Cost-effectiveness of bariatric surgery in adolescents with severe obesity in the UK

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What this paper adds

What is already known about this subject?

- Severe obesity presents an increasing source of clinical and economic strain to healthcare providers.
- Most adults who underwent bariatric surgery experience improved health and psychological functioning with bariatric surgery considered cost-effective.
- Data on bariatric surgery for adolescents are extremely limited (and all are from Australia or the US), and it is difficult to draw conclusions as to whether such intervention is cost-effective.

What this study adds?

- We compared the costs and quality-adjusted life years (QALYs) of two types of surgery (laparoscopic Roux en Y Gastric Bypass (RYGB) and laparoscopic Sleeve Gastrectomy (SG)) versus no surgery in adolescents with severe obesity from the perspective of the UK National Health Service (NHS).
- Bariatric surgery is more costly than no surgery; however it markedly improved quality of life.
- Bariatric surgery is a cost-effective alternative to no surgery.

Abstract

Background

Evidence shows that surgery for severe obesity in adults improves health and psychological functioning, and is cost-effective. Data on bariatric surgery for adolescents with severe obesity are extremely limited, with no evidence on cost-effectiveness.

Aim

To evaluate the lifetime cost-effectiveness of bariatric surgery compared with no surgery in adolescents with severe obesity from the UK's NHS perspective.

Methods

Eighteen adolescents with BMI ≥40kg/m^2 who underwent bariatric surgery (laparoscopic Roux en Y Gastric Bypass (RYGB) (N=9), and laparoscopic Sleeve Gastrectomy (SG) (N=9)) at University College London Hospitals (UCLH) between January 2008 and December 2013 were included. We used a Markov cohort model to compare the lifetime expected costs and quality-adjusted life years (QALYs) between bariatric surgery and no surgery.

Results

Mean cost of RYGB and SG procedures were £7,100 and £7,312, respectively.

For RYGB versus no surgery, the incremental cost/QALY was £2,018 (95% CI £1,942 to £2,042) for males and £2,005 (95% CI £1,974 to £2,031) for females.

For SG versus no surgery, the incremental cost/QALY was £1,978 (95% CI £1,954 to £2,002) for males and £1,941 (95% CI £1,915 to £1,969) for females.

Conclusions

Bariatric surgery in adolescents with severe obesity is cost-effective; it is more costly than no surgery however it markedly improved quality of life.

Introduction

Data from the National Child Measurement Programme (NCMP) in England showed that in 2012/2013, severe obesity (Body Mass Index (BMI) ≥UK90 99.6th centile) equivalent to the adult bariatric threshold of 35kg/m^2 was found in 1.2% of girls and 1.5% of boys aged 10-11 years [1]. Severe obesity presents an increasing source of clinical and economic strain to healthcare providers.

The economic burden of obesity is substantial. In England, the costs of overweight and obesity to the health system have been calculated to be £4.2 billion per annum [2].

Much of this burden is driven by a number of co-morbidities which occur at a higher prevalence among obese young people including type 2 diabetes, hyperlipidaemia, hypertension, sleep apnoea, as well as significant psychosocial consequences and the increased likelihood of becoming obese adults [3-5]. Thus the medical, psychological and economic consequences of obesity represent a significant challenge to healthcare systems.

Bariatric surgery is the only available intervention that results in large magnitudes of weight loss. In adults, conservative treatment of severe obesity (BMI ≥40kg/m^2) largely produced poor long-term results, whereas surgery for obesity usually results in significant permanent weight loss. After obesity surgery, most patients experience improved health and psychological functioning [6] with bariatric surgery considered cost-effective [7].

Outcomes of adolescent bariatric surgery appear similar to those in adults although high quality long term data is limited. Systematic reviews suggest that surgery is highly effective for short-term BMI reduction [8] and improves quality of life [9]. However, there is very little published data on the cost-effectiveness of bariatric surgery in adolescents, and none from the UK. In England, National Institute for Health and Care Excellence (NICE) guidance [10] notes that bariatric surgery is not generally recommended for children and young people (Recommendation 1.10.12), but may be considered in exceptional circumstances in those who have reached psychological maturity (Recommendation 1.10.13) and have BMI ≥40kg/m^2 or BMI ≥35kg/m^2 with significant co-morbidities that would be improved if they lost weight (Recommendation 1.10.1).

We assessed the lifetime cost-effectiveness of bariatric surgery (laparoscopic Roux en Y Gastric Bypass (RYGB) or laparoscopic Sleeve Gastrectomy (SG)) compared with no intervention, using data from a cohort of 18 adolescents with severe obesity undergoing surgery in one NHS centre in the UK.

Methods

Framework of Economic Model

We conducted a cost-utility analysis using lifetime expected costs and quality-adjusted life years (QALYs) that compared bariatric surgery with no surgery.

A Markov model was used to project costs, body mass index (BMI) and QALYs over lifetime. The Markov transition model comprised five health states such as "no co-morbidity", "diabetes", "coronary heart disease (CHD)", "stroke" and "colon cancer", and death (Figure 1).

Adolescents with severe obesity (BMI ≥40kg/m^2) enter the model in the "no co-morbidity" health state at age of 18 years. BMI starting point for adolescents in group RYGB was

48.3kg/m^2 and for those in SG group was 60.03kg/m^2. The model consisted of yearly cycles. At the end of each one-year period, a proportion of the cohort can move from one health state to another or stay in the same health state. We assumed that adolescents remain in the co-morbid health states until they die (age-specific death or obesity-related co-morbidity death). The disease transition probabilities are based on disease progression related to age, gender, BMI and cycle. The model is run over 82 years (until patients are 100 years old or have died) to estimate the lifetime costs and effects of the intervention. Costs were calculated in 2013/14 UK pounds, inflated where appropriate using the consumer price index [11]. A discount rate of 3.5% was applied for costs and effects [12].

The higher an individual's BMI, the more likely they are to develop obesity-related co-morbidities such as diabetes, CHD, stroke, sleep apnoea and some forms of cancers. Due to lack of accurate data on other risk factors, the model focused on the increased risk of developing diabetes, CHD, stroke and colon cancer, for which there are data on the risks of these conditions by BMI. However, while there are reasonable data on the risks of each individual co-morbidity and BMI, there is no data on the association between BMI and multiple combinations of these co-morbidities. Therefore, the possibility of having multiple co-morbidities at the same time was not incorporated in the model. This assumption is likely to mean that we have underestimated the burden associated with obesity-related co-morbidities.

In the model, a hypothetical cohort of 1,000 adolescents with severe obesity underwent bariatric surgery (RYGB or SG) or no surgery. Effects of surgery were modelled as a reduction in BMI and consequent reduction in the development of diabetes, CHD, stroke and colon cancer. Transitions between BMI levels were modified following bariatric surgery in order to reflect the reduction in BMI observed following surgery. The initial decline in BMI due to surgery was taken from the cohort of 18 adolescents undergoing surgery at University College London Hospitals (UCLH). We then included an annual increment (obesity drift) to update an adolescent's BMI over time. Published literature shows that BMI is predicted to increase by +0.12 kg/m^2 per year in patients aged <45 years [13], +0.07kg/m^2 per year for age between 45 and 65 years and -0.14 kg/m^2 per year for age>=65 years [14].

Transitions into long-term co-morbidities were also modified following bariatric surgery, consistent with the benefits of bariatric surgery.

Our assumption in the no surgery group was for BMI to stay constant with no incremental drift; the assumption of no incremental drift potentially underestimates lifetime BMI in the no surgery group. However, a systematic review shows that interventions that do not include surgery generally have very limited impact on the body weight in adults with severe or morbid obesity [15].

Parameter Estimates and Data Sources

Parameter values for the model were taken from a variety of secondary sources.

The correlation between BMI and annual risk of developing diabetes, CHD, stroke and colon cancer were calculated based on estimates from the DYNAMO-HIA project [16]. This study provides estimates of the relative risks of defined diseases according to BMI status (given as per unit increase from BMI 22=1.0; we then adjusted this estimate for the mean BMI of the adult UK population (BMI 27=1.0) [17]). The risk of co-morbidities was adjusted according to age, gender and prevalence of diabetes, CHD and stroke based on information provided by a large representative population health survey, the 2013 Health Survey for England (HSE) [16], complemented by published source for colon cancer [18].

Mortality due to co-morbidities was taken from UK National Life tables 2011-2013 for diabetes, CHD, stroke and colon cancer [19]. The yearly probability of diabetes, CHD, stroke and colon cancer were obtained from the actual number of deaths [19] and disease disability [17]. Information on length of life associated with each health state was taken from published literature [20-23], interpolated to reflect the remaining length of life after each cycle.

Mortality rates of adolescents with severe obesity in the "no co-morbidity" health state are assumed to be equivalent to those observed in the general population. On the one hand, this may underestimate the mortality risk in this group as the mean BMI in the general population is lower than in our sample. On the other hand, the general population sample will include people with co-morbidities.

Health-Related Quality of Life

We used three published sources to estimate: (1) baseline utilities for people with obesity; (2) utilities associates with changes in BMI over time; and (3) utilities associated with each co-morbidity. For (1) we used a published study that explored the relationship between BMI and health related quality of life (HRQoL), measured using the EQ-5D for men and women within a national population sample [24]. For (2) we used a published study documenting changes in utility associated with the incremental drift in BMI over time: this study reported that a one-unit decrease in BMI over 1-year period was associated with a 0.0170 gain in utility [25]. For (3) multipliers were applied to the utility weights for adolescents with co-morbidities included in the model using a catalogue of EQ-5D scores for a variety of health conditions [26]. A utility profile was constructed from age of 18 to 100 for every patient in the cohort, assigning a utility score of 0 for those who had died.

Costs

Data on resource use and costs associated with bariatric surgery were obtained from UCLH Finance Department and included the costs of the procedure (including pre-operative preparation) and the costs of 24 months of postoperative care. Costs were based on the average costs for each intervention type in the Healthcare Resource Groups (HRGs) costing system.

The direct medical costs for the surgery group were those associated with the intervention and a surgical follow-up including the pre-surgical preparation visits (up to 1 year before surgery) and follow-up costs (dietetic, physician, psychology and nursing follow-up); these were assumed until year 5 post-surgery. From year 6 post-surgery, annual medical costs related to weight control were applied, assuming one GP visit per year.

The direct medical costs for the no surgery group were assumed to be the same as those incurred pre-intervention in the surgical group, plus regular follow-up for the first year (dietetic, psychology and nursing follow-up). After 1 year, no medical costs related to weight control were applied.

The annual cost of diabetes, CHD, stroke [27], and colon cancer [28], were obtained from published sources.

Cost-Effectiveness Analysis

The main result of the study was the incremental cost-effectiveness ratio (ICER) of bariatric surgery versus no surgery. The ICER was calculated by dividing the incremental costs (difference in costs between surgery (RYBG or SG) group and non-surgery group) by incremental QALY (difference in QALYs between the two surgery and non-surgery groups).

The model was developed using Microsoft Excel 2010 Software [29].

Sensitivity Analysis

In order to address parameter uncertainty we used both deterministic and probabilistic sensitivity analyses.

We conducted a series of one-way sensitivity analyses to test the robustness of the cost calculation and to determine how changes in certain parameters affected the total cost helping in revealing the key drivers of the cost-effectiveness.

In one-way sensitivity analyses, the ICERs were recalculated when individual parameters were varied, including the gain in quality of life per unit of BMI, the intervention costs, the initial weight and weight reduction after intervention and the discount rate. The one-way sensitivity analysis was performed on individual parameters over minimum and maximum ranges that were derived from UCLH data.

We also conducted probabilistic sensitivity analyses (PSA) [30] with 1,000 bootstraps replications to assess the robustness of our results to input parameters uncertainty around multiple parameters simultaneously. The analyses were performed with appropriate distributional assumptions for each variable parametrised related to the nature of the variable. The PSA were based on a gamma distribution for intervention, medical costs and disutility scores, a beta distribution for the quality of life gain associated with BMI reduction, a log-normal distribution for post-surgical weight loss and obesity drift. The results of the PSA are summarised as the probability of each procedure being cost-effective at different willingness-to-pay (WTP) levels, or threshold for cost-effectiveness, using cost-effectiveness acceptability curves [31]. We also used the PSA to generate 95% confidence intervals around the point estimates based on the standard error of the values from the 1,000 bootstrap replications.

Results

Participants' Characteristics

Data from 18 adolescents who underwent bariatric surgery were analysed. Nine adolescents underwent RYBG and nine underwent SG. Mean age of adolescents at time of surgery who underwent RYGB was 17.8 years and of those who underwent SG it was 18.7 years. Mean BMI (standard deviation, SD) at baseline for those who underwent RYBG was 48.3kg/m^2 (SD 6.2) and for those who underwent SG it was 60.0 kg/m^2 (SD 9.3) (Table 1).

Base Case Analysis

The parameter values for the cost-effectiveness model and their ranges used in sensitivity analyses are presented in Table 2.

At one year follow up mean reduction in BMI was 12.28 kg/m^2 (SD 2.98) for adolescents who had RYGB and 16.16 kg/m^2 (SD 9.96) for adolescents who had SG.

Compared with no surgery, males who underwent RYBG were estimated to have 5.57 (95% CI 5.55 to 5.59) more QALYs over their lifetime; females were estimated to have 5.66 (95% CI 5.64 to 5.67) more QALYs. For SG the difference was 5.50 (95% CI 5.48 to 5.52) for males and 5.64 (95% CI 5.63 to 5.65) for females (Table 3).Compared with no surgery, the lifetime incremental cost per person of RYGB versus no surgery was £11,245 (95% CI £10,777 to £11,413) for males and £11,343 (95% CI £11,172 to £11,514) for females. For SG the figures were £10,877 (95% CI £10,707 to £11,046) for males and £10,954 (95% CI £10,782 to £11,125) for females (Table 3). The higher costs of surgery were due to the costs of the surgical procedure itself and the costs of pre- and post-operative care. These were offset by the costs of treating co-morbidities, which were slightly lower with surgery.

The incremental cost per QALY gained of RYGB versus no surgery was £2,018 (95% CI £1,942 to £2,042) for males and £2,005 (95% CI £1,974 to £2,031) for females. The mean incremental cost per QALY gained of SG versus no surgery was £1,978 (95% CI £1,954 to £2,002) for males and £1,941 (95% CI £1,915 to £1,969) for females (Table 3).

Sensitivity Analysis

One-way sensitivity analyses were conducted for the most influential variables with the higher impact on the model's results. The results did not vary appreciably in the sensitivity analyses. The incremental cost per QALY gained remained under £5,000 for bariatric surgery versus no surgery for both types of procedures when all the parameter values were varied within plausible limits (Table 4 and Online supplementary Table S1 and Table S2).Results of the probabilistic cost-effectiveness analysis are presented in Online Supplement-Table S3. The cost-effectiveness acceptability curves for bariatric surgery compared to no surgery indicate the probability of bariatric surgery being more cost-effective than the no surgery for a range of values a decision maker is willing to pay for an additional unit of health gain.

At NICE's recommended threshold of £20,000 per QALY gained [32], the probability of bariatric surgery being cost-effective is >90% (Figure 2).

Discussion

Our study shows that bariatric surgery in adolescents with severe obesity is highly cost-effective over the long term and also improves quality-adjusted life years. Costs of surgery are significantly higher than for the non-surgical group; however the benefits of improved quality and length of life result in surgery being highly cost-effective.

Few studies of bariatric surgery in adolescents that include an economic evaluation have been published, all from Australia or the US [33, 37]. Our study is the first published from the perspective of a national health service. Caution is needed when comparing results of cost-effectiveness studies due to variations with respect to type of surgery, population of young people, perspective of the study, time horizon, quality of life instrument and discount rate used.

A meta-analysis of bariatric surgery published in 2011[33] identified three papers [34-36] based on the ACE-Obesity (Assessing Cost-Effectiveness in Obesity) which undertook economic modelling and reported that laparoscopic adjustable gastric band (LAGB) was cost-effective in Australian adolescent population (cost/DALY $AU 4,400). Another more recent study of American adolescents from a single centre [37] concluded that bariatric surgery (RYGB) may be cost-effective when evaluated over a long period of time (ICER under a threshold of $100,000/QALY from year 4).

Our findings are comparable with those reported for adults. A systematic review of bariatric surgery in adults concluded that bariatric surgery was cost-effective in comparison with non-surgical interventions for those with a higher range of BMI [7].

Strengths and weaknesses

We used an unselected cohort from the largest UK centre undertaking adolescent bariatric surgery, together with modelled data from nationally representative surveys and authoritative data sources. Our estimates of cost-effectiveness are likely to be conservative. We accounted for likely upward BMI drift after surgery using data taken from studies of obese adults after bariatric surgery, but did not include drift in the non-surgery group, although this is likely. Quality of life estimates were taken from samples of morbidly obese adults. We included costs of follow-up after surgery up to 5 years, but did not include any follow-up costs for the non-surgery group past 1 year. Obesity is recognised as being a risk factor for co-morbidities other than those included in the model (diabetes, CHD, stroke and colon cancer) and thus our model likely underestimates the impact of obesity. Together, these suggest that our findings likely underestimate the cost-effectiveness of surgery.

We undertook a long-term evaluation of bariatric surgery. Findings were further strengthened by sensitivity analyses showing that large change in cost or utility estimates did not change the main conclusions.

Our findings are subject to a number of limitations. The main limitation is that data on the impact of surgery on BMI was available for only 18 adolescents. While this number is small, it is the largest UK cohort at the time. Further research would be beneficial in future with a larger cohort of UK patients. Our model only captures the direct costs. Cost owing to loss of productivity caused by obesity and its co-morbidities were not included in the analysis. This is a conservative assumption as many of the costs associated with obesity may fall on individuals as well as society.

Also, medication costs were not incorporated in the model.

While we had a precise estimate of the costs of bariatric surgery at UCLH, the lack of empirical quality of life data from patients who underwent bariatric surgery could cause uncertainty in the model. Future evaluation is needed to measure and incorporate changes in quality of life from the adolescent population undergoing bariatric surgery.

Costs for procedures were provided by a single centre (UCLH), which has high costs due to being a central London teaching hospital. Costs shown here therefore may be higher than in other hospitals; however, this would lead to an underestimate of the cost-effectiveness of surgery. Further, our assumptions regarding post-operative resource use may be excessively high. Again, this suggests that the model provides a conservative estimate of the cost-effectiveness of the bariatric surgery and potentially overestimates the overall impact of obesity.

Conclusions

Bariatric surgery of adolescents with severe obesity is a cost-effective alternative to no surgery from the perspective of the UK's NHS.

Conflicts of interest

All authors have completed the ICMJE uniform disclosure form at www.icme.org/coi_disclosure.pdf and declare no competing interests. BW reports personal fees from Lilly UK (speaking fees for industry-funded national paediatric diabetes training not related to bariatric surgery) outside the submitted work.

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SM and PM developed the study design with input from RMV and undertook the economic analysis. MP drafted the initial manuscript. BW provided the person-level data. TP and HM provided financial information. All authors read and approved the final manuscript.

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Table1. Descriptive statistics of adolescents undergoing bariatric surgery

Clinical variable	Roux en Y Gastric Bypass	Sleeve Gastrectomy
	n=9	n=9
Females (%)	56%	44%
Age (years)		
Mean	17.8	18.7
SD	1.2	1.2
Age range (years)	16-19	17-20
BMI at baseline (kg/m2)		
Mean	48.3	60.0
SD	6.2	9.3
Weight at baseline (kg)		
Mean	142.2	170.3
SD	21.1	42.3
Height at baseline (cm)		
Mean	171.3	168.0
SD	7.3	16.3

SD=standard deviation; BMI = body mass index

Table 2. Input parameters for cost-effectiveness model

Parameter	Base case	Standard error	Uncertainty ranges		Uncertainty distribution	Sources for input parameters
Cost of RYGB	£7,100	£32	£5,619	£8,023	Gamma*	UCLH data
Cost of RYGB follow-up 1st year	£2,524	£601	£315	£4,982	Gamma^	Assumption
Cost of RYGB follow-up 2nd-5th year	£445	£106	£56	£879	Gamma^	Assumption
Cost of RYGB follow-up from year 6	£46	£5	£41	£51	Gamma	Curtis L.
Cost of SG	£7,312	£134	£5,787	£8,263	Gamma*	UCLH data
Cost of SG follow-up 1st year	£2,168	£512	£575	£5,030	Gamma^	Assumption
Cost of SG follow-up 2nd-5th year	£383	£90	£102	£888	Gamma^	Assumption
Cost of SG follow-up from year 6	£46	£5	£41	£51	Gamma	PSSRU
Cost diabetes per year	£1,006	£101	£906	£1,107	Gamma	Anokye N et al.
Cost CHD per year	£498	£50	£448	£548	Gamma	Anokye N et al.
Cost stroke per year	£2,475	£247	£2,227	£2,722	Gamma	Anokye N et al.
Cost colon cancer per year	£8,229	£823	£7,406	£9,052	Gamma	Cancer Research UK
Utility male (BMI 30-39.9kg/m2)	0.82	0.082	0.74	0.90	Beta	Macran S
Utility female (BMI 30-39.9kg/m2)	0.78	0.078	0.70	0.86	Beta	Macran S
Utility male (BMI 40-49.9kg/m2)	0.56	0.056	0.50	0.62	Beta	Assumption
Utility female (BMI 40-49.9kg/m2)	0.52	0.052	0.47	0.57	Beta	Assumption
Utility male (BMI >=50kg/m2)	0.30	0.030	0.27	0.33	Beta	Assumption
Utility female (BMI >=50kg/m2)	0.26	0.026	0.24	0.29	Beta	Assumption
Utility gain for 1 unit BMI reduction	0.017	0.0017	0.015	0.019	Beta	Hakim Z et al.
Disutility score age	-0.0003	0.0002	-0.0003	-0.0003	Gamma	Sullivan PW et al.
Disutility score diabetes	-0.0714	0.0048	-0.0643	-0.0785	Gamma	Sullivan PW et al.
Disutility score CHD	-0.0627	0.0131	-0.0564	-0.0690	Gamma	Sullivan PW et al.
Disutility score stroke	-0.0330	0.0223	-0.0297	-0.0363	Gamma	Sullivan PW et al.
Disutility score colon cancer	-0.0674	0.0172	-0.0607	-0.0741	Gamma	Sullivan PW et al.
Obesity drift up to 45 years	0.12	0.012	0.11	0.13	Log-normal	Baum CL et al.

Obesity drift 45-65 years	0.07	0.007	0.06	0.08	Log-normal	Borg S et al.
Obesity drift over 65years	-0.17	-0.017	-0.15	-0.19	Log-normal	Borg S et al.
Mean BMI at 1 year RYGB	34.07	3.54	30.58	38.86	Log-normal^	UCLH data
Mean BMI at 1 year SG	43.88	4.13	30.92	54.83	Log-normal^	UCLH data
Discount rate for cost (%)	3.5%		0.0%	5.0%		NICE
Discount rate for outcomes (%)	3.5%		0.0%	5.0%		NICE

* Lower/Upper Quartile Unit Cost as in National Schedule of Reference Costs - Year 2013-14; ^ Lower/Upper values based on calculations; all others ± 10% around the mean (except discount rate values); RYGB = Roux en Y Gastric Bypass; SG = Sleeve Gastrectomy; CHD = coronary heart disease; BMI = body mass index.

Table 3. Mean cost (2013-2014 UK£), Quality Adjusted Life years (QALY) and Incremental Cost-Effectiveness Ratio (ICER) over lifetime by gender and bariatric surgery type

		Males		**Females**	
		Mean	**95% CI**	**Mean**	**95% CI**
Roux en Y Gastric Bypass	Surgery	£7,100	(£7,037; £7,162)	£7,100	(£7,049; £7,576)
	No co-morbidities	£4,825	(£4,765; £4,886)	£4,879	(£4,819; £4,939)
	Diabetes	£1,421	(£1,417; £1,424)	£1,025	(£1,022; £1,027)
	CHD	£206	(£205; £206)	£150	(£150; 151)
	Stroke	£706	(£704; £708)	£616	(£614;£ 617)
	Colon cancer	£402	(£401; £403)	£333	(£332; £334)
	Total cost	**£14,660**	**(£14,183; £14,836)**	**£14,102**	**(£13,925; £14,279)**
	QALY	**18.84**	**(18.79; 18.89)**	**18.30**	**(18.25; 18.34)**
No surgery	Surgery	**-**	**-**	**-**	**-**
	No co-morbidities	£96	(£93; £96)	£96	(£93; £98)
	Diabetes	£1,912	(£1,908; £1,916)	£1,469	(£1,466; £1,472)
	CHD	£238	(£237; £239)	£184	(£183; £184)
	Stroke	£752	(£750; £754)	£675	(£673; £677)
	Colon cancer	£417	(£416; £418)	£336	(£335; £337)
	Total cost	**£3,414**	**(£3,406; £3,423)**	**£2,759**	**(£2,753; £2,765)**
	QALY	**13.27**	**(13.24; 13.30)**	**12.64**	**(12.61; 12.67)**
Differences	Total cost	**£11,245**	**(£10,777; £11,413)**	**£11,343**	**(£11,172; £11,514)**
	QALY	**5.57**	**(5.55; 5.59)**	**5.66**	**(5.64; 5.67)**
ICER		**£2,018**	**(£1,942; £2,042)**	**£2,005**	**(£1,974; £2,031)**
Sleeve Gastrectomy		**Mean**	**95% CI**	**Mean**	**95% CI**
	Surgery	£7,312	(£7,037; £7,362)	£7,312	(£7,049; £7,576)

	No co-morbidities	£4,232	(£4,181; £4,284)	£4,287	(£4,236; £4,339)
	Diabetes	£1,869	(£1,865; £1,873)	£1,430	(£1,427; £1,433)
	CHD	£236	(£235; £237)	£181	(£181; £182)
	Stroke	£749	(£747; £751)	£670	(£669; £672)
	Colon cancer	£416	(£415; £417)	£336	(£335; £337)
	Total cost	**£14,815**	**(£14,637; £14,994)**	**£14,217**	**(£14,038; £14,396)**
	QALY	**12.47**	**(12.44; 12.51)**	**11.82**	**(11.79; 11.85)**
No surgery	Surgery	-	-	-	-
	No co-morbidities	£96	(£93; £98)	£96	(£93; £98)
	Diabetes	£2,357	(£2,351; £2,362)	£1,894	(£1,890; £1,898)
	CHD	£267	(£266; £267)	£211	(£210; £211)
	Stroke	£794	(£791; £796)	£727	(£725; £729)
	Colon cancer	£426	(£425; £428)	£337	(£336; £338)
	Total cost	**£3,939**	**(£3,930; £3,948)**	**£3,264**	**(£3,256; £3,271)**
	QALY	**6.98**	**(6.96; 6.99)**	**6.18**	**(6.16; 6.20)**
Differences	Total cost	**£10,877**	**(£10,707; £11,046)**	**£10,954**	**(£10,782; £11,125)**
	QALY	**5.50**	**(5.48; 5.52)**	**5.64**	**(5.63; 5.65)**
ICER		**£1,978**	**(£1,954; £2,002)**	**£1,941**	**(£1,915; £1,969)**

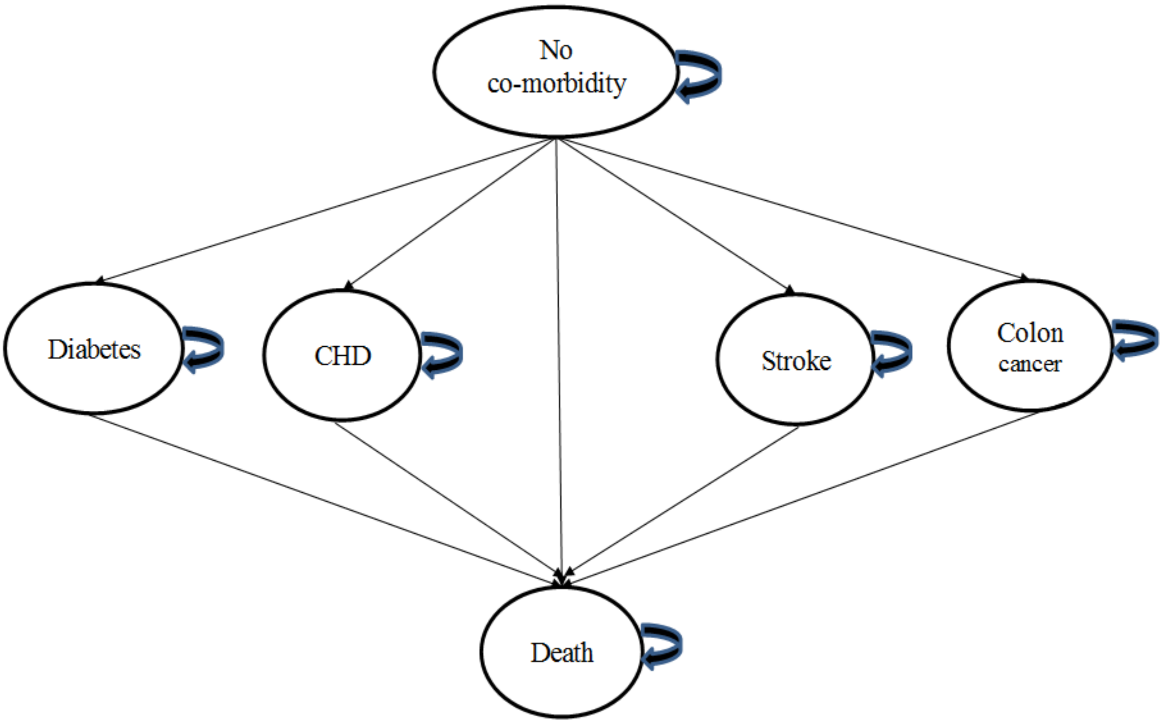
CI = confidence interval; CHD = coronary heart disease

Table 4. Results of univariate sensitivity analysis

	Roux en Y Gastric Bypass		Sleeve Gastrectomy	
Scenario	**Males**	**Females**	**Males**	**Females**
Base case	£2,018	£2,005	£1,978	£1,941
Surgery cost: high	£2,183	£2,168	£2,151	£2,109
Surgery cost: low	£1,752	£1,743	£1,701	£1,670
Baseline utility weight: high	£1,486	£1,493	£1,586	£1,579
Baseline utility weight: low	£3,141	£3,049	£2,628	£2,518
Utility weight associated with changes in BMI over time: high	£2,669	£2,599	£2,283	£2,194
Utility weight associated with changes in BMI over time: low	£1,622	£1,632	£1,745	£1,740
BMI at baseline: high	£914	£905	£1,978	£1,941
BMI at baseline: low	-£15,641	-£14,538	-£14,374	-£14,046
Reduction in BMI: high	£1,973	£1,965	£857	£850
Reduction in BMI: low	£2,075	£2,057	-£14,345	-£14,007
Cost discount rate: high	£2,006	£2,240	£1,968	£2,216
Cost discount rate: low	£1,920	-£385	£1,898	-£778
Outcomes discount rate: high	£2,609	£2,283	£2,554	£2,150
Outcomes discount rate: low	£861	£1,761	£849	£1,883

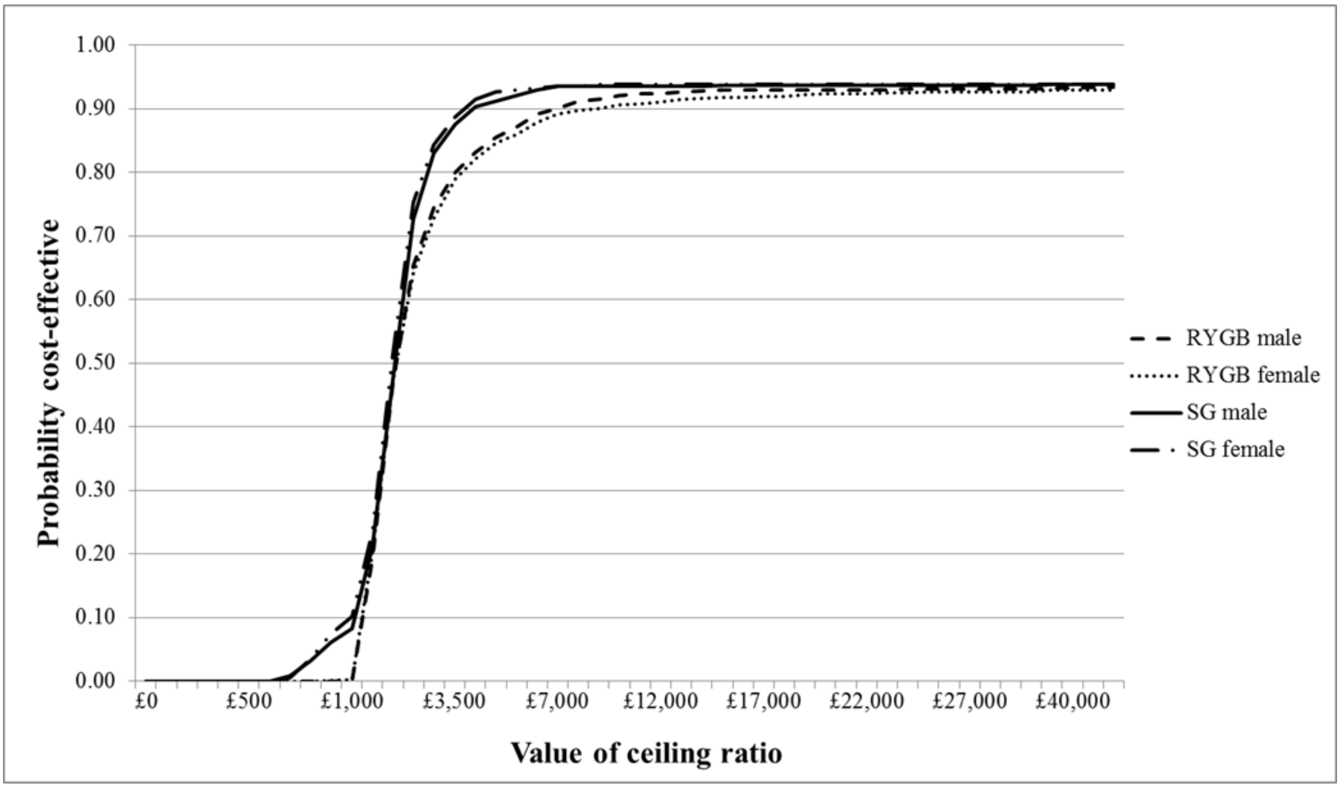
All figures are incremental cost-effectiveness ratios (incremental cost per QALY gained) comparing surgery vs. no surgery. See Online supplementary material (Table 1 and Table 2) for detailed results for every scenario; BMI = body mass index

Fig 1. Structure of the Markov model



CHD = coronary heart disease

Fig 2. Cost-effectiveness acceptability curves



RYGB = Roux en Y Gastric Bypass; SG = Sleeve Gastrectom

Table S1. Sensitivity analysis for Roux en Y Gastric Bypass intervention

Scenario	Intervention	Males					Females				
		Costs	Δ Costs	QALY	Δ QALY	ICER	Costs	Δ Costs	QALY	Δ QALY	ICER
Base case	No surgery	£ 3,414		13.27			£ 2,759		12.64		
	Surgery	£ 14,660	£ 11,245	18.84	5.57	£ 2,018	£ 14,102	£ 11,343	18.30	5.66	£ 2,005
Costs											
Surgery cost											
Upper values	No surgery	£ 3,414		13.27			£ 2,759		12.64		
	Surgery	£ 15,583	£ 12,168	18.84	5.57	£ 2,183	£ 15,025	£ 12,266	18.30	5.66	£ 2,168
Lower values	No surgery	£ 3,414		13.27			£ 2,759		12.64		
	Surgery	£ 13,179	£ 9,765	18.84	5.57	£ 1,752	£ 12,621	£ 9,862	18.30	5.66	£ 1,743
Utility weight											
Utility weight of BMI 30-39.9kg/m2											
Upper values	No surgery	£ 3,414		13.27			£ 2,759		12.64		
	Surgery	£ 14,660	£ 11,245	20.84	7.57	£ 1,486	£ 14,102	£ 11,343	20.24	7.60	£ 1,493
Lower values	No surgery	£ 3,414		13.27			£ 2,759		12.64		
	Surgery	£ 14,660	£ 11,245	16.85	3.58	£ 3,141	£ 14,102	£ 11,343	16.36	3.72	£ 3,049
Utility weight of BMI 40-49.9kg/m2											
Upper values	No surgery	£ 3,414		14.36			£ 2,759		13.93		
	Surgery	£ 14,660	£ 11,245	18.84	4.21	£ 2,669	£ 14,102	£ 11,343	18.30	4.36	£ 2,599
Lower values	No surgery	£ 3,414		11.91			£ 2,759		11.35		
	Surgery	£ 14,660	£ 11,245	18.84	6.93	£ 1,622	£ 14,102	£ 11,343	18.30	6.95	£ 1,632
BMI											
BMI at baseline (39-57kg/m2)											
39kg/m2	No surgery	£ 2,938		19.63			£ 2,320		19.11		
	Surgery	£ 14,660	£ 11,721	18.84	-0.79	-£ 14,863	£ 14,102	£ 11,782	18.30	-0.81	-£ 14,538
57kg/m2	No surgery	£ 3,817		6.99			£ 3,145		6.19		
	Surgery	£ 14,660	£ 10,843	18.84	11.86	£ 914	£ 14,102	£ 10,957	18.30	12.11	£ 905

Reduction in BMI (20%-37%) after surgery											
20% reduction	No surgery	£ 3,414		13.27			£ 2,759		12.64		
	Surgery	£ 14,923	£ 11,509	18.81	5.55	£ 2,075	£ 14,341	£ 11,582	18.27	5.63	£ 2,057
37% reduction	No surgery	£ 3,414		13.27			£ 2,759		12.64		
	Surgery	£ 14,455	£ 11,040	18.86	5.60	£ 1,973	£ 13,920	£ 11,161	18.32	5.68	£ 1,965
Discount rate											
Costs											
0%	No surgery	£ 18,787		13.27			£ 16,278		12.64		
	Surgery	£ 29,488	£ 10,701	18.84	5.57	£ 1,920	£ 14,102	-£ 2,176	18.30	5.66	-£ 385
5%	No surgery	£ 1,799		13.27			£ 1,427		12.64		
	Surgery	£ 12,977	£ 11,177	18.84	5.57	£ 2,006	£ 14,102	£ 12,675	18.30	5.66	£ 2,240
Outcomes											
0%	No surgery	£ 3,414		31.24			£ 2,759		30.84		
	Surgery	£ 14,660	£ 11,245	44.30	13.06	£ 861	£ 27,080	£ 24,321	44.65	13.81	£ 1,761
5%	No surgery	£ 3,414		10.18			£ 2,759		9.62		
	Surgery	£ 14,660	£ 11,245	14.49	4.31	£ 2,609	£ 12,674	£ 9,915	13.96	4.34	£ 2,283

QALY = quality adjusted life year; ICER = incremental cost-effectiveness ratio; BMI = body mass index

Table S2. Sensitivity analysis for Sleeve Gastrectomy intervention

Scenario	Intervention	Males					Females				
		Costs	Δ Costs	QALY	Δ QALY	ICER	Costs	Δ Costs	QALY	Δ QALY	ICER
Base case	No surgery	£ 3,939		6.98			£ 3,264		6.18		
	Surgery	£ 14,815	£ 10,877	12.47	5.50	£ 1,978	£ 14,217	£ 10,954	11.82	5.64	£ 1,941
Costs											
Surgery cost											
Upper values	No surgery	£ 3,939		6.98			£ 3,264		6.18		
	Surgery	£ 15,766	£ 11,827	12.47	5.50	£ 2,151	£ 15,168	£ 11,904	11.82	5.64	£ 2,109
Lower values	No surgery	£ 3,939		6.98			£ 3,264		6.18		
	Surgery	£ 13,290	£ 9,351	12.47	5.50	£ 1,701	£ 12,692	£ 9,428	11.82	5.64	£ 1,670
Utility weight											
Utility weight of BMI 40-49.9kg/m2											
Upper values	No surgery	£ 3,939		6.98			£ 3,264		6.18		
	Surgery	£ 14,815	£ 10,877	13.83	6.86	£ 1,586	£ 14,217	£ 10,954	13.12	6.94	£ 1,579
Lower values	No surgery	£ 3,939		6.98			£ 3,264		6.18		
	Surgery	£ 14,815	£ 10,877	11.11	4.14	£ 2,628	£ 14,217	£ 10,954	10.53	4.35	£ 2,518
Utility weight of BMI >=50kg/m2											
Upper values	No surgery	£ 3,939		7.71			£ 3,264		6.83		
	Surgery	£ 14,815	£ 10,877	12.47	4.76	£ 2,283	£ 14,217	£ 10,954	11.82	4.99	£ 2,194
Lower values	No surgery	£ 3,939		6.24			£ 3,264		5.53		
	Surgery	£ 14,815	£ 10,877	12.47	6.23	£ 1,745	£ 14,217	£ 10,954	11.82	6.30	£ 1,740
BMI											
BMI at baseline (49-77kg/m2)											
49kg/m2	No surgery	£ 3,462		13.26			£ 2,804		12.64		
	Surgery	£ 14,815	£ 11,353	12.47	-0.79	-£ 14,374	£ 14,217	£ 11,413	11.82	-0.81	-£ 14,046
77kg/m2	No surgery	£ 3,939		6.98			£ 3,264		6.18		
	Surgery	£ 14,815	£ 10,877	12.47	5.50	£ 1,978	£ 14,217	£ 10,954	11.82	5.64	£ 1,941

Reduction in BMI (9%-48%) after surgery											
9% reduction	No surgery	£ 3,939		6.98			£ 3,264		6.18		
	Surgery	£ 15,279	£ 11,341	6.19	-0.79	-£ 14,345	£ 14,664	£ 11,401	5.37	-0.81	-£ 14,007
48% reduction	No surgery	£ 3,939		6.98			£ 3,264		6.18		
	Surgery	£ 14,120	£ 10,181	18.86	11.89	£ 857	£ 13,582	£ 10,318	18.32	12.14	£ 850
Discount rate											
Costs											
0%	No surgery	£ 20,869		6.98			£ 18,609		6.18		
	Surgery	£ 31,306	£ 10,437	12.47	5.50	£ 1,898	£ 14,217	-£ 4,392	11.82	5.64	-£ 778
5%	No surgery	£ 2,106		6.98			£ 1,706		6.18		
	Surgery	£ 12,926	£ 10,820	12.47	5.50	£ 1,968	£ 14,217	£ 12,511	11.82	5.64	£ 2,216
Outcomes											
0%	No surgery	£ 3,939		15.99			£ 3,264		14.61		
	Surgery	£ 14,815	£ 10,877	28.80	12.82	£ 849	£ 29,022	£ 25,758	28.29	13.68	£ 1,883
5%	No surgery	£ 3,939		5.39			£ 3,264		4.74		
	Surgery	£ 14,815	£ 10,877	9.65	4.26	£ 2,554	£ 12,588	£ 9,325	9.08	4.34	£ 2,150

QALY = quality adjusted life year; ICER = incremental cost-effectiveness ratio; BMI = body mass index

Table S3. Probabilistic cost-effectiveness analyses

	Males				Females			
	Mean	**(95%CI)**	**QALY**	**(95%CI)**	**Mean**	**(95%CI)**	**QALY**	**(95%CI)**
Roux en Y Gastric Bypass	£14,706	(£14,664; £14,747)	19.10	(18.96; 19.24)	£14,123	(£14,083; £14,163)	18.62	(18.48; 18.76)
No surgery	£3,410	(£3,397; £3,422)	13.97	(13.89; 14.06)	£2,754	(£2,744; £2,764)	13.28	(13.20; 13.36)
Differences	£11,296	(£11,255; £11,337)	5.13	(4.97; 5.29)	£11,369	(£11,329; £11,408)	5.34	(5.18; 5.50)
ICER	**2,201 (£10; £4,393)**				**2,129 (£1,186; £3,071)**			
	Mean	**(95%CI)**	**QALY**	**(95%CI)**	**Mean**	**(95%CI)**	**QALY**	**(95%CI)**
Sleeve Gastrectomy	£14,819	(£14,782; £14,855)	13.49	(13.29; 13.70)	£14,229	(£14,193; £14,265)	13.01	(12.81; 13.21)
No surgery	£3,926	(£3,910; £3,942)	7.70	(7.66; 7.75)	£3,268	(£3,255; £3,281)	6.87	(6.83; 6.91)
Differences	£10,893	(£10,859; £10,928)	5.79	(5.58; 6.00)	£10,961	(£10,927; £10,996)	6.14	(5.94; 6.35)
ICER	**1,882 (£1,637; £2,126)**				**1,784 (£1,580; £1,989)**			

QALY = quality adjusted life year; ICER = incremental cost-effectiveness ratio