



Long-term Impact of Bariatric Surgery on Major Adverse Cardiovascular Events in Patients with Obesity, Diabetes and Hypertension: a Population-level Study

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Abstract

Background The literature on long-term impact of bariatric/metabolic surgery on incidence of major adverse cardiovascular events (MACE) in patients with obesity and metabolic syndrome is still lacking. We aimed to evaluate the long-term relationship between metabolic surgery and MACE in such patients.

Methods In a population-based cohort study, we compared all patients with obesity, diabetes mellitus (DM) and/or hypertension (HTN), who underwent bariatric surgery in Quebec, Canada during 2007–2012, with matched controls with obesity. The incidence of a composite MACE outcome (coronary artery events, heart failure, cerebrovascular events, and all-cause mortality) after bariatric surgery was compared between both groups. Cox regression was used to evaluate the long-term impact of surgery on MACE outcomes.

Results The study cohort included 3627 surgical patients, who were matched to 5420 controls with obesity. Baseline demographics were comparable between groups, but DM was more prevalent among the surgical group. Median follow-up time was 7.05 years for the study cohort (range: 5–11 years). There was a significant long-term difference in the incidence of MACE between the surgical group and controls (19.6% vs. 24.8%, respectively; $p < 0.01$). After accounting for confounders, bariatric surgery remained an independent protective predictor of long-term MACE (hazard ratio [HR], 0.83 [95%CI, 0.78–0.89]). The 10-year absolute risk reduction (ARR) for the surgical group was 5.14% (95%CI, 3.41–6.87).

Conclusions Among patients with obesity, DM and HTN, bariatric/metabolic surgery is associated with a sustained (≥ 10 years) decrease in the incidence of MACE. The results from this population-level observational study should be validated in randomized controlled trials.

Keywords Obesity · Metabolic syndrome · Mortality · Major adverse cardiovascular events · Bariatric surgery · Metabolic surgery

Equal Contribution: All authors have contributed equally to this work.

Key points

- In this population-based study, bariatric/metabolic surgery was linked to a significantly lower long-term incidence of MACE in patients with obesity, DM and HTN.
 - Metabolic surgery was nearly 20% protective against any composite MACE outcome (≥ 10 years after surgery).
 - 10-year ARR for MACE after surgery was 5% i.e., only 20 patients need to have metabolic surgery to prevent one composite MACE outcome including all-cause mortality up to a decade after surgery.
- Presentation: This study was presented at the 2021 American Society for Metabolic and Bariatric Surgery (ASMBS) virtual meeting as a Top Paper presentation.

Extended author information available on the last page of the article

Introduction

Obesity is linked to major cardiovascular risk factors including diabetes mellitus (DM), hypertension (HTN), and dyslipidemia [1, 2]. The ensuing metabolic syndrome accelerates atherosclerosis leading to ischemic heart disease and stroke that are among the top 5 causes of death worldwide and considering the current alarming global trends in obesity, there is a major concern about further rise in major cardiovascular events and related mortality [1, 3]. Therefore, there is a need for effective interventions that can address both metabolic syndrome and obesity.

Bariatric/metabolic surgery is repeatedly and backed by level I evidence recognized as the most effective and durable treatment for obesity and related conditions like metabolic

syndrome including DM and HTN [4–8]. However, these randomized controlled trials were not designed to assess the impact of bariatric/metabolic surgery on major adverse cardiovascular events (MACE) and overall mortality. Since 2018, only a few large observational cohort studies have shed light on the beneficial effects of bariatric/metabolic surgery on composite MACE outcomes [9–11]. However, the literature on the topic is still lacking especially in larger population-level data with long-term follow-up after surgery comprised of a more balanced group of bariatric procedures representative of the modern era of bariatric/metabolic surgery including other robust metabolic procedures like duodenal switch (DS).

Thus, in a population-based study, we aimed to investigate the long-term association between bariatric/metabolic surgery and composite MACE outcomes including all-cause mortality in patients with obesity and metabolic syndrome including DM and HTN.

Materials and methods

Data source

This is a population-level observational cohort study using linkage of administrative healthcare datasets from the province of Quebec, Canada. Information was gathered from the two main provincial healthcare databases: (1) the *Régie de l'Assurance Maladie du Québec* (RAMQ), which includes all hospitalization and physician costs for both inpatient and outpatient claims for more than 97% of residents of Quebec [12]; and (2) the Ministry of Health's *Maintenance et Exploitation des Données pour l'Étude de la Clientèle Hospitalière* (MED-ECHO), which is the hospital administrative database containing records of every in-hospital encounter including emergency room visits, hospital and intensive care unit admissions. Under the single-payer public healthcare system in place in the province of Quebec, bariatric/metabolic surgery is covered as per established indications (Body Mass Index [BMI] ≥ 35 kg/m² with a comorbidity or BMI ≥ 40 kg/m²), but access to care remains poor [13, 14]. The study was approved by the institutional Ethics Review Board.

Study cohort

The base cohort included all patients with obesity aged 18 and older, who underwent adjustable gastric banding (AGB), sleeve gastrectomy (SG), Roux-en-Y gastric bypass (RYGB), and DS in the province of Quebec, Canada, between January 1, 2007 and December 31, 2012 using their respective procedure billing codes (AGB: 5305; SG: 5355, 5114; RYGB: 5306; DS: 5308). For each surgical patient, up to 3 controls with obesity were chosen using the International

Classification of Diseases (ICD) 9 and 10 diagnosis codes for severe obesity (278.0, 278.9 and E66.01, E66.2, respectively) and were subsequently matched with their surgical counterparts based on age, sex and geographical area of residence. Bariatric surgery date was used as the date of index.

The final study cohort was then restricted to only the surgical patients and their control counterparts with a diagnosis of DM and/or HTN prior to the index date.

Outcome and covariates

The primary outcome was defined as the incidence of MACE, which was a composite variable consisting of coronary artery events (myocardial infarction, need for either coronary artery bypass surgery or percutaneous coronary intervention), heart failure, stroke, and all-cause mortality. These outcomes were also defined using the respective ICD 9/10 diagnosis codes along with procedure billing codes where applicable. Secondary outcomes included the 4 individual components of the primary endpoint. The complete and long-term information on primary and secondary endpoints was available subsequent to the index date and until December 31, 2017.

Baseline demographic variables including age, sex, and socioeconomic status (SES) were collected. SES was quantified using ecological level data applied to every patient based on their residential postal codes and using 2011 Canadian Census data and was divided in two components (social and material). Baseline burden of comorbidities was estimated using Charlson Comorbidity Index (CCI) which is adapted to RAMQ data [15]. The respective ICD 9/10 diagnostic codes in the period of the year prior to the index date were used to identify the individual comorbidities.

Statistical analysis

Descriptive statistics are presented as count (percentage), mean (standard deviation), and median (interquartile range) where applicable. Paired *t*-test was used to compare the unadjusted frequency of the outcomes between the two groups. Person-time analysis was used to estimate the incidence rates (IRs) of events per group. Long-term risk difference was calculated and compared using the chi-square test. Incidence rate ratios (IRRs) for surgery vs. controls and for various bariatric procedure types were also provided and when appropriate long-term (at 5 and 10 years) absolute risk reduction (ARR) was calculated.

Cox proportional hazard regression was used to evaluate the effect of bariatric/metabolic surgery on MACE composite outcome and the individual components while adjusting for confounders. The effect measures were described as adjusted hazard ratios (HRs) along with their respective 95% confidence intervals (CI). Follow-up time was started

from the date of index for both groups and continued until the subject was censored or the incidence of a MACE event. Kaplan–Meier method was used to produce survival and cumulative incidence curves.

Inference was based on a two-sided 5% level. Statistical analysis was performed on STATA version 12 (StataCorp LP) and R (R Foundation for Statistical Computing).

Results

The base cohort included 8271 patients who underwent bariatric surgery in the province of Quebec, Canada during the study period along with 23,757 matched controls with obesity. After selecting only subjects who had a baseline diagnosis of DM and/or HTN, the final study cohort included 3627 patients who underwent surgery and 5420 non-surgical counterparts with obesity. Baseline characteristics were comparable between both groups and are described in Table 1. However, there was a higher frequency of HTN among the controls (82% vs. 50%, respectively) and there were more patients with DM in the surgical group (70% vs. 41%, respectively) (Table 1).

At a median follow-up of 7.05 years for the study cohort, 712 (19.6%) individuals suffered from at least one MACE outcome in the surgical group compared to 1346 (24.8%) subjects among the controls ($p < 0.01$). This translated into an IRR of 0.76 (95%CI, 0.69–0.83) favoring the bariatric surgery arm. Table 2 provides the complete list of pertinent crude incidence statistics for the study cohort. During the follow-up period, the 5- and 10-year ARR for any MACE outcome after bariatric/metabolic surgery compared to controls were 4.11% (95%CI, 2.64–5.57) and 5.14% (95%CI, 3.41–6.87), respectively. After adjusting for confounding using the Cox regression analysis, metabolic surgery remained an independent protective predictor of long-term MACE (HR, 0.83 [95%CI, 0.78–0.89]) (Table 3 and Fig. 1A).

In terms of individual components of MACE, the long-term cumulative incidences for both coronary artery events and heart failure were significantly lower in the surgical group compared to the controls (Table 2, Fig. 1B and 1D). When comparing all-cause mortality using the Kaplan–Meier curves, a similar trend towards better survival up to 11 years after the index date was also observed in the surgical group versus the controls with obesity (Fig. 2). Moreover, when comparing the all-cause mortality between both groups, the IR decreased from 0.90 deaths per 100 person-year among the controls with obesity to 0.58 deaths per 100 person-year in the bariatric surgical group translating into an IRR of 0.64 (95%CI, 0.53–0.78) (data not tabulated).

Table 1 Baseline and operative characteristics of the study cohort

	Controls with obesity N = 5420	Surgical cohort N = 3627
Age – Mean (SD)	50 (10)	48 (10)
Sex – N (%)		
Male	1901 (35)	1321 (36)
SES* – Mean (SD)		
Social†	3.1 (0.85)	3.16 (0.84)
Material‡	2.92 (0.76)	2.94 (0.79)
CCI – N (%)		
≤ 1	2716 (50%)	1785 (49%)
2	1179 (22%)	983 (27%)
≥ 3	1525 (28%)	859 (24%)
DM – N (%)	2239 (41%)	2525 (70%)
HTN – N (%)	4418 (82%)	1801 (50%)
Procedures – N (%)		
AGB	—	1509 (42%)
SG	—	819 (23%)
RYGB	—	419 (11%)
DS	—	880 (24%)

SES, Socioeconomical status; CCI, Charlson comorbidity index; DM, Diabetes mellitus; HTN, Hypertension; AGB, Adjustable gastric band; SG, Sleeve gastrectomy; RYGB, Roux-en-Y gastric bypass; DS, Duodenal switch

* SES was obtained using ecological level data expressed by quintile of the postal code of residence of the individuals compared to the Canadian population

† Social index was based on the component of the deprivation index extracted from census information for the proportion of individuals living alone, proportion of lone parent families and proportion of separated, divorced or widowed individuals

‡ Material index was based on the component of the deprivation index extracted from the average income, proportion of individuals without high school diploma and proportion of employed individuals

We found that patients who suffered from both DM and HTN appeared to have higher rates of any MACE outcome than patient with only one of these comorbidities. Of this subgroup, a patient who had undergone surgery had a significantly lower hazard of events after multivariate analysis with an HR of 0.74 (0.65–0.84; data not tabulated). Similarly, the presence of DM was associated with increased effect of surgery with adjusted HR for any MACE outcome of 0.80 (0.74–0.87) in diabetics and 0.85 (0.76–0.96) in non-diabetic patients (data not tabulated).

Table 4 also provides the detailed sub-group analyses of the long-term effect of bariatric surgery on MACE outcomes based on procedure type. Most protective effect against any MACE outcome was associated with RYGB (adjusted HR, 0.77 [95%CI, 0.62–0.99]) followed by DS surgery (HR, 0.84 [95%CI, 0.73–0.97]).

Table 2 Crude incidence of the composite MACE outcome in the study cohort

	Controls with obesity N = 5420	Surgical cohort N = 3627	P value
Coronary artery event *	764 (14)	367 (10)	< 0.01
Cerebrovascular event †	233 (4.3)	163 (4.5)	0.29
Heart failure	377 (7.0)	182 (5.0)	< 0.01
All-cause mortality	345 (6.3)	151 (4.1)	< 0.01
MACE ‡	1346 (25)	712 (20)	< 0.01
Follow-up (year) – Median (IQR)	7.02 (2.83)	7.09 (2.74)	
Time at risk (person-year)	34,455	23,967	
IR (cases per 100 person-year)	3.91	2.97	
IRR (95%CI)	Ref	0.76 (0.69–0.83)	
5-year ARR (95%CI)	Ref	4.11% (2.64–5.57)	
10-year ARR (95%CI)	Ref	5.14% (3.41–6.87)	

MACE, Major adverse cardiovascular events; IQR, Interquartile range; IR, Incidence rate; IRR, Incidence rate ratio; CI, Confidence interval; Ref, Reference category

* Coronary artery event was defined as myocardial infarct or coronary artery disease requiring coronary artery bypass surgery or percutaneous coronary intervention

† Cerebrovascular event was defined as ischemic or hemorrhagic stroke

‡ MACE was defined as a 4-component composite outcome including the first occurrence of any coronary artery event, cerebrovascular event, heart failure or all-cause mortality

Discussion

In this population-level study, we were able to demonstrate that bariatric/metabolic surgery was linked to a significantly lower incidence of MACE (nearly 25%; IRR = 0.76) in patients with severe obesity, DM and HTN beyond a decade after surgery. Our results are not only in keeping with similar findings from other large observational studies with shorter follow-up period [9–11], but are further

testimony to the decade-long extended benefit of bariatric/metabolic surgery on hard outcomes such as MACE and all-cause mortality. Furthermore, given the population-level nature of our observational cohort study, we were able to calculate a long-term 10-year ARR for MACE, which was found to be 5%. This statistic implies that we need to perform bariatric surgery on only 20 patients to prevent a composite MACE outcome including all-cause mortality in patients suffering from obesity, DM and HTN and up to a decade after surgery.

In the past 2 decades, while a handful of large observational studies have demonstrated a link between bariatric surgery and medium to long-term improvements in all-cause mortality and MACE [9–11, 16–19], there is still no level I evidence from randomized controlled trials. The three most recent large matched-cohort studies especially with a focus on composite MACE outcomes all had shorter median follow-up periods (3.9–4.7 years) and included mainly RYGB as the main bariatric procedure (63–80%) [9–11]. Moreover, in terms of MACE as a composite outcome, although all-cause mortality along with coronary artery and cerebrovascular events have been commonly used components, these studies including ours have used different macrovascular complications to construct the composite MACE outcome. This observation may indicate the need to standardize this composite endpoint especially in case of a future randomized controlled trial.

In 2019, in a single institution large matched-cohort study from Cleveland Clinic Health System, Aminian et al. demonstrated that at a median follow-up of 3.9 years after

Table 3 Multivariate analysis for the composite MACE outcome

	Controls with obesity Adjusted HR * (95%CI)	Surgical cohort
Coronary artery event †	0.78 (0.71–0.85)	
Cerebrovascular event ‡	1.05 (0.74–1.12)	
Heart failure	0.80 (0.70–0.90)	
All-cause mortality	0.78 (0.68–0.89)	
MACE §	0.83 (0.78–0.89)	

MACE, Major adverse cardiovascular events; HR, Hazard ratio; CI, Confidence interval

* Multivariate Cox proportional hazard model for MACE was adjusted for age, sex and CCI; controls were used as the reference

† Coronary artery event was defined as myocardial infarct or coronary artery disease requiring coronary artery bypass surgery or percutaneous coronary intervention

‡ Cerebrovascular event was defined as ischemic or hemorrhagic stroke

§ MACE was defined as a 4-component composite outcome including the first occurrence of any coronary artery event, cerebrovascular event, heart failure or all-cause mortality

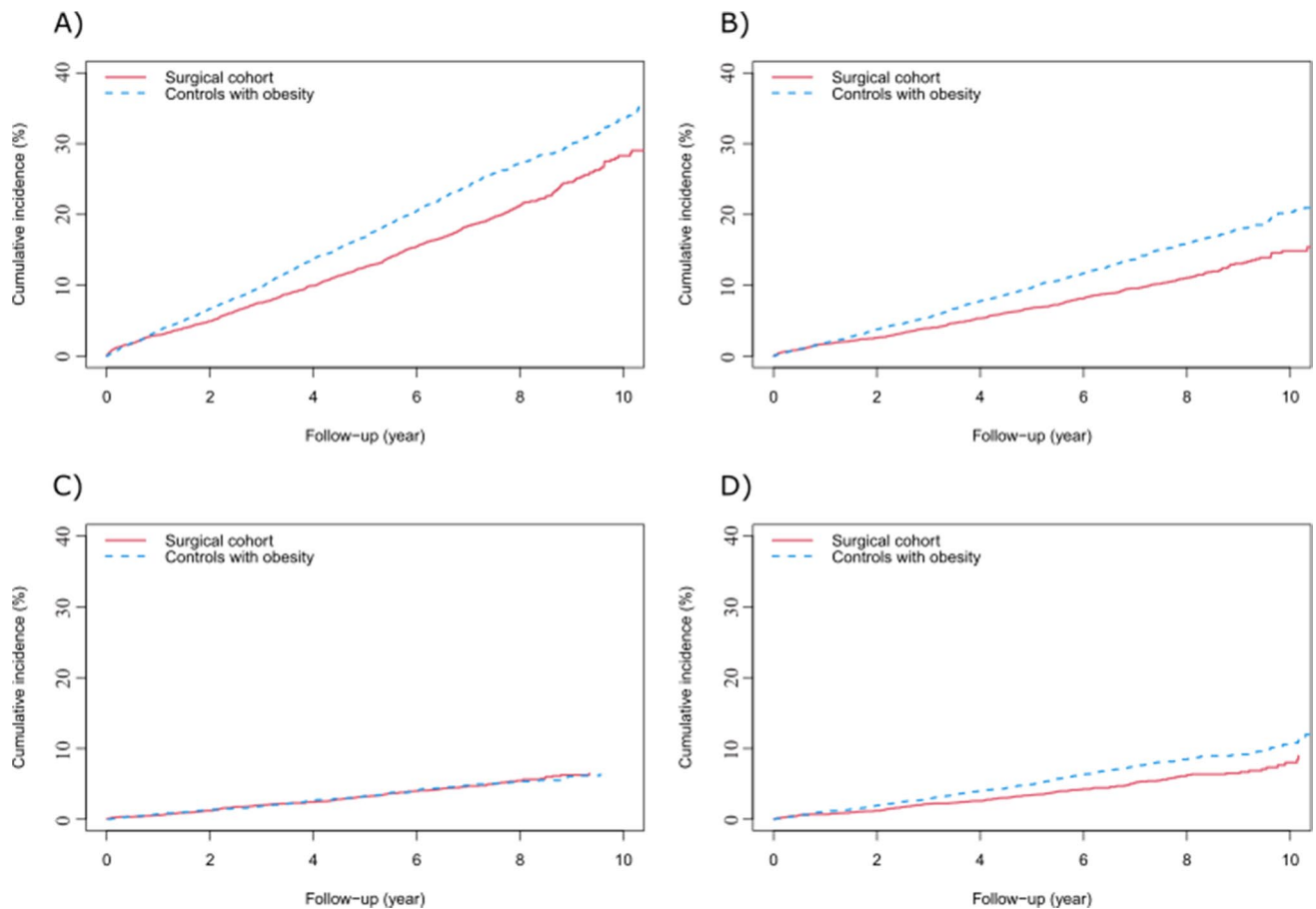


Fig. 1 Cumulative incidence of composite MACE outcome and its components. **A** Composite MACE outcome; **B** Coronary artery events; **C** Cerebrovascular events; **D** Heart failure. MACE=Major adverse cardiovascular events

bariatric surgery, the surgical intervention was nearly 40% protective against a 6-component composite MACE outcome in patients with obesity and DM [10]. Their study included 2287 surgical patients over a 20-year time period where 63% of the procedures were RYGB and only 5 patients had DS as their bariatric procedure. In addition, the definition used for the composite MACE outcome also included some

other important yet softer macrovascular complications such as atrial fibrillation and nephropathy which may result in higher incident rates for the outcome [10]. In another recent population-based matched-cohort study by Doumouras et al. where similar to our study, the composite MACE was more parsimonious yet included hard outcomes like all-cause mortality, coronary artery and cerebrovascular events, and heart failure, also showed that bariatric surgery was associated with a 40% reduction in MACE at a median follow-up of 4.6 years after surgery in patients with obesity and previous cardiovascular disease [11]. Again, among the 1700 surgical patients in their study, 80% underwent RYGB [11]. Similarly, in our population-based study, at a median follow-up time of more than 7 years and up to 11 years after intervention, where nearly 35% of the surgical cohort underwent DS surgery ($N = 880/3627$), we found that bariatric/metabolic surgery was almost 20% protective against the same 4-component composite MACE outcome in patients with obesity and metabolic syndrome including DM and HTN. Hence, regardless of the sub-population, patients with obesity whether they have a history of cardiovascular disease or

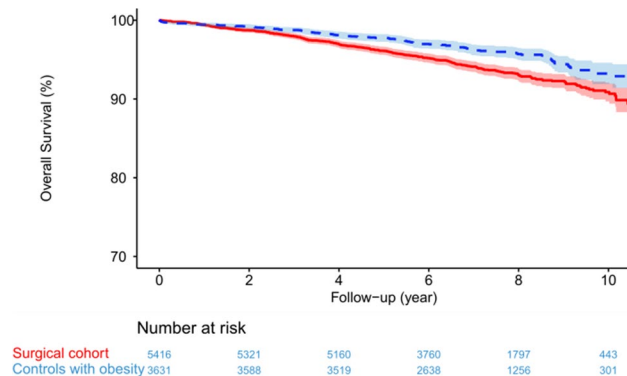


Fig. 2 Kaplan–Meier curves for overall survival for the study cohort

Table 4 Sub-group analysis of the MACE outcome stratified by bariatric procedure type

	SG		RYGB		DS		AGB	
	Control	Surgery	Control	Surgery	Control	Surgery	Control	Surgery
Coronary artery event*	165 (13)	80 (9.7)	68 (13)	31 (7.3)	182 (16)	96 (11)	349 (14)	160 (11)
Cerebrovascular event†	50 (4.2)	42 (5.1)	18 (3.5)	14 (3.3)	52 (4.5)	43 (4.9)	113 (4.4)	64 (4.2)
Heart failure	93 (7.7)	39 (4.7)	27 (5.2)	13 (3.1)	91 (7.8)	46 (5.2)	166 (6.5)	84 (5.6)
All-cause mortality	77 (6.4)	44 (5.3)	31 (6.0)	13 (3.1)	94 (8.0)	46 (5.2)	143 (5.6)	48 (3.1)
MACE‡	309 (26)	170 (20)	115 (22)	63 (15)	315 (27)	188 (21)	607 (24)	291 (19)
Follow-up (year) – Median (IQR)	6.1 (1.9)	6.2 (1.9)	7.5 (3.6)	7.6 (3.1)	8.1 (2.9)	8.1 (2.9)	7.1 (2.5)	7.1 (2.5)
Time at risk (person-year)	6794	4770	3389	2994	8055	6267	16,217	9936
IR (cases per 100 person-year)	4.55	3.56	3.39	2.10	3.91	3.00	3.74	2.93
IRR (95%CI)	0.78 (0.65–0.95)		0.62 (0.45–0.85)		0.77 (0.64–0.92)		0.78 (0.68–0.90)	
5-year ARR (95%CI)	5.22% (1.96–8.47)		8.55% (4.60–12.5)		2.69% (-0.34–5.72)		3.03% (0.80–5.26)	
10-year ARR (95%CI)	4.99% (1.28–8.70)		7.25% (2.32–12.2)		5.54% (1.82–9.25)		4.53% (1.94–7.12)	
Adjusted HR§ (95%CI)	0.89 (0.77–1.03)		0.77 (0.62–0.99)		0.84 (0.73–0.97)		0.87 (0.78–0.96)	

MACE, Major adverse cardiovascular events; SG, Sleeve gastrectomy; RYGB, Roux-en-Y gastric bypass; DS, Duodenal switch; AGB, Adjustable Gastric band; IQR, Interquartile range; IR, Incidence rate; IRR, Incidence rate ratio; CI, Confidence interval

* Coronary artery event was defined as myocardial infarct or coronary artery disease requiring coronary artery bypass surgery or percutaneous coronary intervention

† Cerebrovascular event was defined as ischemic or hemorrhagic stroke

‡ MACE was defined as a 4-component composite outcome including the first occurrence of any coronary artery event, cerebrovascular event, heart failure or all-cause mortality

§ Multivariate Cox proportional hazard model for MACE was adjusted for by age, sex, hypertension, diabetes, chronic pulmonary disease, anemia, and depression

suffer from DM or a more extended metabolic syndrome like additional HTN, are less likely to experience major cardiovascular sequelae long-term after bariatric surgery.

In fact, the sooner we offer patients bariatric/metabolic surgery during the course of their metabolic syndrome, the more effective the intervention becomes. This temporal relationship is repeatedly demonstrated by various studies especially among the patients with DM [20–22]. In a large prospective study by Carlsson et al. nested within the Swedish Obese Subjects (SOS) study with a median follow-up of 19 years after surgery, the highest protective effect of bariatric/metabolic surgery against microvascular complications including diabetic retinopathy, neuropathy and nephropathy, was among pre-diabetic patients (HR = 0.18) versus those with diabetes (HR = 0.54) [22]. This is not a surprising finding since atherosclerosis is a chronically progressive disease that at certain point becomes irreversible. The long-term protective effect of bariatric surgery is also not only due to weight loss alone and likely in large part due to changes made to the metabolic milieu after bariatric/

metabolic surgery. The weight loss independent protective impact of bariatric surgery against MACE outcomes was recently shown in a large matched-cohort study by Aminian et al. with a median follow-up of nearly 5 years [23]. The authors demonstrated that long-term risk of MACE was reduced after approximately 10% of weight is lost in the surgical group versus nearly 20% in the non-surgical group and for all-cause mortality, the threshold for benefit was evident after approximately 5% weight loss post metabolic surgery versus 20% in the non-surgical group [23]. Despite the consistently shown long-term protective effects of bariatric/metabolic surgery against hard MACE outcomes including all-cause mortality by studies like ours, access to surgery continues to be poor and impacted by socioeconomic and health provider disparities [13, 24, 25]. The findings from our study among others, can lay the ground for a randomized controlled trial that while may require a tedious multi-center and perhaps international effort to carry out, its impact will likely be monumental in improving access to surgery by providers.

In terms of procedure type, it is also demonstrated that different common bariatric surgeries like SG and RYGB may lead to clinically similar long-term (≥ 5 years) metabolic outcomes including complete remission among patients with DM when performed early in the course of their disease [26]. Moreover, RYGB may lose its superior anti-diabetic effect compared to SG when glycemic control is very poor despite multiple agents including insulin therapy as a proxy of worn-out pancreatic beta cell function [26]. It is also shown that some hypo-absorptive procedures like biliopancreatic diversion or DS-type surgeries may be more of a robust metabolic procedure especially for diabetes and compared to RYGB and lead to more long-term weight loss, albeit at a higher cost in terms of long-term micronutrient deficiencies and malnutrition [5, 27]. Unlike other large matched-cohort studies on the association between bariatric surgery and MACE outcomes [9–11], our study has a more balanced distribution of the four bariatric procedures including a large number of patients who underwent DS ($N = 880$; 24%). Interestingly in our sub-group analysis, we found that RYGB had the highest long-term protective effect against the composite MACE outcome even compared to DS procedure ($HR = 0.77$ vs. 0.84 , respectively). However, this observation in our study may be partially explained by the fact that the patients who underwent DS surgery compared to those who had RYGB, were older and had a higher comorbidity burden (higher CCI; data not shown).

Our study has several limitations that should be taken into account. Primarily, since the utilized datasets are mainly administrative healthcare registries that are predominantly designed for billing purposes and not research, we were not able to gather information on some important parameters including weight outcomes including absolute weight measures, BMI, and other important clinical information such as glycated hemoglobin and blood pressure measurements. The absence of such information does not allow for a better matching of surgical cases with their controls with obesity, as well as exploring the effect of weight loss-independent effect of surgical procedures on MACE outcomes. In addition, while the completeness of information on major chronic diagnoses such as DM, HTN, coronary artery disease, and stroke that involve multiple specialists is very high in the used datasets [28–30], the accuracy might be lower and unreliable in correctly identifying other important baseline risk factors such as dyslipidemia. Nevertheless, several studies have also demonstrated the robustness of the used administrative healthcare datasets in providing accurate accounts of patients' comorbidities and proper risk adjustment in research studies [31–33].

Moreover, since bariatric surgery is likely performed on patients with obesity who have a more severe burden of related comorbidities e.g., worse DM, due to higher likelihood of being referred, this may have introduced a selection bias which is likely toward the null value given their presumed

worse metabolic syndrome at baseline. Also, misclassification bias of the outcome measure and other variables is possible. However, the prevalence and distribution of these characteristics are also likely similar among all patients with obesity and so the bias is again likely toward the null value. As in all observational and retrospective studies, other unknown and unmeasured confounders may also exist between the bariatric surgery patients and the non-surgical controls in our study. Despite these limitations, the consistency of our findings with other similar studies [9–11], the very long median follow-up period (≥ 1.5 times longer than the three recent studies), inclusion of patients with DM and HTN, large proportion of patients that underwent DS surgery, the magnitude of the effect measures, and the use of population-level data generating population-level effect measures like 10-year ARR are important strengths and cannot be overstated.

Conclusion

Bariatric/metabolic surgery is associated with a sustained decrease in the incidence of composite MACE outcomes including all-cause mortality and beyond a decade after surgery in patients with obesity and metabolic syndrome including DM and HTN. Results from this population-level observational study should be validated in randomized controlled trials with long-term follow-up.

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Declarations

Ethics approval and consent to participate For this type of study, formal consent is not required. Informed consent does not apply.

Conflict of interest The authors declare no competing interests.

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