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Effect of Roux-en-Y gastric bypass on patients with type 2 diabetes mellitus and body mass index of 27.5–35 kg/m^2–a single center retrospective cohort study

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Abstract

Introduction While Roux-en-Y gastric bypass (RYGB) has been extensively studied in patients with type 2 diabetes mellitus (T2DM) and preserved islet function, the significance of insulin resistance in guiding RYGB treatment remains unclear. This study aimed to evaluate the efficacy of RYGB in T2DM patients with a low body mass index (BMI, 27.5–35 kg/m^2), insulin resistance, and impaired β-cell function.

Methods A retrospective cohort of 34 T2DM patients with low BMI who underwent RYGB at our institution was analyzed. Insulin resistance was assessed using hyperinsulinemic euglycemic clamp. The indicators related to glucose and lipid metabolism were also assessed and collected at baseline and 12 months postoperatively.

Results Significant reductions in BMI and HbA1c were observed within 12 months post-surgery ($P < 0.05$). Fasting plasma glucose decreased from 9.40 ± 3.12 mmol/L to 5.87 ± 2.67 mmol/L ($P < 0.05$). Complete remission rates were 31.25% for T2DM, 100% for hypertriglyceridemia, and 70% for hypertension. Multivariable logistic analysis identified shorter diabetes duration (odds ratio [OR] 0.89, 95% confidence interval [CI] 0.83–0.95, $P = 0.025$), higher BMI (OR 1.14, 95% CI 1.06–1.34, $P = 0.033$), and lower peripheral glucose disposal rate (OR 0.95, 95% CI 0.93–0.97, $P = 0.043$) as independent predictors of diabetes remission.

Conclusions Patients with T2DM and low BMI who have insulin resistance may still benefit from RYGB, even if they exhibit impaired β cell function. Shorter duration of diabetes, higher BMI and lower peripheral glucose disposal rate were independent predictors of diabetes remission after RYGB.

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Keywords Roux-en-Y gastric bypass, Insulin resistance, Impaired β-cell function, Hyperinsulinemic-euglycemic clamp, T2DM

Introduction

With the development of the economy and the improvement of living standards, obesity, and its related complications became common in China. In particular, the number of individuals with obesity and type 2 diabetes mellitus (T2DM) has increased rapidly [1]. In total 10% of the population has T2DM, accounting for 92.4 million adults in China [2]. The epidemic of T2DM is linked etiologically with obesity and results in an enormous economic burden and decreased quality of life, making it a serious public health problem in China. In 1995, Pories et al. reported in their landmark article that metabolic bariatric surgery (MBS) was the most effective therapy for T2DM in obese patients after long-term follow-up [3]. Increasing evidence has shown the remarkable remission of T2DM after MBS. As a result, over 200,000 bariatric surgeries are performed annually in the United States, and most surgeries are performed on patients with T2DM.

According to established guidelines, MBS is recommended for non-Asian individuals with a BMI of 35 kg/m^2, irrespective of the presence or severity of comorbidities. Additionally, MBS should be considered for patients with metabolic diseases whose BMI falls within the range of 30–34.9 kg/m^2 [4]. However, central fat deposition and visceral adiposity are the characteristics of Chinese individuals, and obesity-related T2DM can be developed at a lower BMI [5]. Because of the epidemiological characteristics of Chinese patients with T2DM, we cannot simply replicate the MBS prerequisites from the West. Considering that the BMI of patients with T2DM in China is often less than 35 kg/m^2, β cell function may play a key role in T2DM remission after MBS. According to the guidelines set by the Chinese Society for Metabolic and Bariatric Surgery (CSMBS) in 2014, a fasting C-peptide level greater than half of the lower limit of the normal value was defined as a better β-cell function. In addition, the latest 2019 guidelines did not clearly specify the specific value of islet function, but only mentioned that it had certain islet function, which further weakened the importance of islet function in the indications of the Roux-en-Y gastric bypass (RYGB).

T2DM is a disease characterized by a reduction in insulin secretion from β cells and the development of insulin resistance. A normal weight with lower BMI standards in patients with T2DM is characterized by increased central obesity in China, also known as an increasing risk for insulin resistance [5–6]. Furthermore, insulin resistance may remain after β cell function begins to decline in patients with T2DM. Therefore, insulin resistance occurs in individuals with lower BMI, and impaired β-cell function is common at the early stages of patients with T2DM in China. Most clinical studies of RYGB have included patients with T2DM with better islet function regardless of insulin resistance. The role of insulin resistance is important in terms of MBS. In our study, we aimed to determine the effect of RYGB in T2DM and low BMI with insulin resistance and β cell failure.

Materials and methods

We conducted a retrospective study of 34 patients who underwent RYGB at the Department of Bariatric and Metabolic Surgery in the Third Hospital of Central South University. All patients met the inclusion criteria of this study. All surgeries were performed by using standard laparoscopic procedures. All patients were subjected to an oral glucose tolerance test (OGTT) as an essential component of their preoperative assessment. The OGTT, involving a 75-gram glucose load, provides a reliable means of assessing islet function, with venous blood samples obtained at fasting (0 min), 60 min, and 120 min post-administration. This study has been approved by the institutional review board of the third xiangya hospital. This study was conducted following the Helsinki Declaration, and informed consent was obtained from all patients.

All patients received structured nutritional and lifestyle counseling from professional nutritionists. This included individualized dietary guidance, recommendations for physical activity, and continuous health education to facilitate long-term adherence to new dietary habits. Follow-up was conducted regularly through phone calls or social media to reinforce these recommendations and address patient concerns. Regarding medication management, adjustments were made based on clinical assessments and laboratory results.

Inclusion and exclusion criteria

Patients were eligible for RYGB if they met the following criteria: BMI of 27.5–35 kg/m^2 with poorly controlled T2DM or metabolic syndrome, age between 16 and 65 years, and T2DM duration of ≤15 years. All subjects fulfilled the inclusion criteria, including a diagnosis of T2DM by the American Diabetes Association diagnosis standard. All patients were required to meet al.l of the following conditions: fasting C-peptide level is less than 2 ng/ml or OGTT, a ratio of peak to fasting < 2 ng/mL; (impaired β-cell function). Peripheral glucose disposal rate was calculated by the hyperinsulinemic-euglycemic clamp, and a value less than 4.93 mg/kg/min was defined as insulin resistance according to the reference used in China [7]. Subjects who fulfilled any of the following criteria were excluded; type 1 diabetes, gestational diabetes, other rare type of diabetes mellitus, uncontrollable mental disorder, alcohol addiction or drug abuse, and patients who underwent other open gastrointestinal surgery.

Surgical procedure of RYGB

The RYGB procedure primarily involves the following key steps: creation of a 30 mL gastric pouch below the cardia using a linear stapler, followed by an anastomosis between the alimentary limb and the gastric pouch with a stoma diameter of 1.5 cm by linear stapler. The biliopancreatic limb was measured at 100 cm, and the alimentary limb was similarly constructed to a length of 100 cm. Additionally, meticulous closure of the mesenteric defect and Petersen's space was performed to prevent potential complications. All procedures were performed by a single experienced surgeon.

Clinical data and follow-up

All participants completed the preoperative evaluation, 3 months and 12 months follow-up. Hyperinsulinemic-euglycemic clamp performed at baseline was required for inclusion. Variables collected at baseline, 3 months and 12 months after surgery included BMI, blood pressure, high-density lipoprotein cholesterol (HDL), low-density lipoprotein cholesterol (LDL), total cholesterol (TC), triglycerides (TG), glycosylated hemoglobin, systolic blood pressure (SBP), diastolic blood pressure (DBP) fasting plasma glucose (FPG), fasting C-peptide (FCP), and fasting insulin (FINS).

The criterion for remission of hypertension is the discontinuation of medication for 3 months (< 140/90 mmHg), while the remission of dyslipidemia is similarly defined by ceasing medication for the same duration (TC < 5.18 mmol/l, TG < 1.76 mmol/l). Remission of T2DM is mainly divided into partial remission (defined by HbA1c < 6.5%, fasting blood glucose levels < 6.9 mmol/l and no use of anti-diabetic medications, for a minimum of 12 months) and complete remission (defined by HbA1c < 6.0%, fasting glucose < 5.6 mmol/l, and no use of antidiabetic medication for least 12 months) according to ADA standards.

The procedures for the hyperinsulinemic-euglycemic clamp were as follows: catheters were placed in the antecubital vein for infusion and in a dorsal vein in the hand for blood sampling, with the hand placed in a heated box for arterialization. Insulin (Humulin R, Eli Lilly, USA) (40 mU/kg/min) infusion was initiated and continued for 150 min using a precision infusion pump. Blood samples were drawn through an intravenous catheter from a heated vein, and glucose concentrations were measured at 5-min intervals. Euglycemia (5.0 ± 0.1 mmol/l) was reached and maintained via variable infusion of 20% dextrose. The time to reach euglycemia was calculated from the beginning of the experiment to the moment euglycemia was reached in this study. Peripheral glucose disposal rate was calculated as the glucose infusion rate at steady-state (the final 30 min) [6]. All medications impacting blood glucose were discontinued for a minimum of three days prior to conducting the OGTT and the hyperinsulinemic-euglycemic clamp procedure.

Statistical analysis

Based on our previous study [6], we estimated that the difference in peripheral glucose disposal rate between preoperative and 12-month postoperative measurements would be 2.5, with a standard deviation of approximately 2.6. With a statistical power of 90% and an alpha level of 0.05, accounting for a dropout rate of 20%, the final calculated sample size was determined to be 30.

All data are presented as the means ± standard deviations (SDs). Statistical significance was indicated by a two-tailed P value < 0.05. Preoperative and postoperative data were analyzed using a paired t-test. Pearson's bivariate correlations were applied for all continuous variables. Additionally, a multivariate logistic regression analysis was conducted to identify independent factors associated with T2DM remission. Variables with a P value < 0.10 in univariate analysis were included in the multivariate model. The results are presented as odds ratios (OR) with 95% confidence intervals (CI). Analyses were performed using SPSS version 22.0 for Windows (SPSS IBM, Chicago, IL, USA).

Results

Preoperative patient demographics

We included 34 T2DM patients (15 man and 19 women) with low body mass index (BMI, 27.5–35 kg/m^2). All patients were followed up for more than 12 months. Preoperatively, the patients were 42.15 ± 7.41 years of age with a BMI of 30.90 ± 1.75 kg/m^2, and 15 of the patients were male (44.12%). The average duration of diabetes was 5.94 ± 1.76 years, the number of patients with a history of insulin use and those who smoke was 11 (32.3%) and 12 (35.3%) respectively (Table 1). The mean SBP was 135.32 ± 12.01 mmHg, ranging from 123 to 156 mmHg; the mean DBP was 86.61 ± 11.41 mmHg, ranging from 75 to 99 mmHg; the mean HDL was 1.01 ± 0.29 mmol/l, ranging from 0.72 to 1.3 mmol/l; the mean LDL was 2.37 ± 1.03 mmol/l, ranging from 1.34 to 3.40 mmol/l; the mean TC was 4.89 ± 1.10 mmol/l, ranging from 3.79 to 5.99 mmol/l; the mean TG was 4.04 ± 1.41 mmol/l, ranging from 2.63 to 2.63 mmol/l; the mean HbA1c was (8.65 ± 1.89)%, ranging from 6.76 to 10.54%; the mean FPG was 9.81 ± 4.02 mmol/l, ranging from 5.79 to 13.83 mmol/l; the mean FINS was 29.27 ± 14.57μU/ml, ranging

Table 1 Patients characteristic at baseline

	All (N = 34)
Age(year)	42.15 ± 7.41
Male (female)	15(19)
BMI	30.90 ± 1.75
Fasting glucose (mmol/l)	9.81 ± 4.02
HbA1c (%)	8.65 ± 1.89
Duration of diabetes (year)	5.94 ± 1.76
Smoking (%)	12 (35.3%)
History of insulin use	11 (32.3%)

BMI, body mass index;

from 14.70 to 43.84 μU/ml; the mean FCP was 1.78 ± 1.26 ng/ml, ranging from 1.52 to 4.04 ng/ml; the mean peripheral glucose disposal rate was 3.23 ± 0.98 mg/kg/min, ranging from 2.25 to 4.21 mg/kg/min.

Postoperative outcomes

All patients underwent successful MBS with no serious postoperative complications. Specifically, there were no occurrences of bleeding, gastric leakage, or severe malnutrition. The postoperative recovery for all patients was uneventful, with no adverse events requiring reoperation or extended hospitalization. The clinical and laboratory characteristics of the 34 subjects are summarized in Table 2. The indicators such as BMI, SBP, DBP, TG, HbA1c, FPG and Peripheral glucose disposal rate were reduced significantly in the 3 months and 12 months after surgery; their differences were statistically significant ($P < 0.05$). SBP and DBP decreased significantly at 3months and 12months ($P < 0.05$). The level of LDL, FCP was reduced significantly at 3 months ($P < 0.05$). The HDL level was significantly increased at 3 months ($P < 0.05$) and was increased at 12months without statistical significance after surgery. The level of TC was decreased from 4.89 ± 1.10 mmol/l to 4.59 ± 0.84 mmol/l significantly at 12 months ($P < 0.01$) and was decreased at 12months without statistical significance. The level of FINS was decreased from 29.27 ± 14.57 μU/ml to 27.27 ± 18.57 μU/ml significantly at 12months.Compared with the preoperative data, fasting plasma glucose decreased from 9.81 ± 4.02 mmol/l to 6.21 ± 2.14 mmol/l in the 3 months ($P < 0.05$) and to 5.87 ± 1.81 mmol/l in the 12 months ($P < 0.001$).

Remission of comorbidities

At the 12-month follow-up, all 34 patients with preoperative hypertriglyceridemia showed decreased TGs, and the hypertriglyceridemia remission rate was 100%. TC also decreased in patients with preoperative hypercholesterolemia, and the hypercholesterolemia remission rate was 100%. The hypertension of the patients improved significantly after surgery, with an average SBP of 122.18 ± 12.26 mmHg and DBP of 81.30 ± 4.18 mmHg, and a hypertension remission rate was 100%. The level of HbA1c in 18 patient was between 6.5 and 8%, the levels of HbA1c 3 patients were between 6.0 and 6.5%; and 13 patients were less than 6.0%. The partial remission and complete remission rates of T2DM were 8.9%, and 38.2%, respectively.

Parameters related to diabetes remission

In Table 3, the differences in relevant clinical indicators between the diabetes remission group and the non-remission group at 12 months postoperatively are presented. It was found that age, duration of diabetes BMI, FINS, and peripheral glucose disposal rate showed significant differences between the two groups. Fasting C-peptide levels were significantly higher in the remission group compared to the no remission group (3.43 ± 1.41 vs. 2.18 ± 0.72, $P = 0.002$). In multivariable

Table 2 Change in clinical characteristic at baseline and post-surgery

	Baseline	3 months	12 months
BMI (kg/m^2)	30.90 ± 1.75	25.40 ± 2.17**	24.40 ± 3.26***
SBP (mmHg)	135.32 ± 12.01	128.51 ± 10.63*	122.18 ± 12.26*
DBP (mmHg)	86.61 ± 11.41	83.41 ± 6.98*	81.30 ± 4.18*
HDL (mmol/l)	1.01 ± 0.29	1.36 ± 0.42*	1.22 ± 0.47
LDL (mmol/l)	2.37 ± 1.03	2.16 ± 0.63*	2.17 ± 0.81
TC (mmol/l)	4.89 ± 1.10	4.84 ± 0.77	4.59 ± 0.84**
TG (mmol/l)	4.04 ± 1.41	1.11 ± 0.68*	0.93 ± 0.46**
HbA1c (%)	8.65 ± 1.89	6.18 ± 1.32**	6.17 ± 1.57**
FPG (mmol/l)	9.81 ± 4.02	6.21 ± 2.14*	5.87 ± 1.81***
FINS(μU/ml)	29.27 ± 14.57	28.26 ± 17.34	27.27 ± 18.57*
FCP (ng/ml)	1.78 ± 1.26	2.50 ± 0.25*	2.53 ± 0.44
Peripheral glucose disposal rate (mg/kg/min)	3.23 ± 0.98	6.81 ± 1.81**	7.92 ± 2.01***
Completed remission	-	-	13 (38.2%)
Partial remission	-	-	3 (8.9%)

BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; LDL, low density lipoprotein cholesterol; HDL, high-density lipoprotein cholesterol; TC, total cholesterol; TG, triglycerides; FPG, fasting plasma glucose; FCP, fasting C-peptide; FINS, fasting insulin. *$P < 0.05$, ** $P < 0.01$, *** $P < 0.001$ vs. baseline

Table 3 Preoperative clinical characteristics in patients with and without T2DM remission (Including complete and partial remission) at 12 months after surgery

Variable	No Remission (*N* = 18)	Remission (*N* = 16)	*P*
Age(year)	44.5 ± 7.22	39.50 ± 6.89	0.047
Male (female)	8(10)	7(9)	0.968
Duration of diabetes (year)	6.83 ± 1.58	4.94 ± 1.39	0.001
Smoking (%)	10(55.6%)	8(50%)	0.746
BMI (kg/m^2)	29.95 ± 1.07	31.97 ± 1.76	0.000
HDL (mmol/l)	1.05 ± 0.29	0.96 ± 0.29	0.404
LDL (mmol/l)	2.22 ± 0.85	2.53 ± 1.21	0.393
TC (mmol/l)	4.70 ± 1.14	5.11 ± 1.03	0.279
TG (mmol/l)	3.21 ± 2.79	4.99 ± 3.63	0.244
HbA1c (%)	8.35 ± 1.75	8.98 ± 2.04	0.338
FPG (mmol/l)	8.95 ± 3.39	10.77 ± 4.54	0.192
FINS(μU/ml)	23.40 ± 16.01	35.88 ± 9.41	0.010
FCP (ng/ml)	2.18 ± 0.72	3.43 ± 1.41	0.002
Peripheral glucose disposal rate (mg/kg/min)	3.65 ± 1.02	2.76 ± 0.71	0.006

BMI, body mass index; LDL, low density lipoprotein cholesterol; HDL, high-density lipoprotein cholesterol; TC, total cholesterol; TG, triglycerides; FPG, fasting plasma glucose; FCP, fasting C-peptide; FINS, fasting insulin

Table 4 Multivariable logistic regression models for diabetes remission 12 months after RYGB

Variable	Adjust OR (95%CI)	*P*
Age(year)	0.96(0.97–1.02)	0.051
Duration of diabetes (year)	0.89(0.83–0.95)	0.025
BMI (kg/m^2)	1.14(1.06–1.34)	0.033
FINS(μU/ml)	1.09(0.75–1.12)	0.238
FCP (ng/ml)	1.03(0.96–1.13)	0.485
Peripheral glucose disposal rate (mg/kg/min)	0.95(0.93–0.97)	0.043

BMI, body mass index; FCP, fasting C-peptide; FINS, fasting insulin

logistic analysis, patients with diabetes remission were higher BMI ($P = 0.033$), had a shorter duration of diabetes ($P = 0.025$), and lower peripheral glucose disposal rate ($P = 0.043$) (Table 4).

Discussion

This study investigated the effects of MBS on low BMI patients with T2DM, insulin resistance, and impaired β-cell function. Our findings clearly demonstrate the efficacy of MBS in this population. Notably, at 12 months postoperatively, insulin resistance and fasting C-peptide levels significantly increased. Furthermore, compared to the non-remission group, patients who achieved diabetes remission had higher preoperative fasting C-peptide and insulin levels, as well as greater insulin resistance. Multivariable regression analysis further confirmed that fasting C-peptide levels and insulin resistance were significantly associated with diabetes remission. These results underscore the critical role of insulin resistance and C-peptide levels in diabetes remission, suggesting that both factors should be carefully considered alongside β-cell function when evaluating candidates for MBS in China, particularly in the low BMI population.

In the West, the BMI of patients with T2DM who undergo MBS is always ≥ 35 kg/m^2 [8–9], the surgeon does not need to pay attention to insulin resistance or β-cell function. In contrast, the proportion of patients with T2DM and a BMI ≥ 35 kg/m^2 was only 0.6% in Asians, but the percentage of patients with T2DM and a BMI ≥ 27.5 kg/m^2 was 15.3% [10–11]. Since central fat deposition and visceral adiposity are characteristics of Chinese, patients and since these characteristics are associated with an increased risk for insulin resistance, T2DM and associated complications [12], insulin resistance occurs in individuals with lower BMIs, and impaired β-cell function at early stages is common for patients with T2DM in China. The patients in our study with a BMI less than 35 kg/m^2 showed notable insulin resistance as measured by a hyperinsulinemic-euglycemic clamp, considered to be the gold standard for evaluating sensitivity to insulin in peripheral tissue [13]. As the procedure of the hyperinsulinemic-euglycemic clamp is complicated and requires several hours to perform, insulin levels are usually used to calculate the insulin resistance of patients, but this method is less accurate.

Many studies have focused on the effect of MBS on patients with T2DM and low BMI in China, and found that T2DM improved markedly after surgery. Additionally, all patients in these studies were shown to have better β-cell function defined by the C-peptide level [14–15].

The ABCD scoring system (designed by Lee Weijie in Taiwan to predict the outcome of T2DM after MBS) including: age (0–1 point), BMI (0–3 point), C-peptide (0–3 point) and duration of diabetes (0–3 point) is widely used in China, with a higher score indicating a better effect after surgery [16]. Similar to the scoring system designed by Lee Weijie, in the guideline set by the Chinese Society for Metabolic and Bariatric Surgery (CSMBS) in 2014, age, BMI, C-peptide level and duration of diabetes were the inclusion criteria for the patients with T2DM to undergo MBS. The indexes including C-peptide and duration of diabetes were evaluated to determine β-cell function. Our study enrolleded patients with T2DM and impaired β-cell function according to the C-peptide level, and examined the effect after the operation, only 34 patients were included in our research.

Many studies have shown that patients with type 2 diabetes and a BMI < 35 kg/m^2 can benefit from MBS [17, 18]. Consistent with our research, it has been found that in Chinese patients with type 2 diabetes, preoperative BMI, duration of diabetes, and insulin resistance are independent factors associated with the resolution of type 2 diabetes following MBS [19]. Additionally, several articles showed that preoperative β-cell function or C-peptide levels (greater than 3.75 ng/ml) can be used to predict T2DM remission after MBS [20, 21]. In our investigation, 12 months post-operation BMI, TGs, blood pressure and HbA1c were markedly reduced. This finding means that glucose and lipid metabolisms were improved after surgery, and patients with T2DM can benefit from MBS. Furthermore, the comorbidities of the patients, such as hypertriglyceridemia, hypercholesterolemia, hypertension and T2DM were all ameliorated postoperatively. The mechanism might be related to the loss of weight, reduced food intake, changes in gastrointestinal hormones [22, 23]. However, in our opinion, the key point of improvement after surgery is the remission of insulin resistance, and peripheral glucose uptake at baseline along with HbA1c and fasting plasma glucose confirmed our theory.

This study showed that fasting plasma glucose decreased from 9.81 ± 4.02 mmol/l to 5.87 ± 1.81 mmol/l, the difference was significant, and peripheral glucose uptake rate at baseline correlated with fasting plasma glucose. The relationship between hypertension and insulin resistance has been reported previously [24]. Jung chan-hee et al. reported that the adverse effect of insulin resistance on blood pressure was aggravated in older individuals [25]. Luo Ping et al. also found that RYGB surgery significantly improved insulin resistance in patients with type 2 diabetes with a BMI of 27.5 to 35 kg/m^2 and increased peripheral glucose uptake by 4.19 [26]. Our research suggested that insulin resistance is strongly correlated with blood pressure, Thus, MBS could reduce insulin resistance and increase insulin sensitivity in patients with T2DM [27]. In the short term, glycemic control after MBS is primarily driven by the rapid increase in gastrointestinal hormones such as GLP-1 and PYY, which enhance insulin secretion, suppress glucagon release, and delay gastric emptying, independent of weight loss [28]. These hormonal changes lead to immediate improvements in glucose homeostasis within days to weeks post-surgery. In the long term, sustained glycemic control is predominantly attributed to significant weight loss and the resolution of insulin resistance, as reduced adiposity decreases lipotoxicity, systemic inflammation, and hepatic glucose production [29]. This transition from hormone-mediated to weight-loss-driven metabolic improvements underscores the multifaceted mechanisms by which MBS facilitates durable diabetes remission.

The present study had several limitations. First, this study is the small sample size, which is further reduced when patients are divided into remission and non-remission groups. While this may impact statistical robustness and increase the likelihood of random variation, subgroup analysis remains valuable in identifying potential influencing factors. Such exploratory analyses can provide preliminary insights that warrant further investigation in larger cohorts. Second, we did not include specific indexes for evaluating β-cell function, which could have provided a more comprehensive assessment of pancreatic function. Despite these limitations, a major strength of our study is the use of the hyperinsulinemic-euglycemic clamp and the direct measurement of peripheral glucose uptake, which are more sensitive and accurate methods for evaluating insulin resistance compared to traditional surrogate markers.

Conclusions

Our study explored the role of RYGB in insulin resistance from a new point of view, and revealed that patients with T2DM (BMI < 35 kg/m^2) and insulin resistance can benefit from RYGB, Shorter duration of diabetes, higher BMI and lower peripheral glucose disposal rate were independent predictors of diabetes remission after RYGB. However, further large-scale cohort studies are needed to validate these findings.

Author contributions

Study was designed by X.G., T.W., G.H.W., P.Z.L. and W.Z.L. Data collection was conducted by X.G., G.H.W. W.Z.L. P.Z.L. and L.Y.Z. Data analyses and interpretation were performed by X.G. J.H.L. G.H.W. S.H.Z. Z.S. and W.Z.L. Manuscript was written by X.G. T.W., G.H.W. and W.Z.L. and reviewed by L.Y.Z. S.H.Z. Z.S. and P.Z.L.

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Data availability
Data will be made available from the corresponding author (Pengzhou Li) upon reasonable request.

Declarations

Ethics approval and consent to participate
This retrospective study was approved by the Ethics Committee of the Third xiangya hospital of ventral south university and was conducted in accordance with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Informed consent was waived by our Institutional Review Board because of the retrospective nature of our study.

Consent for publication
Not Applicable.

Competing interests
The authors declare no competing interests.

Clinical trial number
Not applicable.

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