Title: Does bariatric surgery reduce future hospital costs? A propensity score-matched analysis using UK Biobank Study data

Short running title: Bariatric surgery in the UK Biobank

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Abstract

Objectives: To estimate the hospital costs among persons with obesity undergoing bariatric surgery compared to those without bariatric surgery.

Methods: We analysed the UK Biobank Cohort study linked to Hospital Episode Statistics, for all adults with obesity undergoing bariatric surgery at National Health Service hospitals in England, Scotland, or Wales from 2006 to 2017. Surgery patients were matched with controls who did not have bariatric surgery using propensity scores approach with a ratio of up to 1-to-5 by year. Inverse probability of censoring weighting was used to correct for potential informative censoring. Annual and cumulative hospital costs were assessed for the surgery and control groups.

Results: We identified 348 surgical patients (198 gastric bypass, 73 sleeve gastrectomy, 77 gastric banding) during the study period. 324 surgical patients and 1,506 matched control participants were included after propensity-score matching. Mean five-year cumulative hospital costs were €11,659 for 348 surgical patients. Compared with controls, surgical patients (n=324) had significantly higher inpatient expenditures in the surgery year (€7,289 vs. €2,635, $P<0.001$), but lower costs in the subsequent 4 years. The five-year cumulative costs were €11,176 for surgical patients and €8,759 for controls ($P=0.001$).

Conclusions: Bariatric surgery significantly increased the inpatient costs in the surgery year, but was associated with decreased costs in the subsequent 4 years. However, any cost savings made up to 4 years were not enough to compensate for the initial surgical expenditure.

Keywords: Bariatric surgery, Comorbidity, Mortality, Readmission, UK Biobank, cost effectiveness

Introduction

The increased prevalence of obesity and obesity-related comorbidities, such as diabetes, are placing a significant strain on health, health care and the economy worldwide[1-3]. It is projected that the global prevalence of obesity will reach 18% and 21% in men and women respectively by 2025[4]. The economic impact of obesity is also substantial, causing an estimated gross domestic production loss of 2.08% in the US[5]. Several large cohort studies and systematic reviews have shown a positive relationship between body mass index (BMI) and healthcare costs, driven by the increased use of hospital in-patient services, primary care services and medications[6-8]. Such evidence raises questions about the extent to which reducing obesity can reduce this strain. Standard treatment for adult obesity management takes a stepwise approach, first offering lifestyle modifications, followed by pharmacological or surgical approaches. In order to understand the potential for these treatments to help reduce the wide-ranging pressures from obesity, it is important to compare their costs against costs offset the following treatment. In this paper, we explicitly examine whether surgical treatment for obesity is able to reduce health care costs, by comparing healthcare costs of obese patients who undergo bariatric surgery against people with obesity who do not undergo surgery.

In the United Kingdom (UK), National Institute for Health and Care Excellence (NICE) guidance on obesity management[9] considers bariatric surgery as a treatment option for those with a BMI ≥40kg/m^2 or a BMI of 35-40kg/m^2 and pre-existing comorbidity that could be improved with weight loss (e.g. type 2 diabetes mellitus (T2DM) or high blood pressure or for individuals with a BMI of 30-35kg/m^2 and recent-onset of T2DM.

Several studies have demonstrated that bariatric surgery can reduce the incidence of new-onset diseases, such as cardiovascular disease, end-stage renal disease and cancer, and alleviate the impact of existing comorbidities, for example, diabetes and hypertension[10-14]. However, despite evidence showing that bariatric surgery is effective, several issues relating to safety, including hospital re-admission, re-operation and surgery-related mortality remain[15,16]. A systematic review and meta-analysis found that bariatric surgery is associated with low short-term mortality (<30 days), and may reduce long-term all-cause mortality (≥2 years) [17]. However, for other safety outcomes, most published papers only report short-term safety outcomes (i.e. no more than one year), with results varying across studies. For example, rates of hospital readmission range from 1.2% to 6.5% within 30 days[18,19], 10% within 90 days[20], and up to 13% within one year after the surgery[21]. Similarly, there is heterogeneity in reoperation rates, which are dependent on the type of bariatric surgery performed[22] and surgical skills[23].

In terms of information on treatment costs, these are available from several sources[24]. For example, a detailed UK micro-costing study reported the mean procedural costs were £5,002, £4,306 and £2,527 for Roux-en-Y gastric bypass, sleeve gastrectomy and adjustable gastric band, respectively[25]. However, the impact of bariatric surgery on the costs incurred after surgery and subsequent years was not measured in this study. Cost-utility and cost-effectiveness analyses also assessed the costs of bariatric surgery in UK contexts[26,27], but their estimates may be largely affected by the underlying model assumptions and input variables. Several studies have measured the medical costs incurred by patients with bariatric surgery in other countries[28-32]. Nevertheless, different healthcare systems and analytic perspectives made these results not generalizable to the UK. Besides, mixed results showed by these studies led to uncertainty surrounding the net impact of bariatric surgery on future healthcare costs.

Our study primarily aimed to compare the annual and cumulative inpatient costs of bariatric surgery patients, compared to individuals with obesity who did not have surgery using data from the UK Biobank (UKB) cohort. We also examined the impacts of pre-existing morbidities (e.g diabetes) on hospital costs as well as potential percentage changes in patients who have been diagnosed with various comorbidities over the years, and finally to report the alternative types of bariatric surgery by measuring re-operation, hospital readmission, and all-cause mortality.

Materials/Subjects and methods

UK Biobank and data linkage

The UKB project is a large cohort study, which recruited approximately 500,000 adults aged 40-69 years from England, Scotland and Wales between 2006 and 2010[33]. UKB has approval from the North West Multi-centre Research Ethics Committee. At recruitment, participants, who consent to participate UKB, completed a detailed questionnaire including information on their demographics, physical characteristics and health history. Data collection is still ongoing for participants recruited and can be seen in the Biobank showcase: https://biobank.ctsu.ox.ac.uk/showcase/.

UKB participant data are linked to NHS central registers for information on death and cancer registrations, and to country-specific (England, Scotland, Wales) hospital admission records for information on inpatient and day-case admissions up to March 31st, 2017 and diagnoses and operations made during hospital inpatient admissions. The hospital admission records used were Hospital Episode Statistics (HES) for participants in England, Scottish Morbidity Records and the Patient Episode Database for Wales. Record linkage was joined records from different data sources by NHS number, postcode, sex, and age. Data are available on hospital admissions from 1985 for Scotland, and from 1997 for England and Wales.

Data collection

Demographic characteristics (age, gender, ethnicity, country of birth, education, socioeconomic status, BMI categories), lifestyle information (smoking and drinking status), and self-reported health outcomes at baseline were collected for UKB. Dates and duration of hospitalisation, and International Classification of Diseases 10th revision (ICD-10) diagnostic codes[34] and Office for Population Censuses and Statistics (OPCS-4) procedural codes recorded during each hospital episode were also extracted from linked HES data for each patient. While demographic information, some self-reported outcomes, and BMI were recorded at the UKB entry, clinical laboratory test results, date of disease remission, use of medications, and change in BMI over time were unavailable.

Study participants

All adult participants who participated in the UKB study from 2006 onwards were included in our analysis. Patients having sleeve gastrectomy, gastric bypass and gastric banding were assigned to the surgery group but duodenal switch was excluded due to small sample size (n=1 procedure) in the UKB data. Participants without diagnostic codes of overweight and obesity or those with diagnostic codes of malignant neoplasms were also excluded. The list of the OPCS-4 codes used for identifying bariatric surgery was referenced to previous literature [15,35] and found in Supplemental Material (Supplemental Table 1). Bariatric surgery patients were then matched with controls using the propensity score matching method with a ratio of up to 1-to-5.

Propensity Score matching and inverse probability of censoring weighting

Propensity score is a measure of the probability that a patient receives treatment given observed covariates. Propensity scores were estimated by logistic regression with the dependent variable as the treatment of bariatric surgery vs control, and the observed baseline covariates. Stata command 'gmatch' with calliper criterion of 0.05 was used to match each bariatric surgery patient with up to 5 closest controls, who have never undergone bariatric surgery on or before the initial surgery date of their matched surgery patients. The index date of the surgery group was the date of the first bariatric surgery, and that of controls was the index date of their matched surgical patients. The inverse probability of censoring weighting technique was applied to correct for the informative censoring by giving extra weights to subjects who are not censored. In our case, control participants who received bariatric surgery after the index date or lost to follow up were considered as censored cases. The logistic regression modelled by gender, age, waist circumstances, hip circumstance, smoking and drinking status, and history of comorbidities, was used to estimate the probability of censoring.

Participants were matched according to their index year and baseline covariates. Baseline covariates included the age, gender, ethnicity (British or non-British/missing), alcohol consumption status (never, previous, or current), smoking status (never, previous, or current), socioeconomic status, and pre-existing comorbidities. Socioeconomic status was based on the Townsend deprivation index[36] collected at UKB study entry. Pre-existing comorbidities included abnormal glucose tolerance, atrial fibrillation, ischaemic heart diseases, cerebrovascular diseases, degenerative joint disease, type 2 diabetes, dyslipidaemia, gallstone, gastroesophageal reflux disease, hypertension, obstructive sleep apnoea, infertility, and nutritional anaemias and deficiencies, defined by ICD-10 codes in linked HES data (both primary and secondary diagnoses were considered). However, when identifying patients with diabetes at baseline, those who either with self-reported doctor diagnosis diabetes in UKB data or with diagnosis codes of diabetes in HES data were regarded as patients with diabetes. A standardised mean difference of <0.2 indicated optimal balance between the two groups[37].

Hospital costs estimation

Hospital resource use and associated costs for preoperative diagnostic tests, surgical procedures (sleeve gastrectomy, gastric bypass, and gastric banding), post-operative complications, and obesity-related and non-obesity-related comorbidities were included in the analysis. Hospital admission records provide data including start and end dates, ICD-10 codes and OPCS-4 codes. Each record is attached to one core healthcare resource group (HRG) and any number of additional unbundled HRGs, representing high-cost components of care. HRGs include clinically similar admissions requiring similar resources[38,39]. Costs in UK 2016 prices are then attached to the HRGs using NHS Reference Costs 2016-17, which provide the average cost of treating patients within a given HRG across different settings in England[40]. Hospital records were deemed to be part of the same admission if they had overlapping durations. For each patient, inpatient costs incurred in each hospital episode were collected. Monetary values in £GBP were converted to €EUR at a rate of £1.00 = €1.1414 (the average exchange rate in 2017).

Stata command ‘hcost’ was applied to estimate the annual and cumulative inpatient costs[41]. This command can estimate the mean health costs accumulated within any time period with censored data. Variables, including survival times or censoring time, start and end date of hospital episode, costs incurred during each hospital episode, and death indicators, were incorporated in this command.

Statistical Analysis

Descriptive statistics including mean, standard deviation (SD) and 95% confidence interval (CI) were used to present patients baseline demographics and clinical characteristics according to bariatric surgery and matched control groups.

The total inpatient costs in the surgery year and subsequent 4 years were reported for the surgery group and the control group. We further examined whether the effects of bariatric surgery on 5-year cumulative costs were different among patients with a history of comorbidities. Annual and cumulative inpatient costs were visualised and compared among patients with and without above pre-existing comorbidities between groups. A sensitivity analysis, excluding patients with highest and lowest 5% inpatient costs, was conducted in overall patients and patients with different pre-existing comorbidities. Also, the 5-year inpatient costs of patients who had BMI recordings within 3 years of the index date were measured. BMI was included as restricted cubic splines with 5 knots at the BMI values of 33.67, 40.05, 44.02, 48.03, and 57.20 kg/m^2 in the logistic regression when calculating the propensity score.

Percentages of patients with different comorbidities were tracked from the index date to up to 5 years after the index date. Numerous studies have reported remissions of obesity-related comorbidities, such as type 2 diabetes, hypertension, dyslipidaemia and cardiovascular diseases, following bariatric surgery[42]. However, we did not adjust the number of patients with comorbidities for disease remissions, since relevant data, such as date of remission, clinical laboratory test results and prescriptions, were unavailable in our dataset. Instead we assumed that once patients were diagnosed with the disease, they would carry the disease without remissions; and percentages in this study were calculated as the number of patients who have ever had the diagnosis code of the disease at each measurement point divided by the total number of patients. Incidence rates of readmission and all-cause mortality were measured. Besides, 1-month, 1-year and lifetime reoperation rates, re-admission rates and mortality rates were measured for matched surgical patients.

All statistical analyses were performed using Stata version 13.1 (StataCorp LP, College Station, Texas). All significance tests were two- tailed and P-values <0.05 were taken to indicate statistical significance.

Results

Baseline Characteristic of Study Participants

A total of 783 out of 502,616 UKB participants were identified as having bariatric surgery codes. After removing patients whose surgery was before the UKB registration date, those with a prior cancer diagnosis and those without ICD-10 code of obesity or overweight, 348 eligible bariatric surgery patients remained (Figure 1). Of these, 198 (56.9%), 73 (21.0%) and 77 (22.1%) underwent gastric bypass, sleeve gastrectomy, and gastric banding, respectively. The mean age (SD) of 348 surgical patients was 55 years (7.0). (Table 1)

After 1-to-5 propensity score matching, 324 surgical patients (187 [57.7%] gastric bypass, 67 [20.7%] gastric banding and 70 [21.6%] sleeve gastrectomy) and 1,506 matched controls were included in the analysis. The baseline characteristics of the surgery group and the control group were well balanced, as all absolute standardised mean difference (ASMD) values were less than 0.2 [37]. The age of included patients were 55 years, and all of them were categorised as having obesity (BMI ≥30kg/m^2). Most patients in both groups were female (≥69.8%), British (≥80.2%), current drinkers (≥82.3%) and non-current smokers (≥89.4%).

Trends of Hospital Costs

The hospital costs incurred in the surgery year were lowest for gastric banding (€6,510, 95% CI: €5,758-€7,263) and sleeve gastrectomy (€6,886, 95% CI: €5,568-€8,204), and highest for gastric bypass (€7,889, 95% CI: €6,986-€8,793). Thereafter, the inpatient costs dropped significantly for all surgical patients. The mean inpatient expenditure for bariatric surgery patients decreased from €7,378 (95% CI: €6,763-€7,993) to €1,451 (95% CI: €1,077-€1,826) at year 2, reducing further to €714 (95% CI: €406-€1,022) at the last year of follow-up. Sleeve gastrectomy incurred the lowest hospital costs at year 5 (€238, 95% CI: €-151-€626), followed by gastric banding (€466, 95% CI: €73-€859) and gastric bypass (€979, 95% CI: €490-€1,468). Over the five years, the mean cumulative hospital costs for bariatric patients reached €11,659 (95% CI: €10,304-€13,014), ranging from €9,274 (95% CI: €7,162-€11,387) for sleeve gastrectomy patients to €13,061 (95% CI: €10,979-€15,143) for gastric bypass patients. (Figure 2a and Supplemental Table 2)

Although surgical patients had significantly higher inpatient expenditure in the index year (surgery: €7,289 vs control: €2,635, $P<0.001$), the inpatient costs of surgical patients were nearly half those of controls and the differences were statistically significant. The mean hospital costs of both bariatric patients and controls dropped to €464 and €816, respectively ($P=0.018$). However, patients in the surgery group had significantly higher cumulative hospital costs than matched controls over the five years (surgery: €11,176 vs control: €8,759, $P=0.001$). (Figure 2b and Supplemental Table 2)

Trends of Hospital costs by pre-existing comorbidities

Hospital costs incurred by patients with different pre-existing comorbidities over the five years are displayed in Supplemental Figure 1. There was no evidence indicating that bariatric surgery significantly altered the 5-year cumulative inpatient costs of patients with a history of ischaemic heart diseases, obstructive sleep apnoea, type 2 diabetes and dyslipidaemia(Supplemental Table 3). However, bariatric surgery significantly increased the cumulative costs of patients with degenerative joint disease by €3,641 (P=0.034). Of special note, the cumulative inpatient costs for surgical and control patients with pre-existing diabetes or ischaemic heart disease converged at 3 years and afterwards (Supplemental Figure 1).

Re-operation, re-admission and all-cause mortality

Over a mean follow-up period of 59 months with 1,714 person-years, 10 and 235 out of the 348 surgical patients died and had hospital re-admission events, respectively. Estimated incidence rates of all-cause mortality and hospital re-admission were 0.58 and 33.78 cases per 100 person-years, respectively. Gastric bypass had the higest incidence of all-cause mortality (0.82/100 person-years, 95% CI: 0.35-1.62/100 person-years); gastric banding had the higest incidence of hospital re-admission (41.61/100 person-years, 95% CI: 31.35-54.16/100 person-years) but the lowest incidence of all-cause mortality (0.25/100 person-years, 95% CI: 0.01-1.40/100 person-years); and sleeve gastrectomy had lowest incidence of hospital re-admission (21.86/100 person-years, 95% CI: 15.76-29.55/100 person-cases). (Supplemental Table 4)

Reoperation and all-cause mortality events did not occur within one month after the surgery. No gastric bypass patients were found to have re-operation after the initial surgery, while up to 12.3% of patients with gastric band have reoperations after the first month following their initial surgery. (Supplemental Figure 2)

However, there is no strong evidence in our study indicating that one surgical type is superior to the orther tow in terms of risks of all-mortliaty, hospital readmission and re-operations.

Changes of comorbidities

Changes of percentages of patients who have ever been diagnosed with comorbidities were depicted in Supplemental Figure 3. The percentages increased over time, since the UKB dataset did not include adjustments for patients who had disease remissions. Percentages of control patients who have ever diagnosed with degenerative joint disease (5.2% vs. 5.8%), obstructive sleep aopnoea (0.3% vs. 1.3%), and malignant neoplasms (1.5% vs. 1.9%) increased more rapidly than those of patients in the surgery group during the 5-year observation. However, surgical patients had higher incremental percentages of atrial fibrillation (1.9% vs. 0.9%), dyslipidaemia (3.1% vs. 1.4%), gastroesophageal reflux disease (2.8% vs. 1.2%), and nutritional anaemias and deficiencies (3.1% vs. 2.2%) than control patients over the years.

Sensitivity analysis

The results of sensitivity analysis are displayed in Supplemental Table 5. After excluding patients incurred highest and lowest 5% inpatient costs, 5-year cumulative costs for surgical patients and controls are €9,111 (95%CI: €8412-€9811) and €5,950 (95%CI: €5555-€6345) (P<0.001), respectively. As for patients with pre-existing comorbidities, the results were similar to those in the main analysis.

For patients who had BMI recordings within 3 years of the index date, the baseline covariates were balanced between the surgery and the control groups after incorporating BMI in the propensity score matching. Surgical patients (€7828, 95%CI €6539-€9116) had higher inpatient costs than controls (€2055 95%CI: €1494-€2617) in year 1 (P<0.001). Also, surgical patients incurred greater 5-year cumulative costs than control subjects. However, surgical patients had smaller inpatient costs than controls in year 2 to 5.

Discussion

This study assessed the inpatient costs of 324 surgical patients and 1,506 matched control participants who participated in the UKB study over a five-year time horizon, using a propensity score-matching approach. The key finding was that despite bariatric surgery substantially increasing inpatient costs in the year of surgery, it reduced expenditures in next four years. However, the costs saved in these further years were not enough to fully compensate the initial costs of surgery. The increased inpatient costs were mainly due to the re-operations and re-admissions that occurred intensively within the year of surgery, apart from inpatient costs due to first surgery (Figure 3). However, it should be noted that UKB does not contain data on surgical learning curves, and whether the observed re-operations or re-admissions of a specific procedure occurred in surgical centres that were past the learning curve is unknown.

Our finding was in agreement with previous studies[30,32,43-45], which suggested that inpatient expenditures for bariatric surgery patients were highest in the year of surgery and decreased in the subsequent years. However, evidence is mixed on whether bariatric surgery is cost-saving within a time horizon of less than 10 years[46]. Makary et al. (2010) concluded that bariatric surgery was associated with reduced healthcare costs over a 3-year follow-up[47]. A systematic review and meta-analysis from Xia et al[46] found that compared with 1-year pre-surgical costs, the annual post-surgical health care costs in terms of the longest post-surgical follow up (Follow-up years after surgery ranged from 1 to 6 years) was lower. However, unlike our study, the above two studies did not provide results from comparisons between groups, therefore any cost comparisons between a surgery and a control group are unknown. Weiner et al. (2013) found that inpatient costs of surgical patients reduced after the index year but were higher than those of control patients in the 6-year post-surgery period[31]. Keating et al. (2015) suggested that bariatric surgery patients had similar inpatient costs to control participants from year 2 to year 15[30]. Smith et al. (2019) predicted that inpatient costs of the surgery cohort decreased after the date of surgery, but would not be lower than those of the control cohort until 85-90 months after surgery[43]. Similarly, Tarride and his team found Roux-en-Y gastric bypass increased the healthcare expenditures in 3 years[48]. Our study suggested that bariatric surgery lowered the inpatient costs immediately after the year of surgery. Whilst bariatric surgery was not cost saving at five years, the gaps of cumulative inpatient expenditures between the two groups become narrower over the years, thus there is possibility that the cumulative costs of controls would exceed those of surgical patients after 5 years. Indeed, many cost-effectiveness analyses of bariatric surgery have suggested that bariatric surgery is a cost-saving alternative to conventional therapies in the long term (≥10 years)[27,46,49,50]. Although bariatric surgery may not be cost-saving in the short term, several studies suggests that bariatric surgery is associated with substantial health gains at costs that are well below willingness to pay thresholds typically adopted for cost-effectiveness evaluations[26,45].

Our study also provided inpatient costs of patients with three main types of bariatric procedures separately. Most previous studies conducted costing analyses for a single surgical procedure[45,48,51-53] or provided a combined result[47], while few of them measured the costs by surgical types[31,54]. We observed that the inpatient expenditures were the lowest for gastric banding but were the highest for gastric bypass in the year of surgery. This finding was supported by a previous study, which found that the mean hospital stays of patients who underwent gastric bypass were longer than those of patients treated with gastric banding in the surgery year[44]. One plausible explanation is that gastric bypass exposes patients to higher risks of early complications when compared with gastric banding[55-57]. With the lowest five-year cumulative costs, sleeve gastrectomy incurred the lowest inpatient costs in the later years. In fact, previous cohort studies comparing the effectiveness of sleeve gastrectomy, gastric bypass and gastric banding concluded that sleeve gastrectomy would be a reasonable choice for the treatment of obesity, as this surgery had lower complications[57] and risks of hospitalisation[58] than the other two procedures. However, large-scale randomised controlled trials, such as the UK By-Band-Sleeve study[59], designed to provide comprehensive outcomes on weight loss, quality of life and reductions in comorbidities among patients with different surgery types would be preferred, as it has been designed to provide generalizable results. In addition, both patients' preferences and bariatric surgeons' suggestions are important determinants when choosing a suitable bariatric procedure for patients.

The exploratory analysis assessed the impacts of bariatric surgery on 5-year cumulative inpatient expenditures among patients with certain comorbidities. The results indicated that bariatric surgery significantly increase the cumulative inpatient costs of patients with degenerative joint disease over the five years. Though the mechanism behind the finding is unknown, possible explanations are 1) treating degenerative joint disease incurs great health care costs, especially when a hip and knee replacement is needed[60]; and 2) saved inpatient costs from receiving bariatric surgery can hardly compensate for the costly treatment for patients with degenerative joint disease. As for patients with diabetes, however, our finding suggested that the savings in hospitalization costs for surgical patients could offset the initial surgical costs, since the cumulative inpatient costs between the two groups converged at 3 years and afterwards. It is probably because bariatric surgery can alleviate the disease or reduce the risks of diabetes-related hospitalization. Indeed, previous studies have already shown that bariatric surgery patients had higher diseases remission rates of T2DM than non-surgical patients[42,61]. Potential cost savings may be achieved for surgical patients in later years, if their annual medical costs were lowered because of reduced risks of hospitalization due to diabetes or diabetes-related comorbidities. In this regards, underlying comorbidities should be taken into considerations when addressing the trade-offs between potential benefits and costs of bariatric surgery.

Several limitations of our study should be acknowledged. Firstly, there was potential bias due to the observational study design. Although propensity-score matching was used to balance the observable characteristics of two groups, several unmeasured covariates, such as health seeking behaviour, use of medications, BMI, and other critical clinical parameters were not incorporated and may bias the study results. In addition, neither the baseline characteristics of surgical patients with different surgical types, nor the baseline characteristics of patients with or without different comorbidities, were balanced. Thus, the results from these comparisons could be confounded and should be interpreted with caution. Secondly, only inpatient costs were presented in this study. Other direct cost items including outpatient services, ambulatory services, and pharmacy costs were not considered. Besides, indirect health costs due to early mortality, absenteeism and reduced productivity of employees were also not measured in our study[46,62]. Thirdly, both the duration of follow-up period and the sample size were limited. We set the observation period as 5 years because over half (55.5%) of the people who underwent bariatric surgery in and after 2012 did not reach more than 5 year follow up on March 31st, 2017 (latest records in HES data). However, studies with a longer follow-up period and larger sample size are needed to depict the changes of medical costs and comorbidities over a longer time period. Fourthly, the reported inpatient costs incurred in our study may be biased. It was because there was potential misclassification when comorbidities (except diabetes) were defined purely based on HES data; that is, comorbidities for some patients were not recorded in the HES data, and thus those patients were regarded as ones without comorbidities in analyses. Evidence could be found in Supplemental Table 6, which shows that the number of patients with diabetes based on HES data is significantly different from the UKB data and is lower than the number identified either by HES or UKB data (all P<0.001). Therefore, inpatient costs for patients without comorbidities may be amplified. In addition, given the fact that the UKB participants have fewer self-reported health conditions, have less risks of all-cause mortality, and are less obese than the general population [63], patients in the general population tended to have larger inpatient expenditures. In addition, percentages of patients who have ever been diagnosed with different comorbidities in the present study were measured without consideration of disease remissions, as relevant data were unavailable. Finally, our study did not examine health outcome measures (including body weight, cardiovascular risks, quality of life, etc.) that might be important to bariatric surgery[64] and therefore future work should explore our findings in the context of health outcomes.

To conclude, bariatric surgery was associated with an increase in inpatient hospital costs in the surgery year but was associated with reduced inpatient costs in the subsequent years. However, compared to individuals who did not undergo surgery, these cost savings in the last 4 years, were not enough to compensate for costs in the first year.

Abbreviations

Body mass index (BMI)

Cardiovascular diseases (CVD)

Confidence interval (CI)

Healthcare resource group (HRG)

Hospital Episode Statistics (HES)
International Classification of Diseases 10th revision (ICD-10)
National Health Service (NHS)
National Institute for Health and Care Excellence (NICE)
Office of Population Censuses and Surveys, Classification of Surgical Operation and Procedures (OPCS-4)
Standard deviation (SD)
Standardised mean difference (SMD)
Type 2 diabetes mellitus (T2DM)
UK Biobank (UKB)

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Competing Interests

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Data and code availability

The data that support the findings of this study are available from UK Biobank, but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data and codes are however available from the authors upon reasonable request and with permission of UK Biobank.

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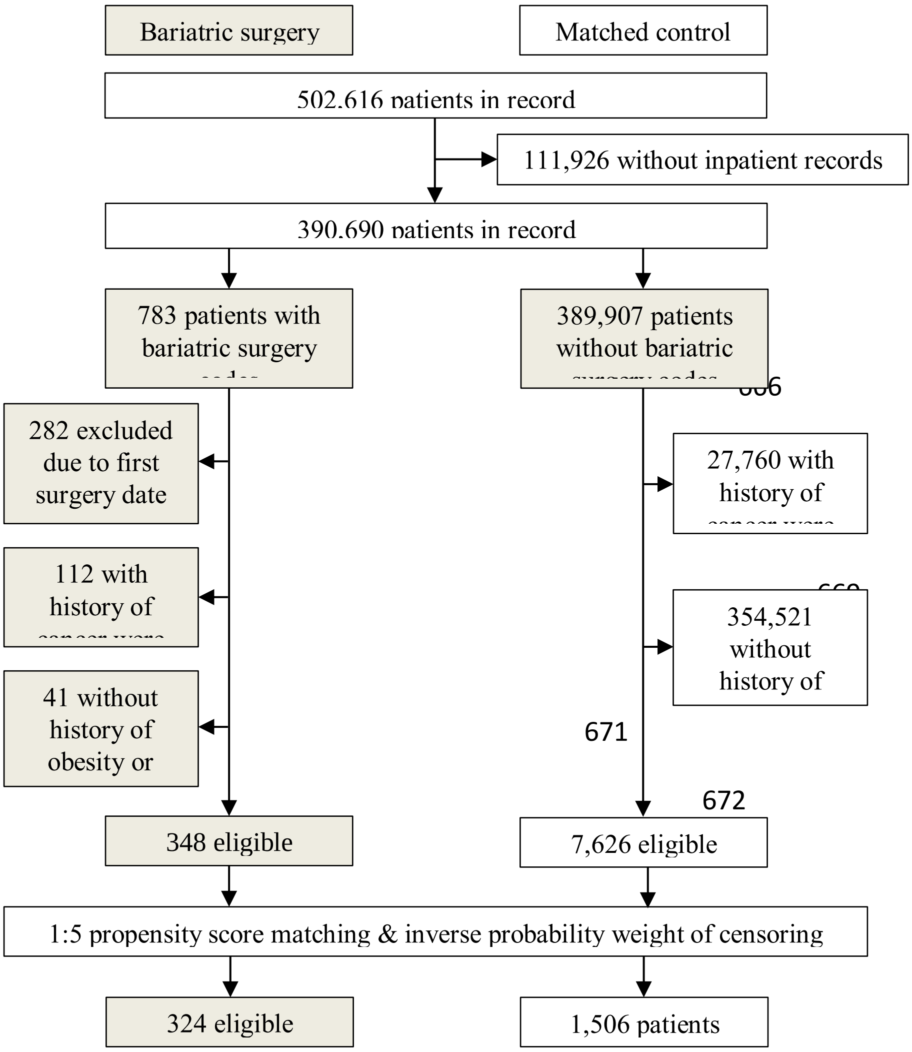
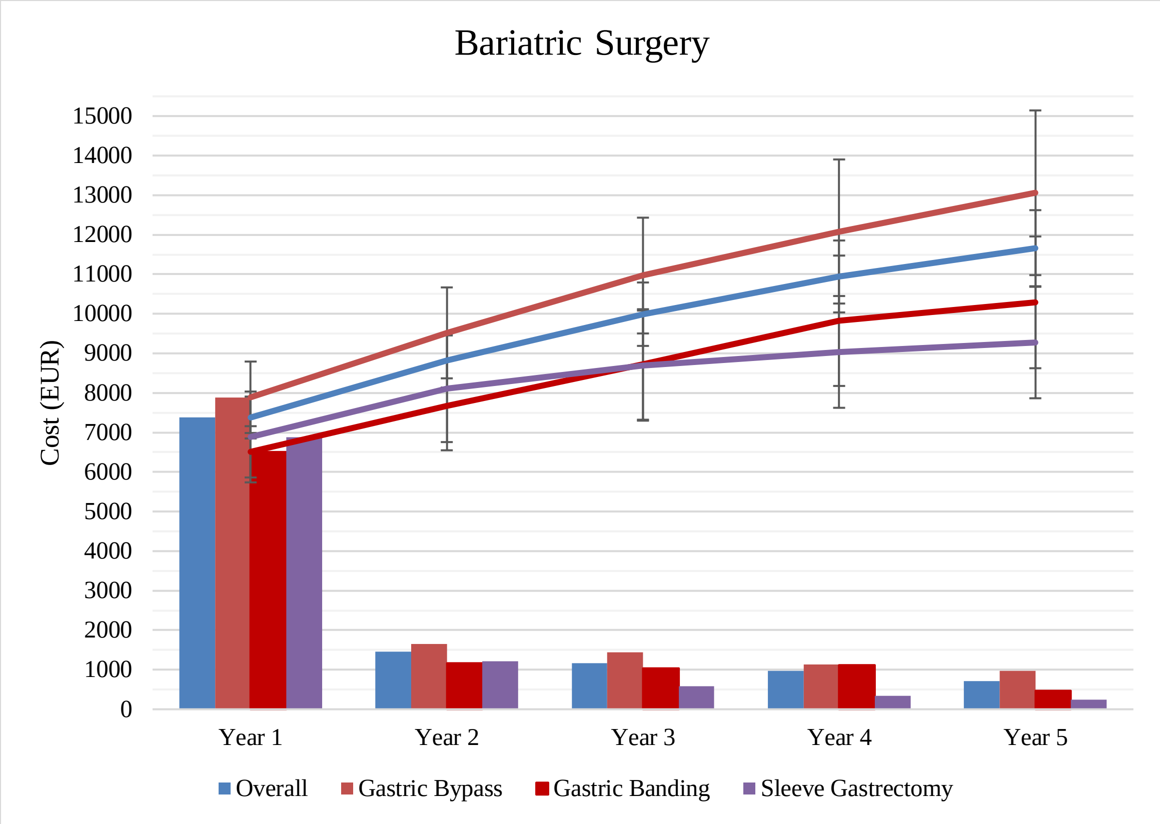


Index year	Bariatric surgery group	Matched control group
2007	1 (0.31%)	2 (0.13%)
2008	5 (1.54%)	24 (1.59%)
2009	28 (8.64%)	131 (8.70%)
2010	52 (16.05%)	248 (16.47%)
2011	60 (18.52%)	272 (18.06%)
2012	61 (18.83%)	288 (19.12%)
2013	63 (19.44%)	303 (20.12%)
2014	48 (14.81%)	213 (14.14%)
2015	6 (1.85%)	25 (1.66%)

Figure 1 Flowchart of the study



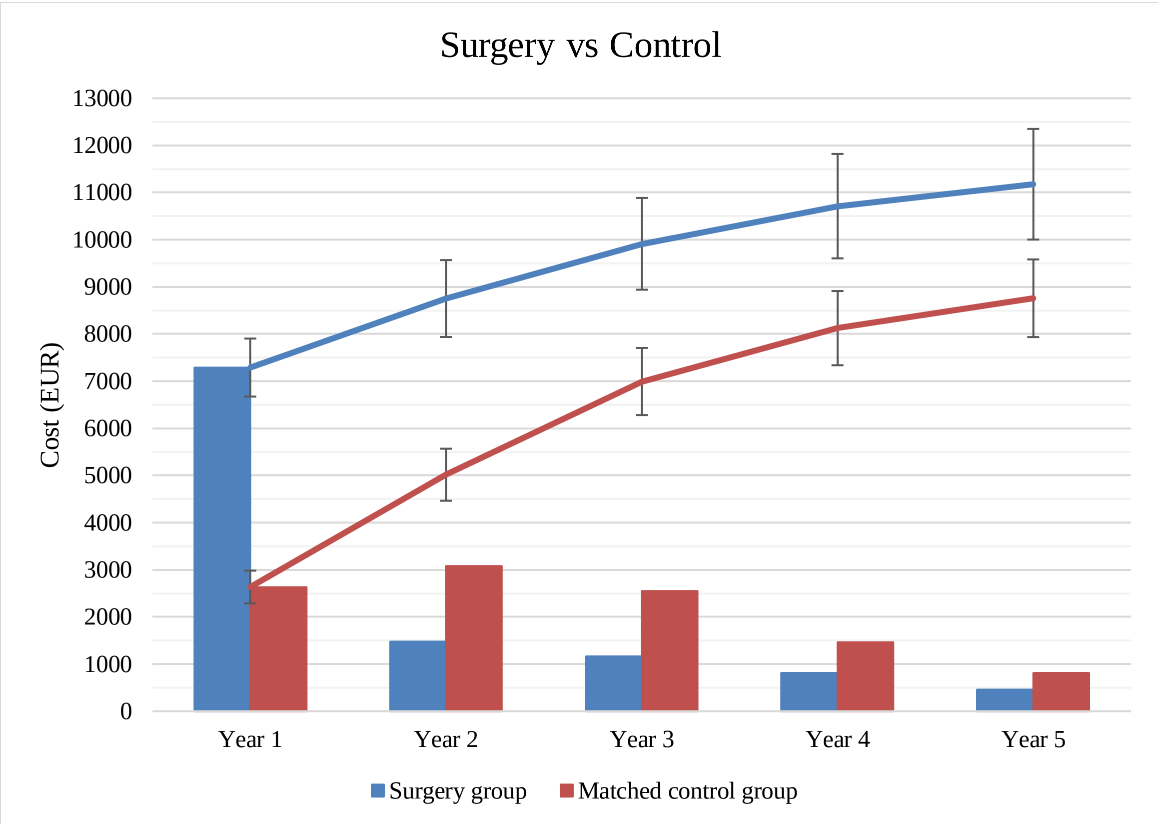


Figure 2 Mean annual and 5-year cumulative inpatient costs of (a) surgical patients before matching and (b) surgery and control patients after matching

Table 1. Baseline characteristics of obese patients undergoing bariatric surgery and matched control patients.

	Initial surgery					After 1-vs-5 Propensity Score matching			
	Overall (N=348)	Gastric Bypass (N=198)	Gastric Banding (N=73)	Sleeve Gastrectomy (N=77)	P-value*	Surgery group (N=324)	Matched control group (N=1,506)	P-value*	ASMD†
Mean age, year (SD)	55.04 (6.99)	54.23 (6.58)	55.30 (6.98)	56.86 (7.71)	0.018	55.13 (7.03)	55.48 (7.85)	0.459	0.047
Female, n (%)	247 (71.0)	137 (69.2)	57 (78.1)	53 (68.8)	0.322	226 (69.8)	1,107 (73.5)	0.168	0.083
Country of birth, n (%)					0.655			0.268	0.066
UK	300 (86.2)	173 (87.4)	63 (86.3)	64 (83.1)		282 (87.0)	1,343 (89.2)		
Elsewhere/missing	48 (13.8)	25 (12.6)	10 (13.7)	13 (16.9)		45 (13.4)	137 (8.3)		
Ethnicity, n (%)					0.408			0.837	0.013
British	276 (79.3)	161 (81.3)	58 (79.5)	57 (74.0)		260 (80.2)	1,216 (80.7)		
Non-British/missing	72 (20.7)	37 (18.7)	15 (20.5)	20 (26.0)		64 (19.8)	290 (19.3)		
Mean townsend deprivation index (SD)	1.14 (3.56)	1.12 (3.42)	1.18 (3.72)	1.17 (3.78)	0.989	1.11 (3.57)	0.93 (3.42)	0.410	0.050
Deprivation tertile, n (%)					0.473			0.823	0.039
Least	51 (14.7)	29 (14.6)	12 (16.4)	10 (13.0)		49 (15.1)	231 (15.3)		
Middle	65 (18.7)	33 (16.7)	12 (16.4)	20 (26.0)		61 (18.8)	305 (20.3)		
Most	230 (66.1)	135 (68.2)	48 (65.8)	47 (61.0)		214 (66.0)	970 (64.4)		
Smoking status, n (%)					0.600			0.841	0.036
Never	165 (47.4)	96 (48.5)	36 (49.3)	33 (42.9)		158 (48.8)	747 (49.6)		
Previous	148 (42.5)	80 (40.4)	30 (41.1)	38 (49.4)		134 (41.4)	599 (39.8)		
Current	34 (9.8)	22 (11.1)	7 (9.6)	5 (6.5)		32 (9.9)	160 (10.6)		
Alcohol status, n (%)					0.601			0.883	0.031
Never	31 (8.9)	16 (8.1)	8 (11.0)	7 (9.1)		29 (9.0)	147 (9.8)		
Previous	27 (7.8)	17 (8.6)	7 (9.6)	3 (3.9)		27 (8.3)	119 (7.9)		
Current	287 (82.5)	164 (82.8)	57 (78.1)	66 (85.7)		268 (82.7)	1,240 (82.3)		

Table 1. Baseline characteristics of obese patients undergoing bariatric surgery and matched control patients. (Cont.)

Obesity-related comorbidity, n (%)									
Atrial fibrillation	17 (4.89)	9 (4.55)	2 (2.74)	6 (7.79)	0.337	16 (4.94)	98 (6.51)	0.289	0.068
Ischaemic heart diseases	51 (14.66)	28 (14.14)	11 (15.07)	12 (15.58)	0.949	47 (14.51)	243 (16.14)	0.466	0.045
Cerebrovascular diseases	10 (2.87)	7 (3.54)	0.00% (0)	3 (3.9)	0.252	9 (2.78)	69 (4.58)	0.145	0.096
Degenerative joint disease	99 (28.45)	59 (29.80)	18 (24.66)	22 (28.57)	0.707	91 (28.09)	447 (29.68)	0.568	0.035
Type 2 diabetes mellitus	134 (38.51)	82 (41.41)	23 (31.51)	29 (37.66)	0.326	125 (38.58)	551 (36.59)	0.500	0.041
Dyslipidaemia	103 (29.60)	61 (30.81)	18 (24.66)	24 (31.17)	0.581	94 (29.01)	438 (29.08)	0.980	0.002
Gallstone	28 (8.05)	15 (7.58)	6 (8.22)	7 (9.09)	0.916	25 (7.72)	120 (7.97)	0.879	0.009
Gastroesophageal reflux disease	73 (20.98)	46 (23.23)	14 (19.18)	13 (16.88)	0.466	63 (19.44)	295 (19.59)	0.953	0.004
Hypertension	10 (2.87)	4 (2.02)	1 (1.37)	5 (6.49)	0.094	10 (3.09)	46 (3.05)	0.976	0.002
Obstructive sleep apnoea	107 (30.75)	55 (27.78)	24 (32.88)	28 (36.36)	0.347	96 (29.63)	417 (27.69)	0.481	0.043
Nutritional anaemias and deficiencies	18 (5.17)	7 (3.54)	4 (5.48)	7 (9.09)	0.173	17 (5.25)	67 (4.45)	0.533	0.037

Note: ASMD = Absolute standardised mean difference; BMI = Body mass index; SD = Standard deviation*P-value <0.05 indicates statistically significant difference; † ASMD<0.200 indicates optimal balance.