Cost-Effectiveness of Bariatric Surgery for Severely Obese Adults With Diabetes

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OBJECTIVE — To analyze the cost-effectiveness of bariatric surgery in severely obese (BMI ≥35 kg/m^2) adults who have diabetes, using a validated diabetes cost-effectiveness model.

RESEARCH DESIGN AND METHODS — We expanded the Centers for Disease Control and Prevention–RTI Diabetes Cost-Effectiveness Model to incorporate bariatric surgery. In this simulation model, bariatric surgery may lead to diabetes remission and reductions in other risk factors, which then lead to fewer diabetes complications and increased quality of life (QoL). Surgery is also associated with perioperative mortality and subsequent complications, and patients in remission may relapse to diabetes. We separately estimate the costs, quality-adjusted life-years (QALYs), and cost-effectiveness of gastric bypass surgery relative to usual diabetes care and of gastric banding surgery relative to usual diabetes care. We examine the cost-effectiveness of each type of surgery for severely obese individuals who are newly diagnosed with diabetes and for severely obese individuals with established diabetes.

RESULTS — In all analyses, bariatric surgery increased QALYs and increased costs. Bypass surgery had cost-effectiveness ratios of $7,000/QALY and $12,000/QALY for severely obese patients with newly diagnosed and established diabetes, respectively. Banding surgery had cost-effectiveness ratios of $11,000/QALY and $13,000/QALY for the respective groups. In sensitivity analyses, the cost-effectiveness ratios were most affected by assumptions about the direct gain in QoL from BMI loss following surgery.

CONCLUSIONS — Our analysis indicates that gastric bypass and gastric banding are cost-effective methods of reducing mortality and diabetes complications in severely obese adults with diabetes.

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In recent years, bariatric surgery has emerged as a popular treatment to reduce body weight and improve obesity-related complications, particularly in the diabetic population. Several studies have shown that surgery can lead to significant weight loss, with excess body weight reduced by >50% (1,2). Although weight loss declines over time, the Swedish Obese Subjects (SOS) Study found significant weight loss even 10 years after surgery (3,4). In addition to sustained weight loss, bariatric surgery may provide additional benefits to people with diabetes. Among severely obese patients with diabetes, bariatric surgery often leads to diabetes remission, with remission rates that are as high as 80% in the short run (1) and that remain significant in the long run (3,4).

Although the evidence suggests that bariatric surgery is a successful long-term treatment of obesity for people with diabetes, it is an expensive procedure. The average cost of surgery exceeds $13,000 (5), with additional costs possible in the months following surgery (6). This raises the question of whether bariatric surgery is cost-effective for severely obese people with diabetes.

Several studies have estimated the cost-effectiveness of bariatric surgery and found that surgery is either cost-effective (7–10) or that it leads to cost savings over time (6,11–13). The existing studies tend to be relatively simple, and only two (10,13) focus on people with diabetes. The studies generally do not model the microvascular complications associated with diabetes, the effect of surgery on blood pressure and cholesterol levels, or the resulting outcomes.

This study used the Centers for Disease Control and Prevention (CDC)-RTI Diabetes Cost-Effectiveness Model to analyze the cost-effectiveness of bariatric surgery in severely obese adults with diabetes. We separately estimated the cost-effectiveness of gastric bypass surgery relative to usual diabetes care and the cost-effectiveness of gastric banding surgery relative to usual diabetes care. Gastric bypass and gastric banding are the two forms of bariatric surgery most commonly studied (1). We examined the cost-effectiveness of each type of surgery for severely obese people who are newly diagnosed with diabetes (no more than 5 years after diagnosis) and for people with established diabetes (at least 10 years after diagnosis).

RESEARCH DESIGN AND METHODS

The CDC-RTI Diabetes Cost-Effectiveness Model is a Markov simulation model of disease progression and cost-effectiveness for type 2 diabetes that follows patients from diagnosis to either death or age 95 years. The model simulates development of diabetes-related complications on three microvascular disease paths (nephropathy, neuropathy, and retinopathy) and two macrovascular disease paths (coronary heart disease [CHD] and stroke). Model outcomes include disease complications, deaths, costs, and quality-adjusted life-years (QALYs). In the model, progression between disease states is governed by transition probabilities that depend on risk

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factors and duration of diabetes. Interventions affect the transition probabilities and resulting complications. The model has been used to estimate the cost-effectiveness of interventions for patients with diagnosed diabetes or prediabetes (14,15). Details about the model and its validation are presented elsewhere (14–16).

Bariatric surgery is incorporated in the following ways. First, the model allows for diabetes remission and improvement, important results of bariatric surgery. We defined remission as normal glycemic levels following surgery without antidiabetes medications. This was incorporated in the model as no progression along the microvascular paths, no diabetes treatment costs, elimination of the diabetes indicator variable in the CHD and stroke equations, and elimination of the diabetes other-cause mortality multiplier. We created an "improved diabetes" state for people who reduced the use of antidiabetes medications but did not achieve full diabetes remission. The rates of diabetes remission and improvement following bariatric surgery procedures are shown in Table 1 with values based on a meta-analysis (1). The reduction in costs for improvement is based on two smaller studies (17,18). The online appendix (available at http://care.diabetesjournals.org/cgi/content/full/dc10-0554/DC1) provides additional details on sources and parameter derivation for the variables described in this section.

Second, the model includes an annual probability of relapse from remission to diabetes. Because few studies examine the long-term effects of bariatric surgery, we focused on the SOS study, which followed patients for 10 years after bariatric surgery (3). We used the diabetes remission rates reported at 2 and 10 years to calculate the probability of relapse in Table 1.

Third, the model accounts for perioperative mortality and the long-term effects of surgery on mortality. For perioperative mortality, we used separate rates for bypass and banding surgery (19). The model calculates future changes in mortality based on surgery's effects on blood pressure, cholesterol, and the remission or improvement of diabetes. We used multiple literature sources to estimate the effect of surgery on blood pressure and cholesterol values. Remission or improvement in diabetes stops or slows progression of diabetes complications, which reduces mortality. For people in diabetes remission, we also lowered other-cause mortality to the baseline rate among people with no diabetes. These effects are listed in Table 1.

Fourth, the model includes the costs of bariatric surgery. First-year bypass and banding surgery costs are based on an analysis of Medstat claims by Eric A. Finkelstein et al. (2008, unpublished data). The analysis calculated the costs attributable to surgery, including the surgery costs and any complication costs in the first year. For costs in subsequent years, we included costs of follow-up care visits; nutritional supplements; long-term complications, such as revisional surgery, cholelithiasis, abdominoplasty, and nonoperative leaks; and band removal (for gastric banding). Table 1 lists the complication costs by year after surgery.

Finally, in addition to changes in quality of life (QoL) following surgery that result from reductions in diabetes complications, the model includes changes in QoL directly associated with bariatric surgery. We included a change in QoL associated with bariatric surgery that was the product of the change in utility for a 1–BMI unit change in weight and the change in BMI associated with surgery.

To analyze the cost-effectiveness of bariatric surgery, we focused on the population with BMI $\geq$35 kg/m^2 and diabetes. We defined the characteristics of this population by estimating the distribution of age, sex, race, hypertension status, cholesterol status, and smoking status as well as systolic blood pressure, total cholesterol, and HDL levels within the National Health and Nutrition Examination Survey for the subset of the obese population (BMI $\geq$30 kg/m^2) with self-reported diabetes. Values for the population with BMI $\geq$35 kg/m^2 were similar, so we used data from the full obese population with its larger sample size.

Within the severely obese diabetic population, we separately analyzed the newly diagnosed diabetic population and the established diabetic population. We distinguished between these two groups because studies have shown that surgery leads to significantly less weight loss and lower rates of diabetes remission in people with longer diabetes duration (17,18). The primary differences between the populations are that the newly diagnosed diabetic population is younger (aged 35–74 years) than the established diabetic population (aged 45–74 years) to represent the 10-year difference in duration, and the diabetes remission rate is lower for the established diabetic population (18). We adjusted diabetes duration to 10 years in the model to reflect changes in glycemic control and complications in the established diabetic population.

Using these two severely obese diabetic populations, we estimated the cost-effectiveness of gastric bypass and gastric banding surgery. The two surgeries differ in several factors, including diabetes remission rate, diabetes improvement rate, perioperative mortality rate, first-year and following-year costs, and effect on blood pressure, cholesterol, and QoL. Table 1 includes the specific parameter values for each surgery type. For our baseline analyses for each type of surgery, we compared the surgery to usual diabetes care that included tight glycemic control similar to that provided in the UK Prospective Diabetes Study (20). We assumed that patients who were not in diabetes remission would also receive tight glycemic control. In total, our baseline analyses included four model runs, with separate runs for each type of surgery and for each diabetic population (newly diagnosed and established).

We converted all costs to 2005 U.S. dollars using the medical-care component of the Consumer Price Index (21). We discounted costs and QALYs by a 3% annual rate, and we estimated incremental cost-effectiveness ratios that were rounded to the nearest $1,000/QALY. We also report undiscounted remaining life-years.

We ran one-way sensitivity analyses to determine how key factors affected the cost-effectiveness ratios. When possible, we used end points of the published 95% (90% for surgery costs) CI of the model parameter to determine upper and lower values to input into the model. For most parameters where CIs were unavailable, we halved and doubled the baseline values. We varied the change in QoL per unit BMI change from 0 (i.e., surgery-related weight loss has no direct effect on QoL) to 0.017. We also analyzed the effect of surgery on the diabetic population with a BMI between 30 and 34 kg/m^2. We assumed a similar percentage change in excess weight loss (22) as in our main analysis, which leads to a smaller change in BMI and QoL improvement.

To examine how conjoint parameter uncertainty affected the model results, we conducted probabilistic sensitivity analysis (PSA) on key parameters involved in estimating the cost-effectiveness ratios. Applying distributions for surgery costs,

Table 1—*Key surgery-related model parameter values*

Variable	Bypass	Banding	Parameter value	Range for sensitivity analysis
Parameter values for people with newly diagnosed diabetes				
Diabetes remission rate	√		80.3%	74.4–86.1%
		√	56.7%	46.7–66.8%
Glycemic level after remission	√	√	6.0%	
Diabetes improvement rate	√		0.0%	
		√	24.0%	19.8–28.3%
Glycemic level after improvement	√	√	5.9%	
Reduction in oral medications usage due to diabetes improvement	√	√	51.8%	
Annual probability of relapse	√	√	8.3%	
Perioperative mortality rate	√		0.253%	0.143–0.365%
		√	0.068%	0.009–0.136%
Effect of surgery on systolic blood pressure	√		11.25% reduction first 2 years	
			Effect then reduced by 1.4% each year until no reduction in year 10	
		√	3.2% reduction first 2 years then reduction to 0	
Effect of surgery on total cholesterol	√		16.1% reduction first 2 years	
			Effect then reduced by 1.2% each year until no reduction in year 10	
		√	5.0% reduction first 2 years then reduction to 0	
Effect of surgery on HDL	√		No effect first 2 years	
			Effect then increased by 1.7% each year until year 10	
		√	10.0% increase first 2 years	
			Effect then decreased by 0.05% each year until year 10	
Effect of surgery on QoL (equals utility improvement per 1 unit BMI decline times BMI loss following surgery)	√		0.0899	0–0.275
		√	0.0668	0–0.204
Mean utility improvement per 1 unit BMI decline	√	√	0.0056	0–0.017
Mean BMI loss following surgery	√		16.17	14.07–18.27
		√	12.01	10.78–13.24
Surgery and first year costs	√		$23,871	$6,612–55,261
		√	$15,169	$2,857–30,186
Year 2 costs	√		$3,207	$1,603–6,414
Year 3 costs	√		$1,990	$995–3,981
Year 4 costs	√		$1,469	$734–2,938
Year 5 costs	√		$1,469	$734–2,938
Year ≥6 costs	√		$330	$165–661
Year 2 costs		√	$3,300	$1,650–6,600
Year 3 costs		√	$1,940	$970–3,880
Year 4 costs		√	$1,940	$970–3,880
Year 5 costs		√	$1,940	$970–3,880
Year ≥6 costs		√	$802	$401–1,604
Parameter values that differ for people with established diabetes				
Diabetes remission rate	√	√	40%	37.2–43.1%
Diabetes improvement rate	√	√	40%	37.2–43.1%
Glycemic level after improvement	√	√	7.0%	
Reduction in oral medication usage due to diabetes improvement	√	√	24.9%	12.45%
Reduction in insulin usage due to diabetes improvement	√	√	62.5%	31.25%

See online appendix for details on sources and parameter derivation.

Table 2—*Life-years gained and cost-effectiveness ratios (relative to no surgery) for baseline analyses*

	Total costs*	Remaining life-years	QALYs*	Cost-effectiveness ratio ($/QALY)†
Patients with newly diagnosed diabetes				
No surgery (standard care)	$71,130	21.62	9.55	
Bypass surgery	$86,665	23.34	11.76	
Incremental (vs. no surgery)	$15,536	1.72	2.21	$7,000
Banding surgery	$89,029	22.76	11.12	
Incremental (vs. no surgery)	$17,900	1.14	1.57	$11,000
Patients with established diabetes				
No surgery	$79,618	16.86	7.68	
Bypass surgery	$99,944	17.95	9.38	
Incremental (vs. no surgery)	$20,326	1.09	1.70	$12,000
Banding surgery	$96,921	17.80	9.02	
Incremental (vs. no surgery)	$17,304	0.94	1.34	$13,000

*Costs and QALYs are discounted at a 3% annual rate. †Cost-effectiveness ratios are rounded to the nearest $1,000/QALY.

remission rates, BMI loss, and other input parameters (see online appendix), we drew 1,000 parameter combinations and ran the model separately for each combination for newly diagnosed patients undergoing bypass surgery. We repeated the process for newly diagnosed patients undergoing banding surgery. Due to run time constraints, we only looked at patients in the 45- to 54-year age-group, which had a cost-effectiveness ratio that was close to the cost-effectiveness ratio for the entire population.

RESULTS— Based on the model assumptions, bariatric surgery leads to diabetes remission, and the share of patients in remission declines over time as patients relapse or die. Surgery also reduced the incidence of many diabetes-related complications for people with newly diagnosed diabetes (see online appendix).

In each of our main analyses, bariatric surgery had cost-effectiveness ratios between $7,000 and $13,000/QALY. Table 2 shows total costs, life-years, QALYs, and cost-effectiveness ratios (cost/QALY gained) by surgery type and patient group. Within the newly diagnosed diabetic population, gastric bypass led to 1.72 life-years gained, 2.21 QALYs gained, and a cost-effectiveness ratio of $7,000/QALY; gastric banding led to 1.14 life-years gained, 1.57 QALYs gained, and a cost-effectiveness ratio of $11,000/QALY. Relative to the newly diagnosed diabetic population, bariatric surgery led to fewer life-years gained and higher incremental cost-effectiveness ratios within the established diabetic population. Gastric bypass led to 1.09 life-years gained, 1.70 QALYs gained, and a cost-effectiveness ratio of $12,000/QALY, whereas gastric banding led to 0.94 life-years gained, 1.34 QALYs gained, and a cost-effectiveness ratio of $13,000/QALY in the established diabetic population.

One-way sensitivity analyses

Fig. 1 shows the effect on the cost-effectiveness ratio of varying each parameter in one-way sensitivity analyses. The figure includes separate panels for each baseline analysis group (i.e., bypass and banding surgery for the newly diagnosed and established diabetic populations). For each analysis population, varying the effects of surgery on remission rates, perioperative mortality, and relapse rate had relatively small effects on the cost-effectiveness ratios. Varying the change in BMI from surgery also had little effect, but varying the direct QoL improvement per unit of BMI loss from 0.017 (which reduces the cost-effectiveness ratio) to 0 (which increases the cost-effectiveness ratio) had the biggest impact on the cost-effectiveness ratios. Doubling the cost of tight glycemic control (i.e., increasing the cost of treating active diabetes) produces the lowest or second lowest cost-effectiveness ratio in each analysis population. Varying surgery costs had a bigger impact on the bypass cost-effectiveness ratios than on the banding ratios, while varying follow-up costs had a bigger impact on the banding cost-effectiveness ratios than on the bypass ratios. Halving the reduction in medication usage associated with diabetes improvement increased the cost-effectiveness ratios by <$1,000/QALY for each analysis population (not shown).

In addition, we ran analyses for different subpopulation groups. Running the analysis for a diabetic population with a BMI of 30–34 kg/m^2 approximately doubled the cost-effectiveness ratios, due primarily to the lower BMI loss and consequently smaller change in QoL. We also ran analyses with each 10-year age-group (not shown). Within the newly diagnosed diabetic population, cost-effectiveness ratios ranged from $5,000/QALY at ages 35–44 years to $12,000/QALY at ages 65–74 years for bypass surgery and from $9,000 to $17,000/QALY for the same ages for banding surgery. Within the established diabetic population, cost-effectiveness ratios ranged from $9,000/QALY at ages 45–54 years to $18,000/QALY at ages 65–74 years for bypass surgery and from $11,000 to $19,000/QALY for the same ages for banding surgery. The age-group analyses assumed (due to lack of age-specific data) that remission, perioperative mortality, and other direct surgical outcome rates and costs did not vary by age. Therefore, the age-group results were driven by higher mortality rates in older populations.

PSA

For bypass surgery, the median cost-effectiveness ratio for the 1,000 simulations on newly diagnosed patients aged 45–54 years was $6,000/QALY, and 95% of the values fell between −$2,000 and $23,000/QALY. All simulations with a negative cost-effectiveness ratio had lower costs and higher QALYs. For banding, the median cost-effectiveness ratio for the 1,000 simulations was $10,000/QALY, and 95% of the estimates fell between just under $0 and $30,000/QALY. Again, all simulations with a negative cost-effectiveness ratio had lower costs and higher QALYs. For detailed PSA results, including cost-effectiveness acceptability curves, see the online appendix.

CONCLUSIONS— Overall, we find that gastric bypass and gastric banding appear to be relatively cost-effective treatments in the severely obese diabetic population, with cost-effectiveness ratios ranging from $7,000 to $13,000/QALY. These cost-effectiveness ratios are lower than the cost-effectiveness ratios for commonly applied diabetes interventions and well below the $50,000/QALY benchmark sometimes applied (23) as a mea-

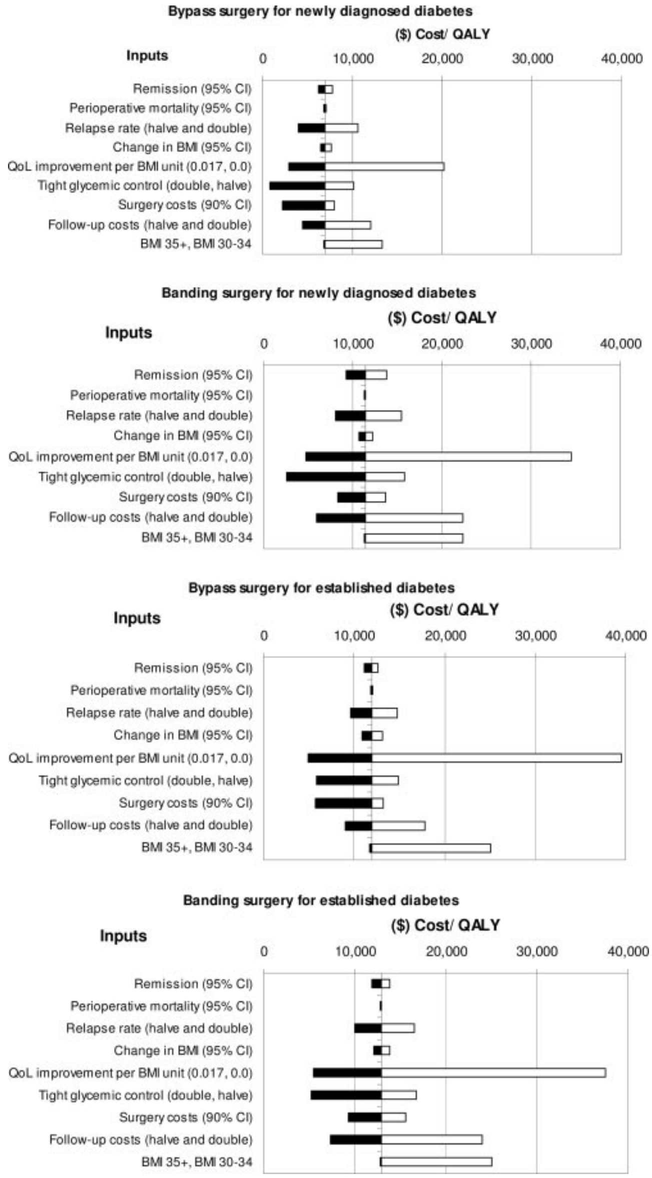

Figure 1—*Sensitivity analyses: cost-effectiveness ratios for lower and upper bound of input values. The range of cost-effectiveness ratios after varying input parameters. For example, using the 95% CI values of remission for bariatric surgery in newly diagnosed patients, we find cost-effectiveness ratios ranging from \$6,000 to \$8,000/QALY. A QoL improvement of 0.017 leads to a lower cost-effectiveness ratio, and an improvement of 0 leads to a higher cost-effectiveness ratio. Doubling tight glycemic control costs leads to a lower cost-effectiveness ratio, and halving them leads to a higher cost-effectiveness ratio.*

sure of society's willingness to pay for health interventions. The cost-effectiveness ratios are lower for the newly diagnosed diabetic population than for the established diabetic population because the diabetes remission rate is higher for those newly diagnosed.

Although our cost-effectiveness ratios are in a similar range as several studies that found that bariatric surgery increases costs and QALYs (7–10), we do not find cost savings from either gastric bypass or gastric banding surgery as several other studies have reported (6,11–13). There are at least three reasons why we did not find cost savings. First, the two cost-effectiveness models that find cost savings (11,13) are set outside of the U.S. Because our model reflects U.S. treatment costs, our results may not be comparable. Second, neither U.S.-based study that found cost savings (6,12) used a cost-effectiveness model. One study (6) compared total costs for a surgery population and a nonsurgery population; it assumed that any cost differences were attributable to surgery and that savings in the years following surgery would persist. The second study (12) estimated cost differences related to BMI in cross-sectional data and then calculated the effect of surgery on costs based on the decrease in BMI following surgery. It also assumed that cost reductions after surgery would persist. We explicitly model relapse to diabetes, which leads to decreasing cost savings over time. Third, our approach only includes diabetes-related costs that are saved as a result of diabetes remission and the reduction of micro- and macrovascular complications; this could result in lower savings than those found by the two U.S. studies, which considered all obesity-related costs.

In our analysis, bypass surgery leads to greater gains in QALYs and has lower costs than banding surgery for patients with newly diagnosed diabetes. The principal parameters that led to this result are the higher diabetes remission rate in bypass surgery and the larger BMI loss and therefore larger QoL improvement associated with bypass surgery. The two parameters favoring banding surgery—bypass surgery has higher first-year costs and higher perioperative mortality—do not offset the parameters favoring bypass surgery. The difference in cost-effectiveness ratios between the two surgeries is less pronounced in the established diabetic population than in the newly diagnosed diabetic population. In the established diabetic population, bypass and banding were assumed to have the same rates of remission and improvement.

Although the model parameters appear to favor bypass surgery, there have not been direct trials of the two types of surgeries. The more favorable bypass surgery parameters may be due to the different characteristics of people who opt for bypass surgery. This population tends to have a higher initial BMI and a greater prevalence of comorbidities (1). A randomized trial comparing bypass and banding would provide more compelling evidence on the relative cost-effectiveness of the two procedures than our simulation provides.

Current National Institutes of Health (24) guidelines state that patients with a BMI ≥40 kg/m^2 or a BMI between 35 and 40 kg/m^2 plus a comorbidity such as diabetes may be candidates for bariatric surgery. Most key model parameters are based on surgery for extremely obese individuals (in a key meta-analysis [1], the mean BMI is 47.9). One study (25), however, shows good results for diabetes remission in people with relatively low BMI. In our sensitivity analysis for people with a BMI between 30 and 34 kg/m^2, we estimated higher cost-effectiveness ratios than those for more obese patients, but the ratios are still reasonably attractive.

Our analysis has several limitations. First, our model is limited by the health parameters included in the model. We only measure the benefits of bariatric surgery arising from its effect on diabetes remission, blood pressure, and cholesterol levels—which in turn affect diabetes micro- and macrovascular complications—and the effect of BMI loss on QoL. These benefits include reduced rates of coronary heart disease and stroke, important drivers of morbidity and mortality in people with diabetes. Second, limited data are available on the long-term effects of bariatric surgery. Sensitivity analyses on the diabetes remission rate and diabetes relapse rate—two important long-term effects—suggest that varying these parameters may not change the general conclusion that bariatric surgery is cost-effective. More broadly, the long-term impacts of surgery on diabetes complications, costs, and QALYs are generated by our simulation model. There are little or no direct data on surgery's long-term impact on these variables. In the absence of long-term study data, a simulation model may provide policy makers with useful information about the possible effects of interventions. Third, we assumed a QoL improvement directly associated with BMI loss based on cross-sectional data due to limited data on QALYs per BMI unit loss following surgery. Fourth, few studies examine diabetes remission in the population with longer-term diabetes. Based on a single study (18), we assumed rates of 40% remission and 40% improvement for bypass and banding in the established diabetic population.

Fifth, data on surgical outcomes for patients with established diabetes are limited. We incorporated lower rates of remission in established patients in our analysis, but we assumed (due to lack of data) that surgical costs and perioperative mortality rates were the same for established patients as for newly diagnosed patients. If the outcomes are less favorable for established patients, their cost-effectiveness ratios would increase. Data on surgical outcomes for older patients are also limited, with similar implications for the cost-effectiveness ratios.

Finally, our model assumes that diabetes progression rates are homogeneous, in the sense that a severely obese person with active diabetes and an A1C of 8.0% has the same progression rates for diabetes complications as a nonobese person with active diabetes and an A1C of 8.0%. This assumption is reasonable given current evidence, but it ignores alternative possibilities.

Subject to these limitations, our analysis indicates that gastric bypass and gastric banding surgery appear to provide a cost-effective method of reducing mortality and diabetes complications in severely obese adults with diabetes. We do not find that bariatric surgery is cost-saving. Therefore, health care costs will increase if more individuals receive bariatric surgery, but the increased costs appear to offer good value. As trials directly comparing bypass and banding surgery emerge and more studies examine the long-term effects of bariatric surgery, estimates of the cost-effectiveness of surgery can become more fine tuned, helping to guide future policy decisions.

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