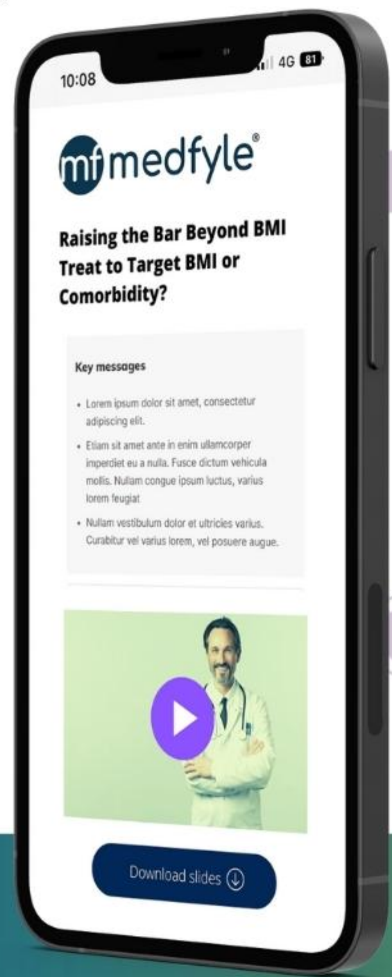
obesityweek® | medfyle®

Medfyle Conference Coverage from ObesityWeek® 2022

Discover a new way to catch up with the latest advances in obesity research and care presented at ObesityWeek® 2022.

- Medfyle summaries
- Expert interviews
- Expert presentations
- Posters

CLICK TO ACCESS NOW



This activity is supported by an educational grant from Lilly

Received: 27 July 2022 | Revised: 5 October 2022 | Accepted: 18 October 2022

DOI: 10.1002/oby.23646

Obesity A Research Journal | THE OBESITY SOCIETY | WILEY

ORIGINAL ARTICLE

Epidemiology/Genetics

Long-term all-cause and cause-specific mortality for four bariatric surgery procedures

Ted D. Adams[1,2,3] | Huong Meeks[4] | Alison Fraser[4] | Lance E. Davidson[2,5] | John Holmen[6] | Michael Newman[7] | Anna R. Ibele[8] | Nathan Richards[1] | Steven C. Hunt[2,9] | Jaewhan Kim[10]

[1]Intermountain Surgical Specialties/Digestive Health Clinical Program, Intermountain Healthcare, Salt Lake City, Utah, USA

[2]Division of Epidemiology, Department of Internal Medicine, University of Utah School of Medicine, Salt Lake City, Utah, USA

[3]Department of Nutrition and Integrative Physiology, University of Utah, Salt Lake City, Utah, USA

[4]Huntsman Cancer Institute, University of Utah, Salt Lake City, Utah, USA

[5]Department of Exercise Sciences, Brigham Young University, Provo, Utah, USA

[6]Intermountain Biorepository, Intermountain Healthcare, Salt Lake City, Utah, USA

[7]University of Utah Health, Data Science Services, Salt Lake City, Utah, USA

[8]Division of General Surgery, Department of Surgery, University of Utah School of Medicine, Salt Lake City, Utah, USA

[9]Department of Genetic Medicine, Weill Cornell Medicine, Doha, Qatar

[10]Department of Physical Therapy, College of Health, University of Utah, Salt Lake City, Utah, USA

Correspondence
Ted D. Adams, Digestive Health Clinical Program & Intermountain Surgical Specialties, Intermountain Healthcare, 5026 S. State St., 3rd Floor, Murray, UT, 84157-7000, USA.
Email: ted.adams@utah.edu

Funding information
Ethicon Endo-Surgery (Johnson & Johnson); NIDDK-NIH, Grant/Award Numbers: DK-55006, DK-099619; US Public Health Service, Grant/Award Number: MO1-RR00064; Intermountain Research and Medical Foundation of Intermountain Healthcare

Abstract

Objective: This retrospective study incorporated long-term mortality results after different bariatric surgery procedures and for multiple age at surgery groups.

Methods: Participants with bariatric surgery (surgery) and without (non-surgery) were matched (1:1) for age, sex, BMI, and surgery date with a driver license application/renewal date. Mortality rates were compared by Cox regression, stratified by sex, surgery type, and age at surgery.

Results: Participants included 21,837 matched surgery and non-surgery pairs. Follow-up was up to 40 years (mean [SD], 13.2 [9.5] years). All-cause mortality was 16% lower in surgery compared with non-surgery groups (hazard ratio, 0.84; 95% CI: 0.79-0.90; $p < 0.001$). Significantly lower mortality after bariatric surgery was observed for both females and males. Mortality after surgery versus non-surgery decreased significantly by 29%, 43%, and 72% for cardiovascular disease, cancer, and diabetes, respectively. The hazard ratio for suicide was 2.4 times higher in surgery compared with non-surgery participants (95% CI: 1.57-3.68; $p < 0.001$), primarily in participants with ages at surgery between 18 and 34 years.

Conclusions: Reduced all-cause mortality was durable for multiple decades, for multiple bariatric surgical procedures, for females and males, and for greater than age 34 years at surgery. Rate of death from suicide was significantly higher in surgery versus non-surgery participants only in the youngest age at surgery participants.

Obesity A Research Journal THE OBESITY SOCIETY WILEY

INTRODUCTION

Among US adults, prevalence of severe obesity (body mass index [BMI] ≥ 40 kg/m^2) doubled from 1999-2000 (4.7%) to 2017-2018 (9.2%) in the National Health and Nutrition Examination Survey (NHANES) [1]. Population studies have observed that patients with severe obesity have increased risks of cardiometabolic diseases [2] and mortality [3]. Although bariatric surgery is the most successful treatment for the population with severe obesity [4], it remains underused [5]. Patients who have undergone bariatric surgery have demonstrated significant improvement in obesity-related comorbidity such as remission of type 2 diabetes mellitus and decreased long-term mortality when compared with nonsurgical patients with severe obesity [4,6,7], stimulating intense interest in discovery of causal pathophysiologic mechanisms that may facilitate nonsurgical treatment(s) of obesity [8].

This retrospective study compared long-term mortality of bariatric surgery patients and matched non-surgery participants identified from driver licenses. Whereas mortality after gastric bypass surgery was previously reported from 1984 to 2002 [9], this study extends mortality follow-up through 2021. Additional gastric bypass patients and patients who had gastric banding, sleeve gastrectomy, or duodenal switch from 1982 to 2018 have been included. Mortality outcomes were also analyzed stratified by sex, types of bariatric surgeries, and patients' ages at surgery.

Study Importance

What is already known?

- Multiple retrospective studies and one prospective study (Swedish Obesity Subjects study) have reported lower all-cause mortality among patients who have undergone bariatric surgery when compared with BMI-matched patients who have not undergone bariatric surgery. In addition to reduced all-cause mortality, studies have reported reduced cardiovascular-, cancer-, and diabetes-related death rates among bariatric surgery patients compared with matched non-surgery patients.
- Our group has previously reported on long-term mortality of Roux-en-Y gastric bypass patients compared with BMI-matched participants identified from driver licenses. This previous study was limited to only gastric bypass patients (approximately 7000), and follow-up was conducted only to 2002.

What does this study add?

- The current study extends follow-up up to 40 years and includes almost 22,000 surgical patients representing all four major types of bariatric procedures performed today.
- Lower all-cause mortality was reported for male bariatric surgery patients as well as female patients when compared with sex-matched non-surgery participants.

How might these results change the direction of research or the focus of clinical practice?

- Reported findings of increased suicide rates among bariatric surgical patients who underwent surgery at younger ages (i.e., 18-34 years) may result in more aggressive presurgical psychological screening and postsurgery follow-up, especially among patients representing this age group.
- As a result of the decades-long durability of bariatric surgery in reducing death from all causes and reducing deaths related to cardiovascular disease, cancer, and diabetes when compared with matched participants with severe obesity, these findings may not only increase interest in bariatric surgery treatment for patients with severe obesity, but in addition, further stimulate important research related to the discovery of physiologic and biomolecular mechanisms leading to nonsurgical treatment that results in weight loss and improved mortality similar to that achieved by bariatric surgery.

METHODS

This study was approved by the University of Utah's Resource for Genetic and Epidemiologic Research. Because of deidentification, the study was considered non-human subjects research by the University Institutional Review Board (IRB #00095902). IRB approval was also obtained at Intermountain Healthcare, Salt Lake City, Utah.

Study aims

The primary aim was to determine the association of all-cause and cause-specific mortality risk between bariatric surgery patients and matched non-surgery participants identified from driver license applications or renewals. Secondary aims were to determine whether age at surgery influenced mortality outcomes and whether mortality rates differed between sexes and between surgical procedures, which included gastric bypass, gastric banding, sleeve gastrectomy, and duodenal switch. Duodenal switch included single and double anastomosis procedure types primarily performed from 2010 to 2018.

Participants

Our study used information from the Utah Population Database (UPDB). The UPDB includes linked population-based information from

Utah with statewide birth and death certificates, driver licenses and ID cards, and voter registration records. It also contains statewide cancer registry records and health facility records, including inpatient discharge, ambulatory surgeries, and emergency claims. The UPDB creates and maintains links between the database and the medical records held by the two largest health care providers in Utah.

Patients who had undergone bariatric surgery in Utah between 1982 and 2018 were identified from three large bariatric surgical practices in Salt Lake City and from medical records from the University of Utah and Intermountain Healthcare Enterprise Data Warehouses in Salt Lake City (Figure 1). Exclusion criteria are shown in Figure 1, and the counts in each line of the boxes represent the number of missing or nonqualifying records for that variable out of the total records listed in the box above. Each record could have multiple missing values (such as missing age and BMI) and would be counted multiple times so that the total counts within a box do not add up to the total in the preceding box. The qualifying bariatric surgery procedures were Roux-en-Y gastric bypass, adjustable gastric banding, sleeve gastrectomy, and biliopancreatic diversion with duodenal switch.

Non-surgery participants were selected from Utah driver license records or ID cards. Because driver licenses are generally renewed every 5 years, there were multiple records to choose from for matching to the bariatric surgeries. Exclusions were made on a record basis (Figure 1), resulting in 694,909 qualifying records for matching to surgical patients in a 1:1 ratio. Matching variables were sex, BMI category, age category (18-19, 20-24, 25-29, …, 75-80 years), and year of surgery, which was matched to year of driver license application or renewal (±2 years). The subset of surgery and non-surgery participant pairs used in our prior study [9] was previously matched using microfilm records by three BMI categories (33-44, 45-54, and ≥55). Because UPDB now has electronic records for the later years, adjusted BMI categories of 18.5 to 24.9; 25 to 29.9; 30 to 34.9; 35 to 39.9; 40 to 44.9; 45 to 49.9; and ≥50 were used for the additional surgery patients in order to get even closer BMI matching. All controls were required to have never had bariatric surgery determined from the three large bariatric surgery registries, health facility records, or the Enterprise Data Warehouses. Clinical records were generally available only after 1995, and statewide coverage of clinical data was also not available, preventing the use of clinical data to create a subset or correlate with the mortality data. As previously described [9], self-reported heights and weights on driver licenses were corrected using sex-specific regression equations to address overestimation of height and underestimation of weight. Because these regression equations were developed using only participants with BMI ≥ 33, unadjusted self-reported BMI values under 30 were excluded.

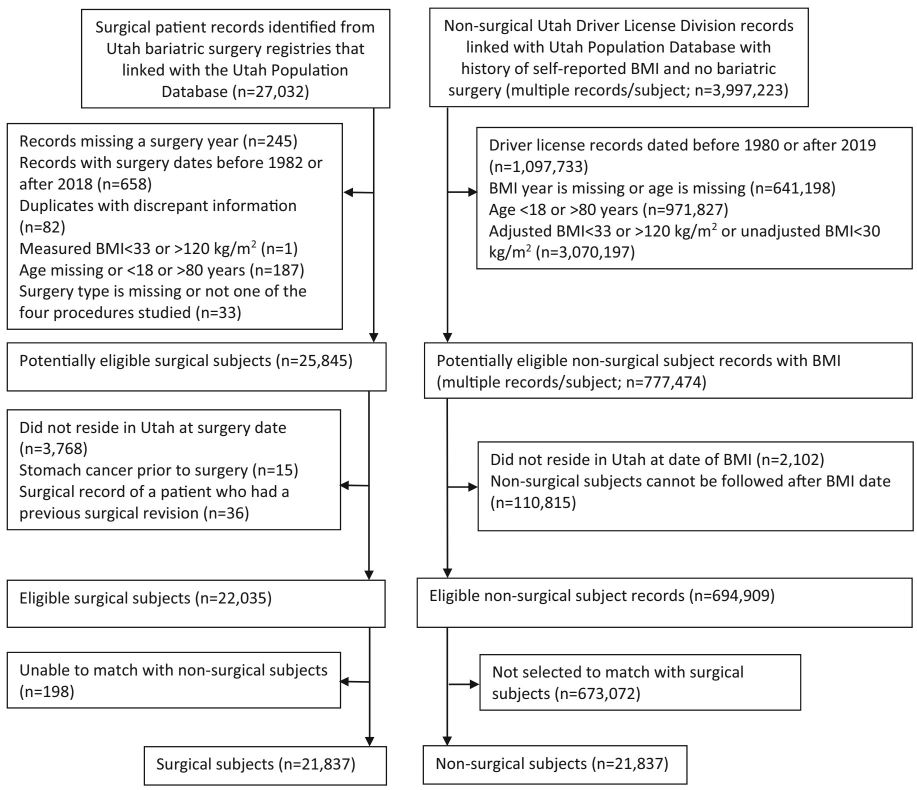


FIGURE 1 Retrospective study design and exclusions. The counts in each line of the boxes represent the number of missing or nonqualifying data points out of the total records listed in the box above. Each record could have multiple missing values (such as missing age and BMI) and would be counted multiple times so that the total counts within a box do not add up to the total in the preceding box. This allows the counts to represent the amount of missing data for that variable

TABLE 1 Characteristics of bariatric surgery patients and matched driver license participants linked to Utah death certificates

	All matched participants			All female matched participants			All male matched participants		
	Non-surgery group	Surgery group	*p* value	Non-surgery group	Surgery group	*p* value	Non-surgery group	Surgery group	*p* value
n	21,837	21,837		17,271	17,271		4566	4566	
Sex						–			–
Female	17,271 (79.1%)	17,271 (79.1%)		–	–	–	–	–	–
Male	4566 (20.9%)	4566 (20.9%)		–	–	–	–	–	–
Birth year, mean (SD)	1962.4 (13.8)	1962.4 (13.8)	0.78	1962.4 (13.9)	1962.4 (13.9)	0.87	1962.2 (13.4)	1962.3 (13.4)	0.77
Age at index date (y)[a], mean (SD)	42.3 (11.9)	42.2 (11.7)	0.60	41.5 (11.7)	41.4 (11.5)	0.63	45.3 (12.2)	45.2 (12.1)	0.83
Index year[a], mean (SD)	2004.7 (10.2)	2004.6 (10.4)	0.75	2003.9 (10.4)	2003.9 (10.6)	0.71	2007.5 (9.0)	2007.5 (9.1)	0.98
BMI at index date (kg/m^2)[b], mean (SD)	46.2 (6.8)	46.0 (8.3)	0.003	45.8 (6.2)	45.3 (7.9)	<0.001	47.5 (8.5)	48.3 (9.2)	<0.001
White			<0.001			<0.001			<0.001
Yes	19,136 (87.6%)	20,625 (94.4%)		15,229 (88.2%)	16,339 (94.6%)		3907 (85.6%)	4286 (93.9%)	
No	1729 (7.9%)	890 (4.1%)		1317 (7.6%)	663 (3.8%)		412 (9%)	227 (5%)	
Unknown	972 (4.5%)	322 (1.5%)		725 (4.2%)	269 (1.6%)		247 (5.4%)	53 (1.2%)	
Hispanic			<0.001			<0.001			<0.001
No	17,600 (80.6%)	19,397 (88.8%)		13,896 (80.5%)	15,259 (88.4%)		3704 (81.1%)	4138 (90.6%)	
Yes	2708 (12.4%)	1700 (7.8%)		2204 (12.8%)	1399 (8.1%)		504 (11%)	301 (6.6%)	
Unknown	1529 (7%)	740 (3.4%)		1171 (6.8%)	613 (3.5%)		358 (7.8%)	127 (2.8%)	
Type of surgery[c]			–			–			–
RYGB	–	15,110 (69.2%)		–	12,288 (71.1%)		–	2822 (61.8%)	
Banding	–	2629 (12%)		–	2045 (11.8%)		–	584 (12.8%)	
Sleeve	–	3050 (14%)		–	2260 (13.1%)		–	790 (17.3%)	
Duodenal switch	–	1048 (4.8%)		–	678 (3.9%)		–	370 (8.1%)	
Censoring status in 2021[d]			0.001			0.007			0.062
Alive	18,656 (85.4%)	18,894 (86.5%)		14,868 (86.1%)	15,039 (87.1%)		3788 (83%)	3855 (84.4%)	
Died (total)	3181 (14.6%)	2943 (13.5%)		2403 (13.9%)	2232 (12.9%)		778 (17%)	711 (15.6%)	
Died within the 1st year	89 (0.4%)	111 (0.5%)	0.14	49 (0.3%)	73 (0.4%)	0.037	40 (0.9%)	38 (0.8%)	0.91
Follow-up time to death[e], mean (SD)	13.2 (9.5)	13.3 (9.8)	0.20	13.9 (9.8)	14.0 (10.1)	0.23	10.6 (8.0)	10.7 (8.3)	0.65
Follow-up time to death[e], median (IQR) and (Min, Max)	10.8 (5.0-19.1) (0.0, 39.1)	11.0 (4.9-19.4) (0.0, 39.6)		11.8 (5.3-20.1) (0.0, 39.1)	11.9 (5.2-20.6) (0.0, 39.6)		8.2 (4.4-14.9) (0.0, 38.2)	8.2 (4.3-15.1) (0.0, 38.8)	

Note: Demographic characteristics between surgery patients and their matching controls were compared using *t* tests for continuous variables and χ^2 tests for categorical variables. Data are presented as *n* (%) unless otherwise indicated.
Abbreviations: Max, maximum; Min, minimum; RYGB, Roux-en-Y gastric bypass.

[a]Index date is defined as date of bariatric surgery for surgery patients and date of driver license applications for matching controls. If only index year is known, then index date is set as July 1 of that year.

[b]Unadjusted BMI for surgery patients and corrected self-reported BMI for matching non-surgery participants.

[c]See Supporting Information Table S3 for distribution of index year by bariatric surgery type.

[d]Cause of death is defined as primary causes of death as recorded in Utah death certificates. Follow-up time (years) is determined as time from index date to follow-up date.

[e]Follow up date is determined (1) as the date that a person is considered to still live in Utah, (2) when a surgery patient undergoes revision bariatric procedures, or (3) December 31, 2021 (the last year UPDB received Utah death certificate records), or (4) death date, whichever occurred first.

TABLE 2 Distribution of deaths and death rates per 10,000 person years for all matched surgery and non-surgery participants and sex-specific matched participants

	All matched participants				Matched participants, female				Matched participants, male			
	Non-surgery group (n = 21,837)		Surgery group (n = 21,837)		Non-surgery group (n = 17,271)		Surgery group (n = 17,271)		Non-surgery group (n = 4566)		Surgery group (n = 4566)	
End point	*n*	Rate	*n*	Rate	*n*	Rate	*n*	Rate	*n*	Rate	*n*	Rate
All causes of death[a]	3181	110.7	2943	101.4	2403	100.6	2232	92.5	778	160.5	711	145.4
Non-external causes of death[b]	2846	99.0	2422	83.4	2151	90.0	1843	76.4	695	143.3	579	118.4
Malignant neoplasms	581	20.2	397	13.7	467	19.5	306	12.7	114	23.5	91	18.6
Alzheimer disease	40	1.4	49	1.7	35	1.5	45	1.9	<11	-	<11	–
Diabetes mellitus	629	21.9	210	7.2	455	19.0	123	5.1	174	35.9	87	17.8
Major cardiovascular diseases	728	25.3	646	22.3	531	22.2	469	19.4	197	40.6	177	36.2
Ischemic heart disease	239	8.3	197	6.8	160	6.7	125	5.2	79	16.3	72	14.7
Hypertensive heart disease	30	1.0	32	1.1	20	0.8	26	1.1	<11	-	<11	–
Hypertension	20	0.7	37	1.3	16	0.7	29	1.2	<11	-	<11	–
Cerebrovascular disease	93	3.2	99	3.4	79	3.3	82	3.4	14	2.9	17	3.5
Chronic obstructive pulmonary disease/chronic lower respiratory disease	105	3.7	67	2.3	78	3.3	51	2.1	27	5.6	16	3.3
Chronic liver disease cirrhosis	51	1.8	85	2.9	40	1.7	67	2.8	11	2.3	18	3.7
All other diseases	1085	37.7	1100	37.9	806	33.7	860	35.6	279	57.5	240	49.1
External causes of death[c]	153	5.3	379	13.1	110	4.6	280	11.6	43	8.9	99	20.2
Select accidents and adverse effects	32	1.1	53	1.8	22	0.9	38	1.6	<11	2.1	15	3.1
Suicide	44	1.5	112	3.9	30	1.3	72	3.0	14	2.9	40	8.2
All other external causes	77	2.7	214	7.4	58	2.4	170	7.0	19	3.9	44	9.0

Note: All disease classifications were taken from the primary causes of death except diabetes and Alzheimer disease, which also used secondary causes of death. Malignant neoplasms used codes defined in Supporting Information Table S1. Cells with less than 11 counts must be reported as less than 11 according to Utah Department of Health policy.

[a]If Manner of Death and *International Classification of Diseases* codes are both missing, the death was included in the all causes of death row but excluded from all other rows. Therefore, the counts of non-external and external causes of death do not add up to the all causes of death counts.

[b]Determined by Manner of Death as Natural or Pending Investigation or Undetermined if Injured Purposely or Accidentally or Missing (NA) with specified codes listed in the non-external causes of death categories (Supporting Information Table S2).

[c]Determined by Manner of Death as Suicide or Homicide or Accident or Missing (NA) with specified codes listed in the external causes of death categories (Supporting Information Table S2).

Obesity A Research Journal THE OBESITY SOCIETY WILEY

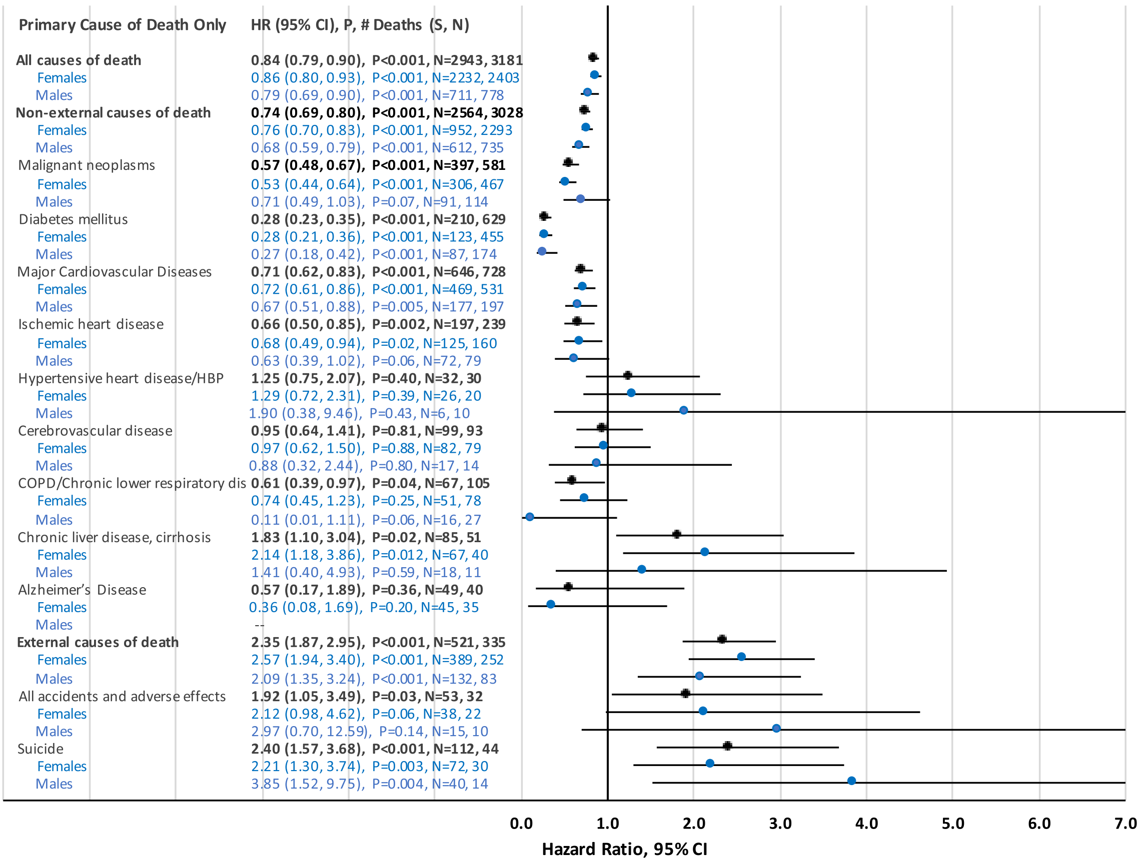


FIGURE 2 Mortality risk of bariatric surgery patients compared with non-surgery driver license applicant participants stratified by sex. Non-external causes of death defined as Natural or Pending Investigation with specified codes listed in the non-external causes of death categories (Supporting Information Table S2). External causes of death defined as Suicide or Homicide or Accident or Missing (NA) with specified codes listed in the external causes of death categories (Supporting Information Table S2). All disease classifications were taken from the primary causes of death except diabetes and Alzheimer disease, which also used secondary causes of death. Malignant neoplasms used codes defined in Supporting Information Table S1. Counts less than 11 are required by the Utah Department of Health to be reported only as <11. COPD, chronic obstructive pulmonary disease; HBP, high blood pressure; HR, hazard ratio; N, non-surgery group; S, surgery group

Statistical analyses

Demographic characteristics between surgery patients and matched non-surgery participants were compared using *t* tests for continuous variables and χ^2 tests for categorical variables. Unadjusted absolute death rates per 10,000 person years were calculated by sex and specific causes of death. Index date was defined as date of bariatric surgery or date of driver license application/renewal and set as July 1 if only year was known. All-cause mortality risks were estimated using Cox proportional hazard models, additionally adjusting for age at index year, index year, BMI, sex, whether White, whether Hispanic, and clustering by matched pairs. Cause-specific mortality risks were estimated using competing risk models [10]. All individuals were followed until death, last date known to reside in Utah, date of revision surgery, or December 31, 2021, whichever occurred first. All records in UPDB, including the clinical data records, were used to determine continued residency in Utah during follow-up. There were 3086 surgery patients and 2715 non-surgery pairs who presumably moved after their last known residency date in Utah. The proportional hazards assumptions were checked using statistical tests and graphical diagnostics based on scaled Schoenfeld residuals. Analyses were stratified by sex, age at index date (<35, 35-44, 45-54, and 55-80 years), and surgical procedure. All causes of death were derived from primary causes of death as reported in Utah death certificates, except for Alzheimer disease and diabetes mellitus, which were derived from both primary and secondary causes of death and defined with *International Classification of Diseases*, *Ninth Revision* and *Tenth Revision* codes (Supporting Information Tables S1 and S2). The *p* values and 95% confidence intervals (CIs) are all two-sided, and the criterion used for statistical significance was $p < 0.05$. Statistical analyses were conducted using R version 4.1.0. Finally, non-external deaths were defined as deaths related to diseases such as diseases of the heart, cancer, and diabetes, whereas external deaths were defined as deaths related to accidents, self-harm such as suicide, and related adverse effects. Deaths from all causes included combined non-external and external deaths.

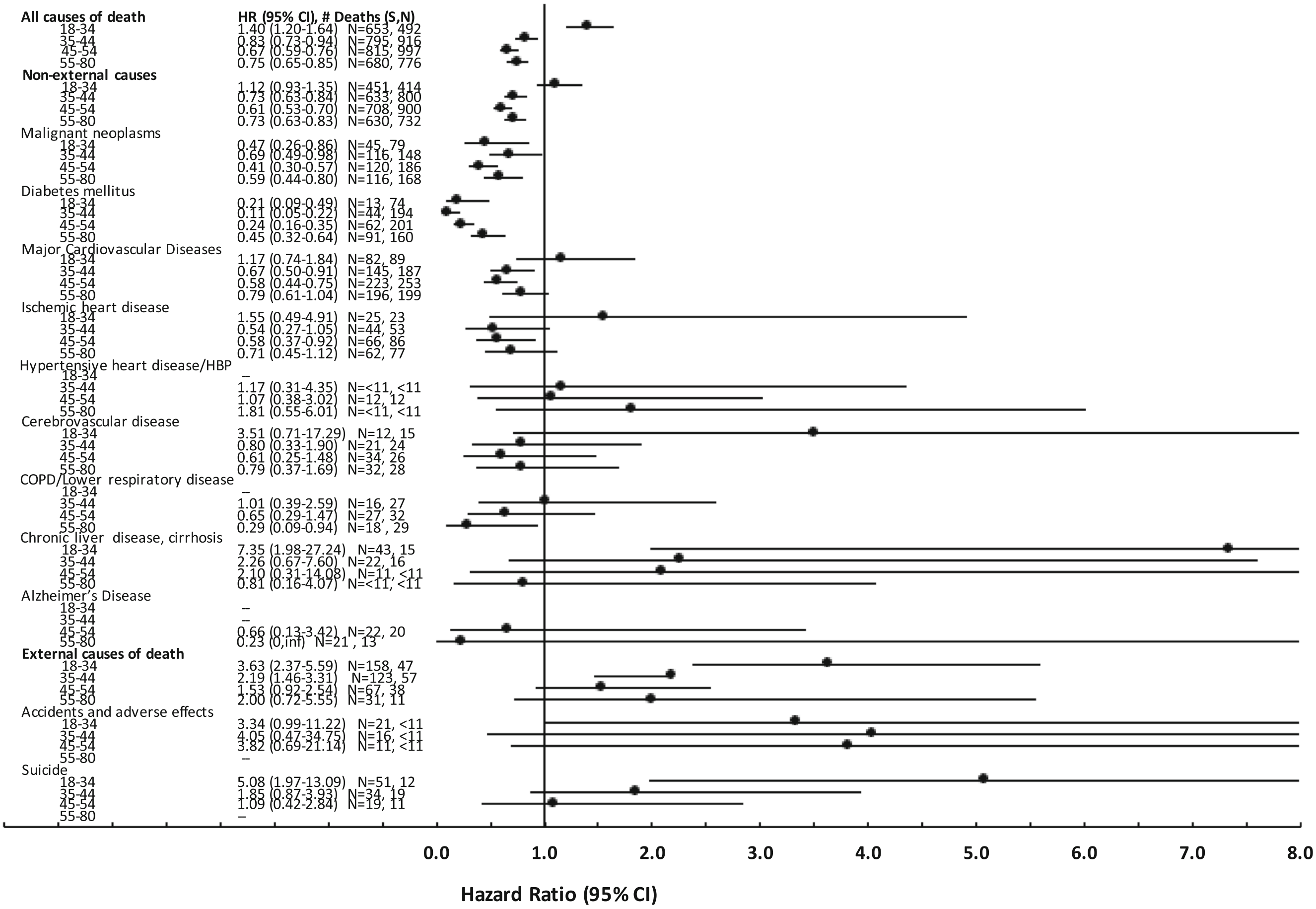


FIGURE 3 Mortality risk of bariatric surgery patients compared with non-surgery driver license applicant participants stratified by age category (years) at surgery. Non-external causes of death defined as Natural or Pending Investigation with specified codes listed in the non-external causes of death categories (Supporting Information Table S2). External causes of death defined as Suicide or Homicide or Accident or Missing (NA) with specified codes listed in the external causes of death categories (Supporting Information Table S2). All disease classifications were taken from the primary causes of death except diabetes and Alzheimer disease, which also used secondary causes of death. Malignant neoplasms used codes defined in Supporting Information Table S1. Counts less than 11 are required by the Utah Department of Health to be reported only as <11. HR, hazard ratio; N, non-surgery group; S, surgery group

RESULTS

Table 1 indicates basic characteristics of the 21,837 matched surgery and non-surgery pairs. The majority of participants were female (79%). The most common procedure used was Roux-en-Y gastric bypass ($n = 15{,}110$; 69.2%), followed by gastric sleeve ($n = 3050$; 14.0%), adjustable gastric banding ($n = 2629$; 12.0%), and duodenal switch ($n = 1048$; 4.8%). Over 40 years (median = 10.8, IQR: 5.0-19.1 years), there were 2943 (13.5%) deaths for surgery patients and 3181 (14.6%) deaths for non-surgery participants. Death rates during the first year following index date were similar between groups, 111 deaths (0.5%) and 89 deaths (0.4%) in the surgery and non-surgery groups, respectively, $p = 0.14$ (Table 1). Mean age at index date was 42.2 years (SD: 11.7 years) and 42.3 years (SD: 11.9 years, $p = 0.60$), for surgery and non-surgery participants, respectively. Although mean BMI was significantly different between groups, the difference was only 0.2, indicating close BMI matching. Of the surgery and non-surgery participants, 94.4% and 87.6% ($p < 0.001$) were White, respectively, whereas 7.8% and 12.4% ($p < 0.001$) of surgery and non-surgery participants were Hispanic, respectively. Numbers of patients undergoing each type of bariatric surgery and year of surgery are shown in Supporting Information Table S3. In addition, the numbers of participants in each group meeting study inclusion and exclusion criteria are presented in Figure 1.

Distribution of deaths and death rates per 10,000 person years for all matched participants and for sex-specific matched participants are presented in Table 2. Rate of death from all causes was 16% lower in the surgery compared with non-surgery groups (hazard ratio [HR], 0.84; 95% CI: 0.79-0.90; $p < 0.001$; Figure 2). Total mortality was also significantly lower for surgery than non-surgery participants for both females (HR, 0.86; 95% CI: 0.80-0.93; $p < 0.001$) and males (HR, 0.79; 95% CI: 0.69-0.90; $p < 0.001$). Non-external deaths were lower among surgery versus non-surgery participants for combined sexes (HR, 0.74; 95% CI: 0.69-0.80; $p < 0.001$), females (HR, 0.76; 95% CI: 0. 70-0.83; $p < 0.001$), and males (HR, 0.68; 95% CI: 0.59-0.79; $p < 0.001$; Figure 2). Death rates were significantly lower for surgery compared with non-surgery participants (combined sexes) for diabetes (72% lower, $p < 0.001$), major cardiovascular

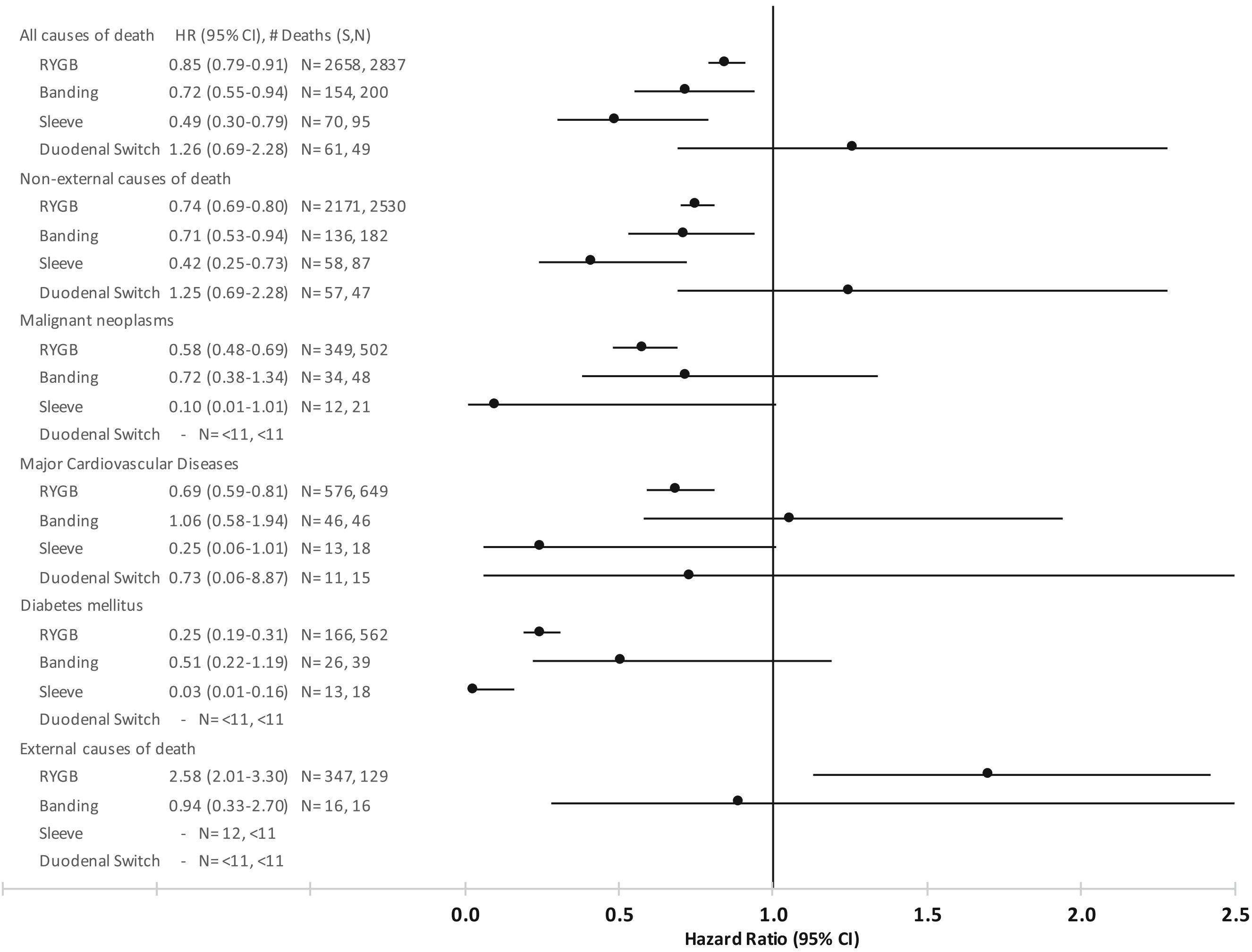


FIGURE 4 Mortality risks of bariatric surgery patients compared with non-surgery driver license applicant participants stratified by surgery type. Non-external causes of death defined as Natural or Pending Investigation with specified codes listed in the non-external causes of death categories (Supporting Information Table S2). External causes of death defined as suicide or homicide or accident or missing (NA) with specified codes listed in the external causes of death categories (Supporting Information Table S2). All disease classifications were taken from the primary causes of death except diabetes and Alzheimer disease, which also used secondary causes of death. Malignant neoplasms used codes defined in Supporting Information Table S1. Counts less than 11 are required by the Utah Department of Health to be reported only as <11. HR, hazard ratio; N, non-surgery group; RYGB, Roux-en-Y gastric bypass; S, surgery group

disease (29% lower, $p < 0.001$), cancer (43% lower, $p < 0.001$), and chronic lung disease (39% lower; $p = 0.04$). However, deaths from chronic liver disease were significantly greater among surgery than non-surgery participants (combined sexes; 83% higher, $p = 0.02$). For combined sexes and for females and males, external-caused death rates were significantly greater in the surgery group compared with the non-surgery group. Accidents and adverse effects were 92% higher ($p = 0.03$) and suicide was 140% higher ($p < 0.001$; Figure 2). Suicide after bariatric surgery was also significantly greater for both females and males.

Figure 3 indicates relative mortality risk in the surgery patients compared with non-surgery participants by age category at the time of surgery or driver license application/renewal. Although the 18- through 34- and 35- through 44-year age categories were the only groups to have significantly greater risk for external causes of death (HR, 3.63; 95% CI: 2.37-5.59; $p < 0.001$ and HR, 2.19; 95% CI: 1.46-3.31; $p < 0.001$, respectively), only the 18- through 34-year group had significantly greater suicide mortality (HR, 5.08; 95% CI: 1.97-13.09; $p = 0.001$).

Except for the 18-to-34-year group, all age categories had significantly lower mortality from all causes of death for surgery compared with non-surgery participants (Figure 3). The significantly greater all causes of death risk for surgery versus non-surgery participants in the 18- through 34-year category appeared related to greater risk for external causes of death among surgical patients in this age group. Chronic liver disease death risk was significantly greater among surgery versus non-surgery participants in the 18- through 34-year age category, but the number of deaths was small, leading to large CIs.

Analyses of mortality risk between surgery patients and non-surgery participants were stratified by type of bariatric surgical procedure (Figure 4). Gastric bypass, gastric banding, and sleeve gastrectomy each showed significantly lower total mortality risk for surgery compared with non-surgery participants: gastric bypass (HR, 0.85; 95% CI: 0.79-0.91; $p < 0.001$); gastric banding (HR, 0.72; 95% CI: 0.55-0.94; $p = 0.017$); and sleeve gastrectomy (HR, 0.49; 95% CI: 0.30-0.79; $p = 0.004$). Patients undergoing duodenal switch were the fewest in number, and these procedures were performed later in the follow-up time-period. Cancer, diabetes, and cardiovascular disease mortality were all significantly reduced after gastric bypass surgery. The number of deaths for other surgery procedures for cause-specific mortality were small, although diabetes mortality was significantly lower after sleeve gastrectomy.

Unadjusted Kaplan–Meier survival curves were estimated for non-external-, external-, and all-cause mortality risk by surgery and non-surgery participants (Supporting Information Figure S1). Restricted mean survival time for non-external deaths was 1.72 years longer (95% CI: 1.35 to 2.09; $p < 0.001$) for surgery compared with non-surgery participants (Supporting Information Figure S1). Survival time for external deaths was 0.4 years less (95% CI: −0.56 to −0.25; $p < 0.001$) for surgery patients versus non-surgery patients (Supporting Information Figure S2). Combined, survival time for all causes of death was 1.3 years (95% CI: 0.93 to 1.67; $p < 0.001$) longer for surgery compared with non-surgery participants (Supporting Information Figure S3).

DISCUSSION

Advancing the understanding of clinical efficacy of bariatric surgery has focused on short- and long-term outcomes of obesity-related comorbidities, including type 2 diabetes mellitus [4, 11–13], primary cardiovascular risk factors [14–16], cardiovascular events such as myocardial infarction and stroke [17–19], cancer [20, 21], and all-cause mortality [7, 9, 22]. Multiple association studies relating bariatric surgery and mortality outcomes have been reported, with wide variation in study design pertaining to the following: participant number; control cohorts; mean follow-up; procedure type; age at surgery; clinical end points (i.e., life expectancy and death rates for all cause and cause specific); and presence or absence of prevalent diabetes [3, 6, 23–35]. Study type has been predominately retrospective in nature, with the Swedish Obesity Subjects (SOS) study prospectively studied [7, 22].

This 40-year retrospective Utah study extends the mortality risks after bariatric surgery from the previously reported matching of 7925 surgical and non-surgical pairs to 21,837 matched pairs. This study now includes patients who had undergone the most common bariatric procedures performed today, doubling the number of previously reported gastric bypass patients ($n = 15{,}110$) and including 2629 gastric banding, 3050 sleeve gastrectomy, and 1048 duodenal switch patients. Mortality benefits related to bariatric surgery were shown to remain durable for multiple decades following surgery, with a significant 16% lower all causes of death for surgical versus matched non-surgical participants and a significant 14% and 21% reduction in all-cause mortality for female and male surgical patients, respectively, compared with non-surgical participants. Previously reported results did not show reduced mortality among the male surgical population but they were based on much smaller numbers of males. Furthermore, improved cause-specific mortality (cardiovascular, diabetes, and cancer) was shown for surgical patients compared with matched non-surgical participants. Cardiovascular and diabetes mortality risk was lower for both male and female surgical patients and lower for cancer for female surgical patients compared with the respective non-surgical participants. Finally, new to this study is a reported increase in deaths from cirrhosis of the liver, occurring primarily among the surgical patients who underwent bariatric surgery between ages 18 through 34 years. Clinical information concerning details of liver cirrhosis were not available, preventing us from further investigation of alcohol use, viral hepatitis, or fibrosis before or after baseline.

Surgical patients undergoing surgery between ages 35 and 44 years, 45 and 54 years, and 55 and 80 years had significantly lower mortality from all causes of death compared with non-surgical participants, suggesting bariatric surgery to be associated with a lower non-external mortality risk (i.e., cardiovascular disease and cancer). Significant results only in the older age groups should not imply patients necessarily postpone surgery until older age, as postsurgical complications have been shown to increase with increasing age at surgery and surgical postponement may result in worsened clinical status related to certain conditions such as orthopedic joint health. Finally, significantly improved all-cause mortality for surgical versus non-surgical participants was shown for individual surgical procedures (gastric bypass, gastric banding, and sleeve gastrectomy).

Consistent with previous findings [9], deaths related to external causes such as suicide and accidents were significantly greater (2.35 times) among bariatric surgery patients compared with matched non-surgical participants, with most of this increased mortality risk occurring among patients who were ages 18 to 34 years at the time of surgery. Utah state mortality rates for suicide were 1.0/10,000 person years for females and 3.6/10,000 for males ages 15 through 74 for the years 1999 to 2020 (https://ibis.health.utah.gov/). These rates are comparable to the non-surgical participants of our study with severe obesity suicide rates of 1.3/10,000 person years (female) and 2.9/10,000 person years (male). The surgery group rates of 3.0 for females and 8.2/10,000 persons-years for males are clearly higher than the population as a whole.

As mentioned, among the youngest age group there was a significant increase in mortality from cirrhosis of the liver. Mitchell et al. have reported that following certain bariatric surgery procedures there is increased disinhibition and impulsivity and increased rates of absorption of alcohol [36]. However, a recent study by Aminian et al. retrospectively followed patients who underwent bariatric surgery ($n = 650$) and non-surgical patients with obesity ($n = 508$) who all had baseline biopsy-proven fibrotic nonalcoholic steatohepatitis without cirrhosis [37]. After median follow-up of 7 years, bariatric surgery was significantly associated with a lower risk of major adverse liver outcomes, with five surgical and 40 non-surgical patients experiencing the adverse liver outcomes [37]. Alcohol use and clinical liver disease details were not available in our study. One possibility that would explain these discrepant results is that the increased mortality after bariatric surgery in our study was derived from those with possible liver cirrhosis at baseline, and, once cirrhosis has occurred, resolution is limited after surgery. Another possibility is that the risk estimates are unstable, despite the statistical significance, due to small sample sizes.

Recently reported mortality outcomes of the SOS study, with median follow-up of 20 to 24 years, reported a 23% lower mortality in the bariatric surgery group ($n = 2007$ patients) compared with the matched control group (HR, 0.77; 95% CI: 0.68-0.87; $p < 0.001$). With 69%, 18%, and 13% of surgical patients undergoing vertical banded gastroplasty, banding, and gastric bypass, respectively, their results showed an unadjusted median life expectancy of 2.4 years greater than non-surgical matched controls (95% CI: 1.2-3.5; $p < 0.001$). This reduction in mortality was similar to our Utah study, in which risk from all causes of death was 16% lower among surgical patients compared with non-surgical participants (HR, 0.84; 95% CI: 0.79-0.90; $p < 0.001$), with a mean extended life expectancy for all causes of deaths of 1.3 years (95% CI: 0.93-1.67; $p < 0.001$) The SOS study also reported a significantly reduced mortality of 30% and 23% for cardiovascular and cancer, respectively, for the surgery compared with non-surgical groups, similar to our Utah study, which reported a significant 29% and 43% lower risk for major cardiovascular diseases and cancer, respectively, when comparing the two groups. Finally, as pointed out by SOS authors [7], when considering populations who are at increased clinical risk such as patients with severe obesity, minimal gains in mean life expectancy (i.e., 1.3 years) are meaningful. Even with minimal benefits on overall mortality, studies have shown significantly increased quality of life after bariatric surgery [12].

A recently published one-stage meta-analysis explored the association of bariatric surgery with long-term survival, including patients with and without diabetes prior to their surgery. The study, which included 174,772 participants from 16 matched cohort studies and 1 prospective controlled trial, reported that bariatric surgery was associated with a significantly reduced hazard rate of death of 49.2% (95% CI: 46.3%-51.9%; $p < 0.0001$), with a calculated mean life expectancy of 6.1 years (95% CI: 5.2-6.9) longer among the surgical patients when compared with the usual care, non-surgical controls [38]. Furthermore, Syn et al. [38] performed subgroup analyses and reported that although surgical patients who did and did not have baseline diabetes had lower mortality rates when compared with non-surgical participants, long-term mortality and survival were more favorable for the bariatric surgery patients who at surgery had diabetes compared with surgical patients without baseline presence of diabetes. Further evidence of improved long-term survival following bariatric surgery was recently reported by Homberg et al. [39]. Investigators compared the all-cause mortality of patients in Sweden and Finland who had undergone gastric bypass with patients receiving sleeve gastrectomy. Among the 61,503 patients who were followed for a mean of 6.8 person years, both bariatric surgical procedures had similar all-cause mortality over the entire study duration. Subgroup analyses suggested that patients presenting with diabetes at time of surgery may have more favorable long-term mortality following gastric bypass when compared with sleeve gastrectomy [39]. Our retrospective study did not have clinical outcomes relating to whether patients and driver license participants had baseline diabetes.

An important limitation of our study relates to the lack of clinical data at the time of bariatric surgery or application date as well as the absence of clinical surveillance throughout the study. For example, we do not know how much weight was lost after surgery and throughout the follow-up period or the degree of weight maintenance in the driver license participants. The possibility that surgical and non-surgical participants were similar in physical health status at surgery or at driver license application is supported by a long-term prospective study our group has conducted on a subset of these surgical patients [12]. At baseline of the prospective study, there were no significant differences in clinical end points, (smoking status, hypertension, diabetes, dyslipidemia, or sleep apnea) between patients undergoing bariatric surgery ($n = 420$), patients seeking bariatric surgery but who did not have surgery ($n = 415$), and participants randomly selected from the population who had severe obesity and were not seeking bariatric surgery ($n = 321$) [40]. Current smoking prevalence in that study was 8% in the surgical patients compared with a northern Utah prevalence of 11% in persons aged ≥18 years using data from the Behavioral Risk Factor Surveillance System (https://healthassessment.utah.gov/access-brfss-data/). The low state smoking prevalence and similar prevalence in participants having bariatric surgery hopefully minimize bias from not having smoking data. Furthermore, at 12-year follow-up of our prospective study, with more than a 90% follow-up rate, the bariatric surgery group had sustained a mean change in body weight from baseline of −35 kg (−26.9%), while mean weight changes of the two non-surgical groups were −2.9 kg and 0 kg, respectively, minimizing the effects weight change might have over the follow-up period. Nevertheless, whether non-surgical participants who were part of our mortality analysis were less likely to choose and participate in healthy lifestyle practices or were less likely to engage in medical screening and treatment compared with patients who underwent bariatric surgery remains in question.

Because some of the bariatric procedures were developed more recently, follow-up time of these procedures was much shorter than for gastric bypass surgery. Therefore, the numbers of deaths after these surgeries were smaller, resulting in wider CIs around the HRs. HRs were separately provided for each procedure to address this limitation.

Multiple methodological-related strengths are associated with our study, specifically extended length of follow-up and different bariatric surgery procedures. This study extends from near the time gastric bypass procedures began in the United States to approval and initiation of gastric banding, followed by the rise in gastric sleeve. Close matching of surgical patients to driver license participants facilitated important physiologic and temporal alignment by which to compare mortality between groups, and the analyses of age at surgery provided unique insight into study results. Finally, UPDB strengthened the accuracy of mortality data extraction.

CONCLUSION

Results of this study attest to the decades-long durability of bariatric surgery in reducing death from all causes and reducing deaths related to cardiovascular disease, cancer, and diabetes when compared with matched participants with severe obesity. In addition, favorable mortality outcomes were evident for major bariatric surgery procedures. Serious concern, however, continues to be exhibited regarding increased mortality following bariatric surgery in relation to suicide, accidents, and cirrhosis of the liver. This study showed that the primary group associated with this untoward mortality outcome is patients choosing to have bariatric surgery between ages 18 and 34 years, suggesting that this age group may require more aggressive presurgical psychological screening and postsurgery follow-up. Finally, with what appears to be an ever-increasing rise in the percentage of individuals with severe obesity, coupled with the realization that, in practicality, bariatric surgery has limited treatment delivery, there remains an important research need to discover physiologic and biomolecular mechanisms leading to nonsurgical treatment that results in weight loss and improved mortality similar to that achieved by bariatric surgery.O

AUTHOR CONTRIBUTIONS

Huong Meeks, Alison Fraser, Steven C. Hunt, Jaewhan Kim, and Ted D. Adams conducted data analysis. John Holmen, Michael Newman, Alison Fraser, Lance E. Davidson, Jaewhan Kim, Anna R. Ibele, and Ted D. Adams extracted data for analysis. Huong Meeks, Steven C. Hunt, and Ted D. Adams prepared tables and figures. Ted D. Adams, Steven C. Hunt, Huong Meeks, Alison Fraser, Jaewhan Kim, and Lance E. Davidson interpreted analyses. Ted D. Adams was the main writer of manuscript. All authors were involved in writing the paper and had final approval of the submitted and published versions.

ACKNOWLEDGMENTS

Expressed thanks to Shelly Brimhall, Intermountain Surgical Specialties/Digestive Health Clinical Program, for assisting with the oversight of this study. Appreciation is expressed to staff members of the Utah Population Database who assisted with data linkage. We recognize the contributions of the following bariatric surgeons who performed patient surgeries: Legrand P. Belnap, MD, Daniel Cottam, MD, Charles Edwards, MD*, Gerald Goodman, MD*, Chad Halverson, MD*, Darrin Hansen, MD, Anna R. Ibele, MD, Rodrick D. McKinlay, MD, Walter Medlin, MD, John T. Miller, MD, Ellen Morrow, MD, Nicholas J. Paulk, MD, R. Richard Rasmussen, MD, Christina G. Richards, MD, Steven C. Simper, MD, Sherman Smith, MD*, J.J. Speakman, MD, Eric T. Volckmann, MD, and David Watts, MD (*deceased). We also acknowledge the contribution of specific personnel who assisted with data identification associated with bariatric surgical centers: Vikrant Deshmukh, PhD, Alicia Allen, MBA, RD, Amit Surve, MD, Ray Wilde, Roger L. Naylor, and Joel Upshaw. Finally, partial support for all data sets within the Utah Population Database was provided by the University of Utah Huntsman Cancer Institute and the Huntsman Cancer Institute Cancer Center Support grant P30 CA2014 from the National Cancer Institute. The Utah Cancer Registry is funded by the National Cancer Institute's Surveillance, Epidemiology, and End Results Program, Contract No. HHSN261201800016I, and the US Centers for Disease Control and Prevention's National Program of Cancer Registries, Cooperative Agreement No. NU58DP006320, with additional support from the University of Utah and Huntsman Cancer Foundation.

CONFLICT OF INTEREST

Ted D. Adams has received research funding from Ethicon Endo-Surgery and Intermountain Medical Research and Education Foundation of Intermountain Healthcare. Steven C. Hunt has received funding the Biomedical Research Program at Weill Cornell Medicine in Qatar, a program funded by the Qatar Foundation. All other authors declared no conflict of interest.

ORCID

Ted D. Adams https://orcid.org/0000-0002-9853-446X
Lance E. Davidson https://orcid.org/0000-0002-1383-0666

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*, no. 360. National Center for Health Statistics; 2020.
2. Kuno T, Tanimoto E, Morita S, Shimada YJ. Effects of bariatric surgery on cardiovascular disease: a concise update of recent advances. *Front Cardiovasc Med*. 2019;6:94. doi:10.3389/fcvm.2019.00094
3. Moussa OM, Erridge S, Chidambaram S, Ziprin P, Darzi A, Purkayastha S. Mortality of the severely obese: a population study. *Ann Surg*. 2019;269:1087-1091.
4. Gloy VL, Briel M, Bhatt DL, et al. Bariatric surgery versus non-surgical treatment for obesity: a systematic review and meta-analysis of randomised controlled trials. *BMJ*. 2013;347:f5934. doi:10.1136/bmj.f5934
5. 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;271:201-209.
6. Kauppila JH, Tao W, Santoni G, et al. Effects of obesity surgery on overall and disease-specific mortality in a 5-country population-based study. *Gastroenterology*. 2019;157:119-127.e1.
7. Carlsson LMS, Sjoholm K, Jacobson P, et al. Life expectancy after bariatric surgery in the Swedish Obese Subjects study. *N Engl J Med*. 2020;383:1535-1543.
8. Sandoval DA. Mechanisms for the metabolic success of bariatric surgery. *J Neuroendocrinol*. 2019;31:e12708. doi:10.1111/jne.12708
9. Adams TD, Gress RE, Smith SC, et al. Long-term mortality after gastric bypass surgery. *N Engl J Med*. 2007;357:753-761.
10. Therneau T, Grumbsch P. *Modeling Survival Data: Extending the Cox Model*. I. Springer-Verlag; 2000.
11. Carlsson LM, Peltonen M, Ahlin S, et al. Bariatric surgery and prevention of type 2 diabetes in Swedish obese subjects. *N Engl J Med*. 2012;367:695-704.
12. Adams TD, Davidson LE, Hunt SC. Weight and metabolic outcomes 12 years after gastric bypass. *N Engl J Med*. 2018;378:93-96.
13. Schauer PR, Bhatt DL, Kashyap SR. Bariatric surgery or intensive medical therapy for diabetes after 5 years. *N Engl J Med*. 2017;376:1997. doi:10.1056/NEJMc1703377
14. Buchwald H, Avidor Y, Braunwald E, et al. Bariatric surgery: a systematic review and meta-analysis. *JAMA*. 2004;292:1724-1737.
15. Sjostrom L, Lindroos AK, Peltonen M, et al. Lifestyle, diabetes, and cardiovascular risk factors 10 years after bariatric surgery. *N Engl J Med*. 2004;351:2683-2693.

16. Ikramuddin S, Korner J, Lee WJ, et al. Roux-en-Y gastric bypass vs intensive medical management for the control of type 2 diabetes, hypertension, and hyperlipidemia: the diabetes surgery study randomized clinical trial. *JAMA*. 2013;309:2240-2249.
17. Sjostrom L, Peltonen M, Jacobson P, et al. Bariatric surgery and long-term cardiovascular events. *JAMA*. 2012;307:56-65.
18. Fisher DP, Johnson E, Haneuse S, et al. Association between bariatric surgery and macrovascular disease outcomes in patients with type 2 diabetes and severe obesity. *JAMA*. 2018;320:1570-1582.
19. Aminian A, Aleassa EM, Bhatt DL, et al. Bariatric surgery is associated with a lower rate of death after myocardial infarction and stroke: a nationwide study. *Diabetes Obes Metab*. 2019;21:2058-2067.
20. Adams TD, Stroup AM, Gress RE, et al. Cancer incidence and mortality after gastric bypass surgery. *Obesity (Silver Spring)*. 2009;17:796-802.
21. Schauer DP, Feigelson HS, Koebnick C, et al. Bariatric surgery and the risk of cancer in a large multisite cohort. *Ann Surg*. 2019;269:95-101.
22. Sjostrom L, Narbro K, Sjostrom CD, et al. Effects of bariatric surgery on mortality in Swedish obese subjects. *N Engl J Med*. 2007;357:741-752.
23. Adams TD, Mehta TS, Davidson LE, Hunt SC. All-cause and cause-specific mortality associated with bariatric surgery: a review. *Curr Atheroscler Rep*. 2015;17:74. doi:10.1007/s11883-015-0551-4
24. Eliasson B, Liakopoulos V, Franzen S, et al. Cardiovascular disease and mortality in patients with type 2 diabetes after bariatric surgery in Sweden: a nationwide, matched, observational cohort study. *Lancet Diabetes Endocrinol*. 2015;3:847-854.
25. Davidson LE, Adams TD, Kim J, et al. Association of patient age at gastric bypass surgery with long-term all-cause and cause-specific mortality. *JAMA Surg*. 2016;151:631-637.
26. Cardoso L, Rodrigues D, Gomes L, Carrilho F. Short- and long-term mortality after bariatric surgery: a systematic review and meta-analysis. *Diabetes Obes Metab*. 2017;19:1223-1232.
27. Aminian A, Zajichek A, Arterburn DE, et al. Association of metabolic surgery with major adverse cardiovascular outcomes in patients with type 2 diabetes and obesity. *JAMA*. 2019;322:1271-1282.
28. Reges O, Greenland P, Dicker D, et al. Association of bariatric surgery using laparoscopic banding, Roux-en-Y gastric bypass, or laparoscopic sleeve gastrectomy vs usual care obesity management with all-cause mortality. *JAMA*. 2018;319:279-290.
29. Pontiroli AE, Zakaria AS, Fanchini M, et al. A 23-year study of mortality and development of co-morbidities in patients with obesity undergoing bariatric surgery (laparoscopic gastric banding) in comparison with medical treatment of obesity. *Cardiovasc Diabetol*. 2018;17:161. doi:10.1186/s12933-018-0801-1
30. Singh P, Subramanian A, Adderley N, et al. Impact of bariatric surgery on cardiovascular outcomes and mortality: a population-based cohort study. *Br J Surg*. 2020;107:432-442.
31. Ceriani V, Sarro G, Micheletto G, et al. Long-term mortality in obese subjects undergoing malabsorptive surgery (biliopancreatic diversion and biliointestinal bypass) versus medical treatment. *Int J Obes (Lond)*. 2019;43:1147-1153.
32. Lim RBC, Zhang MWB, Ho RCM. Prevalence of all-cause mortality and suicide among bariatric surgery cohorts: a meta-analysis. *Int J Environ Res Public Health*. 2018;15:1519. doi:10.3390/ijerph15071519
33. Dhalwani NN, Zaccardi F, Waheed H, et al. Cardiovascular, cancer and mortality events after bariatric surgery in people with and without pre-existing diabetes: a nationwide study. *J Diabetes*. 2019;11:265-272.
34. White GE, Courcoulas AP, King WC, et al. Mortality after bariatric surgery: findings from a 7-year multicenter cohort study. *Surg Obes Relat Dis*. 2019;15:1755-1765.
35. Thereaux J, Lesuffleur T, Czernichow S, et al. Long-term adverse events after sleeve gastrectomy or gastric bypass: a 7-year nationwide, observational, population-based, cohort study. *Lancet Diabetes Endocrinol*. 2019;7:786-795.
36. Mitchell JE, Crosby R, de Zwaan M, et al. Possible risk factors for increased suicide following bariatric surgery. *Obesity (Silver Spring)*. 2013;21:665-672.
37. Aminian A, Al-Kurd A, Wilson R, et al. Association of bariatric surgery with major adverse liver and cardiovascular outcomes in patients with biopsy-proven nonalcoholic steatohepatitis. *JAMA*. 2021;326:2031-2042.
38. Syn NL, Cummings DE, Wang LZ, et al. Association of metabolic-bariatric surgery with long-term survival in adults with and without diabetes: a one-stage meta-analysis of matched cohort and prospective controlled studies with 174 772 participants. *Lancet*. 2021;397:1830-1841.
39. Holmberg D, Santoni G, Kauppila JH, Markar SR, Lagergren J. Long-term survival after sleeve gastrectomy versus gastric bypass in a binational cohort study. *Diabetes Care*. 2022;45:1981-1986.
40. Adams TD, Pendleton RC, Strong MB, et al. Health outcomes of gastric bypass patients compared to nonsurgical, nonintervened severely obese. *Obesity (Silver Spring)*. 2010;18:121-130.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Adams TD, Meeks H, Fraser A, et al. Long-term all-cause and cause-specific mortality for four bariatric surgery procedures. *Obesity (Silver Spring)*. 2023;31(2):574-585. doi:10.1002/oby.23646