparative effectiveness study to test the hypothesis that, among adults with obesity and CVD, gastric bypass is associated with a lower rate of CVD-related acute care use (ED visits and unplanned hospitalizations) compared to gastric banding. We also aimed to determine the differences in the rate of acute care use related to individual CVD categories (e.g., CAD, HF, hypertension, dysrhythmia, and VTE) after gastric bypass versus banding.

Methods

Study design and setting

We performed a comparative effectiveness study of gastric bypass versus banding on the rate of ED visits and unplanned hospitalizations for CVD in adults with obesity. We used population-based datasets – the Healthcare Cost and Utilization Project (HCUP) State Emergency Department Databases (SEDD) and State Inpatient Databases (SID) – from three states (California, Florida, and Nebraska) from 2005 through 2011 [6,7]. We chose these states because of geographic diversity and unique patient identifiers which enabled us to perform longitudinal follow-up across the study years. The HCUP is the largest longitudinal hospital care database in the U.S. [6,7]. In the participating states, all ED visits regardless of disposition are captured in the HCUP SEDD [6], and all inpatient discharges regardless of source of hospitalization are recorded in the SID [7]. By integrating the HCUP SEDD and SID, we identified all ED visits and hospitalizations within the three study states [6,7]. Details of the databases have been published previously [6–10]. The institutional review board of Massachusetts General Hospital approved this study.

Study population

We took the following steps to identify all adult patients with obesity and CVD who underwent either gastric bypass or banding within the study states. First, we identified adults (aged ≥18 years) with obesity by using the *International Classification of Diseases, Ninth Revision, Clinical Modification* (*ICD*-9-CM) diagnosis codes 278.0–278.1, V77.8, V85.3x, and V85.4 [8–10]. Second, among these adults with obesity, we further identified patients who underwent either gastric bypass or banding. We used the *ICD*-9-CM procedure codes 44.31, 44.38, and 44.39 to determine gastric bypass and the *ICD*-9-CM procedure codes 44.68 and 44.95 for gastric banding [11]. We excluded patients with diagnostic codes for gastrointestinal cancer (*ICD*-9-CM codes, 150.0–159.9) [8–10,12]. We included patients who had either gastric bypass or banding between January 1, 2006 and December 31, 2009 to allow for a two-year follow-up. Last, among these patients with obesity who underwent either gastric bypass or banding, we further identified patients with at least one ED visit or unplanned hospitalization for CVD during the preoperative period by using the *ICD*-9-CM codes 390–459.9 in the primary diagnosis field. We excluded patients who died during the hospitalization for bariatric surgery and those who had two or more bariatric surgeries during the study period [8–10,12]. We also excluded residents outside the study states [8–10,12].

Measurements and outcomes

We retrieved data from the HCUP SEDD and SID on the patient demographics (age, sex, and race/ethnicity), primary insurance type, quartiles for estimated median household income of residents in the patient's ZIP code, *ICD*-9-CM diagnosis, procedures, season and year of surgery, state, and comorbidities defined by Elixhauser comorbidity measures. We used the baseline characteristics information recorded during the index hospitalization for bariatric surgery.

The primary outcome measure was acute care use (ED visits and unplanned hospitalizations) with a primary diagnosis of CVD. The *ICD*-9-CM diagnosis codes for CVD were 390–459.9. The secondary outcome measures were acute care use for each of the five most common CVD categories – CAD (*ICD*-9-CM codes, 410.00–414.9), HF (402.01, 402.11, 402.91, 404.01, 404.03, 404.11, 404.13, 404.91, 404.93, and 428.0) [8], hypertension (401.0–405.99 and 437.2) [13], dysrhythmia (427.xx), and VTE (415.1x, 416.2, 451.xx, and 453.2–453.9) [14].

Statistical analysis

For comparisons of the baseline characteristics between patients with gastric bypass and those with gastric banding, Mann-Whitney-Wilcoxon or chi-squared test was used, as appropriate. The frequency and rate of the outcome events was determined for 0–6 months, 7–12 months, 13–18 months, and 19–24 months after bariatric surgery. Unadjusted and adjusted rate ratios (RRs) were computed by fitting negative binomial regression models – with gastric banding group as the reference – for each corresponding 6-month period with generalized estimating equations to account for patient clustering within hospitals. This model has advantages that there is no need to define an arbitrary cutoff and that it accounts for statistical overdispersion [15]. Multivariable models adjusted for age, sex, race/ethnicity, insurance type, median household income quartile, season and year of surgery, state, and Elixhauser comorbidity measures.

Several sensitivity analyses were performed to determine the robustness of our inferences. First, the analysis was repeated after stratifying by age group (18–44, 45–54, and ≥55 years) or sex [16]. Second, by fitting logistic regression models, the risk of outcomes was modeled as a binary, instead of a count, variable. Third, to address the possibility of loss to follow-up (e.g., out-of-hospital deaths, emigration from the study states), a subgroup analysis was conducted by limiting the population to those with any ED visit or hospitalization during 25–36 months after surgery. Fourth, propensity score (PS)-matched analysis was performed to address possible confounding by indication. PS was computed with the use of a logistic regression model to estimate the propensity that patients would undergo gastric bypass [17]. The variables included in the propensity model were the selected variables above and hospital sites. Patients who underwent gastric bypass were matched to patients who received banding according to PS at a 1:1 ratio. The matching was performed without replacement, by using calipers (width = 0.1) of the standard deviation of the logit of the PS. While PS-matching may lead to a smaller sample size, it provides a clinically-relevant estimate of the effects since patients in the matched sample are potential candidates for either surgical procedures [17]. Standardized difference was calculated as the difference of means divided by square root of average of variances. An absolute value of the standardized difference <10% was considered as adequate balance [18]. In the PS-matched groups, the event rates and RRs were also calculated. Lastly, an instrumental variable analysis was performed by using a “preference-based” instrument, namely, the proportion of gastric bypass versus banding in each hospital [19]. When hospitals always or nearly always use gastric bypass or banding, the preference suggests that the choice is largely independent of patient characteristics. Therefore, the instrumental variable analysis simulates a natural randomization of patients into hospital groups with gastric-bypass-preferring (or gastric-banding-preferring) use, and potentially adjusts for unmeasured confounders. The causal RRs for outcome events were estimated between gastric-bypass-preferring hospitals (those with ≥85% use of gastric bypass) and gastric-banding-preferring hospitals (those with ≥85% use of gastric banding) using two-stage instrumental variable method. Patients who underwent bariatric surgery at a hospital outside the range of the gastric-bypass-preferring or gastric-banding-preferring use were excluded.

All analyses were performed at a two-sided significance level of 0.05, and all confidence intervals (CIs) were reported as two-sided values with a confidence level of 95%. Statistical analyses were performed using STATA 14.1 (StataCorp; College Station, TX).

Results

There were 17,426 adults with obesity and a prior history of CVD who underwent bariatric surgery during the study period. Of these, 1689 patients who underwent bariatric surgery with methods other than gastric bypass and gastric banding, 37 patients who died during the index hospitalization for bariatric surgery, 468 patients who had multiple bariatric surgeries, and 107 patients who lived outside the study states were excluded. The remaining 15,125 patients – 11,229 with gastric bypass and 3896 with gastric banding – were included in the analysis. The baseline characteristics are described in Table 1 and Supplemental Table 1. Overall, the median age was 50 years, 73% were female, and 70% were non-Hispanic white.

The number and event rate of ED visits and unplanned hospitalizations for overall CVD according to the type of bariatric surgery are shown in Fig. 1A. During the first 6 months after surgery, there was no significant difference in the event rate of ED visits and unplanned hospitalizations for CVD between the two groups. By contrast, patients who underwent gastric bypass had a significantly lower event rate in the 7–12 months postoperative period (RR 0.69, 95% CI 0.56–0.87, $P = 0.002$) when compared to those with gastric banding. Additionally, the significant reduction in the event rate persisted during 13–18 months (RR 0.68, 95% CI 0.55–0.84, $P < 0.001$) and 19–24 months (RR 0.61, 95% CI 0.50–0.75, $P < 0.001$) after bariatric surgery. Similarly, in the multivariable-adjusted analysis (Fig. 1B), patients with gastric bypass had significantly lower event rates during the 7–12, 13–18, and 19–24 month postoperative periods (all $P < 0.05$).

The sensitivity analyses demonstrated the robustness of the findings. In the stratified analyses by age group (Supplemental Table 2) and sex (Supplemental Table 3) as well as the logistic regression model with the outcome as a binary variable (Supplemental Table 4), the findings were similar. Furthermore, the subgroup analysis limiting to patients with any healthcare utilization during 25–36 months after bariatric surgery replicated the results (Supplemental Table 5).

In the PS-matched cohort, the baseline characteristics of two patient groups were all balanced as indicated by absolute standardized difference of <10% in all covariates (Table 2, Supplemental Table 6, and Supplemental Fig. 1).

Table 1 Baseline characteristics of patients with obesity and cardiovascular disease according to bariatric surgery procedures.

Characteristics	Gastric bypass	Gastric banding	Absolute standardized difference, %[c]
	n = 11,229 (74%)	n = 3896 (26%)	
Age (yr), median (IQR)	49 (42–57)	53 (44–61)	30.6
Female sex	8246 (74)	2755 (71)	6.1
Race/ethnicity[a]			
Non-Hispanic white	7290 (68)	2727 (75)	10.7
Non-Hispanic black	1398 (13)	466 (13)	1.6
Hispanic	1739 (16)	337 (9)	21.0
Other	299 (3)	103 (3)	0.2
Primary insurance			
Medicare	2177 (19)	1202 (31)	26.9
Medicaid	979 (9)	166 (4)	18.3
Private	7250 (65)	2086 (54)	22.8
Self-pay	462 (4)	308 (8)	15.9
Other	360 (3)	132 (3)	1.1
Quartiles for median household income			
1 (lowest)	2770 (25)	867 (23)	5.7
2	3120 (28)	1050 (28)	1.8
3	2877 (26)	1033 (27)	2.0
4 (highest)	2255 (20)	862 (23)	4.7
Season of bariatric surgery			
January–March	2416 (22)	777 (20)	4.0
April–June	2543 (23)	902 (23)	1.0
July–September	3066 (27)	1017 (26)	2.0
October–December	3204 (29)	1200 (31)	4.6
Year of bariatric surgery			
2006	1795 (16)	335 (9)	22.3
2007	2408 (21)	748 (19)	5.7
2008	3204 (29)	1289 (33)	10.1
2009	3822 (34)	1524 (39)	10.1
Hospital state			
California	7613 (68)	2009 (52)	29.8
Florida	3500 (31)	1769 (45)	33.8
Nebraska	116 (1)	118 (3)	14.3
Selected comorbidities[b]			
Heart failure	502 (4)	174 (4)	0.5
Arrhythmia	902 (8)	287 (7)	2.6
Valvular heart disease	194 (2)	83 (2)	2.8
Hypertension	9190 (82)	3128 (80)	4.0
Pulmonary circulatory disease	115 (1)	36 (1)	1.1
Peripheral vasculitis	138 (1)	28 (1)	4.8
Chronic pulmonary disease	2643 (24)	764 (20)	9.5
Diabetes mellitus	5578 (50)	1752 (45)	9.1
Hypothyroidism	1350 (12)	457 (12)	0.8
Renal failure	326 (3)	120 (3)	1.3
Liver disease	1499 (13)	532 (14)	1.1
Rheumatoid arthritis	212 (2)	67 (2)	1.0
Coagulopathy	68 (1)	23 (1)	0.4
Fluid and electrolyte disorder	500 (4)	60 (2)	17.1
Anemia	164 (1)	26 (1)	7.8
Depression	2378 (21)	827 (21)	0.2

Data were expressed as numbers (percentages) unless otherwise indicated.
IQR, interquartile range.
[a] Analyzed for 14,359 (94.9%) patients with race/ethnicity data. Race/ethnicity data were not available in Nebraska.
[b] Defined by Elixhauser comorbidity measures. Full list of comorbidities is displayed in Supplemental Table 1.
[c] Standardized difference was calculated as the difference of means divided by square root of average of variances. Imbalance was defined as absolute standardized difference >10%.

Consistent with the main analysis, patients who underwent gastric bypass had significantly lower event rates of ED visits and unplanned hospitalizations for CVD during 7–12, 13–18, and 19–24 months after surgery when compared with PS-matched patients who underwent gastric banding (Fig. 1C). Similarly, the instrumental variable analysis also demonstrated that the event rate after surgery was lower in patients who underwent bariatric surgery in gastric-bypass-preferring hospitals (Fig. 1D).

With further classification according to the CVD categories, the event rates of CAD and HF were significantly lower in patients with gastric bypass when compared to those with gastric banding (Fig. 2). By contrast, there were no significant differences in the event rates for hypertension and dysrhythmia-related acute care use. The event rate of VTE was significantly higher in patients with gastric bypass than banding during the first 6-month postoperative period.

Discussion

Principal findings

In this comparative effectiveness study using population-based data of 15,125 adults with obesity and prior CVD, patients who underwent gastric bypass, compared to those with gastric banding, had significantly lower event rates of ED visits and unplanned hospitalizations for CVD in the 7–24 months after surgery. The difference persisted across several analytical models and was consistently observed with PS-matching and instrumental variable methods. The between-group difference was primarily driven by the lower rates of acute care use related to CAD and HF in gastric bypass group. By contrast, we observed a higher event rate of VTE with gastric bypass than banding in the early postoperative period. To the best of our knowledge, this is the first study that has examined the effectiveness of different types of bariatric surgery on acute healthcare utilization for the overall and individual CVD subtypes.

Results in context

Studies have reported that individual types of bariatric surgery – e.g., gastric bypass, gastric banding – not only result in anatomical differences (e.g., patients status post gastric bypass cannot undergo gastric endoscopy) but also have different effects on weight and metabolism. A recent

Analysis model and months from bariatric surgery	Number of events: Gastric bypass	Number of events: Gastric banding	Event rate (per 100 person-years): Gastric bypass	Event rate (per 100 person-years): Gastric banding	RR (95% CI)	*P* value
A. Unadjusted model	(n=11,229)	(n=3,896)				
0-6 months	375	114	6.7	5.9	1.14 (0.92-1.42)	.23
7-12 months	243	122	4.3	6.3	0.69 (0.56-0.87)	.002
13-18 months	256	127	4.6	6.5	0.68 (0.55-0.84)	<.001
19-24 months	262	147	4.7	7.5	0.61 (0.50-0.75)	<.001
B. Adjusted model	(n=11,229)	(n=3,896)				
0-6 months	375	114	6.7	5.9	1.18 (0.94-1.49)	.15
7-12 months	243	122	4.3	6.3	0.77 (0.61-0.98)	.03
13-18 months	256	127	4.6	6.5	0.71 (0.57-0.90)	.005
19-24 months	262	147	4.7	7.5	0.66 (0.52-0.82)	<.001
C. Propensity score-matching	(n=3,745)	(n=3,745)				
0-6 months	135	107	7.2	5.7	1.26 (0.98-1.63)	.08
7-12 months	86	118	4.6	6.3	0.73 (0.55-0.97)	.03
13-18 months	92	122	4.9	6.5	0.75 (0.57-0.99)	.04
19-24 months	94	138	5.0	7.4	0.68 (0.52-0.89)	.005
D. Instrumental variable method	(n=5,885)	(n=421)				
0-6 months	181	17	6.2	8.1	0.80 (0.53-1.19)	.27
7-12 months	117	12	4.0	5.7	0.98 (0.53-1.80)	.94
13-18 months	127	19	4.3	9.0	0.35 (0.21-0.57)	<.001
19-24 months	136	27	4.6	12.8	0.31 (0.18-0.55)	<.001

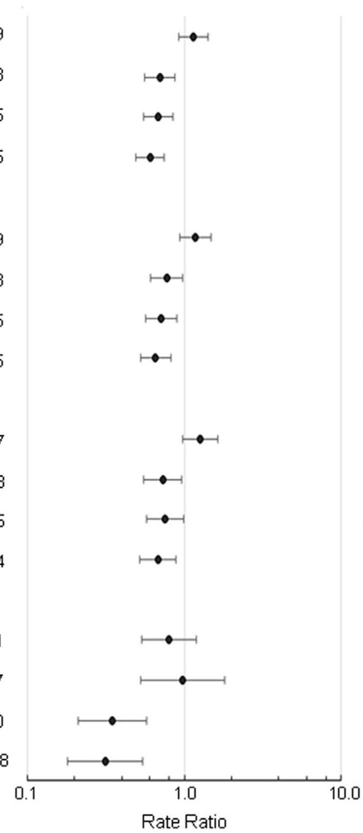

Figure 1 Number of events and rate ratios of acute care use for cardiovascular disease in 6-month intervals among patients with obesity who underwent gastric bypass and those who underwent gastric banding. Shown are the number of ED visits and unplanned hospitalizations for CVD, event rates, and rate ratios in 6-month intervals, using (A) unadjusted model, (B) multivariable model adjusting for age, sex, race/ethnicity, insurance type, household income quartile, season and year of surgery, state, and Elixhauser comorbidity measures, (C) propensity score-matching, and (D) instrumental variable method. Event rates are displayed as the number of outcome events per 100 person-years. Rate ratios were calculated for each 6-month period with gastric banding group (or patients who received bariatric surgery in gastric-banding-preferring hospitals for the instrumental variable method) as the reference, by using negative binomial regression model with generalized estimating equations to account for patient clustering within hospitals. Comorbidities with prevalence <0,5% in both groups were excluded from the multivariable model. Abbreviations: CI, confidence interval; CVD, cardiovascular disease; ED, emergency department; RR, rate ratio.

meta-analysis of 37 randomized-controlled trials (RCTs) has shown that gastric bypass results in twice as much excess weight loss compared to gastric banding (72% versus 33%) and achieves higher remission rates of diabetes mellitus (95% versus 74%), hypertension (81% versus 54%), and dyslipidemia (80% versus 40%) [5]. However, no prior studies have tested whether such different impacts on CVD risk factors are translated into differential effects on CV outcomes. Our study builds on these prior reports on the distinctive weight reduction and metabolic effects of gastric bypass and banding, and extends them by demonstrating more favorable effectiveness of gastric bypass on CVD-related morbidities than gastric banding.

Our observations on the effectiveness for individual CVD categories (e.g., CAD, HF, and dysrhythmia) are in line with what has been documented in the literature. Indeed, our group has recently reported that bariatric surgery is associated with a lower risk of healthcare utilization for CAD and HF, whereas there was no risk reduction with regard to dysrhythmia [8–10]. If there is a dose-response relationship between the magnitude of weight reduction and changes in the CVD risk, one would expect to observe lower event rates of CAD and HF with gastric bypass than banding and no difference regarding dysrhythmia. The findings in the present study – i.e., the association of gastric bypass with the lower event rates of CAD and HF and no significant differences in the rate of dysrhythmia – logically conform to the predicted results inferred from the prior reports.

The lack of significant difference in the event rate of dysrhythmia-related acute care use may seem to contradict with the findings in a matched cohort study of 4021 patients with obesity reporting that bariatric surgery was associated with a lower risk of incident (i.e., new-onset) atrial fibrillation [20]. However, their inferences may not be directly applicable to the present study that examined a

Table 2 Baseline Characteristics of Patients with Obesity and Cardiovascular Disease who Underwent Gastric Bypass and Propensity Score-Matched Patients who Underwent Gastric Banding.

Characteristics	Gastric bypass n = 3745	Gastric banding n = 3745	Absolute standardized difference, %[c]
Age (yr), median (IQR)	53 (45−60)	52 (44−60)	2.8
Female sex	2676 (72)	2670 (71)	0.4
Race/ethnicity[a]			
Non-Hispanic white	2655 (75)	2652 (75)	0.2
Non-Hispanic black	434 (12)	462 (13)	2.3
Hispanic	341 (10)	337 (9)	0.4
Other	108 (3)	102 (3)	1.0
Primary insurance			
Medicare	1129 (30)	1094 (29)	2.0
Medicaid	162 (4)	164 (4)	0.3
Private	2012 (54)	2076 (55)	3.4
Self-pay	316 (8)	279 (7)	3.7
Other	125 (3)	131 (3)	0.9
Quartiles for median household income of patient's ZIP code			
1 (lowest)	827 (23)	837 (23)	0.6
2	1034 (28)	1009 (27)	1.5
3	1020 (28)	999 (27)	1.3
4 (highest)	778 (21)	825 (22)	3.1
Season of bariatric surgery			
January−March	737 (20)	756 (20)	1.3
April−June	838 (22)	862 (23)	1.5
July−September	1000 (27)	986 (26)	0.8
October−December	1170 (31)	1141 (30)	1.7
Year of bariatric surgery			
2006	289 (8)	334 (9)	4.4
2007	722 (19)	728 (19)	0.4
2008	1228 (33)	1223 (33)	0.3
2009	1506 (40)	1460 (39)	2.5
Hospital state			
California	1870 (50)	1991 (53)	5.5
Florida	1786 (48)	1683 (45)	6.5
Nebraska	89 (2)	71 (2)	3.3
Selected Comorbidities[b]			
Heart failure	183 (5)	168 (4)	1.9
Arrhythmia	285 (8)	279 (7)	0.6
Valvular heart disease	83 (2)	79 (2)	0.7
Hypertension	3088 (82)	3032 (81)	3.9
Pulmonary circulatory disease	37 (1)	35 (1)	0.5
Peripheral vasculitis	29 (1)	28 (1)	0.3
Chronic pulmonary disease	754 (20)	750 (20)	0.3
Diabetes mellitus	1705 (46)	1702 (45)	0.2
Hypothyroidism	449 (12)	448 (12)	0.1
Renal failure	113 (3)	108 (3)	0.8
Liver disease	529 (14)	522 (14)	0.5
Rheumatoid arthritis	74 (2)	66 (2)	1.6
Coagulopathy	23 (1)	23 (1)	0
Fluid and electrolyte disorder	51 (1)	60 (2)	2.0
Anemia	25 (1)	26 (1)	1.4
Depression	806 (22)	800 (21)	0.4

Data were expressed as numbers (percentages), unless otherwise indicated.
IQR, interquartile range.
[a] Analyzed for 7091 (94.7%) patients with race/ethnicity data. Race/ethnicity data were not available in Nebraska.
[b] Defined by Elixhauser comorbidity measures. Full list of comorbidities is displayed in Supplemental Table 6.
[c] Standardized difference was calculated as the difference of means divided by square root of average of variances. Imbalance was defined as absolute standardized difference >10%.

different patient population (i.e., patients who had already developed CVD prior to bariatric surgery), exposures (i.e., gastric bypass versus banding), and outcomes (e.g., dysrhythmia-related acute care use).

Potential mechanisms underlying differential CV effects

Our findings suggest that gastric bypass, when compared to gastric banding, may offer a higher degree of CV protection in the long term, whereas there was a non-significantly higher event rate of CVD in the early post-operative period. Additionally, our analysis of the individual types of CVDs revealed that this short-term non-significant increase may be explained, at least partially, by the significantly higher rate of VTE-related events during the first 6-month postoperative period. As postoperative VTEs are theoretically preventable, our study underscores the importance of optimal preventive measures against VTE and frequent VTE surveillance in patients with obesity who have recently undergone bariatric surgery, especially gastric bypass.

By contrast, in the long term, gastric bypass was associated with lower rates of acute care use for CAD and HF compared to gastric banding. The potential explanation includes the larger weight reduction and metabolic effects achieved by gastric bypass, which in turn lead to reversal of some of obesity-related changes − e.g., left ventricular hypertrophy and diastolic dysfunction [21], sleep apnea, lipotoxicity [21], systemic inflammation [22], endothelial dysfunction, activation of the renin-angiotensin-aldosterone system [23], and higher sympathetic tone [24].

Advantages of the study design and methods

The PS-matching analysis augments the internal validity as it reduces inter-group differences at baseline and enables a more precise assessment of effectiveness of the different interventions (i.e., gastric bypass versus banding) [17]. Additionally, we also performed sensitivity analysis using instrumental variable method [25]. This method attempts to balance both measured and unmeasured confounders between patient groups, similar to RCTs, by exploiting situations where some degree of randomness affects how a patient is selected for treatment [25]. This, in turn, minimizes confounding by indication for which traditional methods of adjustment may not account [25]. Owing to these advantages, instrumental variable method has been

CVD category and months from bariatric surgery	Number of events: Gastric bypass (n=11,229)	Number of events: Gastric banding (n=3,896)	Event rate (per 100 person-years): Gastric bypass	Event rate (per 100 person-years): Gastric banding	Adjusted RR (95% CI)	*P* value
Coronary artery disease						
0-6 months	44	22	0.8	1.1	0.74 (0.43-1.29)	.29
7-12 months	47	30	0.8	1.5	0.62 (0.38-1.02)	.06
13-18 months	53	26	0.9	1.3	0.78 (0.47-1.30)	.35
19-24 months	53	45	0.9	2.3	0.49 (0.32-0.75)	.001
Heart failure						
0-6 months	17	9	0.3	0.5	0.61 (0.24-1.53)	.29
7-12 months	22	22	0.4	1.1	0.30 (0.15-0.60)	.001
13-18 months	16	19	0.3	1.0	0.23 (0.11-0.51)	<.001
19-24 months	18	21	0.3	1.1	0.46 (0.22-1.01)	.052
Hypertension						
0-6 months	35	14	0.6	0.7	0.75 (0.38-1.46)	.39
7-12 months	39	17	0.7	0.9	0.79 (0.44-1.43)	.44
13-18 months	32	12	0.6	0.6	0.91 (0.44-1.86)	.79
19-24 months	45	12	0.8	0.6	1.19 (0.60-2.37)	.61
Dysrhythmia						
0-6 months	89	47	1.6	2.4	0.75 (0.50-1.10)	.14
7-12 months	65	35	1.2	1.8	0.71 (0.45-1.11)	.13
13-18 months	75	30	1.3	1.5	0.89 (0.56-1.41)	.62
19-24 months	76	39	1.4	2.0	0.74 (0.48-1.12)	.15
Venous thromboembolism						
0-6 months	95	11	1.7	0.6	3.03 (1.60-5.75)	.001
7-12 months	22	11	0.4	0.6	0.79 (0.37-1.69)	.54
13-18 months	21	11	0.4	0.6	0.62 (0.29-1.35)	.23
19-24 months	19	12	0.3	0.6	0.62 (0.28-1.35)	.23

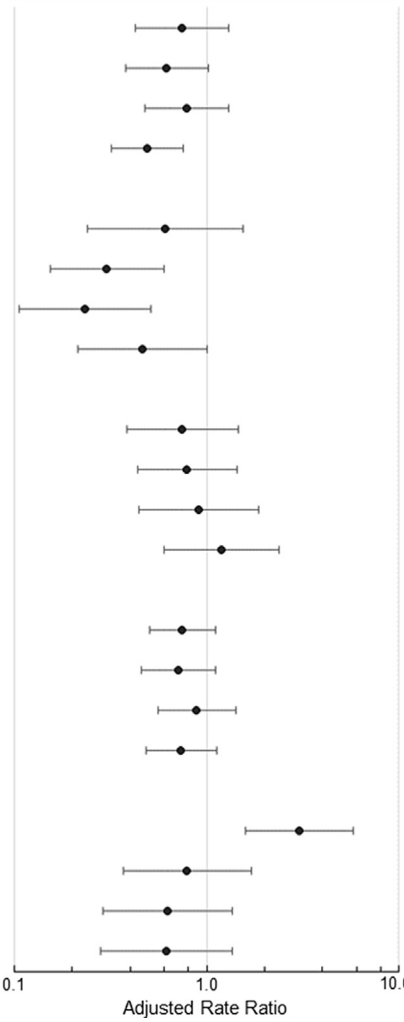

Figure 2 Number of events and rate ratios of acute care use for five major categories of cardiovascular disease in 6-month intervals among patients with obesity who underwent gastric bypass and those who underwent gastric banding. Shown are the number of ED visits and unplanned hospitalizations for CVD, event rates, and rate ratios in 6-month intervals for each of the five most common categories of CVD. Event rates are displayed as the number of outcome events per 100 person-years. Rate ratios were calculated for each 6-month period with gastric banding group as the reference, using negative binomial regression model with generalized estimating equations to account for patient clustering within hospitals. Rate ratios were adjusted for age, sex, race/ethnicity, insurance type, household income quartile, season and year of surgery, state, and Elixhauser comorbidity measures. Comorbidities with prevalence <0.5% in both groups were excluded from the multivariable model. Abbreviations: CI, confidence interval; CVD, cardiovascular disease; ED, emergency department; RR, rate ratio.

successfully used to demonstrate the effectiveness of different types of interventions on CV outcomes [25].

With regard to the external validity, it has been reported that subjects participating in RCTs may be highly selected or behave differently compared to the general populations in the real world setting [26]. For instance, most previously published RCTs on bariatric surgery enrolled <10% of the patients assessed for eligibility [27,28]. By contrast, the patient population in the present study is racially/ethnically-, socioeconomically-, and geographically-diverse. Furthermore, the use of large population-based databases that capture all ED visits and hospitalizations in the study states strengthens the external validity of our inferences.

Potential limitations

Our study has several potential limitations. First, misclassification is possible with any study using administrative data. However, the HCUP databases have been widely utilized in the past studies and the quality has been extensively tested [8–10,12]. For example, our method to identify patients with obesity was reported to have a specificity of 99.4% [29]. With respect to the outcome, it has been shown that administrative data to identify HF- and hypertension-related acute care use perform well with a high specificity and positive predictive value, most reporting values of >95% [13,30,31]. Second, despite rigorous adjustment for confounders with multivariable and PS-matched analyses, there are variables that may have contributed for which our study was unable to control or that were not collected *a priori* – e.g., chronic severity of comorbidities. Nevertheless, we observed consistent findings with the use of instrumental variable analysis that could potentially account for unmeasured confounders. Lastly, patients might have been lost to follow-up after bariatric surgery. However, the sensitivity analysis limiting to patients who were confirmed to be alive for at least two years after surgery showed consistent findings. Moreover, patients who receive bariatric surgery are required to be compliant with lifelong follow-up for possible nutritional impairment.

Conclusions

In this comparative effectiveness study using large population-based datasets from three diverse states in the U.S., we found that, among 15,125 adults with obesity and CVD, gastric bypass is associated with a significantly lower rate of overall CVD-related acute care use after surgery when compared to gastric banding. The favorable effects of gastric bypass were mainly driven by the lower event rates of CAD and HF, whereas its favorable effects were partially offset by the higher rate of VTE in the early postoperative period. In conjunction with the findings from physiological studies reporting larger weight reduction and metabolic effects of gastric bypass compared to banding, the present study lends a significant support to the concept that the individual types of bariatric surgery have different effectiveness on CVD-related morbidities. Yet, many patients with obesity and CVD choose weight reduction interventions other than gastric bypass or banding (e.g., non-surgical management, a different type of bariatric surgery). Our data also stress the importance of further investigating differential CV effects of distinctive weight loss strategies and the underlying mechanisms to mitigate the large societal burden of CVD in patients with obesity.

Funding

Dr. Shimada was supported in part by unrestricted grants from the American Heart Association Career Development Award [#18CDA34110245], the American Heart Association National Clinical and Population Research Award [#17MCPRP33670415], Korea Institute of Oriental Medicine [K18190], Honjo International Scholarship Foundation, and Massachusetts General Hospital Executive Committee on Research Fund for Medical Discovery Award. The funding organizations had no role in design or conduct of the study; collection, management, analysis, or interpretation of the data; preparation, review, or approval of the manuscript; or decision to submit the manuscript for publication. The researchers were independent from the funding organizations.

Conflict of interest disclosures

The authors have no relevant financial relationships to disclose.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.numecd.2019.02.001.

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