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Systematic Review

The Comparative Effects of Bariatric Surgery on Weight and Type 2 Diabetes

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Background: Epidemiological evidence confirms that risk of developing type 2 diabetes is related to weight gain. Weight reduction is beneficial as relative risk is reduced to 0.13 for weight loss >20 kg. This raises the question of effectiveness of bariatric surgery on 1) weight loss and 2) diabetes-related outcomes in morbidly obese patients.

Methods: We reviewed the literature using Medline. Only 2 meta-analyses reporting on both outcomes were included, as well as 50 systematic reviews or primary studies.

Results: Meta-analyses mainly based on case series data as well as controlled studies confirm that bariatric surgery is highly effective in obtaining weight reduction in morbidly obese patients up to 60% of the excess weight, along with resolution of preoperative diabetes in more than 75% of cases. Among bariatric surgery techniques, malabsorptive procedures (biliopancreatic diversion and gastric bypass) appear to be more effective on both outcomes than restrictive procedures (gastroplasty and gastric banding).

Conclusion: Even if more studies are needed to confirm current evidence, bariatric surgery is effective for controlling diabetes. It appears as an efficient strategy from economic modeling due to savings from reduction in diabetes-related costs.

Key words: Bariatric surgery, type 2 diabetes mellitus, morbid obesity, literature review, treatment outcome, weight loss

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Introduction

The two current epidemics of type 2 diabetes and obesity are closely linked, as confirmed by escalating prevalence in developed countries such as the USA,[1-4] Europe,[5,6] and elsewhere.[7,8] According to the American Heart Association, >80% of cases of type 2 diabetes can be attributed to obesity,[9] and diabetes is one of the most important complications of obesity.[10]

From epidemiological studies, the overall relative risk (RR) for type 2 diabetes was estimated to be 1.19 per unit of BMI in one recent meta-analysis.[11] Compared to subjects with stable weight, those who gained weight as adults increased significantly their risk for diabetes. For instance, compared to adults who had a weight gain <5 kg, the RR of developing diabetes for women who gained 11.0 to 19.9 kg was 5.5 (95%CI, 4.7 to 6.3), for women who gained >20 kg[12] was 12.3 (95%CI, 10.9 to 13.8), and for men who gained >13.5 kg was 4.8 (95%CI, 2.5 to 9.2).[13] Three studies using epidemiological data estimated that for each kg of weight gain, RR increased by 4.5% to 9%.[2,14,15]

In direct contrast, adult weight loss significantly decreases the risk for diabetes. Weight loss of 5 kg lowered the hazard ratio for developing diabetes to 0.49,[16] weight loss >6 kg over the preceding 10 years reduced the risk for diabetes by ~50%,[15] and weight loss >20 kg reduced the risk to 0.13.[12]

Weight loss is also important for established diabetes, with a large body of evidence showing that weight loss improves glycemic control. One systematic review used data from prospective or cohort studies with a follow-up of at least 5 years (2 years for non-surgical studies) to develop a model of long-term effects of weight loss.[17] From the estimated relation, it may be inferred that for every 1 kg of weight loss, glucose level decreases by 0.217 mmol/L (adjusted $R^2 = 0.557$). Authors of this meta-analysis interestingly note that predictions from this model could grossly underestimate glucose fall when weight losses are larger. Weight loss in newly diagnosed diabetics has also been shown in one retrospective study to reduce mortality.[18] These findings indicate that obesity is a major risk factor for the development of type 2 diabetes and, conversely, that weight loss can delay or even prevent the onset of diabetes.[19]

Bariatric surgery is being increasingly performed for morbid obesity (defined as BMI >40 kg/m^2 or BMI >35 kg/m^2 with secondary disease such as diabetes or high blood pressure), either through restrictive procedures, including gastric banding (LAGB) and vertical banded gastroplasty (VBG), mixed operations such as Roux-en-Y gastric bypass (RYGBP), or malabsorptive procedures such as biliopancreatic diversion (BPD), duodenal switch (DS) or bilio-intestinal bypass.

The aim of the present study is to review articles published during the last 10 years to assess comparative effectiveness of bariatric surgery on body weight and diabetes-related outcomes.

Materials and Methods

This systematic review is based on a computerized literature search of MEDLINE performed in July 2006 to identify both meta-analyses and original studies or systematic reviews. For meta-analyses, 140 references were identified but only two studies were included after assessment.[20,21]

The parallel search for systematic reviews identified 131 references, 22 of which were included after a close examination, as well as 28 primary studies selected from 244 identified references.

Results

Meta-analytic Results on Clinical Effectiveness

As the two meta-analyses differ in inclusion criteria used for selecting primary studies and precision given to reporting diabetes outcomes, presentation of their relevant findings is done separately.

The US Agency for Healthcare Research and Quality (AHRQ) recently sponsored an evidence report on pharmacological and surgical treatment of obesity,[22] including a meta-analysis of surgical treatment of obesity.[21] Because published comparative studies [Randomized Controlled Studies (RCTs), controlled clinical trials, cohort studies] were rare, case series with at least 10 patients were also included in this review based on an electronic search of MEDLINE and EMBASE updated in July 2003.

Pooled results from controlled trials on weight loss were derived from five RCTs and presented for each paired-comparison at 12 months and 36 months or longer. They were generally confirmed by aggregated results for each type of surgical procedure based on 89 studies including case series.

In two studies comparing RYGBP with VBG, pooled weight loss outcomes for both operations were substantial (≥30 kg at 36 months for both) and favored RYGBP at both 12 and 36 months (8 and 9 kg of additional weight loss).[23,24] These results are both in line with pooled results from all studies combining RCTS and case series, indicating a 10-kg difference in weight loss in favor or RYGBP. In two other RCTs, the weight lost with VBG compared with LAGB was 14 kg more at 12 months follow-up but only about 3 kg more at 36 months follow-up.[25,26] This difference in weight loss at 1 year was not replicated by pooled results for all studies, mean weight loss being nearly the same at both 12 months and longer follow-up for both procedures.

One RCT compared open and laparoscopic RYGBP and found no significant differences (≥30 kg for both at 12 months).[27] This result was supported by the "all studies" pooled analysis at both 12 months and up to 36 months.

For diabetes, our review included 21 studies reporting results on this co-morbidity, which were mainly case series because only four studies were RCTS and one was the Swedish Obese Subjects (SOS) study with numerous reports. From a proportion of 11% (range 3%-100% according to primary study) of patients who had preoperative diabetes, it was estimated that 64%-100% of these patients experienced improvement or resolution of diabetes after surgery, depending on primary study considered, with a median value of 100%.

The second meta-analysis of interest presented more detailed results due to less restrictive inclusion criteria applied during literature selection: extracted studies could be of any design and had to have enrolled at least 10 patients undergoing bariatric surgery with a follow-up of at least 30 days.[20] As this study was mostly based on case series data, the authors were able to derive differentiated effects on weight change and diabetes-related outcomes according to surgical procedure and diabetic status, at the price of a lower level of evidence.

More precisely, results were reported individually for each type of surgical procedure (gastric banding, gastric bypass, gastroplasty, biliopancreatic diversion or duodenal switch), as well as for all surgical procedures for unselected populations of all included studies on the one hand (16,944 patients with a mean baseline BMI of 46.85 kg/m^2) and for the sub-population of patients having preoperative diabetes or impaired glucose tolerance on the other hand (16,342 patients).

Considering aggregated results for the total population, weight reduction appears to be very important whatever the efficacy outcome measure used (weight loss ~40 kg or >60% excess weight loss). Mean length of follow-up was not stated, although the authors specified that in most cases, weight loss outcomes did not differ significantly between assessments at 2 years compared with those >2 years. Improvement in type 2 diabetes was dramatic, fully resolving in nearly 77% of patients with the condition.

When considered separately, all categories of operative procedures were significantly effective in reducing initial weight at the $P<0.01$ level, but malabsorptive procedures were more effective than restrictive techniques. With respect to diabetes resolution, malabsorptive procedures dominated restrictive procedures, as there was a gradation of the effect from 98.9% for BPD or DS to 83.7% for RYGBP, to 71.6% for VBG, to 47.9% for LAGB.

Results for weight loss for surgically-treated patients with diabetes or impaired glucose tolerance at baseline were quite similar to the unselected population:

- the mean change in excess weight loss was >57% and the absolute weight loss nearly 42 kg;
- BPD was more effective in reducing body weight than restrictive procedures;
- reductions in HbA1c and fasting glucose levels were much greater in these patients, mean reduction of fasting glucose levels being 3.97 mmol/L ([95%CI, 2.74 to 5.20 mmol/L], n = 296 by meta-analysis).

These results should be interpreted with caution because they were derived mostly from case series and an unspecified mean length of follow-up.

Clinical Effectiveness in Primary Studies

Comparative primary studies are useful to check whether meta-analytic results are replicated when study design is restricted to level of evidence 3 or higher. We will first refer to four primary studies comparing surgical treatment to non-surgical intervention or no treatment before turning to comparisons of surgical procedures.

Surgery versus Non-surgical Interventions

Results on the comparative effectiveness of bariatric surgery on both weight and diabetes were reported in only a small number of papers which referred either to the SOS cohort study[28-31] or to case-control studies based on the experience of Pories and colleagues[32,33] or Italian surgeons in Milan.[34]

The SOS study is a prospective multicenter (25 surgical and 480 non-surgical) ongoing cohort study with matched concurrent controls. Included patients could choose conventional or surgical treatment. Several publications reported comparative results on weight loss and diabetes-related outcomes at various points of time. The first report was based on 2-year results from the first 845 patients included in the surgically-treated group and their 845 matched controls.[28] A second report presented 2-year and 8-year results from the first 346 patients included in the surgically-treated group and their 346 matched controls,[29] and a third publication focused on effectiveness of bariatric surgery on diabetes, considering patients on anti-diabetic medication at 2-year and 6-year follow-up according to their medication status at baseline.[30] Because of mortality, drop-outs, pending data, and pregnancies, data were available only in a lower number of patients.

The main results from these intermediate studies show that whereas patients in control groups experienced a small weight loss at 2 years and a small weight gain at 6 years and 8 years, surgically-treated patients had an important weight loss at all terms. In the first two reports, the authors noted that RYGBP was more effective for weight reduction than VGB and gastric banding. After 8 years of follow-up, there was a 5-fold decrease in the risk of developing type 2 diabetes for surgically-treated patients. In patients who were diabetic at baseline, the relative risk of recovery at 2-year follow-up was 3.7 in the surgically-treated group compared to the control group.[29] At the same time, changes in use of medication were more favorable in the surgery group compared to the control group. Among subjects who were not on anti-diabetic medication at baseline in the third report, the use of medication was 5 times more frequent in the control group (11.3%) compared to the surgery group (2.1%) after 6 years of follow-up.[30] For the small number of patients who were on diabetic medication at baseline, the proportion of surgery subjects still on medication was significantly lower than controls at 6 years (68.8% versus 100.0%, $P<0.05$).

Most recent results from the SOS study were published on patients who completed 10 years of follow-up[31] (Table 1). In that paper, all subjects who had been enrolled at least 2 years (4,047 subjects) or 10 years (1,703 subjects) were included. Long-term effectiveness of bariatric surgery resulted in a weight loss of 16.1% of initial weight in the surgical group at 10 years, compared to patients in the control group who experienced a small weight gain. At the same time, fasting blood glucose level increased in the control group (18.7% at 10 years), whereas substantial decrease was seen in the surgically-treated group at both 2-year (-13.6%) and 10-year (-2.5%) follow-up. This beneficial effect was further demonstrated when considering differences in incidence of and recovery from diabetes. The risk of developing diabetes was more than 3 times lower for surgically-treated patients at 10 years. Recovery from diabetes for patients with the condition at baseline was also more frequent in the surgical group than in the control

Table 1. Percentage changes in weight, BMI, and glucose level at 2 and 10 years§ (from Sjostrom et al[31])

	Changes at 2 years (%)#			Changes at 10 years (%)#			Changes at 10 years in surgery subgroups (%)		
	Control group	Surgery group	Difference (95%CI)	Control group	Surgery group	Difference (95%CI)	Gastric band	VBG†	RYGB†
Patients (n)	1660	1845		627	641		156	451	34
Weight (kg)	0.1	-23.4	22.2 (21.6 to 22.8)*	1.6	-16.1	16.3 (14.9 to 17.6)*	-13.2	-16.5	-25.0*
BMI (kg/m^2)	0.1	-23.3	22.1 (21.5 to 22.7)*	2.3	-15.7	16.5 (15.1 to 17.8)*	-12.8	-16.0¶	-23.8*
Fasting blood glucose level	5.1	-13.6	16.6 (15.0 to 18.3)*	18.7	-2.5	18.4 (14.7 to 22.1)*	-0.8	-2.5	-10.0
Incidence of diabetes (whole-period unadjusted)	8	1	OR 0.14 (95%CI, 0.08 to 0.24)	24	7	OR 0.25 (95%CI, 0.17 to 0.38)			
Resolution of diabetes (whole-period unadjusted)	21%	72%	OR 8.42 (95%CI, 5.68 to 12.25)	13%	36%	OR 3.45 (95%CI, 1.64 to 7.68)			

§ Data are for all subjects who completed 2 and 10 years of the study. The changes within each group are unadjusted, whereas the differences between the groups have been adjusted for sex, age, BMI, and the baseline level of the respective variable.

For values within each group, minus signs denote decreases.

† *P* values are for the comparison with the gastric banding subgroup.

* $P<0.001$; ¶ $P<0.05$.

group, both at 2 and 10 years. Here again, resolution of diabetes was 3 times more frequent for the surgically-treated patients at 10 years.

Results on differential outcome according to the surgical procedure also exist (Table 1).[31] Mean weight losses were significantly greater in patients treated by RYGBP than in those treated by LAGB or VBG. Decreases in fasting blood glucose paralleled these decreases in body weight, but differences between surgical subgroups did not reach statistical significance. This was due to the low number of subjects who were followed for 10 years after RYGBP, but there is growing understanding that RYGBP may have efficacy beyond that of the weight loss alone through altered endocrine signaling from the gut to the pancreas and the brain.[35]

Similar results were obtained from case-control studies on different subsets of population identified according to their glucose tolerance. Two complementary case-control studies were performed, focusing on morbidly obese patients with either impaired glucose tolerance (IGT)[32] or type 2 diabetes[33] who underwent RYGBP, but none reported on weight change during follow-up. For subjects with IGT and morbid obesity (mean BMI at baseline 48 kg/m^2), the rate of conversion from IGT to diabetes was 0.15 per 100 person-years (95%CI, 0.05 to 0.25) in the surgical group, in contrast to 4.72 (95%CI, 3.46 to 5.98) in the control group (P<0.0001).[32]

For subjects who were diabetic at baseline, the percentage of patients in the control group who were on anti-diabetic medication significantly increased from 56.4% at entry to 87.5% at last contact (mean follow-up 6.2 years) (P=0.0003).[33] Conversely, the proportion of surgically-treated patients on medication fell from 31.8% preoperatively to 8.6% at last contact (mean follow-up 9.0 years) (P=0.0001). During follow-up, 14 of the 154 surgical patients and 22 of the 78 controls died. This difference in mortality rates – 9% in the experimental group vs 28% in the control group – was highly significant (P<0.0003). When the difference in follow-up was taken into account to estimate the incidence of death per patient-year of follow-up, the incidence in the control group was 4.5 times higher than in the surgical group (P<0.0001).

Findings from a case-control study performed in Italy comparing LAGB using the Lap-Band® and conventional diet (no-LAGB) were published in 2005.[34] In this 4-year study, 122 morbidly obese patients were included either in the surgery group (73 patients) or in the control group (49 subjects who refused surgery). Results on body weight and BMI at 1, 2, 3, and 4 years were given in detail for two sub-populations, depending on the absence (primary intervention) or presence (secondary intervention) of type 2 diabetes at inclusion. Diabetes-related outcomes were also assessed using HbA1c levels for both sub-populations as well as the incidence of diabetes in primary intervention and remission of the condition in secondary intervention.

In both sub-populations, body weight, BMI, and HbA1c levels were significantly decreased in the surgical group compared to the control group. Surgically-treated patients lost weight during the 4-year follow-up period, contrary to controls, even if they experienced a small regain during the last year. HbA1c was also significantly decreased in the LAGB but not in the no-LAGB group. Furthermore, Kaplan-Meier survival estimates based on the primary intervention study showed that type 2 diabetes appeared at a rate of 0.0 per 100 person-years in the surgical group and 4.0 per 100 person-years in the control group. In the secondary intervention study, Kaplan-Meier survival estimates showed that type 2 diabetes decreased at a rate of 26.7 per 100 person-years in the surgical group and 1.2 per 100 person-years in the control group. The authors concluded that LAGB is an effective procedure in inducing weight loss and promoting the remission of type 2 diabetes.

Comparison of Different Bariatric Operations

Meta-analytic results as well as findings from the SOS study suggest superiority of malabsorptive procedures over restrictive procedures for obtaining weight loss and improvement in diabetes-related outcomes in morbidly obese patients.[20,21,31] Few controlled studies have compared alternative surgical interventions and include small numbers of patients. Apart from two early RCTs, which were included in the AHRQ meta-analysis, comparing gastric bypass to gastroplasty,[36,37] two recent papers of interest have been published. One was a case-control study comparing in a 2-year follow-up two groups of 23 super-obese patients (BMI >50 kg/m^2) who underwent either a BPD or a LAGB.[38] Weight loss at 24 months was significantly greater in BPD patients than in LAGB patients measured by BMI and the %EWL. Findings on resolution of diabetes are inconclusive because it was obtained in both patients of the BPD group who had diabetes at baseline and 2 of 3 patients in the LAGB group.

The second RCT was a pilot study comparing LAGB to LAGB *plus* surgical removal of the total greater momentum (omentectomy).[39] Both treatment groups enrolled 11 men and 14 women aged 23 to 57 years who were followed 24 months postoperatively. Six patients in the experimental group and seven patients in the control group were lost to follow-up. Mean BMI reduction from baseline was greater (13 kg/m^2) in the omentectomy group for completers, but the difference from the control group (9 kg/m^2) was only of border-line significance (P= 0.049). However, the fall in fasting plasma glucose was significantly greater in omentectomized patients (1.6 mmol/L) than in controls (0.6 mmol/L). Furthermore, authors analyzed the time-course of the changes in plasma glucose. A significant effect over time induced by omentectomy appeared as glucose started to fall more rapidly in omentectomized patients at 6 months following surgery, whereas the time course of the fall in BMI and body weight did not differ significantly between the groups. This suggests a benefit of omentectomy when added to a bariatric operation.

Cost Considerations on Bariatric Surgery and Type 2 Diabetes

A growing number of studies focusing on economic aspects of surgical treatment of obesity and two systematic reviews of economic studies or costing papers have recently been published.[40-42] These reviews do not mention any published article which specifically investigated the economic impact of bariatric surgery on diabetes-related costs. In our own systematic literature search, we mainly identified cost studies on medical or indirect costs before and after surgery[43-45] and cost-effectiveness or cost-utility studies[46-48] which neglected diabetes, but we also found several papers mentioning diabetes-related costs[40,41,49,50] and two original studies specifically considering cost-effectiveness and budget impact analyses of bariatric surgery in patients with type 2 diabetes.[40,41,51]

One cost study compared the average yearly drug costs of the first 647 surgically-treated patients in the SOS study to their 647 matched controls.[49] Whereas the average annual drug cost during the 6 years of follow-up was similar in the surgical group (€203) and the control group (€210), with a marked increase over time in both groups, differences were found in drug cost for type 2 diabetes. During the year preceding the intervention, the cost for diabetes medication was higher in the surgical group (€15) compared with the control group (€6), with an adjusted difference of €11 (95%CI, 1 to 23). On the contrary, the average yearly cost for diabetes medication during the 6 years of follow-up was markedly lower for surgically-treated patients (€5) than for controls (€15), with an adjusted difference of €-10 (95%CI, -14 to -7).

Another cost comparison examined retrospectively diabetic pharmaceutical utilization and cost in 51 patients who underwent RYGBP at one US center.[50] The number and average monthly cost for diabetic medication was tabulated preoperatively and at 9 months postoperatively, using average national wholesale pricing. Results revealed a preoperative monthly mean use of 1.12 ± 1.15 compounds, costing $136.89 ± $206.60. After surgery, the diabetes medication number and cost fell to 0.12 ± 0.48 (P<0.001) and $26.58 ± $107.05 (P<0.001) respectively.

One cost-utility evaluation of surgery which specifically included treatment cost of diabetes was performed as a model running for a hypothetical cohort of 100 patients, using effectiveness results from several studies and UK data from the CODE2 study for mean annual cost of treatment.[40,41] The cost per Quality-Adjusted Life-Year (QALY) was estimated over a time horizon of 20 years, with costs discounted at 6% while QALYs were discounted at 1.5%. Assessment was done for three surgical procedures, RYGBP, VBG and LAGB compared to no surgery. As the additional cost of surgery was partly offset by costs averted from resolution of preoperative diabetes and reduction in risk of developing diabetes associated with each surgical procedure, the net cost per QALY gained with RYGBP was £6,289.

The last publication of interest presented results from a model developed to obtain the cost per QALY and budget impact of RYGBP and LAGB for diabetic patients compared to conventional treatment in three European countries: Germany, UK and France.[51] Using data from different sources, the authors estimated the incremental cost and QALY of each surgical procedure in comparison to conventional treatment over a 5-year period, both parameters being discounted at 3.5%. For each strategy, costs included resources used for the treatment of morbid obesity and its complications as well as the treatment of type 2 diabetes given its residual prevalence. Effectiveness of each treatment option was based on its effects on both BMI and prevalence of diabetes and then transformed in utility scores using EQ-5D (EuroQOL 5 dimensions) questionnaire to derive QALYs as estimated from an existing database. In Germany and France, both surgical procedures were dominant as they yielded at the same time cost-savings (-€5030 for RYGBP and -€3586 for LAGB in Germany; -€5877 for RYGBP and -€4480 for LAGB in France) and increased QALYs (1.34 QALYs for RYGBP, 1.03 QALYs for LAGB) in comparison with conventional treatment. In the UK, increased costs associated with surgery (£2033 for RYGBP and £1984 for LAGB) resulted in highly cost-effective ratios (£1517/QALy for RYGBP and £1929/QALY for LAGB).

Discussion

Despite the large volume of literature devoted to bariatric surgery and diabetes, only a small number of studies have been performed in a comparative way, with a level of evidence 3 or higher. In contrast, results from numerous case series are available, which have been used in a small number of meta-analyses.

Meta-analytic results lead to some clear conclusions. First, bariatric surgery is confirmed to be highly effective in obtaining weight reduction up to 60% EWL. Secondly, surgery is effective in resolving preoperative existing diabetes in >75% of patients. In addition, surgical treatment is more effective in improving blood glucose levels in morbidly obese patients with type 2 diabetes or impaired glucose tolerance. In paired-comparisons between surgical procedures on both weight loss and resolution of diabetes, findings generally favor DS, BPD or RYGBP over restrictive procedures.

Controlled primary studies further demonstrate that in comparison to conventional non-surgical treatment, bariatric surgery is effective in obtaining weight loss and improvement in the control of diabetes, as illustrated by several reports from the SOS cohort study at different terms from 2 to 10 years. Three case-control studies concluded similar effects in different populations: incidence of diabetes was significantly reduced in patients with normal glucose tolerance or impaired glucose tolerance, whereas remission from diabetes was significantly more frequent in surgically-treated diabetics. Comparative effectiveness of alternative surgical procedures is much less documented because we noted a paucity of controlled studies. The few available RCTs had small sample sizes, precluding any firm conclusion on the comparative effects of interventions on diabetes-related outcomes, and much of the evidence is being based on the SOS study. As most patients underwent VBG or LAGB whereas RYGBP was only done on a small number of patients, greater effectiveness of RYGBP over restrictive techniques was significant for weight loss but did not reach statistical significance for changes in fasting blood glucose.

Beyond this associated effect of surgery on weight loss and control of type 2 diabetes, several researchers have observed that improvement in glucose metabolism is obtained within days after surgery, long before significant weight loss appears.[52-58] The time-pattern of this associated effect on body weight and type 2 diabetes is of interest; however, substantial reduction in caloric intake in the immediate postoperative period (due to I.V. support, ileus, etc.) has to be taken into account. The effect of gut-brain and gut-pancreas signaling through incretin hormones may explain why malabsorptive operations are more effective than restrictive in alleviating type 2 diabetes rather than greater weight loss alone.

Not only is bariatric surgery an effective therapy for metabolic and other complications of obesity (e.g. osteoarthritis, sleep apnea), quality of life, and reduction in mortality but it is also an efficient strategy.

Bariatric surgery reduces the cost for diabetic medication, illustrated by the small number of cost studies. It is an efficient strategy from economic modeling, taking into account both savings from reduction in diabetes-related costs and improvement in quality of life.

Further controlled studies with large sample size are needed to confirm further these positive effects on weight loss and diabetes-related outcomes. There is also a need to improve knowledge on the etiology of type 2 diabetes, to better understand comparative benefits from alternative operations.

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