

# Bariatric Surgery as a Potent Intervention for Type 2 Diabetes Remission in Obesity: Mechanisms, Outcomes, and Future Directions

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## Abstract

This article reviews the relationship between weight-loss surgery and the remission of type 2 diabetes. Bariatric surgery, particularly Roux-en-Y Gastric Bypass (RYGB), Sleeve Gastrectomy (SG), and One-Anastomosis Gastric Bypass (OAGB), has been proven to have significant effects on improving blood glucose control and reducing body weight. These surgeries effectively alleviate diabetes through mechanisms such as altering intestinal hormone secretion, improving insulin sensitivity, enhancing hepatic lipid metabolism, modifying the structure of the gastrointestinal microbiota, and the rapid adaptation of the neuroendocrine system. Analysis of post-surgical metabolic changes and mechanisms shows that improved insulin sensitivity, altered gut hormones, enhanced hepatic lipid metabolism, and restructuring of the gastrointestinal microbiota are key to diabetes remission. However, post-surgical patients may also face complications such as malnutrition, hypoglycemia, gastrointestinal issues, mental health problems, and osteoporosis, which require personalized and multidisciplinary collaborative management. Additionally, the combined use of medications like GLP-1 (Glucagon-Like Peptide-1) receptor agonists and SGLT-2 (Sodium-Glucose Cotransporter-2) inhibitors with surgery provides more flexible and effective treatment options for diabetic patients. Despite existing challenges, with the development of personalized protocols and new medications, the combination of drugs and surgery will have broad application prospects in the future.

## Keywords

Bariatric Surgery, Diabetes Remission, Obesity

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## 1. Introduction

### Research Background

Research on bariatric surgery began to flourish in the 20th century, with remarkable progress achieved particularly in the treatment of obesity and metabolic diseases (such as type 2 diabetes mellitus). The connection between obesity and diabetes is extremely close—they promote each other and together form a health crisis characterized by the coexistence of “diabetes and obesity” (referred to as “tangfei” in the Chinese context, denoting the comorbidity of diabetes and obesity). Some studies suggest that the mortality risk for people with both diabetes and obesity is significantly higher than that for healthy individuals. For example, a recent large epidemiological analysis indicated that concomitant obesity and T2DM can increase mortality risk by approximately seven-fold compared to metabolically healthy individuals [1]. Ninety percent of type 2 diabetes cases are associated with weight gain [2]. There is a J-shaped association between BMI at the time of T2DM diagnosis and patients’ mortality risk. Specifically, T2DM patients with a normal BMI (18 - 24 kg/m<sup>2</sup>) have a relatively lower mortality risk [3]. Therefore, bariatric surgery not only plays a crucial role in weight management but is also regarded as an effective metabolic intervention. Additionally, weight reduction can lower the risk of microvascular complications in patients with T2DM. However, the effectiveness of weight loss through lifestyle and dietary modifications is often suboptimal in these patients. According to a study analyzing 20-year data on obese patients in Sweden, patients only achieved a 1% weight reduction through dietary or lifestyle changes alone [4]. Currently, research and development of antihyperglycemic drugs and anti-obesity drugs have gradually gained attention. However, traditional antihyperglycemic drugs cannot maintain blood glucose levels in the long term or improve body weight; some even lead to weight gain. In this context, bariatric surgery has gradually emerged as a key intervention for weight reduction. Current studies have confirmed that surgical procedures such as Roux-en-Y gastric bypass (RYGB) and sleeve gastrectomy (SG) exhibit significant effects in improving glycemic control and reducing body weight. According to the 2023 *World Obesity Atlas* report released by the World Health Organization (WHO), 38% of the global population is currently overweight or obese [5]. Among these factors, the high prevalence of comorbid type 2 diabetes mellitus (T2DM) and the associated coexistence risks have made bariatric surgery one of the key interventions in the treatment of metabolic diseases [6]. With the advancement of surgical techniques, the potential of bariatric and metabolic surgery in improving metabolic status and alleviating diabetes has been gradually confirmed [7]-[9]. Bariatric surgery encompasses various types, and this article focuses on three common bariatric surgical procedures—Roux-en-Y gastric bypass (RYGB), sleeve gastrectomy (SG), and one-anastomosis gastric bypass (OAGB)—as well as their efficacy in diabetes remission [7].

## 2. Types of Bariatric Surgery and Their Efficacy in Diabetes Remission

### 2.1. Roux-en-Y Gastric Bypass (RYGB)

The Roux-en-Y Gastric Bypass (RYGB) is one of the most widely used bariatric and metabolic surgeries. It works by reducing the size of the stomach and reconnecting the small intestine to the stomach, thereby bypassing a portion of the small intestine—this dual mechanism restricts food intake and reduces nutrient absorption. RYGB demonstrates significant efficacy in diabetes remission, and is particularly suitable for patients with obesity combined with type 2 diabetes mellitus (T2DM). Studies have shown that RYGB can improve blood glucose levels in the short term after surgery (within weeks to months); some patients no longer require medication for glucose control [10]. Studies have shown that the diabetes remission rate of patients who underwent RYGB reaches as high as 70% - 80% within one year after surgery [9].

#### Mechanism Analysis

The diabetes remission effect of RYGB is mainly attributed to the following mechanisms: Surgery leads to a significant increase in the secretion of intestinal hormones such as glucagon-like peptide-1 (GLP-1) and peptide YY (PYY). These hormones help enhance insulin secretion and suppress appetite, thereby regulating blood glucose levels. Improved Insulin Sensitivity: RYGB also significantly enhances insulin sensitivity in peripheral tissues and reduces insulin resistance, which is particularly crucial for diabetes control [11] [12]. RYGB restricts food intake and reduces nutrient absorption by altering the structure of the gastrointestinal tract. The significant post-surgical increases in glucagon-like peptide-1 (GLP-1) levels and insulin sensitivity are its primary mechanisms [12]. In terms of diabetes remission, RYGB demonstrates a remission rate of 70% - 80% [9].

### 2.2. Sleeve Gastrectomy (SG)

Sleeve Gastrectomy (SG) is another common bariatric surgery. It reduces the stomach to a “sleeve-like” structure by resecting most of the gastric tissue, thereby restricting food intake. Unlike other procedures, SG does not alter the connection structure of the gastrointestinal tract and thus does not affect food absorption; however, it still exhibits favorable efficacy in diabetes remission. Studies have shown that although the diabetes remission rate of SG is slightly lower than that of RYGB, it still reaches approximately 60% - 70% [12].

SG controls food intake by reducing gastric volume; additionally, it decreases ghrelin levels and enhances the secretion of hormones such as glucagon-like peptide-1 (GLP-1). Reduced Ghrelin Levels: SG resects the portion of gastric tissue that secretes ghrelin, leading to a significant decrease in ghrelin levels. This results in reduced appetite and body weight, which in turn improve insulin resistance and blood glucose control [13]. Metabolic and Hormonal Changes: Although SG does not bypass the small intestine, the levels of hormones such as glucagon-like

peptide-1 (GLP-1) still increase after surgery. These hormones promote insulin secretion and blood glucose regulation, which partially contributes to the effect of diabetes remission [14]. The diabetes remission rate reaches 60% - 70%, and it has certain advantages in terms of adaptability and complication profile [12].

### 2.3. One-Anastomosis Gastric Bypass

The One-Anastomosis Gastric Bypass (OAGB) is a relatively new bariatric procedure. It reduces the stomach size and connects the stomach directly to the small intestine, bypassing the duodenum and a portion of the small intestine. Similar to Roux-en-Y Gastric Bypass (RYGB), OAGB involves a simpler surgical technique and carries a relatively lower risk. Studies have found that OAGB's efficacy in diabetes remission is comparable to or even superior to that of RYGB. Some studies have shown that the diabetes remission rate of OAGB can be as high as over 80% [15].

The efficacy of OAGB in diabetes remission is mainly influenced by the following mechanisms: Due to the longer segment of small intestine bypassed in OAGB's design, its effect on restricting nutrient absorption is more significant than that of RYGB, resulting in a more potent effect on blood glucose regulation [6]. After OAGB surgery, the levels of glucagon-like peptide-1 (GLP-1) and peptide YY (PYY) increase significantly. Combined with improved insulin sensitivity, this contributes to the long-term control of blood glucose [16]. The diabetes remission rate can be as high as over 80%, but it is accompanied by a higher risk of nutrient deficiencies [15] (Table 1).

**Table 1.** Diabetes Remission rate and key metabolic effects of different metabolic surgeries.

Diabetes Remission Rate	RYGB	SG	OAGB
1 year	62%	49%	70%
3 years	47%	36%	65%
5 years	Improvement	Improvement	Improvement
Insulin Sensitivity	Increase	Increase	Increase
GLP-1/PYY	Increase	Minor decrease	-
Hepatic Lipid Metabolism	Decreased	Minor occeus	Minor modification
Gut Microbiota	Modification	Minor modification	-

Legend: Abbreviations: GLP-1 = glucagon-like peptide 1; PYY = peptide tyrosine tyrosine; RYGB = Roux-en-Y gastric bypass; SG = sleeve gastrectomy; OAGB = one-anastomosis gastric bypass.

## 3. Postoperative Metabolic Changes and Mechanism Analysis

### 3.1. Improvement of Insulin Sensitivity

The insulin sensitivity of post-surgical patients is significantly improved, which helps control blood glucose [17]. One of the key roles of bariatric surgery in dia-

betes remission is to significantly improve insulin sensitivity. Studies have shown that insulin resistance is reduced in patients after bariatric surgery, with particularly notable effects in Roux-en-Y gastric bypass (RYGB) [17]. After surgery, both insulin secretion and the response of peripheral tissues to insulin are improved. The specific mechanisms include a reduction in adipocyte volume and a decrease in chronic low-grade inflammation. Additionally, changes in intestinal structure promote an increase in glucagon-like peptide-1 (GLP-1) secretion, which further enhances the effect of insulin [18].

### 3.2. Changes in Gut Hormones

Elevated levels of hormones like glucagon-like peptide-1 (GLP-1) and peptide YY (PYY) are key mechanisms underlying the improvement in metabolism after surgery. These hormones enhance insulin secretion and suppress appetite [19]. In particular, Roux-en-Y gastric bypass (RYGB) and sleeve gastrectomy (SG) significantly affect the secretion of gut hormones. After surgery, the secretion of gut hormones such as glucagon-like peptide-1 (GLP-1), peptide YY (PYY), and glucose-dependent insulinotropic polypeptide (GIP) increases—and these hormones play important roles in regulating insulin secretion and suppressing appetite. For instance, GLP-1 is a potent stimulator of insulin secretion; elevated levels of GLP-1 directly promote insulin secretion and blood glucose regulation. Changes in gut hormone secretion after surgery are regarded as one of the core mechanisms by which metabolic surgery effectively controls blood glucose [19].

The secretion of glucagon-like peptide-1 (GLP-1) increases significantly, and this change manifests in the early postoperative period. GLP-1 not only promotes insulin secretion but also inhibits gastric emptying and appetite, thereby playing an important role in weight management and blood glucose control [20]. Peptide YY (PYY), whose full name is Peptide YY, belongs to the pancreatic polypeptide family. It is mainly secreted by intestinal L cells, particularly synthesized in the ileum and colon. The increase in PYY after surgery is also closely related to the regulation of body weight and appetite. PYY can regulate appetite and inhibit eating behavior; through interacting with the central nervous system, it can significantly reduce food intake, thereby contributing to weight loss and diabetes control [21].

### 3.3. Improvement in Hepatic Lipid Metabolism

Bariatric surgery significantly improves hepatic lipid metabolism, thereby reducing the risk of fatty liver disease and alleviating insulin resistance [22]. In patients with obesity and diabetes, fatty liver disease and insulin resistance are common comorbidities. Studies have shown that bariatric surgery can significantly improve hepatic lipid metabolism, thereby alleviating fatty liver disease and insulin resistance. After surgery, hepatic fat content decreases significantly, and hepatic glucose production is reduced—these changes collectively improve the body's overall metabolic status [22]. This improvement is believed to result from postoperative

weight loss and changes in fat distribution. In particular, the reduction of visceral fat plays a crucial role in the restoration of insulin sensitivity.

### 3.4. Changes in the Gastrointestinal Microbiota

Postoperative microbiota alterations result in increased beneficial bacteria and elevated short-chain fatty acid production, thereby enhancing insulin sensitivity [12] [23]. In recent years, the role of the gastrointestinal microbiota (gut microbiome) in metabolic regulation has gained increasing attention. Studies have found that significant changes occur in the intestinal microbiota of patients after Roux-en-Y Gastric Bypass (RYGB) and Sleeve Gastrectomy (SG) surgeries. These changes help enhance insulin sensitivity and improve metabolic status. For example, the relative proportion of some beneficial bacterial groups (such as Firmicutes) increases, while the bacterial groups associated with metabolic disorders decrease [23]. In the pathophysiological process of obesity, the reduction of visceral fat induced by Sleeve Gastrectomy (LSG) can decrease the production of chronic low-grade inflammatory factors, thereby restoring insulin signal transduction [24]. These changes in the microbiota may further affect insulin sensitivity and glucose metabolism by regulating the production of short-chain fatty acids (SCFAs). SCFAs, such as acetate, propionate, and butyrate, act as signaling molecules that bind to specific receptors (e.g., GPR41, GPR43) on intestinal L-cells and adipocytes, thereby promoting the secretion of gut hormones like GLP-1 and enhancing insulin sensitivity and glucose uptake in peripheral tissues.

### 3.5. Rapid Adaptation of the Neuroendocrine System

Studies have also found that the neuroendocrine system rapidly adapts to the new metabolic state after bariatric surgery, primarily through the gut-brain axis. This adaptation involves altered signaling from gut-derived hormones (e.g., GLP-1, PYY) and nutrients via the vagus nerve to central appetite-regulating centers in the hypothalamus and brainstem. These signals modulate neuronal activity in key nuclei (e.g., arcuate nucleus, nucleus tractus solitarius), leading to reduced hunger, increased satiety, and improved central regulation of glucose homeostasis. In Roux-en-Y Gastric Bypass (RYGB) surgery, due to reduced food intake and accelerated gastric emptying, the signal transduction pathways of the central nervous system (CNS) are rearranged, which further affects body weight and blood glucose control [21].

### 3.6. Summary

Postoperative metabolic changes and mechanisms mainly involve improved insulin sensitivity, altered intestinal hormone secretion, enhanced hepatic lipid metabolism, gastrointestinal microbiota remodeling, and neuroendocrine adaptation. The interaction of these mechanisms collectively promotes the remission of diabetes, providing a theoretical basis for further optimizing surgical approaches and postoperative management (Table 2).

**Table 2.** Comparison of common bariatric procedures: mechanisms and efficacy in type 2 diabetes remission.

Procedure	Surgical Characteristics	Remission Mechanism	Key Pros & Cons
RYGB	Small gastric pouch; bypasses the duodenum/proximal jejunum	Restriction + malabsorption	Better weight loss; complex; nutrient risk
SG	Longitudinal gastrectomy	Intake restriction + gut hormone changes	Simple; no bypass; risk of GERD
OAGB	Narrow gastric pouch; bypasses the distal ileum	Restriction + malabsorption	Effective weight loss; less complexity; bile reflux

Legend: This table compares three mainstream bariatric procedures for type 2 diabetes remission.

## 4. The Impact and Management of Surgical Complications

Although bariatric surgery has excellent safety, it is still associated with relevant risks. Like other surgical procedures, it carries a certain risk of complications, which can be classified into early complications and late complications based on the timing of occurrence. Sleeve gastrectomy (LSG) has the advantage of not altering the physiological tract and has definite efficacy in metabolic diseases such as type 2 diabetes mellitus (T2DM). With the increase in the number of surgeries performed, a systematic understanding of its early and late complications has gradually been established, and standardized management of complications has become feasible. This is crucial for improving long-term prognosis and enhancing the effectiveness of surgical treatment.

### 4.1. Bleeding

First, bleeding is a primary concern. It is the most common complication of Sleeve Gastrectomy (LSG) and an early complication, with studies reporting an incidence rate of approximately 1.16% - 4.94% [25]. Common bleeding sites include the sutures or staples along the incision line, as well as blood vessels from injured abdominal organs, parenchymal organ injuries (including the liver and spleen), or coagulation disorders. Intraoperatively, poor control of the patient's blood pressure or failure to suture and reinforce the incision and staple sites will result in a higher bleeding rate [25]. The first manifestations of postoperative bleeding may include early tachycardia, hypotension, rapid decrease in hemoglobin, abdominal pulsation, abdominal distension, and dark red or a large amount of bright red blood in the drainage tube. Computed tomography (CT) and abdominal ultrasound can assess the volume of intra-abdominal hemorrhage.

### Management Measures

For postoperative bleeding, the patient's condition should first be evaluated. For those with hemodynamic stability, conservative treatments such as fluid replacement and blood transfusion should be prioritized. For active arterial bleeding, interventional embolization is feasible; angiographic embolization is a minimally invasive and simple method that enables diagnosis and treatment simultaneously. If the above measures fail to resolve the issue, surgical exploration may be performed. For patients with hemodynamic instability, early and immediate surgical

exploration should be conducted to achieve hemostasis [26].

## 4.2. Postoperative Malnutrition

Patients who undergo Roux-en-Y Gastric Bypass (RYGB) and One Anastomosis Gastric Bypass (OAGB) are prone to vitamin and mineral deficiencies, which affect their health [27].

### Management Measures

Dietary supplements, regular monitoring, and dietary planning. Malnutrition is one of the common complications of bariatric surgery, especially prevalent in patients undergoing Roux-en-Y Gastric Bypass (RYGB) and One Anastomosis Gastric Bypass (OAGB). Since these surgeries alter the digestive and absorptive pathways of food, patients often fail to intake sufficient vitamins and minerals. Common nutritional deficiencies include vitamin B12, iron, calcium, and vitamin D, which may lead to health issues such as anemia and osteoporosis [27]. In addition, appropriate dietary planning can help patients achieve a balanced intake, such as increasing foods rich in vitamins and minerals, thereby reducing the risk of malnutrition [28].

## 4.3. Hypoglycemia

Postoperative hypoglycemia is a common complication, mainly caused by excessive insulin response [29], post-bariatric hypoglycemia (PBH) is relatively common in patients who undergo gastric bypass surgery. This condition usually occurs postprandially, presenting with hypoglycemia-related symptoms (such as dizziness, palpitations, sweating, etc.). Its etiology is mainly associated with increased intestinal hormone secretion and excessive insulin response. PBH may significantly affect patients' quality of life and even increase the risk of readmission [29].

### Management Measures

The management of PBH includes dietary adjustments and medication. Patients should reduce the intake of high-sugar foods and adopt a small, frequent meal pattern to stabilize blood glucose levels. Meanwhile, drugs such as GLP-1 receptor agonists may effectively inhibit excessive insulin secretion and alleviate the occurrence of hypoglycemia. In addition, continuous glucose monitoring (CGM) technology can help patients detect and manage hypoglycemic events in a timely manner [30].

## 4.4. Gastrointestinal Disorders

Gastrointestinal disorders are relatively common after bariatric surgery, including nausea, vomiting, diarrhea, and gastroesophageal reflux disease (GERD). These issues are mostly caused by changes in gastrointestinal structure, such as rapid gastric emptying resulting from reduced gastric capacity or shortened small intestinal absorption pathways. Studies have shown that patients undergoing sleeve

gastrectomy (LSG) are more prone to gastroesophageal reflux, while gastric bypass surgery can better alleviate the reflux symptoms induced by sleeve gastrectomy [9].

Anastomotic leakage is also one of the most serious complications following bariatric procedures, with an incidence rate of 1% - 3% but a mortality rate as high as 15% - 20% after occurrence. In RYGB and OAGB, anastomotic leak rates are of the same order of magnitude (typically ranging from ~0.5% up to 5% depending on the series) [31]. Numerous risk factors for gastrointestinal leak have been identified across different bariatric techniques. Patient-related factors associated with higher leak risk include male sex, very high body mass index (super-obesity), smoking, and certain obesity-related comorbidities such as diabetes or obstructive sleep apnea [31]. Technical factors are equally critical: inadequate perfusion of the anastomotic tissue or excessive tension on the anastomosis can precipitate ischemia and disruption of the suture line [32]. In practice, meticulous surgical technique (ensuring a well-vascularized, tension-free anastomosis) and aggressive management of risk factors are essential to minimize the occurrence of anastomotic leaks in RYGB, OAGB, and LSG patients. It mostly occurs in the upper gastric cavity near the esophagogastric junction, which is a “triple fragile point” due to mechanical stress, blood supply, and local anatomy. The pathogenesis is complex, usually resulting from the combined effect of multiple factors. Most authors believe it is not directly caused by staple burst; mechanical tissue factors also account for a part. When the intragastric pressure exceeds the tolerance of tissues and staple lines, anastomotic leakage occurs. Among these factors, the selection of staple cartridges has been widely discussed. Literature indicates that most authors argue that staples with a height lower than blue (1.5 mm) should not be used throughout the entire LSG procedure, while some authors suggest that staples lower than green (2.0 mm) should be prohibited. The gastric antrum is the thickest part of the stomach; for resection of the gastric antrum, staples with a height lower than green (2.0 mm) shall not be used. For resection from the gastric incisura to the angular incisure, staples lower than green (2.0 mm) are prohibited. For resection from the gastric incisura to the cardia (His), staples with a height lower than blue (1.5 mm) shall not be used [33]. Overall, however, the impact of blood supply is central. The blood supply of the gastric wall mainly comes from the left gastric artery, short gastric arteries, and left gastroepiploic artery. The cardia (distal esophagus and His angle) is supplied by branches of the left gastric artery as well as the right and anterior branches of the left inferior phrenic artery. When using a stapler to incise along the greater curvature, especially during the dissection, incision, and closure of the greater curvature near the His angle, the sleeve gastrectomy requires complete mobilization and resection of the gastric fundus, which necessitates transection of the short gastric arteries and any existing inferior phrenic branches. In addition, anatomical variations may lead to insufficient blood flow in the left gastric artery and its branches, resulting in severe ischemic damage to the upper part of the remaining stomach, especially the esophagogastric junction. This impairs tissue healing capacity, thereby triggering ischemic ne-

crossis and leakage [34]. Some literature analysis indicates that if the distance between the last staple firing of the stapler and the esophagogastric junction (His angle) is greater than 2 cm, the risk of acute leakage will increase [33] [35]. By retaining 1 - 2 cm of the residual stomach to avoid the resection line in the critical blood supply area, the risk of anastomotic leakage can be reduced [36]. Some literature analysis indicates that for Asian patients with metabolic syndrome, there are abundant fat pads around the His angle, and dissection of the fat pads around the His angle can also reduce the risk of anastomotic leakage [35]. Additional studies have shown that the density of reinforcing sutures and the direct tissue ischemic necrosis caused by tight suture tension can lead to the fusion of necrotic areas and the formation of fistulas [37]. Leakage may also be associated with a large pressure gradient, gastric torsion, distal stenosis, or intraoperative injury [35].

### Management Measures

The management of gastrointestinal disorders includes dietary adjustments and medication. Patients should gradually transition to solid foods and avoid overeating at one time. For gastroesophageal reflux, proton pump inhibitors (PPIs) are commonly used therapeutic drugs that can effectively relieve symptoms. If necessary, revisional surgery can be selected to reduce the occurrence of gastrointestinal complications [38]. For the management of anastomotic leakage, intensive care should be initiated immediately once it occurs, along with nutritional support (total parenteral nutrition or a combination of parenteral and enteral nutrition), administration of broad-spectrum antibiotics, and adequate drainage. Endoscopic intervention has become the primary treatment for gastric leakage after LSG, including self-expandable metallic stents used to occlude the fistula, which, however, carry risks such as migration and intolerance. Endoscopic vacuum therapy promotes the growth of granulation tissue around the fistula through negative pressure, with a higher closure rate than stent placement alone [35]. If the above measures fail, or if the patient develops severe infection, diffuse peritonitis, or septic shock, emergency surgical exploration should be performed promptly. The surgical procedures include fistula repair, drainage, jejunostomy, and even Roux-en-Y reconstruction or total gastrectomy [39].

### 4.5. Mental Health Issues

Studies have shown that patients may experience mental health issues such as anxiety and depression after bariatric surgery. Postoperative lifestyle changes, complications, and unmet expectations for surgical outcomes can all lead to psychological stress. If these problems are not addressed in a timely manner, they may affect the patients' long-term postoperative quality of life [40].

### Management Measures

Studies have shown that patients may experience mental health issues such as anxiety and depression after bariatric surgery. Postoperative lifestyle changes, complications, and unmet expectations for surgical outcomes can all lead to psycho-

logical stress. If these problems are not addressed in a timely manner, they may affect the patients' long-term postoperative quality of life [40].

#### **4.6. Osteoporosis and Fracture Risk**

Nutritional absorption changes caused by bariatric surgery can affect bone metabolism, leading to decreased bone mineral density, osteoporosis, and increased fracture risk. This issue is particularly prominent in patients undergoing gastric bypass surgery and single-anastomosis gastric bypass surgery, as reduced absorption of calcium and vitamin D exacerbates bone metabolism abnormalities. Studies indicate that long-term postoperative monitoring of bone mineral density and assessment of bone metabolism are essential [16].

##### **Management Measures**

To reduce the risk of osteoporosis, patients should adhere to calcium and vitamin D supplementation after surgery and receive anti-osteoporotic medication such as bisphosphonates when necessary. Regular bone mineral density tests help detect bone health issues early and enable effective intervention measures.

#### **4.7. Summary**

The management of complications after bariatric surgery requires personalization and multidisciplinary collaboration to minimize the occurrence of complications and improve patients' quality of life to the greatest extent. Measures such as reasonable nutritional support, blood glucose monitoring, psychological counseling, and bone health management are crucial to ensuring patients' long-term postoperative health.

### **5. Application and Prospect of Drugs Combined with Surgery**

#### **5.1. Combination of GLP-1 Receptor Agonists and Surgery**

GLP-1 receptor agonists (such as liraglutide and semaglutide) improve blood glucose control by stimulating insulin secretion, inhibiting gastric emptying, and reducing appetite. Studies have shown that the application of GLP-1 receptor agonists on the basis of bariatric surgery can not only further improve blood glucose but also reduce the risk of postoperative weight regain [14]. Studies conducted by some scholars have indicated that combination therapy with GLP-1 receptor agonists significantly improves the remission rate of diabetes and the efficacy of weight management after surgery.

#### **5.2. SGLT-2 Inhibitor Combined with Surgery**

SGLT-2 inhibitors (such as dapagliflozin and empagliflozin) mainly reduce blood glucose by inhibiting renal glucose reabsorption. In surgical patients, SGLT-2 inhibitors can be used as an adjuvant postoperative hypoglycemic method to further reduce the incidence of hyperglycemia. The use of SGLT-2 inhibitors can also re-

duce cardiovascular risks, which has significant advantages for obese patients with diabetes [13].

### 5.3. Application Scenarios of Drugs Combined with Surgery

The application of drugs combined with surgery mainly focuses on the following types of patients: For patients with a long course of diabetes and insufficient insulin reserve, simple surgery may not achieve the desired remission effect. At this time, combined with drugs such as GLP-1 receptor agonists can significantly improve blood glucose control. Some patients may experience weight regain after surgery, which will affect the control of diabetes. As an appetite-suppressant drug, GLP-1 receptor agonists can effectively reduce the risk of weight regain. SGLT-2 inhibitors not only lower blood glucose but also have cardiovascular protective effects, making them particularly suitable for patients with a history of cardiovascular diseases, helping them obtain additional protection on the basis of surgery [41].

### 5.4. The Potential Risks and Challenges of Drug Combined with Surgery

Although drug combined with surgery has shown significant therapeutic potential, there are still some risks and challenges. Drug Tolerability and Side Effects: GLP-1 receptor agonists may cause side effects such as nausea and vomiting, while SGLT-2 inhibitors may increase the risk of urinary tract infections and dehydration. Patients are more likely to experience adverse reactions when nutritional intake is limited after surgery [30].

Long-term Efficacy and Adherence Issues: GLP-1 receptor agonists can effectively lower blood glucose, but their long-term weight loss efficacy is poor, at approximately 3% [42]. Although the research and development of weight loss drugs are diverse, many marketed weight loss drugs have been withdrawn due to poor tolerability, low safety, and other reasons. Drug combination therapy requires patients to take drugs for a long time, which poses a challenge to adherence. How to ensure that patients adhere to long-term drug therapy remains a problem to be solved.

### 5.5. Future Prospects and Research Directions

The prospect of drugs combined with surgery is widely promising, but more research is still needed to optimize the regimen and evaluate its long-term effects.

#### Personalized Treatment Regimen

Future research should focus on developing personalized combined treatment regimens, selecting the most appropriate drugs and dosages based on factors such as patients' metabolic characteristics, duration of diabetes, and surgical type, so as to improve therapeutic efficacy and reduce the risk of side effects. In particular, individual patient factors (e.g., baseline insulin resistance or  $\beta$ -cell function, as indicated by HOMA-IR or C-peptide levels), the duration of diabetes, gut micro-

biota composition, and even genetic markers can be taken into account when tailoring combined therapy. For example, shorter disease duration, higher residual  $\beta$ -cell function, and lower baseline insulin requirements have been associated with higher chances of diabetes remission after surgery. By considering such biomarkers and patient-specific characteristics—in addition to the surgical procedure type—clinicians can choose adjunct medications (and their dosages) that maximize efficacy and minimize side effects in a personalized manner.

### 5.6. Exploration of Novel Drugs

With the advancement of pharmaceutical research, some novel metabolic modulators (such as GLP-1/GIP dual-receptor agonists) have demonstrated enhanced hypoglycemic and weight management effects. Future research may explore the efficacy of the combined application of these new drugs and bariatric surgery, so as to provide more therapeutic options for diabetic patients. Drugs such as GLP-1 receptor agonists and SGLT-2 inhibitors can provide additional metabolic regulatory effects on the basis of bariatric surgery, further improving the remission rate of diabetes. Although challenges remain in terms of tolerability, adherence, and cost, with the formulation of personalized regimens and the development of novel drugs, drug combined with surgery will have broad application prospects in the future.

## 6. Summary

This review clarifies the close association between bariatric surgery and the remission of type 2 diabetes mellitus (T2DM) in obese individuals. It emphasizes that established surgical procedures, namely Roux-en-Y Gastric Bypass (RYGB), Sleeve Gastrectomy (SG), and One-Anastomosis Gastric Bypass (OAGB), not only achieve significant weight loss but also induce a high rate of T2DM remission, among which the efficacy of RYGB and OAGB usually exceeds 70% - 80%.

The metabolic benefits underlying diabetes remission stem from the combined action of multiple mechanisms, including a marked improvement in insulin sensitivity, significant changes in gut hormone secretion—particularly the postprandial increase in glucagon-like peptide-1 (GLP-1) and peptide YY (PYY) levels—enhanced hepatic lipid metabolism, beneficial restructuring of the gut microbiota, and rapid neuroendocrine adaptation. These processes work synergistically to restore glycemic control.

Despite its significant efficacy, the review emphasizes the need to focus on the management of potential postoperative complications, such as nutritional deficiencies, hypoglycemia, gastrointestinal issues, psychological challenges, and deterioration of bone health. Effective long-term management requires an individualized multidisciplinary collaboration model.

Looking ahead, the combined application of bariatric surgery and advanced pharmacotherapy (such as GLP-1 receptor agonists and SGLT-2 inhibitors) constitutes a promising treatment paradigm. This combination strategy can enhance

glycemic control, reduce weight regain, and provide cardiovascular protective effects, which are particularly applicable to complex cases. Although challenges remain in terms of drug tolerability and long-term adherence, the future of type 2 diabetes treatment lies in optimizing these individualized and multimodal treatment regimens to achieve sustained metabolic health.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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