Deep brain stimulation compared with bariatric surgery for the treatment of morbid obesity: a decision analysis study

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Object. Roux-en-Y gastric bypass is the gold standard treatment for morbid obesity, although failure rates may be high, particularly in patients with a BMI > 50 kg/m². With improved understanding of the neuropsychiatric basis of obesity, deep brain stimulation (DBS) offers a less invasive and reversible alternative to available surgical treatments. In this decision analysis, the authors determined the success rate at which DBS would be equivalent to the two most common bariatric surgeries.

Methods. Medline searches were performed for studies of laparoscopic adjustable gastric banding (LAGB), laparoscopic Roux-en-Y gastric bypass (LRYGB), and DBS for movement disorders. Bariatric surgery was considered successful if postoperative excess weight loss exceeded 45% at 1-year follow-up. Using complication and success rates from the literature, the authors constructed a decision analysis model for treatment by LAGB, LRYGB, DBS, or no surgical treatment. A sensitivity analysis in which major parameters were systematically varied within their 95% CIs was used.

Results. Fifteen studies involving 3489 and 3306 cases of LAGB and LRYGB, respectively, and 45 studies involving 2937 cases treated with DBS were included. The operative successes were 0.30 (95% CI 0.247–0.358) for LAGB and 0.968 (95% CI 0.967–0.969) for LRYGB. Sensitivity analysis revealed utility of surgical complications in LRYGB, probability of surgical complications in DBS, and success rate of DBS as having the greatest influence on outcomes. At no values did LAGB result in superior outcomes compared with other treatments.

Conclusions. Deep brain stimulation must achieve a success rate of 83% to be equivalent to bariatric surgery. This high-threshold success rate is probably due to the reported success rate of LRYGB, despite its higher complication rate (33.4%) compared with DBS (19.4%). The results support further research into the role of DBS for the treatment of obesity. (DOI: 10.3171/2010.5.FOCUS10109)

Key Words • deep brain stimulation • bariatric surgery • obesity

The high prevalence of obesity in the US has motivated investigation of novel therapeutic approaches. Morbid obesity, defined as a BMI > 40 kg/m², affects more than 8 million adult Americans and reaches a prevalence of 14% in select populations.11,24 Morbid obesity is associated with premature death,11,25 impaired QOL,22 and multiple morbidities, which include Type 2 diabetes, cardiovascular disease, musculoskeletal disorders, and certain cancers.76,85 Significant weight loss, however, may lead to a 25% to 60% reduction in all-cause, cardiovascular, and cancer mortality.1,100,111

Bariatric surgery has emerged as a primary weight loss strategy, given the high relapse rates associated with nonsurgical approaches. Bariatric surgery is reserved for patients with a BMI > 40 kg/m² or a BMI > 35 kg/m² in the presence of significant comorbidities,15 and most commonly involves LAGB or LRYGB.

Laparoscopic adjustable gastric banding is a purely restrictive procedure in which an adjustable device is placed circumferentially around the upper portion of the stomach, thereby creating a small pouch with a restricted outlet, whereas LRYGB involves construction of a gastric pouch in which the outlet is a Y-shaped limb of small bowel of varying length. The multiple mechanisms of weight loss following LRYGB, including restriction, malabsorption, and hormonal alterations may contribute to a higher reported postoperative excess weight loss compared with LAGB.15 Despite reductions in mortality rates389 and improvements in obesity-related morbidi-
ties, weight gain may occur following bariatric surgery due to dietary relapse, particularly in patients with a BMI > 50 kg/m².1,14

An increased understanding of the neuropsychiatric basis of obesity has provided both insight into limitations of available obesity therapies and motivation for new treatment approaches. Deep brain stimulation is currently being investigated as a weight loss strategy for obesity.5,6,8,9 The VMH and LH are known satiety and appetite centers, respectively, in the brain, and represent potential targets for modifying appetite and enhancing the metabolic rate. In early lesioning studies in animals, researchers observed overeating after destruction of the VMH and early satiation after selective destruction of neurons in the LH.2,21,104,105 In more recent DBS studies, high-frequency DBS of the VMH was associated with a moderate increase in food consumption in nonhuman primates.62 Of note, VMH stimulation at low frequencies (for example, 60–100 Hz) inhibited feeding in hungry rats,42,59 and more recently was shown to improve the metabolic rate.56 Sani et al.94 showed that stimulation of bilateral LH was associated with a small amount of weight loss that was believed to be largely due to enhanced metabolism. The concept of a dual-center theory of appetite regulation involving the VMH and LH has given way to a more integrated model, with a focus on energy expenditure and endocrine signaling in association with adipose tissue.53,94 Laut, Hamani et al.36 performed DBS in the LH of an obese patient, with unexpected improvements in memory, although the effect on weight and food consumption was unclear.

A more potent determinant of feeding behavior may be related to the palatability or reinforcing value of food.33,107 which is modulated by the NAc.41,121 Animal and neuroimaging studies support the NAc as an additional target for obesity. Weight loss and decreased hoarding behavior was observed in rats after ablation of dopaminergic input to the NAc. Subsequently, levodopa administration resulted in restoration of hoarding behavior.51 Furthermore, functional MR imaging studies have demonstrated activation of striatal reward areas during exposure to a high-fat stimulus.3 Studies of DBS for obesity are currently investigatory and preclinical. Despite reports of the safety and efficacy of DBS for movement disorders,33,113 this surgery is not without adverse events, which may relate to the surgical procedure, implanted hardware, or the stimulation itself.7 More recently, pilot studies and small clinical trials have demonstrated the efficacy and safety of DBS of the NAc in neuropsychiatric diseases such as obsessive-compulsive disorder12 and major depression that are refractory to treatment.95 To date, however, no clinical trials have been performed for morbid obesity.

At this early stage, it is critical to determine whether DBS may have a role in the treatment of obesity based on the so-called utility associated with the proposed treatment modality. “Utility” refers to a measure of QOL. We developed a decision analysis model, taking into account the complication rates of the two most common bariatric procedures, LAGB and LRYGB, as well as the complication rates of DBS for movement disorders as a proxy of DBS for obesity. Using the success rates of bariatric surgery, we performed a threshold analysis to determine the level of success required for DBS to be at least as effective as bariatric surgery for the treatment of morbid obesity.

Methods

We performed Medline and PubMed searches of studies published in the English language literature. For bariatric surgery outcomes, we searched for articles containing the term “obesity, morbid” in the medical subject heading and “surgery” in the subheading. We limited our review to trials published between January 2000 and March 2010, comparing cases with LAGB to LRYGB, and reporting at least 25 cases in one or both arms. Only studies with a minimum 1-year follow-up were included. For DBS data, our search encompassed trials published between January 1997 and March 2010, containing the term “deep brain stimulation” in the medical subject heading and “complications” in the subheading, and reporting at least 15 cases. For utility values associated with the outcome of various complications, we searched for articles containing “quality of life” in the medical subject heading and the specific complication in the title.

We abstracted estimates of the outcomes of each of these three surgical strategies based on the reported outcomes in the papers selected from our literature search. We considered surgical treatment to be successful if the percentage of postoperative excess weight loss exceeded 45%. If only mean percentages of excess weight loss were reported, we calculated the percent of cases meeting the 45% threshold from the series’ mean and SD values.

A single patient may experience more than one complication. The total number of occurrences per complication was recorded. The mean incidence of complications was derived from the total number of complication occurrences divided by the number of patients at risk. For DBS implant-specific complications, both neurological and mechanical, the frequency of complications was divided by the number of implant sites. Patients who underwent DBS had either unilateral or bilateral implants. A complication not mentioned in a report was not included in the calculations. For each study, patients were considered at risk for a certain complication only if the complication was recorded by study investigators.

We constructed a decision analysis model for treatment by using the pathways and outcomes outlined in the decision tree (Fig. 1). The three surgical approaches were compared. A fourth arm, untreated obesity, was included for reference. Because the frequencies of various complications were different for each of the treatment arms, separate subtrees were constructed for each to calculate the incidence and impact of complications on utility. The utility values were assigned for each outcome outlined in the decision tree and the complications subtrees. These represented the overall effect of the outcome for a patient’s health and well-being and, by consensus, measured between 0 and 1.102 Because there has been no clinical trial on DBS for morbid obesity and, thus, no information on its success rate, we chose an arbitrary rate of 50% as a placeholder.

We multiplied the probability of each treatment
branch by the utility of the outcome of that branch. The number obtained by adding the products is a “point estimate” of the utility of that treatment; the treatment with the highest utility is most favored. The reported point estimates of outcomes and complications from the pooled data represent variance-weighted means, and these were tested for heterogeneity. This step was essential given the disparity among the patients from various studies that made up the pooled data set. The conditional probability of each possible outcome for the three treatment methods (and its SD) was calculated. We used a 1-year timeline for outcome comparisons. A small dysutility, or decrease in QOL, was assigned to each surgical procedure, based on its estimated effect on health-related QOL and the expected duration of effect, consistent with previous cost-effectiveness studies of bariatric surgery. For complications that had only temporary effects, these utilities, or QOL values, only applied to the 1st year. Multiple complications or dysutilities occurring at the same time are multiplied, as is routine in analyses of this sort.

To allow for uncertainty in our data, we used a sensitivity analysis. Sensitivity analysis provides a means of determining how sensitive the conclusions of the decision analysis model are to changes in its parameters; it quantifies the influence of important parameters on utility. One-way sensitivity analyses for each model parameter included all values for that parameter within its 95% CI. Three-way sensitivity analyses, in which the parameters are varied simultaneously when recalculating outcomes, allowed more detailed assessment for parameters having the greatest impact on outcome.

For meta-analyses we used Stata 9 software (StataCorp LP). Sensitivity analyses were done using Tree Age Pro 2009 (TreeAge Software, Inc.). We considered differences for which the probability value was < 0.05 to be statistically significant.

Results

The literature search yielded 268 articles on bariatric surgery, of which 15 met the restrictions outlined above. These 15 publications included a total of 3489
DBS may be < 83% to achieve equivalence. Furthermore, the success rate of DBS must be approximately 83% to equal the success rate of LRYGB. As expected, lower success rates for DBS move the threshold to the left.

**Discussion**

No clinical trial of DBS for morbid obesity has yet been conducted; thus, as derived from our literature search, our results offer the best estimate for the threshold success rate of DBS to meet the well-established efficacy of bariatric surgery. The efficacy and safety of DBS have been studied in depth with regard to the treatment of movement disorders.23 Such investigations demonstrate a motor score improvement as high as 66% in one study.75 Thus, the success rates required for DBS to be comparable to LRYGB may be attainable, based on the favorable results of DBS in other disease processes.

The high threshold success rate for DBS to be equivalent to LRYGB is primarily due to the high success rate (97%) for LRYGB. Buchwald et al.,1 established accepted rates of percentage excess weight loss of 47.5% for LAGB and 61.6% for LRYGB, based on the mean percentage excess weight loss in more than 7000 patients. To maintain the same success rate for each bariatric procedure, we chose to define success as > 45% excess weight loss at 1 year postoperatively. In doing so, we took on a more conservative estimate for the success rate required for DBS to be superior to LRYGB. In reality, the true efficacy requirements of DBS may be < 83% to achieve equivalence. Furthermore, the well-established tendency of the medical literature to favor the report of positive studies, known as publication bias,101 may be considered an alternative explanation.
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Based on sensitivity analysis, LAGB did not result in a superior outcome at any value when compared with the other 2 procedures. The complication rate was 0.217 for LABG and 0.334 for LRYGB. Although we combined short- and long-term complication rates, other studies have demonstrated that complications occurring within 30 days of surgery are more common after LRYGB, whereas bariatric complications after 30 days are more common after LAGB; port problems and band slip - page, rather than the surgical placement of the band, are the most likely reasons for delayed reoperation.

Nevertheless, the superiority of LRYGB in terms of weight loss overshadows differences in complication rates when considering the overall success of LAGB versus LRYGB, as supported by the decision analysis model and several systematic reviews. Decision analysis is necessarily limited by the assumptions on which the final model is based. For example, we have simplified the spectrum of surgical results into success or failure categories. This limits the variety of health outcomes to be expected in an actual clinical trial. Additionally, we used complication rates associated with DBS for movement disorders to approximate those for obesity. The DBS procedure for movement disorders and that for obesity share similar targets or targets in close proximity. The surgical approach to the hypothalamus or NAc may be associated with injury to nearby structures such as the optic nerve, fornix, and mammillary bodies. However, stereotaxy of the hypothalamus and NAc has been shown to be feasible, safe, and even efficacious.

Composite DBS complication rates obtained from the literature search yielded rates similar to those in individual reviews; however, we detected a hardware-related complication rate of 6.8% (Table 2), whereas another group of investigators found the rate of hardware-related complications to be 25.3% among 81 consecutive patients undergoing 160 DBS procedures in the subthalamic nucleus. One potential reason for the discrepancy is the use of varying definitions of hardware malfunction. We considered the following complications requiring repeat operation to be hardware related: malposition, fracture, migration, erosion, extension wire failure, and internal pulse generator malfunction. Additionally, we determined the hardware-related complication rate by dividing

**TABLE 3: Utility values of various treatment outcomes for morbid obesity**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean ± SD</th>
<th>No. of Patients</th>
<th>Authors &amp; Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>unsuccessful treatment for morbid obesity</td>
<td>0.67 ± 0.102</td>
<td>51</td>
<td>Andersen et al., 2009</td>
</tr>
<tr>
<td>perforation†</td>
<td>0.704 ± 0.188</td>
<td>51</td>
<td>Joneja et al., 2004</td>
</tr>
<tr>
<td>conversion to open procedure†</td>
<td>0.9</td>
<td>NA</td>
<td>Craig &amp; Tseng, 2002; Jensen et al., 2005</td>
</tr>
<tr>
<td>DVT</td>
<td>0.95</td>
<td>NA</td>
<td>Danish et al., 2005</td>
</tr>
<tr>
<td>PE</td>
<td>0.926 ± 0.156</td>
<td>44</td>
<td>Lega et al., 2009</td>
</tr>
<tr>
<td>pneumonia</td>
<td>0.948 ± 0.165</td>
<td>44</td>
<td>Lega et al., 2009</td>
</tr>
<tr>
<td>hemorrhage†</td>
<td>0.944 ± 0.163</td>
<td>44</td>
<td>Lega et al., 2009</td>
</tr>
<tr>
<td>superficial infection‡</td>
<td>0.928 ± 0.179</td>
<td>44</td>
<td>Lega et al., 2009</td>
</tr>
<tr>
<td>anastomotic leak‡</td>
<td>0.9</td>
<td>NA</td>
<td>Craig &amp; Tseng, 2002; Jensen et al., 2005</td>
</tr>
<tr>
<td>bowel obstruction†</td>
<td>0.946 ± 0.159</td>
<td>44</td>
<td>Lega et al., 2009</td>
</tr>
<tr>
<td>ulcer</td>
<td>0.785 ± 0.231</td>
<td>771</td>
<td>Lane et al., 2006</td>
</tr>
<tr>
<td>hernia (incisional, internal)†</td>
<td>0.810 ± 0.177</td>
<td>56</td>
<td>Hope et al., 2008</td>
</tr>
<tr>
<td>cholelithiasis‡</td>
<td>0.801 ± 0.198</td>
<td>187</td>
<td>Sandblom et al., 2009</td>
</tr>
<tr>
<td>band/port/tubing events‡,§</td>
<td>0.95</td>
<td>NA</td>
<td>Craig &amp; Tseng, 2002; Jensen et al., 2005</td>
</tr>
<tr>
<td>transient hemiparesis</td>
<td>0.868 ± 0.169</td>
<td>44</td>
<td>Lega et al., 2009</td>
</tr>
<tr>
<td>chronic SDH‡</td>
<td>0.996 ± 0.204</td>
<td>44</td>
<td>Lega et al., 2009</td>
</tr>
<tr>
<td>seizures</td>
<td>0.927 ± 0.168</td>
<td>44</td>
<td>Lega et al., 2009</td>
</tr>
<tr>
<td>hardware malfunction‡</td>
<td>0.996</td>
<td>NA</td>
<td>Craig &amp; Tseng, 2002; Jensen et al., 2005</td>
</tr>
<tr>
<td>subcutaneous hemorrhage/seroma</td>
<td>0.975</td>
<td>NA</td>
<td>expert opinion</td>
</tr>
<tr>
<td>CSF leak‡</td>
<td>0.95</td>
<td>NA</td>
<td>Craig &amp; Tseng, 2002; Jensen et al., 2005</td>
</tr>
<tr>
<td>superficial infection</td>
<td>0.971 ± 0.174</td>
<td>44</td>
<td>Lega et al., 2009</td>
</tr>
<tr>
<td>normal health</td>
<td>1</td>
<td>NA</td>
<td>Gold et al., 1996</td>
</tr>
<tr>
<td>death</td>
<td>0</td>
<td>NA</td>
<td>Gold et al., 1996</td>
</tr>
</tbody>
</table>

* The lack of SD signifies that the means are point estimates rather than measurements. In Craig and Tseng, Jensen et al., and Danish et al., the means represent expert opinion. Gold et al.’s values of 0 and 1 represent consensus values, used universally.† Complications requiring major surgery (laparotomy, craniotomy); utility values reduced by 10%, as specified in Craig and Tseng, and in Jensen et al.‡ Complications requiring minor surgery (laparoscopy, DBS revision); utility values reduced by 5%, as specified in Craig and Tseng, and in Jensen et al.§ Band prolapse, slippage, dilation, erosion of band or port, or other band/port/tubing events.
the number of observed complications by the number of implant sides. Other investigators, however, have used the number of patients rather than number of implants as the denominator, which may result in differing complication rates. Conservative estimates used in the decision analysis model may have underestimated complication rates related to LRYGB. Long-term complications associated with bariatric surgery, such as micronutrient deficiencies, were not included in the model. On the other hand, using the movement disorder population as a stand-in for the population with morbid obesity may have overestimated the expected complication rate of DBS for obesity.

In bariatric surgery, patients older than 60 years of age are approached with caution, because age is a significant predictor of complications after gastric bypass\(^7\) and may be a factor in predicting mortality.\(^6\) Inclusion of elderly patients with movement disorders may contribute to the complication rate associated with DBS.\(^1,5,13,81\) Thus, DBS complications among younger patients who are eligible for bariatric surgery would be expected to occur less frequently. If DBS for obesity is offered to elderly patients with morbid obesity, the complication rates observed in this study would no longer be an overestimate. Although DBS has been performed in the elderly, it has not been studied thoroughly in the obese population. Obese patients are likely to have comorbidities, such as Type 2 diabetes,\(^7\) which may result in increased complications related to wound healing, extension wire erosion, and superficial infection. They are also more likely to develop postoperative complications, such as PE, compared with those with a normal BMI.\(^3\) Because our complication rates were based on nonobese patients with a movement disorder, DBS may have a higher complication rate among its intended population. Occurrences of VTE are relatively common among patients undergoing DBS,\(^4\) and may be even higher among obese patients undergoing DBS. On the other hand, DBS is less invasive and more easily reversible than bariatric surgery, and does not require general anesthesia, thus making it favorable for obese patients with poor health or advanced age. Assuming equal efficacy and safety, certain patients, alternatively, may prefer bariatric surgery to DBS for reasons including

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Success Rate</th>
<th>Incidence of Treatment-Related Complications</th>
<th>QALYs Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAGB</td>
<td>0.30</td>
<td>0.217</td>
<td>1.4826</td>
</tr>
<tr>
<td>LRYGB</td>
<td>0.97</td>
<td>0.334</td>
<td>1.8486</td>
</tr>
<tr>
<td>DBS</td>
<td>0.50†</td>
<td>0.194</td>
<td>1.6320</td>
</tr>
<tr>
<td>no treatment</td>
<td>0</td>
<td>NA</td>
<td>1.3200</td>
</tr>
</tbody>
</table>

* QALY = quality-adjusted life year.
† Placeholder, not a true measure of success.

![Fig. 2. Three-way sensitivity analysis (see Results). QALYs = quality-adjusted life years.](image)
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the need for repeated full-body MR imaging studies or an unsuccessful DBS trial. Thus, a multidisciplinary approach must be taken for patient selection and management.

Complications common to surgical procedures, such as superficial infection and postoperative pneumonia, were collected for both bariatric surgery and DBS groups. The rate of VTE, in particular, was found to be higher among patients receiving DBS. A recent decision analysis from our group supports the safety and efficacy of subcutaneous heparin in addition to mechanical compression for the prophylaxis of VTE.4 Perhaps with the adoption of our protocol endorsing pharmacological prophylaxis, a lower rate of VTE may be seen in patients who undergo DBS.

Our estimates of complications and follow-up duration tend to favor bariatric surgery. Success and complication rates were obtained from the literature at 1 year postoperatively. Christou et al.24 found that significant weight gain occurs 2 years postoperatively in patients with morbid obesity undergoing LRYGB. Because our success values for bariatric surgery were obtained at 1 year, future decreases in weight loss or weight gain, which would have lowered the success rate of LRYGB, were not captured in the current analysis.

Binge eating disorder may contribute to relapse following bariatric surgery in a subset of patients, but few studies commented on inclusion or exclusion of this subgroup. Self-reported binge eating once per week was found in at least 39% of patients prior to gastric bypass,30 and up to 46% of patients reported recurrent loss of control over eating and weight gain at least 2 years following gastric bypass.49 Because we documented weight loss at 1 year only, future relapse secondary to binge eating was not included, which may have contributed to an elevated threshold success rate for LRYGB. Despite multiple conservative estimates relating to the complication rates of bariatric surgery and DBS, the threshold efficacy of DBS nonetheless supports further research.

In addition to the success rate and QOL, monetary cost is an important societal consideration when judging alternative treatment modalities. Deep brain stimulation of the subthalamic region for Parkinson disease is associated with an acceptable incremental cost-effectiveness ratio.114 Although DBS for Parkinson disease is associated with increased costs during the 1st year after surgery, it does become cost effective within the following year as motor symptoms are significantly improved.22 Similar studies will be crucial for assessing the financial impact of DBS for obesity.

Conclusions

This exercise is, at best, an approximation of a well-controlled, randomized clinical trial, comparing the three surgical approaches to morbid obesity. Nevertheless, it does establish that DBS, should it prove promising in preliminary clinical use, might present a feasible adjunct or even alternative to LRYGB. Thus, it supports the need for further translational and clinical research into the potential role of DBS for the treatment of obesity.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Pisapia, Halpern, Williams, Wadden. Acquisition of data: Pisapia. Analysis and interpretation of data: Stein, Halpern. Drafting the article: Pisapia. Critically revising the article: all authors. Reviewed final version of the manuscript and approved it for submission: Stein, Pisapia, Halpern, Baltuch. Statistical analysis: Stein, Pisapia, Halpern. Administrative/technical/material support: Pisapia. Study supervision: Stein, Baltuch.

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