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REVIEW

Bariatric surgery and diabetes: Current challenges and perspectives

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Abstract

Diabetes mellitus (DM) and obesity have become public issues of global concern. Bariatric surgery for the treatment of obesity combined with type 2 DM has been shown to be a safe and effective approach; however, there are limited studies that have systematically addressed the challenges of surgical treatment of obesity combined with DM. In this review, we summarize and answer the most pressing questions in the field of surgical treatment of obesity-associated DM. I believe that our insights will be of great help to clinicians in their daily practice.

Key Words: Bariatric surgery; Diabetes mellitus; Obesity; Metabolic surgery; Challenge

Core Tip: Obesity and diabetes are now public problems that threaten the health of people worldwide. Although bariatric surgery for the treatment of obesity associated with type 2 diabetes mellitus has been shown to be a safe and effective approach, its challenges have not been described systematically and comprehensively. This review is at the forefront of presenting and answering the challenges faced in the field of surgical management of obesity-associated diabetes mellitus today. It provides an up-to-date insight into the daily practice of clinicians.

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INTRODUCTION

Obesity and diabetes mellitus (DM) are now public health problems that threaten the health of people around the world. Obesity is associated with increased morbidity and mortality from various diseases. Historically, DM has long been recognized as a permanent disease that is difficult to cure. In recent years, with the rapid development of metabolic surgery, bariatric surgery has become an effective way to treat obesity and type 2 DM (T2DM)[1]. However, the surgical treatment of obesity and diabetes also faces significant challenges: For example, is bariatric surgery indicated for patients with type 1 DM (T1DM)? Is it suitable for people over 70 or for children under 16? Is it appropriate for people of normal weight or non-diabetics? How is new-onset diabetes managed after bariatric surgery? Here, our review will address these poignant questions and lead to more comprehensive studies in the future. We conducted a comprehensive search of PubMed, MEDLINE, CNKI, Wanfang, Embase, Google Scholar, Scopus, Wiley, Cochrane, and ScienceDirect online databases, as well as the medRxiv and bioRxiv gray literature, using the keywords "bariatric surgery", "diabetes", "obesity", and "metabolic surgery" either individually or in combination, and a final update of the latest cutting-edge researches in bariatric surgery was performed using Reference Citation Analysis (https://www.referencecitation-analysis.com).

Bariatric surgery for the treatment of obesity combined with DM not only results in significant and long-lasting weight loss[2], but also significantly reduces morbidity and mortality from a wide range of obesity-associated diseases, including T2DM[3], cardiovascular disease[4], obstructive sleep apnea[5], non-alcoholic fatty liver disease[6], and osteoarthritis[7]. Bariatric surgery has become an illuminating scientific model that has evolved from the treatment of obesity, to the treatment of T2DM, and further to the treatment of a range of metabolic syndromes centered on obesity and its accompanying metabolic disorders (including endocrine[1], cardiovascular[4], respiratory[5], and reproductive disorders [8]). More surprisingly, bariatric surgery has been reported to improve proteinuria, with a profound effect on chronic kidney disease[9]. The clinical use of laparoscopic bariatric surgery has grown exponentially over the past two decades, and different types of bariatric surgery may have different outcomes. Table 1 lists the major surgical types of bariatric surgery available today, their respective weight loss potential, advantages and disadvantages, and complications.

CHALLENGE ONE, FROM AGE: < 18 OR > 65 YEARS OLD

Childhood obesity is now a truly global health problem[10]. Data suggest that childhood obesity is strongly associated with the development of certain comorbidities, including cardiovascular disease[11,12], endocrine/metabolic disorders [13], respiratory disease[14], and musculoskeletal problems[15]. In addition, obese children often develop psychosocial problems such as mood disorders, anxiety, prejudice, and low self-esteem[16]. A study by Shah *et al*[17] suggests that prepubertal bariatric surgery is safe and effective and may not require age criteria. A review summarizing recent data on long-term outcomes following bariatric surgery in severely obese adolescents suggests that bariatric surgery has a beneficial impact on both weight loss and resolution of comorbidities in severely obese adolescents[18], which may help to remove barriers to the referral of adolescents for bariatric surgery[19]. With the increasing number of cases of metabolic surgery for the treatment of obesity in children and adolescents, the latest guideline, 2019 edition, recommends an age range of 2-18 years for surgery[20]. Even more encouraging is the fact that research has shown that bariatric surgery for severely obese adolescents is cost-effective[21]. Although it is more expensive than not having the surgery, it significantly improves quality of life, and overall costs, including medical care and medication, decrease after surgery. In other words, bariatric surgery increases short- to medium-term healthcare costs but can save money in the long term[22,23]. Of course, some researchers have said that although bariatric surgery in adolescents can result in sustainable weight loss and reverse many of the complications associated with severe obesity, its safety and long-term effectiveness remain unclear, and therefore large, long-term prospective studies are still needed to determine the role of surgical treatment in childhood obesity[24].

Historically, bariatric surgery has been performed in patients < 65 years old because of the balance of risks (surgical safety, survival time, and availability of lifestyle changes) and benefits of surgery in older patients due to reduced cardiorespiratory fitness and frequent comorbidity with other underlying diseases. As quality of life improves and longevity increases, the need for bariatric surgery in older patients > 65 years is increasing, and studies have shown that bariatric surgery is safe and effective in older patients > 65[25,26] and even > 70 years[27-29] and that older patients appear to have better cardiovascular risk improvement[30]. In addition, elderly patients who undergo bariatric surgery also experience improvements in other areas, including physical and mental functioning, work capacity, self-confidence, sexual activity, and health-related quality of life[31]. Therefore, age per se should not prevent older patients from receiving optimal bariatric surgery for obesity and related complications.

Table 1 Types of bariatric surgery, their respective weight loss potential, advantages, disadvantages and complications

Procedure	Target weight loss	Advantages	Disadvantages	Complications
Laparoscopic adjustable gastric banding	20%-25%	No anatomic alteration, removable, adjustable	Erosion, slip, and prolapse	Gastric ptosis, outlet obstruction, erosion of the gastric wall by gastric banding
Sleeve gastrectomy	25%-30%	Easy to perform, no anastomosis, reproducible, few long-term complications	Leaks difficult to manage, 20%-30% risk of GERD	Bleeding of the cutting edge, leakage and stenosis
Roux-en-Y gastric bypass	30%-35%	Effective for GERD, can be used as second stage after sleeve gastrectomy	Internal hernias possible, long-term micronutrient deficiencies	Anastomotic leakage, bleeding, incisional infection, anastomotic stenosis and malnutrition
Biliopancreatic diversion with duodenal switch	35%-45%	Long-lasting weight loss, especially effective in patients with very high BMI	GERD, potential for hernias, technically challenging	Diarrhoea, nutrient deficiency
Single anastomosisduodeno-ileal bypass with sleeve gastrectomy	35%-45%	Single anastomosis with strong metabolic effect and low rate of early complic-ations	Nutritional and micronutrient deficiencies possible, duodenal dissection	GERD, bile reflux
Intragastric balloon	10%-12%	Endoscopic or swallowed, good safety profile	Temporary (6 months) therapy, early removal rate of 10%-19%	Abdominal pain, nausea and vomiting
One-anastomosisgastric bypass	35%-40%	Simpler to perform, strong metabolic effects, no mesenteric defects	Potential for bile reflux, long biliopan-creatic limb	Malnutrition, diarrhea
Transpyloric bulb	14%	Outpatient endoscopic procedures with long implantation times	Gastric mucosal erosion	Gastric ulcer
Aspiration therapy	12%-14%	Endoscopy, treatment is completely reversible	Tube-related problems/complications, 26% early removal	Abdominal pain, gastrostomy site infection
Vagal nerve blocking therapy	8%-9%	No anatomic changes, low complication rate	Explant required for conversion to another procedure	Pain at neuroregulatory site, indigestion, nausea
Gastric electric stimulation	20%-30%	No anatomical changes, minimal surgical trauma, high surgical safety	Difficulty in determining electrode implantation position and electrical stimulation parameters	Perforation, electrode dislodgement, electrode failure
Left gastric artery embolization	3%-14%	No anatomical changes, minimal surgical trauma	Difficulty in selecting embolic materials and target vessels	Ulcer, abdominal pain, and vomiting

GERD: Gastroesophageal reflux disease; BMI: Body mass index.

CHALLENGE TWO, FROM SPECIAL POPULATIONS

T1DM

Bariatric surgery can significantly improve glycaemic control and even alleviate diabetes in people with T2DM, so can it also benefit people with T1DM?

The International Federation for the Surgery of Obesity and Metabolic Disorders stated in 2016 that bariatric surgery not only treats obesity-related diseases but also improves insulin resistance and reduces insulin requirements, so obese T1DM can be used as a therapeutic indication for bariatric surgery[32]. Studies have shown that bariatric surgery leads to significant improvements in weight and cardiometabolic variables and modest improvements in blood glucose with few reported adverse events in cohorts of patients with obesity and T1DM[33]. The study by Vilarrasa *et al*[34] described the long-term outcomes of bariatric surgery in a cohort of patients with T1DM: Bariatric surgery provided some benefits in terms of weight loss, insulin requirements, obesity comorbidities and diabetic complications in patients with T1DM, but the long-term impact on glycaemic control was likely to be small. The study by Landau *et al*[35] demonstrated the same point; in people with obesity and T1DM, weight loss after bariatric surgery was successful without significant improvement in glycaemic control. A meta-analysis involving 9 studies with a total of 78 patients showed that glycated hemoglobin (HbA1c), insulin dose, and body mass index (BMI) improved after surgery, although the improvement in HbA1c did not reach statistical significance (P = 0.40)[36]. It is worth noting that the postoperative risks of diabetic ketoacidosis and severe hypoglycemic episodes should also be considered when performing bariatric surgery in the T1DM population[35].

In summary, bariatric surgery has brought new hope to the treatment of obese T1DM and, apart from its controversial effect on blood glucose, it has played a significant role in reducing BMI, improving obesity-related diseases, improving insulin sensitivity, and alleviating or even reversing diabetic complications. As a result of these positive results, more and more patients with T1DM are willing to undergo bariatric surgery.

Normal weight diabetics

More than 10 years ago, some animal studies have successively confirmed that bariatric surgery has certain effects on non-obese DM[37,38]. Bariatric surgery was performed in 69 patients with T2DM and a BMI of 21-29 kg/m², with a mean follow-up of 21.7 months, resulting in satisfactory glycaemic control in 95.7% of patients[39]. The study of Zhang *et al*[40] showed that Billroth II gastrojejunostomy for the treatment of non-obese patients with T2DM had similar short- and medium-term glycaemic control effects as Roux-en-Y gastric bypass (RYGB) surgery for the treatment of obese patients with T2DM. Malapan *et al*[41] included 29 non-obese (BMI < 27 kg/m²) T2DM patients who underwent laparoscopic RYGB and showed a significant reduction in mean body weight, mean BMI, and mean waist circumference, as well as mean systolic and diastolic blood pressure over a one-year prospective follow-up; and other biochemical variables, including blood glucose, HbA1c, C-peptide, insulin, triglycerides, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, and homeostatic model assessment insulin resistance were significantly improved. More surprisingly, ten patients with T2DM and a BMI < 24.0 kg/m² (mean BMI 23.8 kg/m² ± 1.2 kg/m²) were reported to have undergone duodenojejunal bypass, with resolution of T2DM in one patient and significant reductions in fasting glucose, 2-hour postprandial glucose and HbA1c at all postoperative time points, without significant weight loss[42]. However, the sample sizes of these clinical trials are small, and further large, multicentre, prospective, randomized controlled trials are needed to confirm the role of bariatric surgery in mildly obese or normal-weight patients with T2DM.

Non-diabetics

For obese and diabetic patients, bariatric surgery can provide relief from both conditions. But can bariatric surgery benefit non-diabetic patients? Bariatric surgery has been shown to restore visual cortical plasticity in non-diabetic obese patients [43]. Luo *et al*[44] reported on the effects of bariatric surgery in diabetic and non-diabetic patients who were followed for five years, and final subgroup analyses showed a linear increase in the percentage of non-diabetic patients from the worst clinical outcome to successful weight loss, and even more unexpectedly, non-diabetics lost a higher percentage of excess weight than diabetics over all five years. In addition, the Michigan Bariatric Surgery Collaborative reported that patients without DM were more likely to achieve a post-operative BMI of less than 30 kg/m² within one year[45]. It is well known that the obese population is at an increased risk of microvascular complications, and the risk is even greater in patients with T2DM. Bashir *et al*[46] evaluated the effects of bariatric surgery on microvascular complications in diabetic and non-diabetic patients, and they concluded that obese patients with or without DM benefit from the improvement in microvascular complications with bariatric surgery.

Immunodeficient patients

Although the risks of obesity in people with human immunodeficiency virus (HIV) are unclear, the incidence of DM and cardiovascular disease is increased in HIV-infected people, whether they are obese or not[47]. Many of those treating obese HIV patients are concerned that weight loss is unsafe for these patients. Flancbaum *et al*[48] reported on the first cohort of HIV-infected patients to undergo bariatric surgery, including six morbidly obese patients with obesity-related comorbidities who had asymptomatic, stable HIV infection. In their study, none of the patients showed a clinically significant deterioration in CD4 count or immune status, or progression of acquired immunodeficiency syndrome, and all of the patients' comorbidities improved or resolved. Fazylov *et al*[49] reported two cases of morbidly obese, asymptomatic HIV-infected patients who underwent laparoscopic RYGB, both patients successfully lost weight and maintained their weight loss at the last follow-up. Yang *et al*[50] evaluated the efficacy and safety of bariatric surgery in three HIV-infected patients. In their three cases, bariatric surgery resulted in stable CD4 counts and undetectable viral loads. A growing body of data suggests that bariatric surgery can be safely performed in HIV-infected patients without progression to acquired immunodeficiency syndrome.

Cancer patients

Obesity is a major risk factor for cancer morbidity and mortality[51,52]. Whether the anatomical, physiological, and microbiome changes induced by bariatric surgery in the gastrointestinal tract result in an increased risk of cancer in this area remains an open question. Numerous studies have shown that bariatric surgery is beneficial in reducing morbidity and mortality from all cancers[53-55], particularly breast[56-58] and endometrial cancers[59,60]. In addition to the effects on cancer development, some studies have suggested that bariatric surgery improves cancer prognosis in severely obese patients[61,62]. However, esophagogastric cancers have been reported to be induced after bariatric surgery[63], but epidemiological studies have not shown a higher incidence of these cancers in patients undergoing bariatric surgery compared with the general population[64]. Equally distressing is the conflicting evidence regarding the risk of colorectal cancer after bariatric surgery, with several studies showing a reduced risk of colorectal cancer in patients who have undergone bariatric surgery[65,66], while Aravani *et al*[67] showed that bariatric surgery was not associated with an increased risk of colorectal cancer, and others even suggest that patients who have undergone bariatric surgery are at an increased risk of colorectal cancer[68,69]. There are still some unanswered questions about the possible effects of bariatric surgery on cancer risk in patients with obesity, and there is a need for prospective, randomized controlled, and longer studies in populations undergoing bariatric surgery.

In addition to the special populations mentioned above, it is also important to consider what to do when pregnancy and bariatric surgery conflict, with the best evidence to date coming from expert opinion[70,71] that either pregnancy should be postponed during the bariatric surgery phase or bariatric surgery should be postponed during pregnancy.

More high-quality randomized controlled trials are needed to explore the relationship between bariatric surgery and pregnancy in more detail.

CHALLENGE THREE, FROM RELAPSE, INCLUDES WEIGHT REGAIN AND NEW-ONSET DM

Postoperative recurrence rate

Although a large proportion of patients with T2DM who have undergone bariatric surgery initially experience remission, some patients later relapse. It is estimated that around half of patients regain 5% of their body weight within two years of bariatric surgery[72]. An observational study of 300 patients undergoing RYGB showed that 37% of patients regained ≥ 25% of their maximum weight loss after a mean follow-up of 7 years[73]. The incidence of weight regain ranges from 9% to 91%, depending on the definition used[74]. Similarly, patients are at risk of developing a new onset DM after bariatric surgery[75]. In an analysis of data from a non-randomized, prospective, controlled trial, Carlsson *et al*[76] found that the incidence of new-onset T2DM after bariatric surgery was 6.8 cases per 1000 patient-years during a 15-year follow-up period. In a single-center retrospective study, Nor Hanipah *et al*[77] investigated the incidence of new-onset DM over 17 years after bariatric surgery, and they found that the incidence of new-onset DM was 0.4%; weight regain was common among patients with new-onset DM (> 50%).

Prediction of postoperative recurrence

Many studies have tried to explore the best biological and clinical predictors of T2DM recurrence after surgery[78-81]. Unfortunately, it is still difficult to predict which patients will experience postoperative weight regain or new-onset DM. A prospective study of 175 patients with RYGB T2DM and a 5-year follow-up found that several baseline factors (duration of DM, number of DM medications, HbA1c) and status at 1 year (fasting blood glucose, number of DM medications, remission status, percentage total weight loss) predicted the rate of DM remission and recurrence at 5 years [82]. A growing number of studies have shown that shorter duration of T2DM, better preoperative glycaemic control, lower baseline HbA1c and waist circumference, and greater postoperative weight loss are associated with higher rates of T2DM remission and lower risk of recurrence[83-85]. In addition, it has been suggested that gender is also an important factor in T2DM recurrence, with men having a lower risk of T2DM recurrence[86,87].

Management of postoperative recurrence

Despite the risk of weight regain or a new onset of DM, surgery still has the potential to have beneficial metabolic effects in the long term. Therefore, a higher risk of recurrence should not be a reason for exclusion from surgery. Careful preoperative patient selection and preoperative optimization appear to be important. Patients with postoperative recurrence, either weight regain or diabetic recurrence, are usually re-operated. Previous studies have shown that early surgery reduces the risk of recurrence[85,86]. Therefore, patients with obesity and T2DM should prioritize metabolic surgery at an early stage. Of course, it seems equally important to optimize lifestyle changes in patients after bariatric surgery[88]. In addition, the use of anti-obesity medications may provide more options for patients and healthcare providers[89].

CHALLENGE FOUR, FROM THE OPTIMAL TIMING OF SURGERY

Exactly when surgery is most effective in diabetes remains controversial. Recent studies have confirmed that the chances of achieving complete remission are negatively correlated with the duration of DM[86]. The available evidence strongly supports that patients benefit more from bariatric surgery when it is performed in the pre-diabetic or early stages of DM, or even during periods of abnormal glucose tolerance. Reserving surgery for more advanced and complex stages of the disease appears to be less beneficial for the clinical course of DM[90]. Based on these findings, we should offer bariatric surgery to patients with T2DM at an early stage of their disease. This idea seems revolutionary in the treatment of obesity, and it is exactly the same idea that underlies early cancer screening - offering bariatric surgery as a last resort, after years of obesity and T2DM have wreaked havoc on the body, is like waiting until the cancer has metastasized throughout the body.

CHALLENGE FIVE: WHO BENEFITS MOST FROM BARIATRIC SURGERY?

Obesity has been shown to be a heterogeneous disease. Despite the effectiveness of bariatric surgery, there are large individual differences in surgical outcomes. If we can predict who will benefit most, we may be able to target bariatric surgery more accurately. Previous studies have identified several predisposing factors for benefit from bariatric surgery, including patient factors (*e.g.*, age, BMI, gender, history and duration of DM, family history, glycemic control, and comorbidities), surgical factors (*e.g.*, surgeon experience, type of surgery), and social factors (*e.g.*, socioeconomics, medical conditions, and social discrimination)[91,92]. It has been shown that over 10 years, the number of treatments required to prevent one additional death was 8.4 in diabetic patients compared with 29.8 in non-diabetic patients[93], so diabetic patients benefit more from bariatric surgery than non-diabetic patients in terms of both the relative and absolute risk of reducing morbidity and mortality.

Due to the high degree of patient heterogeneity, it is difficult to tailor surgical techniques to all patients, the decision to operate is empirical and there is no robust evidence-based approach, and predicting which patients will benefit most from bariatric surgery remains a challenge at present. There is evidence that there is less variation in outcomes when identical twins or first-degree relatives undergo bariatric surgery compared with unrelated individuals, but the variation in outcomes increases when bariatric surgery is performed on couples or people living together in the same environment [94-97]. This suggests that there may be biological factors that predict response to bariatric surgery. Studies have shown that a variety of omics technologies such as genomics, transcriptomics, proteomics, metabolomics, and lipidomics can provide a holistic molecular view of systems biology[98]. Unfortunately, currently available biomarkers cannot be used in clinical practice[99]. Prediction of the efficacy of bariatric surgery seems to improve when clinical variables are combined with genetic testing[100]. More research is needed to accurately predict who will benefit most from bariatric surgery.

CHALLENGE SIX, FROM REACTIVE HYPOGLYCEMIA

Reactive hypoglycemia, or post-bariatric surgery hypoglycemia (PBSH), was first described by Service *et al*[101] and most commonly occurs 1-3 years after RYGB[102], but has also been reported after sleeve gastrectomy[103]. Reactive hypoglycemia is a notoriously difficult-to-manage metabolic complication of bariatric surgery, the presentation of which can be non-specific and unrecognizable, and for which there are no clear diagnostic criteria or standardized tests, making it a challenging condition for both surgeons and endocrinologists.

Clinical features

PBSH typically presents with palpitations, sweating, weakness, and dizziness one to three hours after a meal, and some patients experience severe and potentially life-threatening symptoms of hypoglycemia, including seizures, coma, or loss of consciousness. Repeated hypoglycemic events lead to reduced quality of life for patients[104] and are associated with increased all-cause mortality[105], risk of dementia[106], and risk of motor vehicle accidents[107], and severe hypoglycemia increases morbidity and mortality in patients with T2DM[108].

Incidence

The true incidence of PBSH remains uncertain, with previous reports ranging from 0.1% to 50.0%[109-111]. However, as there are cases where hypoglycemia goes undiagnosed due to undetected hypoglycemia[103], it is clear that the true incidence is likely to be underestimated. The incidence of hypoglycemia based on continuous glucose monitoring data has been reported to be as high as 75% in postoperative RYGB patients[112].

Mechanisms

The pathogenesis of PBSH is controversial and involves rather complex mechanisms that can be divided into insulin-dependent and non-insulin-dependent mechanisms. Insulin-dependent mechanisms include excessive insulin secretion by pancreatic beta cells, decreased insulin clearance, and increased insulin sensitivity. Non-insulin-dependent mechanisms include functional and structural adaptations in the gut after bariatric surgery that affect gastric emptying rate, glucose absorption, glucagon-like peptide-1 (GLP-1) levels, bile acid levels, gut microbiota, and counter-regulatory mechanisms to prevent hypoglycemia[113-118].

Management

The management of PBSH is equally challenging and requires a multidisciplinary approach that includes dietary, pharmacological, and surgical interventions. The first line of treatment for PBSH is dietary modification, particularly restriction of carbohydrate intake and avoidance of simple carbohydrates[119,120]. If dietary changes do not adequately control the patient's symptoms, pharmacological treatment with GLP-1 agonists, acarbose, growth inhibitor analogues, and calcium channel blockers may be considered[121-123]. Avexitide and glucagon pumps are two newer therapeutic options that have recently been tested[124,125]. Recent studies have shown that the acute effects of exercise training on glycaemic homeostasis after bariatric surgery can be used as a non-pharmacological adjunctive therapy[126]. Surgery is the last option when all other treatments have failed [127,128].

Predictors

In a prospective controlled Swedish study of patients treated with bariatric surgery for up to 31 years, male gender, older age, and higher HbA1c levels were associated with hypoglycemia-related events[129]. Previous studies have found that preoperative HbA1c, lower BMI, and greater postoperative weight loss are predictors of PBSH[109,130]. A study by Nielsen *et al*[131] showed that younger age and lower postoperative BMI were strong predictors of PBSH, while a study by Belligoli *et al*[132] demonstrated that the incidence of hypoglycemia was higher in younger patients with lower fasting blood glucose levels and higher triglyceride levels before laparoscopic sleeve gastrectomy. It has also been shown that the longer the duration of surgery, the higher the risk of hypoglycemia[109,133].

Much remains to be learned about the causes, diagnosis, and treatment of PBSH, and it will be necessary in the future to reach a consensus on the definition and diagnostic criteria for PBSH and to adopt a more scientifically intelligent diagnostic paradigm for the long-term monitoring of bariatric surgery patients in order to detect and reduce the risk of PBSH promptly. In conclusion, despite the risk of serious adverse events from reactive hypoglycemia, it is not sufficient to be a contraindication to bariatric surgery.

Future prospects

As the prevalence of obesity continues to rise, medical technology improves, and health awareness increases, more and more people with DM will benefit from bariatric surgery. With further basic and clinical research, we believe that the challenges we face today will become clearer in the future. Looking ahead, if one day we discover the mechanism for treating diabetes surgically, looking back, bariatric surgery may be just one step in the treatment of diabetes; we even look forward to the day when a genetic means of curing diabetes in the truest sense of the word will be found, by increasing or eliminating a particular segment of a gene, or by increasing or suppressing the expression of a particular factor.

Limitations

This review also has some limitations. Firstly, most of the studies had a short follow-up period, and the advantages and disadvantages of bariatric surgery for specific populations require longer follow-ups to obtain more stable and reliable results. Secondly, we did not adequately discuss the effects of bariatric surgery on pregnancy and gender.

CONCLUSION

This review summarizes the types of procedures and their advantages and disadvantages for the surgical treatment of DM, highlights the serious challenges faced today, stands at the forefront of perspectives, systematically answers these poignant questions, and boldly envisions the future, providing invaluable insights into the field of surgical treatment of DM.

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FOOTNOTES

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