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ORIGINAL ARTICLE

Evaluating the cost-effectiveness of laparoscopic adjustable gastric banding versus standard medical management in obese patients with type 2 diabetes in the UK

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Aim: To evaluate the cost-effectiveness of laparoscopic adjustable gastric banding (LAGB) versus standard medical management (SMM) in obese patients with type 2 diabetes from a UK healthcare payer perspective.

Methods: A validated computer model of diabetes was used to project outcomes reported from a randomized clinical trial of LAGB versus SMM in obese patients with type 2 diabetes. Two-year follow-up data from the trial were projected over a 40-year time horizon and cost-effectiveness was assessed from the perspective of the National Health Service. Future costs and clinical outcomes were discounted at 3.5% annually and all costs were reported in 2010 pounds sterling. A series of sensitivity analyses were performed.

Results: LAGB was associated with benefits in HbA1c, systolic blood pressure, body mass index and serum lipid concentrations, which led to significant increases in discounted life expectancy (an increase of 0.64 years) and quality-adjusted life expectancy (an increase of 0.92 quality-adjusted life years, QALYs) and reduced incidence of diabetes complications relative to SMM. Treatment costs in the LAGB arm increased by 4552 Great British Pounds (GBP), but this was partially offset by cost savings resulting from a reduction in the incidence of all modelled diabetes complications. The incremental cost-effectiveness ratio of GBP 3602 per QALY in the base case fell well below commonly quoted willingness-to-pay thresholds in the UK setting.

Conclusions: On the basis of data from a recent randomized controlled trial, LAGB is likely to be considered cost-effective from the healthcare payer perspective when compared with SMM of obesity in patients with type 2 diabetes in the UK setting.

Keywords: bariatric surgery, cost-effectiveness, dietary intervention, obesity therapy, type 2 diabetes

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Background and Aims

In 2006, the World Health Organization published projections indicating that, worldwide, approximately 1.6 billion adults (aged 15 years and over) were overweight and at least 400 million adults were obese [1]. In the same year, the Health Survey for England reported that the prevalence of overweight in people aged 16 and over in England was 38% (approximately 15.4 million people) while 24% were obese (approximately 9.8 million people) [2]. As in other Western countries, the prevalence of overweight and obesity in the UK has been increasing for many years [3, 4]. Evidence from several studies has indicated that obesity and weight gain are associated with an increased risk of developing type 2 diabetes and that the increasing prevalence of obesity is one of the key driving factors in the growing global epidemic of type 2 diabetes [5, 6]. Overweight and obesity have also been linked to high blood pressure, high cholesterol, asthma, arthritis, coronary heart disease, cirrhosis and poor health status [7–9]. The wide range of comorbidities associated with obesity has, in concert with the increasing prevalence of the condition, resulted in a substantial economic burden, with an estimated 4.2 billion Great British Pounds (GBP) of NHS expenditure attributable directly to overweight and obesity in 2007, a figure projected to rise as high as GBP 9.7 billion by 2050 [10]. The wider cost to society (including incapacity and unemployment benefits) is estimated to increase to GBP 49.9 billion in 2050.

The National Institute for Health and Clinical Excellence (NICE) published a set of consolidated clinical guidelines for the management of obesity in the UK in 2006. The guidelines emphasize diet and physical activity for patients with a body mass index (BMI) lower than 35 kg/m^2, but recommend pharmaceutical intervention (e.g. orlistat) and/or obesity surgery in those patients whose BMI is greater than 40 kg/m^2 or who have been diagnosed with comorbidities such as type 2 diabetes, hypertension, cardiovascular disease, osteoarthritis, dyslipidaemia or sleep apnea [11]. Increasingly, bariatric surgery is recognized as being a highly effective treatment in obese patients with diabetes. Confirming earlier observations of remission of type 2 diabetes, a number of recent trials have reported complete remission (as per American Diabetes Association criteria) in the majority of obese patients after bariatric surgery [12–15].

One such randomized controlled trial compared laparoscopic adjustable gastric banding (LAGB) with standard

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medical management (SMM) in a cohort comprising exclusively obese patients (BMI between 30 and 40 kg/m^2) with recently diagnosed type 2 diabetes. The 2008 study, conducted by Dixon and colleagues [15], was the first to focus specifically on this high-risk group of patients. In brief, the study recruited 60 patients who were randomly assigned to receive either conventional diabetes therapy with a focus on weight loss by lifestyle changes (n = 30) or LAGB with conventional diabetes care (n = 30). The primary endpoints of the trial related to glycaemic control at 2 years after randomization. Secondary endpoints included percentage change in HbA1c levels, weight, systolic and diastolic blood pressure (SBP and DBP), waist circumference and levels of fasting lipids, including total cholesterol, triglycerides and high-density lipoprotein (HDL) cholesterol. Patients who underwent LAGB experienced significantly larger reductions in bodyweight, HbA1c and serum triglycerides and a significantly larger increase in HDL cholesterol than those in the SMM arm. Furthermore, 73% of patients experienced remission of diabetes in the LAGB arm compared with 13% in the SMM arm ($p < 0.001$).

Despite the clinical benefits of bariatric surgery as illustrated by Dixon et al. and similar studies, the high initial cost of the bariatric procedure has led to uncertainty around its cost-effectiveness, even in obese patients with comorbidities. The aim of this study was therefore to evaluate the projected cost-effectiveness of LAGB versus SMM in obese patients with type 2 diabetes from the perspective of a UK healthcare payer.

Methods

Model

Long-term health and economic outcomes associated with LAGB versus SMM were modelled using version 8.0 of the CORE Diabetes Model (CDM), a published computer simulation model of type 2 diabetes. Whilst a brief description of the model is provided here, a full description of the model has been published previously by Palmer et al. [16, 17]. The CDM was designed as a non-product specific health policy analysis tool, comprising several inter-dependent semi-Markov sub-models, each modelling the progression of a diabetes-related complication (or non-diabetes mortality). Complications modelled include angina, myocardial infarction, congestive heart failure, stroke, peripheral vascular disease, retinopathy, macular oedema, cataract, hypoglycaemia, ketoacidosis, lactic-acidosis, nephropathy, neuropathy, foot ulcer and amputation. Each sub-model uses time, state and diabetes type-dependent transition probabilities to simulate onset or progression of a given complication. Where clinical interactions between diabetes complications have been established, the corresponding sub-models are designed to reproduce such interaction by tracker variable-mediated modification of transition probabilities.

The health economic analysis used a nonparametric bootstrapping approach, which modelled the progression of diabetes in a simulated 1000-patient cohort. Monte Carlo simulation methods were employed to calculate the mean and standard deviation of costs, life expectancy and quality-adjusted life expectancy over 1000 iterations [18]. Mean results from each iteration were used to create cost-effectiveness scatter plots which compared the differences in clinical and cost outcomes for patients undergoing LAGB versus those receiving SMM. These plots were then used to generate acceptability curves to assess the likelihood of LAGB being considered cost-effective over a range of willingness-to-pay thresholds up to GBP 50 000 per QALY gained.

The model estimated the impact of LAGB on life expectancy, quality-adjusted life expectancy, cumulative incidence of diabetes-related complications, direct medical costs and incremental cost-effectiveness ratios (ICERs) over patient lifetimes, when compared to SMM.

Simulation Cohort

In the base case, the baseline cohort characteristics were taken from the Dixon et al. study (Table 1) and supplemented

Table 1. Baseline characteristics of the simulated patient cohort.

Characteristic	Value	Reference
Demographics and risk factors [Mean (SD)]		
Start age (years)	46.9 (8.7)	[15]
Duration of diabetes (years)	1.0 (0.33)*	[15]
Percentage male (%)	46.5	[15]
HbA1c (%)	7.7 (1.4)	[15]
SBP (mmHg)	135.9 (15.6)	[15]
Total cholesterol (mg/dl)	200.0 (56.7)	[15]
HDL-cholesterol (mg/dl)	47.6 (11.1)	[15]
LDL-cholesterol (mg/dl)	114.5 (0)	[15]
Triglycerides (mg/dl)	189.7 (111.8)	[15]
Body mass index (kg/m^2)	37.1 (2.7)	[15]
Proportion smokers (%)	21.78	[19]
Cigarettes per day	13.49	[19]
Alcohol consumption (fl oz/week)	4.63	[19]
Ethnic group (%)		
Percentage White	92.1	[20]
Percentage Black	2.0	[20]
Percentage Hispanic	0.8	[20]
Percentage Native American	0.7	[20]
Percentage Asian/Pacific Islander	4.4	[20]
Baseline cardiovascular complications (%)		
History of myocardial infarction	6.99	[21]
History of peripheral vascular disease	3.48	[21]
History of stroke	6.69	[21]
History of congestive heart failure	4.23	[21]
History of atrial fibrillation	3	Assumed
History of left ventricular hypertrophy	3	Assumed
Baseline renal complications (%)		
History of microalbuminuria	12	[22]
History of gross proteinuria	1.8	[22]
History of end-stage renal disease	0	Assumed
Baseline ocular complications (%)		
History of background diabetic retinopathy	36.1	[23]
History of proliferative diabetic retinopathy	11.8	[23]
History of macular oedema	0.5	[24]
Baseline neuropathy (%)		
History of neuropathy	12.8	[24]

HbA1c, glycated haemoglobin; HDL, high density lipoprotein cholesterol; LDL, low density lipoprotein cholesterol; SBP, systolic blood pressure.
*Assumed, all patients in the Dixon et al. study had a duration of diabetes of less than 2 years.

with UK-specific data where necessary [15, 19–24]. In brief, the cohort was 46.5% male with a mean baseline age of 46.9 years (standard deviation 8.9 years). Mean baseline BMI was 37.1 kg/m^2 and mean HbA1c was 7.7%. Whilst Dixon et al. [25] did not state the mean duration of diabetes, all patients had been diagnosed with diabetes in the 2 years prior to enrolment in the study. A mean duration of diabetes of 1 year was therefore assumed, with a standard deviation of 4 months. A sensitivity analysis was performed to evaluate the cost-effectiveness of LAGB versus SMM in a population with a higher baseline BMI, with the intention of more closely matching a 'typical' UK cohort undergoing bariatric surgery. The baseline BMI in this analysis (42.4 ± 4.5 kg/m^2) was taken from the surgical arm of the Swedish Obese Subjects (SOS) study, a multicentre cohort study with matched concurrent controls comparing surgical interventions (n = 2037) with non-surgical management of obesity (n = 2010).

Treatment Effects

All treatment effects were taken from the Dixon et al. study (Table 2). Treatment effects were applied in the first year of the modelling simulation, after which patients in both treatment arms followed a natural course of risk factor progression based on data from the UKPDS and Framingham studies, as described in Palmer et al. [16]. The base case analysis did not capture any explicit clinical effects of remission of type 2 diabetes (beyond the changes in physiological parameters observed in the Dixon et al. study). Diabetes remission was experienced by 73 and 13% of patients treated with LAGB and SMM in the Dixon et al. study, respectively. Sensitivity analyses were performed in these patients to establish the effect of a hypothetical reduction in the incidence of macrovascular complications, greater than that arising from improvements in HbA1c, blood pressure and serum lipid levels.

Costs and Utilities

Unit costs of diabetes complications were taken from a recent cost-effectiveness analysis in UK patients with type 2 diabetes [26]. Costs of diabetes medications and other pharmaceuticals prescribed for comorbid conditions (aspirin, statins and angiotensin-converting enzyme inhibitors) were taken from the June 2010 NHS Electronic Drug Tariff and a 2010 prescription cost analysis from The Health and Social Care Information Centre [27, 28]. Diabetes-related pharmacy use was based on the diabetes medication use in the LAGB and SMM arms of the Dixon et al. study, including metformin (assumed to be 500 mg q.i.d.), insulin (assumed to be 60 IU per day of insulin glargine) and other hypoglycaemic treatment (assumed to be 2 mg once a day of glimepiride). In patients taking insulin, costs of self-monitoring of blood glucose (SMBG) test strips and lancets were also calculated using unit costs from the June 2010 NHS Electronic Drug Tariff and assuming one SMBG test per day. Diabetes complication costs were taken from a recent cost-effectiveness analysis of diabetes therapies in the UK (Table 3) [26].

Costs associated with gastric band placement were taken from the 2010 to 2011 NHS National Tariff using Healthcare Resource Group (HRG) code FZ05B [29]. Additional resource use including dietitian visits, clinical psychology consultations, contacts with a general practitioner and outpatient visits were also captured based on the resource use assumptions described by Picot et al. The cost of post-surgical complications in the LAGB arm was captured based on the incidence of complications as described in a 2008 cost-effectiveness analysis by Salem et al. [30]. The incidence of each complication was multiplied by a unit cost taken from an appropriate HRG code in the 2010–2011 NHS National Tariff [29]. This yielded a mean per-patient cost of post-surgical complications, which was split evenly over the first 3 years of the simulation and added to the treatment cost of every patient in the LAGB arm. In the first year of the simulation, an additional GBP 897 was added to the treatment costs in the LAGB arm to account for band adjustments after the initial placement. This cost was based on the combined daycase/elective tariff for endoscopic/radiology procedures without complications. Where necessary, all costs were inflated to 2010 values using the healthcare component of the UK consumer price index, as published by the Office for National Statistics [31].

Health-related quality of life (HRQoL) utilities were sourced primarily from the UKPDS and supplemented with

Table 2. Treatment effects from Dixon et al. [15] used in the modelling analysis.

Effect	LAGB	SMM	p value
Change from baseline HbA1c (%)	−1.81 (1.24)	−0.38 (1.26)	<0.001
Change from baseline SBP (mm Hg)	−6.0 (17.9)	−1.7 (14.2)	0.37
Change from baseline total cholesterol (mg/dl)	3.6 (51.6)	−0.4 (31.4)	0.72
Change from baseline triglycerides (mg/dl)	−71.7 (92.9)	−2.1 (120.6)	0.02
Change from baseline HDL (mg/dl)	12.6 (9.8)	2.6 (6.1)	<0.001
Change from baseline BMI (kg/m^2)*	−7.4 (0)	−0.35 (0)	<0.001
Change from baseline weight (kg)†	−21.1 (10.5)	−1.5 (5.4)	<0.001
Minor hypoglycaemic event rate (events/100 patient years)	1.67	1.67	—
Major hypoglycaemic event rate (events/100 patient years)	0	0	—

BMI, body mass index; HbA1c, glycated haemoglobin; HDL, high density lipoprotein cholesterol; LAGB, laparoscopic adjustable gastric banding system; SBP, systolic blood pressure; SMM, standard medical management.

*Change in BMI was not reported. Mean baseline height was calculated from the baseline weight and BMI and used with the change in weight over the study duration to calculate the BMI at end-of-study (and hence the change in BMI).

†Weight change is not directly captured by the CORE Diabetes Model, but is included here for completeness.

Table 3. Costs of treating diabetes complications.

Resource use	Unit cost (GBP)
Myocardial infarction (year of event)	5807
Myocardial infarction (subsequent years)	956
Angina (year of onset)	3011
Angina (subsequent years)	995
Congestive heart failure (year of onset)	3358
Congestive heart failure (subsequent years)	1177
Stroke (year of event)	3552
Stroke (subsequent years)	671
Stroke death within 30 days	4480
Peripheral vascular disease (year of onset)	1728
Peripheral vascular disease (subsequent years)	1728
Annual hemodialysis cost	38 195
Annual peritoneal dialysis cost	21 005
Renal transplant cost (year of transplant)	22 571
Annual renal transplant (subsequent years)	7335
Cataract operation	2418
Cataract operation follow-up cost	409
Annual cost of blindness	1516
Annual cost of neuropathy	370
Amputation	4709
Prosthesis	1787
Gangrene treatment	251
Infected ulcer	144
Standard uninfected ulcer	141

All costs taken from Beaudet et al. [26] and inflated from 2009 to 2010 values.

type 2 diabetes-specific utilities where necessary. In line with time trade-off outcomes from the Costs of Diabetes in Europe – Type 2 (CODE-2) study, a disutility of 0.0038 was associated with every BMI unit over 25 kg/m^2 in the base case analysis [32].

Discounting, Time Horizon and Perspective

In line with guidelines from the National Institute for Health and Clinical Excellence, future costs and clinical outcomes were discounted at 3.5% annually in the base case analysis [33]. The base case analysis was performed over patient lifetimes (a 40-year time horizon with a baseline age of 46.9 years) and costs were accounted from the perspective of a UK health care payer (i.e. the National Health Service).

Sensitivity Analyses

A series of one-way and multi-way sensitivity analyses were performed around key modelling assumptions to assess the magnitude of their influence on outcomes in the base case. Discount rates for future costs and clinical outcomes were changed (symmetrically) to 0 and 6% per annum (from 3.5% in the base case) and the influence of time horizon on the outcomes projected by the model was investigated by running analyses over 10, 20 and 30 years. In terms of analyses around costs, the unit costs of all diabetes complications captured in the analysis were simultaneously increased and decreased by 10% (LAGB and SMM treatment costs and costs of LAGB complications were held constant). Furthermore, sensitivity analyses were performed in which the cost of all LAGB complications were increased and decreased by 10%.

Two sensitivity analyses were performed in which HbA1c, SBP and BMI benefits (i.e. all treatment effects captured by the CDM aside from serum lipids) were set to one standard deviation higher and lower than the base case in the LAGB arm. In both analyses, the SMM treatment effects were simultaneously set to one standard deviation in the opposite direction, resulting in 'SMM best case' versus 'LAGB worst case' and 'SMM worst case' versus 'LAGB best case' analyses. The high standard deviations observed in the lipid concentration changes in the Dixon et al. study precluded their inclusion in these analyses and, as such, changes in total cholesterol, HDL, LDL and triglycerides were left unchanged from the base case.

With regard to BMI and its effect on quality of life, one sensitivity analysis was performed in which the mean baseline BMI was increased to 42.4 kg/m^2 to bring the baseline cohort characteristics more in line with a 'typical' UK cohort undergoing bariatric surgery [25]. An additional sensitivity analysis was then performed in which increased BMI had no effect on quality of life.

A series of sensitivity analyses were performed in which the relative risks of first MI, first stroke, heart failure, angina and peripheral vascular disease were set to 80, 60, 40 and 20%. These risk multipliers were applied to 73 and 13% of patients treated with LAGB and SMM, respectively, representing the proportion of patients who experienced remission of diabetes in each arm of the Dixon et al. study. Finally, a simulation was run with second-order sampling switched on. This option attempts to characterize the effects of structural uncertainties in the CDM (in addition to the effects of variation around the model input parameters).

Results

Long-Term Clinical Outcomes

Use of LAGB was projected to increase life expectancy and quality-adjusted life expectancy and reduce the incidence of diabetes complications when compared with SMM in obese patients with type 2 diabetes in the UK setting. The clinical outcomes observed in the LAGB arm led to an increase in projected life expectancy of 0.64 years (95% CI: 0.20–1.11 years) when compared with SMM, with the survival curve showing clear separation between the proportion of patients alive in the two simulation arms (Figure 1). Similarly, quality-adjusted life expectancy was projected to increase by 0.92 quality-adjusted life years (QALYs; 95% CI: 0.59–1.25). The mean time before onset of any diabetes-related complication increased from 3.16 to 3.74 years in patients undergoing LAGB compared with those receiving SMM. The mean time to onset of all modelled diabetes complications was higher in the LAGB arm relative to the SMM arm.

Long-Term Costs and Cost-effectiveness

LAGB resulted in a projected increase in direct medical costs of GBP 3602 over 40 years (95% CI: GBP 2168–5728). The increase was driven primarily by the increase in treatment

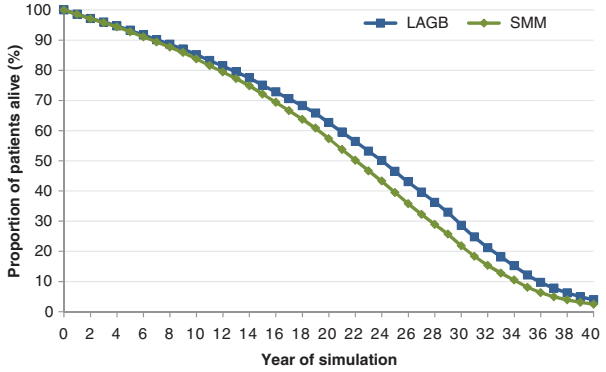

Figure 1. Survival curves showing the proportion of patients still alive in the LAGB and SMM arms over the course of the simulation. LAGB, laparoscopic adjustable gastric banding system; SMM, standard medical management.

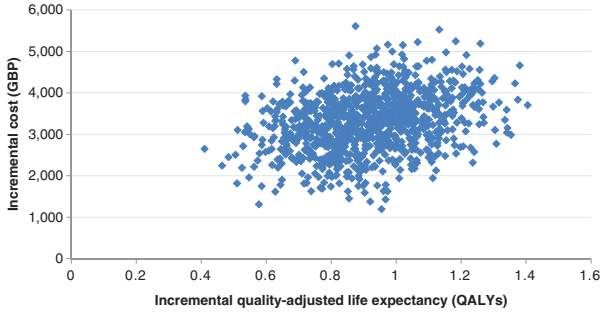

Figure 2. Scatterplot of incremental costs versus incremental quality-adjusted life expectancy for LAGB versus SMM. GBP, 2010 pounds sterling; LAGB, laparoscopic adjustable gastric banding system; SMM, standard medical management; QALY, quality-adjusted life year.

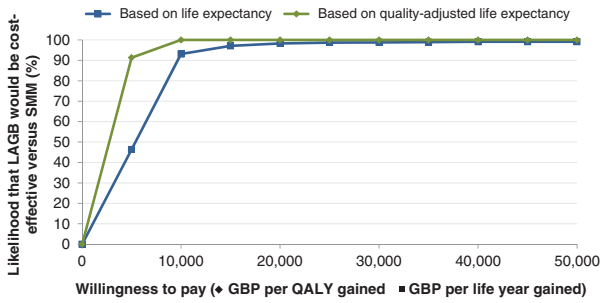

Figure 3. Acceptability curve of the cost-effectiveness of LAGB versus SMM. GBP, 2010 pounds sterling; LAGB, laparoscopic adjustable gastric banding system; SMM, standard medical management; QALY, quality-adjusted life year.

costs (from GBP 6647 to GBP 11 199), corresponding to the costs associated with the gastric banding procedure itself, incidence of post-surgical complications, band adjustment and routine follow-up. However, this increase was, in part, offset by reductions in the costs associated with diabetes complications, including a reduction of GBP 907 in cardiovascular complication costs alone.

The estimated incremental cost-effectiveness ratio was GBP 3602 per QALY gained in patients undergoing LAGB versus those receiving SMM (Table 4). Mean incremental cost and quality-adjusted life expectancy values from the 1000 model iterations were used to generate a scatter plot on the cost-effectiveness plane (Figure 2). The analysis showed that, for all model iterations, LAGB was both more expensive and more effective than SMM. The data from the 1000 model iterations were used to plot a cost-effectiveness acceptability curve to illustrate the proportion of values that fell below a range of willingness-to-pay thresholds and hence the likelihood that LAGB would be considered cost-effective (Figure 3). Assuming a willingness-to-pay threshold of GBP 20 000 per QALY gained (in line with commonly quoted thresholds in the UK setting), the model projected a 100% likelihood that LAGB would be cost-effective when compared with SMM.

Sensitivity Analyses

One-way sensitivity analysis showed that the base case was broadly insensitive to changes in individual input parameters (Table 5). Only one of the sensitivity analyses yielded a mean outcome that would not be considered cost-effective at a willingness-to-pay threshold of GBP 20 000 per QALY gained. Specifically, the LAGB 'worst-case' scenario produced an ICER of GBP 36 377 per QALY gained, based on an increase in quality-adjusted life expectancy of 0.14 QALYs and an increase in costs of GBP 5056. Conversely, the 'best-case' scenario resulted in LAGB being dominant over SMM with an increase in quality-adjusted life expectancy of 2.14 QALYs in patients undergoing LAGB compared with those receiving SMM. This was accompanied by cost savings of GBP 112 over a 40-year time horizon. The use of second-order sampling in the model (i.e. to address structural uncertainty in the CDM itself) resulted in a mean ICER of GBP 3824 per QALY gained, GBP 222 per QALY higher than the base case. However, the 95% CIs around cost and effectiveness outcomes were wider than in the base case

Table 4. Base case cost-effectiveness results based on long-term clinical outcomes.

	LAGB	SMM	Difference
Discounted life expectancy (years)	14.38 (14.05–14.70)	13.74 (13.42–14.06)	+0.64 (0.20–1.11)
Quality-adjusted life expectancy (QALYs)	10.05 (9.80–10.30)	9.14 (8.91–9.36)	+0.92 (0.59–1.25)
Lifetime direct medical costs (GBP)	23 562 (22 754–24 496)	20 263 (19 294–21 320)	+3298 (1837–4647)
ICER based on life expectancy		GBP 5163 per life year gained	
ICER based on quality-adjusted life expectancy		GBP 3602 per QALY gained	

Values are presented as mean (95% CI).

Table 5. Summary of sensitivity analysis results.

	Quality-adjusted life expectancy (QALYs)			Direct costs (GBP)			
Analysis	LAGB	SMM	Difference	LAGB	SMM	Difference	ICER (GBP per QALY gained)
Base case	10.05 (9.80–10.30)	9.14 (8.91–9.36)	+0.92 (0.59–1.25)	23 562 (22 754–24 496)	20 263 (19 294–21 320)	3298 (1837–4647)	3602
With second-order sampling	9.71 (6.67–11.88)	8.84 (5.93–11.16)	+0.88 (0.45–1.33)	23 455 (18 551–28 889)	20 106 (14 627–26 398)	3348 (1499–4815)	3824
10 Year time horizon	5.63 (5.54–5.72)	5.35 (5.26–5.44)	+0.28 (0.15–0.41)	12 584 (12 220–13 005)	7826 (7436–8344)	4758 (4123–5355)	17 176
20-Year time horizon	8.63 (8.45–8.81)	8.05 (7.87–8.24)	+0.58 (0.32–0.84)	18 089 (17 430–18 840)	14 633 (13 885–15 466)	3455 (2388–4472)	5928
30-Year time horizon	9.85 (9.60–10.09)	8.99 (8.77–9.21)	+0.85 (0.53–1.18)	22 203 (21 420–23 145)	19 047 (18 131–20 103)	3157 (1809–4508)	3700
0% Discount rate	15.28 (14.83–15.73)	13.56 (13.12–13.94)	+1.72 (1.12–2.36)	37 723 (36 028–39 563)	35 347 (33 422–37 350)	2376 (−399 to 5157)	1379
6% Discount rate	7.88 (7.70–8.05)	7.25 (7.09–7.40)	+0.63 (0.40–0.86)	18 351 (17 792–19 025)	14 624 (13 943–15 363)	3727 (2714–4680)	5933
10% Decrease in diabetes complication costs	10.05 (9.80–10.30)	9.14 (8.91–9.36)	+0.92 (0.59–1.25)	22 420 (21 687–23 276)	18 993 (18 106–19 948)	3428 (2101–4659)	3743
10% Increase in diabetes complication costs	10.05 (9.80–10.30)	9.14 (8.91–9.36)	+0.92 (0.59–1.25)	24 703 (23 820–25 722)	21 533 (20 481–22 680)	3169 (1577–4642)	3461
University of Michigan QALE estimation	8.51 (8.31–8.70)	7.77 (7.59–7.94)	+0.74 (0.47–1.02)	23 562 (22 754–24 496)	20 263 (19 294–21 320)	3298 (1837–4647)	4435
UKPDS tobit model QALE estimation	11.74 (11.45–12.02)	11.10 (10.83–11.35)	+0.64 (0.26–1.07)	23 562 (22 754–24 496)	20 263 (19 294–21 320)	3298 (1837–4647)	5127
LAGB 'worst case'	9.63 (9.40–9.89)	9.49 (9.25–9.71)	+0.14 (−0.20 to 0.49)	24 374 (23 366–25 501)	19 318 (18 433–20 281)	5056 (3691–6568)	36 377
LAGB 'best case'	10.63 (10.36–10.87)	8.48 (8.27–8.70)	+2.14 (1.81–2.48)	22 268 (21 448–23 149)	22 380 (21 225–23 700)	−112 (−1558 to 1337)	−52
HbA1c benefit only	9.66 (9.43–9.91)	9.14 (8.91–9.36)	+0.53 (0.23–0.83)	23 828 (23 002–24 825)	20 263 (19 294–21 320)	3565 (2260–4968)	16 338
BMI benefit only	9.67 (9.40–9.90)	9.14 (8.91–9.36)	+0.53 (0.19–0.84)	24 536 (23 613–25 688)	20 263 (19 294–21 319)	4273 (2838–5779)	8085
SBP benefit only	9.49 (9.25–9.73)	9.14 (8.91–9.36)	+0.35 (0.05–0.70)	24 465 (23 501–25 532)	20 263 (19 294–21 320)	4202 (2847–5469)	12 027
20% Decrease in event risks in patients with diabetes remission	10.20 (9.96–10.46)	9.16 (8.92–9.39)	+1.04 (0.69–1.40)	22 334 (21 433–23 356)	19 361 (18 327–20 527)	2973 (1472–4297)	2863
40% Decrease in event risks in patients with diabetes remission	10.38 (10.09–10.66)	9.19 (8.95–9.42)	+1.19 (0.83–1.56)	22 155 (21 231–23 134)	19 288 (18 373–20 370)	2868 (1413–4145)	2409
60% Decrease in event risks in patients with diabetes remission	10.58 (10.31–10.86)	9.23 (8.99–9.46)	+1.36 (1.02–1.71)	21 837 (21 075–22 735)	19 284 (18 358–20 317)	2553 (1251–3740)	1883
80% Decrease in event risks in patients with diabetes remission	10.82 (10.54–11.11)	9.29 (9.06–9.52)	+1.53 (1.19–1.90)	21 553 (20 672–22 505)	192 41 (18 193–20 307)	2312 (955–3628)	1509
No BMI disutility	10.31 (10.06–10.57)	9.77 (9.53–10.01)	+0.54 (0.20–0.90)	23 562 (22 754–24 496)	20 263 (19 294–21 320)	3298 (1837–4647)	6068
Morbidly obese population	9.93 (9.68–10.15)	8.99 (8.76–9.21)	+0.94 (0.63–1.27)	23 579 (22 691–24 559)	20 161 (19 235–21 212)	3418 (2111–4779)	3632

Values are presented as mean (95% CI). BMI, body mass index; GBP, 2010 pounds sterling; HbA1c, glycated hemoglobin; ICER, incremental cost-effectiveness ratio; LAGB, laparoscopic adjustable gastric banding; QALE, quality-adjusted life expectancy; QALY, quality-adjusted life year; SBP, systolic blood pressure; SMM, standard medical management.

with considerable overlap between the outcomes in the LAGB and SMM arms.

Discussion

On the basis of effectiveness data from the Dixon et al. study and resource use and cost data from a number of UK-specific sources, the present analysis found that, from the perspective of a UK healthcare payer, LAGB would be considered highly cost-effective in obese type 2 diabetes patients when compared with SMM. The ICER from the base case analysis was GBP 3602 per QALY gained (95% CI: GBP 2168–GBP 5728 per QALY gained), falling well below a hypothetical willingness-to-pay threshold of GBP 20 000 per QALY. Sensitivity analyses found the base case result to be broadly insensitive to changes in individual model parameters.

The finding that LAGB would be cost-effective when compared with SMM is in line with a number of previous health economic studies comparing bariatric surgery with SMM. From a methodological point of view, the most similar study is a 2009 study by Ikramuddin et al. [34] which used the CDM to evaluate the cost-effectiveness of Roux-en-Y gastric bypass compared with SMM in obese patients with type 2 diabetes from the perspective of a US managed care organization. Data on the effectiveness of Roux-en-Y gastric bypass were taken from a prospective observational study, whilst no treatment effects were applied in the SMM arm (with patients therefore following standard 'physiological' progressions as defined by the CDM). The study found Roux-en-Y to be a cost-effective treatment option relative to SMM with an ICER of USD 21 973 per QALY gained. Whilst the findings and modelling methodology are not dissimilar to those in this study, comparisons are difficult to draw as the patient group had a longer duration of diabetes (8.7 years vs. <2 years in Dixon et al.) and a higher BMI (mean 48.4 kg/m^2 vs. 37.1 kg/m^2) than the group in the present analysis.

In 2009, Keating et al. [35] published a cost-effectiveness analysis in the Australian setting which, like the present analysis, was based exclusively on clinical data from Dixon et al. study. Whilst the study provided a useful insight into the costs associated with bariatric surgery in the Dixon cohort, direct comparisons are again difficult to draw as Keating and colleagues focused exclusively on the within-trial period (i.e. with no extrapolation) and reported the cost-effectiveness in terms of cost per diabetes case remitted. However, building on this initial within-trial analysis, Keating and colleagues published a follow-up analysis based on a simple Markov model that projected the trial outcomes over patient lifetimes [36]. The findings of this analysis showed LAGB to be dominant to SMM on incremental costs of AUD −2400 and incremental quality-adjusted life expectancy of 1.2 QALYs. The incremental effectiveness outcome is approximately 30% higher than that reported in this study, but this could be attributed to a number of factors, notably the discount rate, which was 0.5% lower than that used in the present analysis. Whilst incremental costs were directionally different (i.e. LAGB was cost saving), the absolute difference is small enough to be attributable to the costs assigned to the initial surgical procedure or post-surgical follow-up. Given these inevitable differences arising from the different country setting, the findings of this study are broadly supportive of those published by Keating and colleagues.

In the UK setting, the health technology assessment by Picot et al. (on which a number of resource use assumptions in this analysis are based) included a cost-effectiveness evaluation of SMM versus LAGB and gastric bypass [37]. The analysis was based on a relatively simple state transition model to capture common comorbidities of obesity and was run over a 20-year time horizon from the perspective of the NHS and personal social services (i.e. a governmental perspective). Depending on the weight reduction assumptions (the authors included optimistic and pessimistic weight loss scenarios), the analysis reported ICERs of GBP 1897 and GBP 3863 per QALY gained for LAGB versus SMM (in the optimistic and pessimistic scenarios, respectively). Given the significantly different health economic frameworks and modelling approaches used, these outcomes are once again difficult to compare directly with the results of this study, but the similarity in ICERs lends credence to the health economic argument supporting LAGB in obese type 2 diabetes patients in the UK setting.

In discussing the effects of bariatric surgery in the treatment of obese patients with type 2 diabetes, it is worth noting the effects of the glucagon-like peptide 1 (GLP-1) analogues. While the GLP-1 analogues are not currently indicated for the treatment of obesity alone, NICE recommends their use as third-line therapy in patients with type 2 diabetes (after metformin and sulphonylurea), specifically in those patients with HbA1c greater than 7.5% and either a BMI greater than 35 kg/m^2 (in those of European descent) or a BMI less than 35 kg/m^2, but with obesity-related comorbidities that may improve with weight loss [38]. Clinical trials of exenatide in overweight patients have generally shown moderate weight loss, for instance 4.4 kg (from a mean baseline of 99 kg) over 82 weeks in a 2006 study by Blonde et al. and 5.3 kg (from a mean baseline of 102 kg) in a similar study by Ratner et al. [39, 40]. While these improvements are preferable to the weight gain usually associated with insulin initiation, they are substantially less than the 21.1 kg weight reduction observed with LAGB in the Dixon et al. study (from a mean baseline of 105.6 kg). At the time of writing, we are not aware of any head-to-head trials of LAGB versus GLP-1 analogues, making a robust, comparative analysis of cost-effectiveness difficult.

The key strengths of this analysis include the use of cohort characteristics, treatment effects and diabetes medication use data from the same randomized controlled trial and the use of a validated and extensively published computer simulation model of type 2 diabetes to project long-term clinical and cost outcomes. However, the study has a number of limitations that should be addressed. First and foremost, the incidence of post-surgical complications in the LAGB arm was not associated with any decrement in HRQoL. As the CDM was designed to model exclusively diabetes-related complications, the incidence of surgical complications was only captured as an additional cost in the LAGB arm in this analysis (in this case with the costs spread over the first 3 years of the simulation). To associate an HRQoL disutility with each post-surgical complication would require the implementation of post-surgical complication submodels

such that the HRQoL decrements could be captured by the CDM's various quality-adjusted life expectancy algorithms.

This analysis also did not capture any explicit benefits of diabetes remission above and beyond the changes in physiological and clinical parameters observed in the Dixon et al. trial. As such, whilst these parameters (as modelled) were representative of the patients who experienced diabetes remission in Dixon et al., the regression models in the CDM used to project clinical outcomes were derived from a diabetes population (specifically those patients enrolled in the United Kingdom Prospective Diabetes Study). Although the notion of complete diabetes remission is still somewhat contentious, the possibility that patients with remitted diabetes may experience a reduction in the incidence of cardiovascular complications (greater than that implied by changes in physiological and clinical status) was investigated in the series of sensitivity analyses in which relative risks of macrovascular complications were set to 80, 60, 40 and 20% in those patients experiencing remission of diabetes. These analysis yielded ICERs of GBP 2863, GBP 2409, GBP 1883 and GBP 1509 per QALY gained respectively, indicating that, unsurprisingly, additional reductions in the incidence of macrovascular complications would improve the health economic proposition of LAGB relative to SMM.

In interpreting the findings and generalizability of the analysis, the origin of the data should also be taken into consideration. The analysis was based primarily on efficacy data from the Dixon et al. study, which was conducted in the Australian setting in a predominantly White cohort. While the base case cohort was similar to patients eligible for bariatric surgery in the UK (with a mean BMI of 35–40 kg/m^2 and other significant disease that could be improved with weight loss), the findings may not be applicable to patients of other ethnic groups [41, 42]. Similar analyses based on clinical data from populations with different ethnic characteristics would be necessary to ascertain the cost-effectiveness of LAGB in these patients.

Finally, despite the use of data from a randomized controlled trial, the nature of the analysis is such that relatively short-term clinical data were used to make projections over a 40-year time horizon. Such extrapolation remains one of the central tenets of the majority of health economic modelling and, in the absence of robust, long-term clinical trial data, this approach currently represents the best available option. Whilst doubt may still exist around the accuracy of the clinical predictions, use of the peer-reviewed and validated CDM goes some way to mitigating these concerns. In conclusion, this study shows that LAGB is a highly cost-effective treatment in obese patients with type 2 diabetes in the UK setting compared with SMM. The higher initial costs of performing bariatric surgery should therefore not represent a barrier to its reimbursement in obese patients with type 2 diabetes who are fit to undergo bariatric surgery.

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Conflict of Interest

R. F. P. and W. J. V. are full-time employees of Ossian Health Economics and Communications, which received consulting fees from Allergan Ltd (manufacturer of the LAP-BAND LAGB product) to perform the analysis and write the manuscript. G. M. is a full-time employee of Allergan Ltd.

R. F. P., W. J. V. and G. M. contributed to the design of the study. R. F. P. performed the data collection. R. F. P. and W. J. V. performed the analysis. R. F. P., W. J. V. and G. M. wrote the manuscript.

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