Review article

Bariatric surgery as an adjuvant treatment in the management of type 2 diabetes *mellitus*

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Abstract
Type 2 diabetes *mellitus* is considered a chronic disease with high prevalence. Poor glycemic control is directly associated with the development of renal, cardiovascular, ocular, and neuropathic complications. One third of this population is affected by obesity, a condition that significantly hinders diabetes management and worsens its complications. This limits the long-term effectiveness of conventional treatment, highlighting the need for alternative approaches such as bariatric surgery. To evaluate the effect of bariatric surgery as an adjuvant treatment for type 2 diabetes *mellitus*, a literature review was conducted using original articles from primary and secondary sources in English and Spanish, retrieved from PubMed, Cochrane, and Embase databases, published between 2019 and 2025. Bariatric surgery has gained an important role in diabetes treatment by promoting metabolic control of glucose through systemic changes that enhance both insulin sensitivity and secretion, along with significant weight loss. Its introduction as a therapeutic option in patients with obesity and uncontrolled diabetes may lead to remission of type 2 diabetes *mellitus*.

Keywords
Diabetes *Mellitus* Type 2, Bariatric Surgery, Obesity, Glycemic Control.

Resumen
La diabetes *mellitus* tipo 2 se considera una enfermedad crónica de alta prevalencia. El control inadecuado tiene una relación directamente proporcional con el desarrollo de complicaciones renales, cardiovasculares, oculares y neuropáticas. Un tercio de pacientes diabéticos padecen obesidad, factor que contribuye directamente a un peor control de la diabetes. Esto hace que su tratamiento convencional pueda resultar limitado a largo plazo, por lo que es necesario un abordaje diferente como la cirugía bariátrica. Con el objetivo de estudiar el efecto de la cirugía bariátrica como terapia combinada en el tratamiento de la diabetes *mellitus* tipo 2, se realizó una búsqueda bibliográfica de artículos originales de fuentes primarias y secundarias en idiomas inglés y español en bases de datos PubMed, Cochrane y Embase, publicados entre 2019-2025. La cirugía bariátrica ha adquirido un papel relevante en el tratamiento de la diabetes, al favorecer el control metabólico de la glucosa mediante cambios sistémicos que mejoran la sensibilidad y la secreción de insulina, además de producir una pérdida ponderal significativa. Su incorporación como opción terapéutica en pacientes con obesidad y diabetes mal controlada puede incluso conducir a la remisión de la diabetes *mellitus* tipo 2.

Palabras clave
Diabetes *Mellitus* Tipo 2, Cirugía Bariátrica, Obesidad, Control de la Glucosa en Sangre.

Introduction

Type 2 diabetes *mellitus* (DM2) is defined as a chronic disease characterized by varying degrees of insulin resistance or reduced insulin production, accompanied by increased glucose production in the liver.[1] In 2024, the International Diabetes Federation (IDF) reported that 589 million adults between the ages of 20 and 79 have diabetes; 96 % have DM2, and approximately 30 % have it in combination with obesity. In Central and South America, DM2 affects one in ten people, or 35.4 million adults, and was responsible for 224 000 deaths.[2]

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La cirugía bariátrica como terapia combinada en el tratamiento de la diabetes *mellitus* tipo 2

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In El Salvador, the prevalence of DM2 was 12.7 % in 2024, equivalent to 463 300 adults with diabetes.[3] According to the Institute for Health Metrics and Evaluation (IHME) in El Salvador, between 1990 and 2021, the disease accounted for 4.68 % (4.24 %-5.13 %) of healthy life years lost and 5.28 % (4.39 %-6.32 %) of disability-adjusted life years, reflecting its high impact on a person's quality of life.[4] However, 47 % of patients with DM2 fail to achieve adequate weight and glycemic control, which increases the risk of long-term complications.[5]

Diabetic kidney disease occurs in 40 % of diabetic patients, especially in developing countries.[6] Similarly, diabetic retinopathy develops in 60 % of these patients, and by 2020, it affected 103 million people.[7] Different types of diabetic neuropathy affect almost 50 % of people with diabetes, the most common being symmetrical distal polyneuropathy, autonomic neuropathy, radiculoplexopathy, and mononeuropathy.[8] On the other hand, a diabetic person has a 20-30 % probability of developing acute coronary syndromes and peripheral artery disease.[9] The coexistence of diabetes and obesity causes clinical differences. There is a direct proportional relationship between severe obesity (body mass index [BMI] ≥ 35 kg/m^2), DM2, and the development of systemic complications.[10]

Due to the limited effectiveness of lifestyle changes and low adherence to pharmacological treatments, new strategies are needed to treat DM2 and obesity.[11] Bariatric surgery has proven to be a comprehensive option, achieving metabolic control in 72 % of patients with DM2 at 2 years and reducing glycosylated hemoglobin (HbA1c) levels compared with new glucose-lowering agents.[12] In addition, bariatric surgery is a cost-effective alternative, reducing treatment and hospitalization costs due to complications, mainly in patients with obesity, refractory hyperglycemia that is difficult to manage, and a high risk of developing complications.[13]

A literature review was conducted using PubMed, Cochrane, and Embase databases. Search criteria included complete, relevant, and scientifically valid articles in Spanish and English, published between 2019 and 2025, were used. Systematic reviews and meta-analyses, randomized clinical trials, observational studies, review articles, preclinical research, clinical guidelines, and institutional reports were included. The search strategy used the keywords "Diabetes Mellitus, Type 2," "Bariatric Surgery," "Obesity," and "Glycemic Control," as well as the Boolean operators "AND" and "OR." The objective of the review was to analyze the effect of bariatric surgery as an adjunct to the control of DM2.

Discussion

Pathophysiological mechanisms of type 2 diabetes *mellitus*

Type 2 diabetes *mellitus* results from insulin resistance and progressive dysfunction of pancreatic β cells, as well as inflammation secondary to ectopic lipid deposits and oxidative stress, which together contribute to the onset and progression of the disease.[14]

Insulin resistance is the inadequate response of peripheral tissues to the hormone, mainly skeletal muscle.[15] Insulin promotes glycogen formation in skeletal muscle by utilizing glucose present in the blood.[16] When mitochondrial dysfunction is present, glucose uptake decreases, resulting in the hyperglycemic state characteristic of DM2.[17] To compensate, the pancreatic β cells responsible for producing insulin increase their secretion, but over time they become depleted and decrease in function and mass, affecting their ability to secrete insulin.[18]

Ectopic lipid deposition and lipotoxicity play central roles in the pathogenesis of DM2. The limited storage capacity of subcutaneous adipose tissue favors the formation of visceral deposits, which are less sensitive to the antilipolytic action of insulin, thereby increasing circulating free fatty acids, promoting liver dysfunction, and increasing very low-density lipoprotein secretion.[19] On the other hand, oxidative stress and hyperglycemia generate reactive oxygen species, which weaken endogenous antioxidant systems and cause cell damage, inflammation, and increased insulin resistance.[20]

It is common for obesity to occur in combination with diabetes. It is a pathological condition in which there is an overaccumulation of adipose tissue due to an increase in the size and number of adipocytes. In addition to generating an inflammatory state, this alters the insulin signaling chain and accelerates the cellular dysfunction of pancreatic β cells, which contributes to the pathogenesis of DM2.[21,22] The risk of developing DM2 is directly related to an individual's BMI. This risk is three times higher in people with a BMI between 30 and 34.9 kg/m^2, and in those with a BMI above 35 kg/m^2 it is up to eight times higher.[23]

Due to the close relationship between obesity and DM2, BMI plays an important role when considering surgery as a treatment option. Multiple mechanisms have been demonstrated by which bariatric surgery contributes to glycemic control, such as: a significant improvement in the

insulin sensitivity of pancreatic β cells, which increases the response to glucose and reduces its basal secretion.[24] Likewise, due to the remodeling of the extracellular matrix in skeletal muscle and weight loss that reduces systemic inflammation, an increase in insulin sensitivity in peripheral tissues is achieved and glucose uptake is improved.[25]

Regarding insulin sensitivity and secretion, in the experimental clinical study conducted by Lannoo *et al.*, 30 insulin-dependent diabetic patients with obesity were randomly assigned to three groups: Roux-en-Y gastric bypass (RYGB), laparoscopic sleeve gastrectomy (LSG), and dietary change alone. Euglycemic and hyperglycemic tests were performed before treatment and three weeks after, showing an improvement in insulin sensitivity ($p \geq 0.10$) with no significant difference between the three groups; however, LSG showed a significant improvement in the maximum capacity of beta cells to produce insulin ($p < 0.01$). Likewise, the disposition index, which reflects the combined function of insulin sensitivity and secretion, is better in those who underwent surgery compared to those who only made dietary changes.[26]

Bariatric surgery induces significant remodeling of the extracellular matrix of white adipose tissue, suggesting a restructuring that favors greater flexibility and lower tissue density, facilitating fat loss. At the same time, obesity is associated with chronic inflammation, characterized by high levels of pro-inflammatory cytokines (TNF-α, IL-1, IL-6); and a reduction in these has been observed in patients undergoing surgery, contributing to decreased systemic inflammation and metabolic recovery.[27]

Bariatric surgery contributes to physiological changes at the systemic level that improve glucose metabolism, such as: increased secretion of glucagon-like peptide-1 (GLP-1) and bile acids that help maintain glucose homeostasis, a decrease in amino acids such as isoleucine, leucine, and valine, which are highly associated with obesity and DM2, and changes in the gut microbiome that contribute to weight loss and long-term control of DM2.[28]

The aforementioned characteristic pathophysiological changes have a systemic impact. This complex network of alterations has prompted the search for therapeutic alternatives beyond conventional medical and pharmacological treatment. In this context, bariatric surgery emerges as a potentially effective and viable option, not only for weight loss, but also as a metabolic control strategy capable of modifying the natural course of DM2.

Main bariatric procedures

Bariatric and metabolic surgery (BMS) is a group of surgical procedures designed to induce weight loss, being an effective, long-term alternative in obese patients and in difficult-to-manage diabetic patients.[29] Modern BMS began to develop in the 1950s, but it was not until the 2000s, with the advent of laparoscopic surgery, that it really took off.[30] Weight loss is achieved by altering the anatomy of the gastrointestinal tract, reducing caloric intake, and modifying eating behavior by generating greater satiety.[31]

When proposing BMS, an individualized approach must be taken that involves the coordinated participation of specialists in surgery, endocrinology, nutrition, mental health, and physical rehabilitation to ensure a favorable clinical outcome. Although various BMS techniques have been developed, the analysis focuses on the two most established and widely studied modalities: LSG and RYGB count for up to 95 % of bariatric surgeries performed in the United States, especially in obese patients with DM2.[32]

The International Federation for the Surgery of Obesity and Metabolic Disorders, in its evidence-based clinical guidelines, recommends BMS for patients with a BMI > 35 kg/m^2, regardless of the presence of complications. For those with a BMI between 30 and 34.9 kg/m^2, consideration should be given if they do not achieve significant weight loss or improvement in comorbidities through non-surgical treatments and with good adherence. In this group, where the risk of complications is lower, the risk-benefit ratio should be carefully evaluated before opting for surgery, as less invasive interventions may be effective.[33]

For individuals with a BMI > 35 kg/m^2, bariatric surgery is recommended by clinical guidelines, as it is prioritized for those with the greatest need and potential benefit. However, studies involving more than 500 patients with a BMI ≤ 35 kg/m^2 have shown that this intervention results in significant and sustained weight loss at five years, along with improvements in the management of hypertension and dyslipidemia, and, in some cases, remission of diabetes. This remission is defined as maintaining HbA1c values < 6.5 % without the need for drug treatment for at least three months.[34,35] Similarly, in a cohort study of more than 1000 patients comparing bariatric surgery in patients with a BMI ≥ 35 kg/m^2 vs. those with a BMI < 35 kg/m^2, both groups had similar rates of discontinuation of medications for chronic diseases, but the group of patients with lower BMI was more likely to maintain a healthy BMI (< 25 kg/m^2) and a higher body image score.[36]

Laparoscopic sleeve gastrectomy involves surgically removing 85 % of the stomach, creating a tube-shaped stomach, which reduces stomach volume, affects ghrelin production, and consequently influences appetite. On the other hand, RYGB is more complex because it seeks to create a gastric pouch and divert it to the distal jejunum, thus bypassing the duodenum and part of the jejunum (Figure 1). It is a restrictive procedure because it decreases stomach volume, as well as malabsorptive by limiting the absorption of calories and nutrients in the small intestine. Both procedures are performed laparoscopically, but RYGB is considered more invasive due to the multiple anastomoses involved.[37]

The choice of surgical procedure should consider the complication profile associated with each technique. LSG may present short-term complications such as gastrointestinal leaks and gastric obstruction. BGYR may be associated with the development of gastric stenosis and the appearance of internal hernias. Both procedures share the risk of requiring reoperation, depending on the severity and evolution of these complications. In the long term, LSG is mainly associated with the development of gastroesophageal reflux disease, and RYGB presents a higher risk of dumping syndrome (rapid emptying of the stomach into the small intestine) and nutritional deficiencies, due to its malabsorptive component.[38-40]

According to Howard *et al.*, the cumulative incidence of complications is 29.0 % for RYGB and 22.1 % for LSG, while the need for reoperations was 33.6 %, and 25.2 %, respectively. However, it is important to mention the likelihood of bias in this study due to the overreporting of minor events or events not directly related to surgery. In addition, patients undergoing RYGB generally have more severe comorbidities and higher BMI, which could inflate the rate of adverse events in this group.[41]

With regard to costs and postoperative recovery, RYGB is more expensive for the healthcare facility performing it, as it requires a longer operative time and has higher readmission rates in the 30 days following surgery. On the other hand, LSG usually has a shorter surgical time and hospital stay, which can lead to a faster initial recovery.[42] Despite the complications associated with both surgical procedures, when comparing the risk-benefit ratio and given that these complications are controllable, it is beneficial to consider bariatric surgery as a therapeutic option.

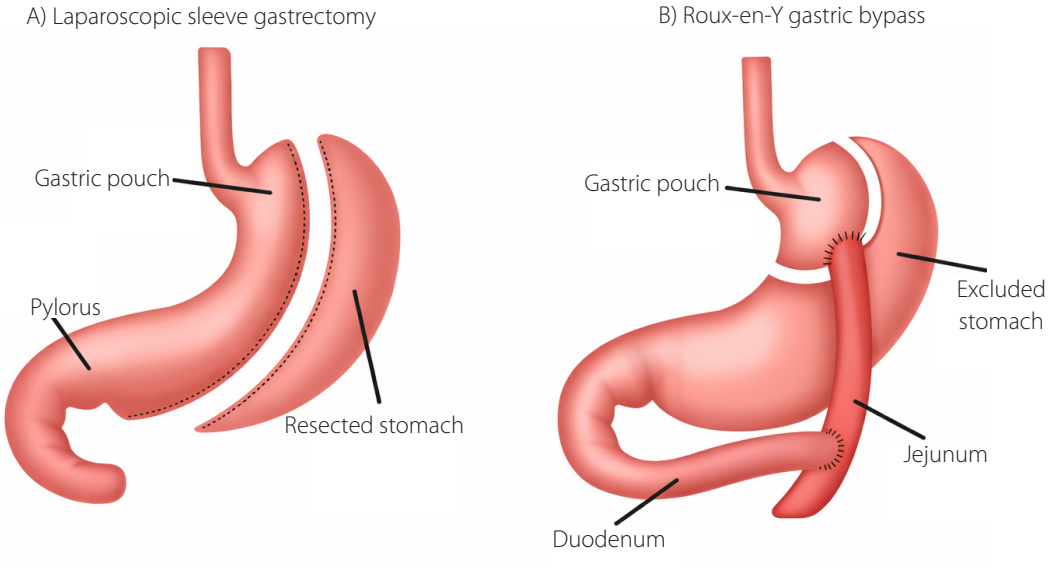

Figure 1. Main bariatric procedures: A) Laparoscopic sleeve gastrectomy (LSG) and B) Roux-en-Y gastric bypass (RYGB).

Source: A) Alejandro Ros Comesaña, Modified by the authors (color, saturation, arrows added, and translation of names into Spanish). License: CC BY-SA 4.0 (https://creativecommons.org/licenses/by- sa/4.0/). and B) Eslam Ibrahim. Modified by the authors (color and saturation adjustment, addition of arrows, and translation of terms into Spanish). License: CC BY-SA 4.0 (https://creativecommons.org/licenses/by- sa/4.0/).

Effect of bariatric surgery on metabolic and glycemic control

The main findings in the literature indicate that BMS promotes remission of DM2 by reducing weight, glucose levels, and the need for antidiabetic medication. Table 1 presents a comparison of these aspects between the two procedures based on multiple articles.[40, 43-50]

In a meta-analysis by Xu Han *et al.*, with a total population of 3855 patients who were part of 39 different studies, it was concluded that BMS resulted in significant reductions in fasting and postprandial glucose and HbA1c levels, thus improving glycemic and metabolic control in obese patients with DM2. These results are consistent with growing evidence showing that BMS offers not only weight loss but also effective glycemic control, resulting in complete or partial remission of DM2.[43]

In the randomized clinical trial conducted by Miras *et al.*, the effect of RYGB was analyzed in a sample of 72 patients with DM2, with an average BMI of 43 kg/m^2 and an average age of 45 to 50 years, on GLP-1 levels and glucose metabolism in patients with DM2. It was concluded that in the groups studied, there was a significant increase in postprandial GLP-1 levels after surgery and a significant improvement in fasting glucose and HbA1c levels.[44]

O'Moore-Sullivan *et al.*, conducted a prospective cohort study in which 212 patients with DM2 and a BMI greater than 35 kg/m^2 underwent RYGB and LSG and were observed for 12 months for parameters such as body weight, BMI, HbA1c, and comorbidities. This study reported that in the first three months, weight loss was similar between patients undergoing RYGB and LSG. However, six months after surgery, patients who underwent RYGB showed greater weight loss than those who underwent LSG, reaching a weight loss of 24.5 % at 12 months for the RYGB group compared to 21.4 % in the LSG group, representing an absolute loss of 3.1 %. Likewise, patients with RYGB experienced a significantly greater reduction in HbA1c than those with LSG, with reductions of 24.6 % and 17.8 % (24.6 ± 13.7 % vs. 17.8 ± 18.8 %, $p = 0.02$) respectively for each group.[45]

Mingrone *et al.*, in a randomized clinical trial involving 60 patients with DM2 and a BMI between 35 and 45 kg/m^2, divided into three different groups receiving conventional medical therapy, RYGB, and LSG, were followed up for ten years, complete remission of diabetes (HbA1c less than 6.5 % without antidiabetic medication) was observed in 50 % of patients in the RYGB group, 25 % in the LSG group, and 0 % in the conventional medical therapy group.[46]

Table 1. Comparison of RYGB vs. GML

Result/Variable	RYGB	LSG
Weight loss	Same loss in the first 3 months, but increases between 6-12 months, approximately 24.5 %-50.7 %	Similar in the first 3 months but lower between 6-12 months: between 21.4 % and 43.5 %
HbA1c (improvement in glycemic control)	Significantly greater reduction in HbA1 c: 24.6 %	Significant improvement, but lower: 17.8 %
Remission of DM2 (HbA1c <6.5% ≥3m without drugs)	• Higher remission rate • 40-80 % remission at 1-3 years • 30-50 % maintain remission at five years	• Frequent but lower than RYGB • 25-60 % remission at 1-3 years • 20-30 % maintain remission at five years
Adverse events	Higher risk of deficiencies, dumping syndrome, hospitalizations	Lower risk of mortality and complications at five years
Reoperations	Less frequent: due to reflux, more frequent due to nutritional complications	More frequent: due to reflux or insufficient loss
Need for supplements (Fe/B12/D)	• Higher risk of deficiencies, greater need for supplements • Vitamin B12 deficiency: 17.56 % at six months post-surgery and 16.40 % at 12 months • Excess PTH at 6 months post- surgery: 16.40 % • Excess ferritin at 12 months post-surgery: 5.15 %	• Lower risk than RYGB, but not absent • Vitamin B12 deficiency: 4.96 % at six months post-surgery and 0.93 % at 12 months • Excess PTH at six months post-surgery: 8.66 % • Excess ferritin 12 months post-surgery: 0.6 %

Source: Prepared by the authors based on data from Vieira *et al.*[40] , Xu Han *et al.*[43], Miras *et al.*[44], O'Moore- Sullivan *et al.*[45] , Mingrone *et al.*[46], Murphy *et al.*[47], Aguirre Talledo *et al.*[48] , Salminen *et al.*[49], Purnell *et al.*[50].

Murphy *et al.*, in a randomized, blinded clinical trial, compared remission of DM2 at five years in patients undergoing RYGB or LSG, where 47 % and 33 % of patients undergoing each procedure, respectively, achieved remission of DM2 defined by the study as an HbA1c below 6 %, without the need for antidiabetic medications. Likewise, body weight loss was greater with RYGB, with an absolute difference of 10.7 % more weight lost compared to LSG, achieving a statistically significant result ($p < 0.01$).[47]

The systematic review and meta-analysis conducted by Aguirre Talledo *et al.*, in which 14 studies were selected to compare the effectiveness of RYGB and LSG in achieving remission of DM2, established that remission was 15 % more effective with LSG (RR: 1.15, [95 % CI: 1.04-1.28]), as was weight loss, with a mean difference of 6.5 kg, accompanied by improvements in the remission of hypertension and dyslipidemia. On the other hand, RYGB proved to be more effective in reducing BMI (-1.31 kg/m^2) and lowering total and LDL cholesterol levels.[48]

The randomized clinical trial SLEVEPASS in Finland conducted by Salminen *et al.*, followed 240 patients with severe obesity, aged 18 to 60 years with an average BMI of 45.9 kg/m^2 who were randomly assigned to LSG (121 patients) and RYGB (119 patients) in order to compare the 10-year effects on weight loss, remission of obesity-related comorbidities, and symptoms associated with gastroesophageal reflux. The results show that there was greater excess weight loss in patients undergoing RYGB (50.7 %) compared to LSG (43.5 %). Likewise, although remission of DM2 was observed in both groups, there was no significant difference with 26 % in LSG vs. 33 % in RYGB.[49]

In a cohort study conducted by Purnell *et al.*, 2467 patients who underwent BMSwere followed for seven years, and their weight, body composition, comorbidities, and metabolic parameters were evaluated. Of these, 827 were receiving drug treatment for diabetes and had an average BMI of 46.59. The percentage of total or partial remission in DM2 was 57.2 % for RYGB and 22.5 % for LSG. Diabetes remission was observed in younger patients with shorter disease duration and lower HbA1c levels. However, it should be noted that this is a non-randomized observational study with heterogeneous procedures, loss to follow-up over time, and the use of variable definitions of remission. In addition, factors such as treatment adherence, lifestyle, and nutritional follow-up were not controlled, which limits comparability with other studies.[50]

The literature shows heterogeneous findings; while some long-term randomized clinical trials favor RYGB for DM2 remission, meta-analyses and observational studies show equivalent or slightly superior results with LSG. These discrepancies are related to differences in the definition of remission (complete or partial), follow-up time, characteristics of the study population (BMI, age, duration of DM2), and variations in surgical techniques. Therefore, both procedures should be considered effective, and the choice should be individualized according to the clinical profile.

Conclusion

In adults with obesity and DM2, achieving adequate glycemic control remains a challenge despite therapeutic advances and adherence to pharmacological treatments. In light of this difficulty, BMS has established itself as an effective adjunct in the comprehensive management of DM2.

Roux-en-Y gastric bypass has demonstrated greater weight loss, greater reduction in HbA1c, and higher rates of DM2 remission compared to LSG, but at the cost of a higher risk of nutritional deficiencies, dumping syndrome, and long-term use of health services. In contrast, LSG exhibits a better short- and medium-term safety profile in population-based series and a lower immediate risk of mortality/complications in some cohorts.

Considering the available evidence, BMS appears to be a valid and effective option for obese patients with DM2. However, patient care requires a comprehensive strategy that includes various disciplines to facilitate adaptation to the anatomical and functional changes resulting from the procedure, prevent nutritional deficiencies, detect complications early, and maintain long-term weight loss. In this way, continuous monitoring becomes a key component of the treatment's efficacy and safety.

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