Obesity Surgery (2019) 29:1867–1873
https://doi.org/10.1007/s11695-019-03783-x

ORIGINAL CONTRIBUTIONS

Analysis of Predictors of Type 2 Diabetes Mellitus Remission After Roux-en-Y Gastric Bypass in 101 Chinese Patients

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Published online: 23 February 2019

Abstract

Background To investigate prognostic factors for complete remission in type 2 diabetes mellitus (T2DM) patients who underwent gastric bypass (GBP) and to establish a prognostic model for risk stratification.

Methods We evaluated the baseline clinical features of patients with T2DM who received at Beijing Tian Tan Hospital from April 2012 to December 2015. Complete remission of T2DM was defined as meeting the following criteria: HbA1c < 6.5%, fasting plasma glucose (FPG) < 100 mg/dL, and absence of hypoglycemic drugs for 1 year following GBP.

Results A total of 101 patients were enrolled in our study, and the complete remission rate of T2DM was 70.3% (71/101). Compared with patients with incomplete remission, patients with complete remission of T2DM had higher C-peptide levels, lower HbA1c, shorter disease duration, better β cell function, and an absence of insulin therapy. HbA1c level, fasting C-peptide, duration of T2DM, and history of medical therapy were important prognostic factors for complete remission of T2DM (P = 0.001, 0.002, 0.01, 0.028, respectively). Patients with HbA1c lower than 7.5%, a history of T2DM shorter than 9.5 years, fasting C-peptide higher than 1.2 ng/mL, and absence of insulin therapy before GBP achieved a higher complete remission rate of T2DM after GBP (AUC of the model was 0.825, 95% CI, 0.741–0.910; P = 0.001).

Conclusions The duration of T2DM, history of medical therapy, and levels of HbA1c and fasting C-peptide are independent predictors for the prognosis of T2DM patients undergoing GBP. Patients with HbA1c lower than 7.5%, a history of T2DM shorter than 9.5 years, a fasting C-peptide higher than 1.2 ng/mL, and an absence of insulin therapy may have a higher complete remission rate of T2DM after GBP.

Keywords Gastric bypass · Type 2 · Diabetes mellitus · HbA1c · C-peptide · BMI · Metabolic · Bariatric · Predictor · Models

Introduction

Diabetes has become a serious public health problem that threatens the health of Chinese people. The prevalence of diabetes in China has reached 11.6%, and 90% of the cases are type 2 diabetes mellitus (T2DM) [1]. Metabolic surgeries are superior to traditional medical therapy in treating T2DM [2–5] and have been widely used to treat T2DM with obesity globally. Among them, gastric bypass (GBP) has been recommended as the gold standard for surgical treatment of T2DM [6]. The current global guidelines still regard body mass index (BMI) as an independent reference standard for surgical indication for metabolic surgery in T2DM [6–10]. However, the complete remission rate of T2DM after GBP surgery varied greatly according to BMI [2–5, 11]. Therefore, whether BMI is an important factor affecting the efficacy of GBP in the treatment of T2DM has also been increasingly questioned [12–14].

What are the factors that influence the efficacy of GBP in the treatment of T2DM? The results of recent studies vary because of the different BMI ranges, age, duration of T2DM, preoperative glycosylated hemoglobin A1c (HbA1c) levels, fasting plasma glucose (FPG) levels, preoperative C-peptide levels, hypoglycemic agents, surgical procedures, major surgical parameters, and criteria for complete remission of T2DM in different studies. At the same time, the majority of

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relevant findings are based on populations with a BMI greater than 35 kg/m^2 [15–22]. However, the predictors of the effects of GBP in the treatment of T2DM are still unclear. In addition, GBP is a relatively young procedure for T2DM in China; presently, there is no accurate preoperative assessment model for GBP in the treatment of T2DM.

The intent of this study was to identify prognostic factors for complete remission of T2DM after GBP in Chinese patients with a BMI of 23~51 kg/m^2 and to establish a prognostic model for T2DM patients' outcome prediction.

Materials and Methods

Patients

Clinical data from T2DM patients who underwent laparoscopic Roux-en-Y gastric bypass (LRYGB) in the Department of General Surgery, Beijing Tian Tan Hospital, Capital Medical University from April 2012 to December 2015 were retrospectively analyzed. For patients with BMI ≥ 27.5 kg/m^2, the surgical indications referred to the statement [6]. The indications for patients with BMI < 27.5 kg/m^2 were inadequately controlled hyperglycemia despite optimal medical treatment with either oral or injectable medications (including insulin) and simultaneous hypertension, abnormal lipid metabolism, polycystic ovary syndrome, or family history of diabetes. All patients signed written informed consent before LRYGB. This study was supported by "Beijing Municipal Science and Technology Commission" (Grant No. Z161100000116068).

Observational Indicators

The individual components of BMI, HbA1c, insulin resistance (HOMA-IR), alanine aminotransferase (ALT), aspartate aminotransferase (AST), glutamyl transpeptidase (GGT), urea nitrogen (BUN), creatinine (Cr), uric acid (UA), triglyceride (TG), total cholesterol (TCHO), high-density lipoprotein (HDL), low-density lipoprotein (LDL), calcium (Ca), ferritin, and vitamin B_{12} (V-B_{12}) were examined before surgery and 12 months postoperatively. The T2DM complete remission criteria [23] were FPG < 5.6 mmol/L and HbA1c ≤ 6.5% without the use of hypoglycemic agents. These parameters and the complete remission rate of T2DM were used to evaluate the efficacy of GBP for T2DM. Important prognostic factors for complete remission of T2DM were extracted from gender, age, BMI, waist circumference, T2DM duration, history of medical therapy, FPG, HbA1c, fasting insulin, fasting C-peptide, C-peptide peak ratio, HOMA-IR, HOMA-β, ALT, AST, GGT, BUN, Cr, UA, TG, TCHO, HDL, LDL, intraoperative blood loss, operative time, postoperative hospital stay, and change in BMI. Then, we calculated the AUC value and cutoff value of the prognostic factors by ROC curve, constructed a prognostic model with a cutoff value of these factors, calculated the AUC value of the prognostic model by ROC curve, and verified the model in these patients.

Perioperative complications involved anastomotic leakage, anastomotic bleeding, anastomotic stenosis, early ileus, perioperative cardiovascular and cerebrovascular accidents, symptomatic pulmonary embolism, and death. Middle- and long-term complications involved malnutrition (lack of trace elements, hypoproteinemia, iron deficiency anemia), anastomotic ulcer, and intestinal obstruction.

Surgical Procedure

We used a standard five-port laparoscopic technique, and LRYGB was performed by antecolic, side-to-side anastomosis between the lesser curvature of the gastric pouch and jejunum. The lengths of the biliopancreatic and gastrointestinal limbs depended on the preoperative BMI of the patient (such as 80 cm length for patients with a BMI ≤ 27.5 kg/m^2, 100 cm length for patients with a BMI > 27.5 and ≤ 50 kg/m^2, and 120 cm length for patients with a BMI > 50 kg/m^2). The gastric pouch was approximately 20~30 cc, and the gastrojejunostomy was created by a stapler technique with an anastomosis of 1.5 cm in diameter. All anastomoses were completed with the LLC Echelon 60 Endopath Stapler (Ethicon Endo-Surgery) without manual stitching. We did not close Petersen and mesenteric defects for all patients. This procedure has been published previously [24].

Statistical Analysis

All statistical analyses were performed using SPSS version 16.0. The quantitative indicators were expressed as the mean ± standard deviation, and qualitative indicators were expressed as the percentage. The comparisons were using *t* tests, chi-square tests, the rank sum test, and logistic regression. A two-side *P* value < 0.05 was considered to indicate statistical significance. The important prognostic factors were selected by logistic regression. The AUC values and cutoff values of the factors were calculated with ROC curve, and the prognostic model for T2DM remission was constructed with cutoff values of the factors. Then, the model was verified in these patients by stratified analysis.

Results

A total of 109 T2DM patients underwent LRYGB from April 2012 to December 2015, including 8 patients with incomplete clinical data. Ultimately, 101 patients (58 women) were qualified to enter the study. None of the patients was switched to laparotomy surgery. The mean age of the T2DM patients was

45.3 ± 11.1 years (range, 19~65), and the mean HbA1c and disease duration were 8.5 ± 1.7% and 7.1 ± 4.8 years (range, 1~15), respectively. The mean BMI was 30.3 ± 5.5 kg/m^2 (range, 23~51), and the number of patients with BMI < 27.5 kg/m^2 and ≥ 27.5 kg/m^2 were 38 and 63, respectively.

Seventy-one patients (70.3%) achieved complete remission of T2DM 1 year after LRYGB. BMI, TCHO, TG, LDL, FPG, HbA1c, fasting C-peptide, fasting insulin, and serum ferritin levels as well as HOMA-IR were significantly lower than those before surgery ($P < 0.05$). Moreover, HDL and ALT levels were significantly higher than preoperative levels, and the difference was statistically significant ($P < 0.05$) (Table 1).

Compared with patients with incomplete remission, patients with complete remission of T2DM had higher C-peptide levels, lower HbA1c, shorter disease duration, better β cell function, and an absence of insulin therapy (Table 2). The HbA1c level ($P = 0.001$), fasting C-peptide level ($P = 0.002$), duration of T2DM ($P = 0.001$), and history of preoperative medical therapy ($P = 0.028$) were found to be important prognostic factors for complete remission of T2DM after LRYGB using logistic regression analysis. The AUC of the HbA1c level, fasting C-peptide level, and duration of T2DM were 0.755, 0.684, and 0.776, respectively. The cutoff values of HbA1c level, fasting C-peptide, and duration of T2DM were 7.5, 1.2, and 9.5, respectively. In the stratification analysis, groups with HbA1c < 7.5%, disease duration < 9.5 years, C-peptide ≥ 1.2 ng/mL, and absence of insulin therapy had higher rates of complete diabetes remission than those with HbA1c ≥ 7.5%, disease duration ≥ 9.5 years, C-peptide < 1.2 ng/mL, and insulin therapy ($P = 0.001$, 0.001, 0.004, 0.032, respectively) (Table 3). The prognostic model of T2DM remission after GBP was constructed according to the cutoff values of HbA1c level, disease duration, C-peptide level, and history of medical therapy (AUC of the model was 0.825, 95% CI 0.741–0.910, $P = 0.001$). The prognostic model included HbA1c level (0–1), fasting C-peptide (0–1), duration of T2DM (0–1), and medical therapy (0–1). HbA1c < 7.5%, duration < 9.5 years, C-peptide ≥ 1.2 ng/mL, and the absence of insulin therapy was a score of 1; otherwise, the score was 0. The scores of the model ranged from 0 to 4. The higher the score, the higher the T2DM remission rate. Patients with HbA1c < 7.5%, disease duration < 9.5 years, C-peptide ≥ 1.2 ng/mL, and the absence of insulin preoperatively achieved a complete T2DM remission rate of 100% after LRYGB in these patients (Table 4).

Table 1 Clinical parameters of the patients at baseline and 1 year after LRYGB

Variables	baseline	1 year after surgery	*P* value (Rank sum test)
BMI (kg/m^2)	30.3 ± 5.5	23.7 ± 4.1	0.000[a]
Weight (kg)	83.7 ± 17.2	65.9 ± 13.9	0.000[a]
AST (U/L)	21.5 ± 8.8	25.2 ± 12.4	0.038[a]
ALT (U/L)	31.4 ± 18.6	30.6 ± 18.1	0.667
GGT (U/L)	28.7 ± 16.7	24.9 ± 17.0	0.078
TCHO (mmol/L)	4.7 ± 0.9	4.3 ± 0.7	0.010[a]
TG (mmol/L)	2.0 ± 1.7	1.1 ± 0.6	0.000[a]
HDL (mmol/L)	1.1 ± 0.2	1.3 ± 0.3	0.000[a]
LDL (mmol/L)	2.9 ± 0.7	2.5 ± 0.6	0.001[a]
Cr (μmol/L)	51.9 ± 15.0	52.0 ± 15.0	0.804
BUN (mmol/L)	6.3 ± 8.9	6.0 ± 6.0	0.760
UA (umol/L)	310.6 ± 112.2	298.7 ± 99.5	0.497
FPG (mmol/L)	7.8 ± 3.2	6.0 ± 1.2	0.000[a]
HbA1 c (%)	8.5 ± 1.7	5.8 ± 0.7	0.000[a]
Fasting C-peptide (ng/mL)	1.6 ± 0.9	1.2 ± 0.5	0.003[a]
FINS (uU/mL)	19.4 ± 13.9	8.5 ± 6.3	0.000[a]
HOMA-IR	6.8 ± 6.3	2.2 ± 1.9	0.000[a]
Ca (mmol/L)	2.3 ± 0.1	2.4 ± 0.3	0.210
Serum ferritin (ng/mL)	213.6 ± 166.4	170.8 ± 144.9	0.037[a]
V-B_{12}(pg/mL)	452.3 ± 184.7	495.1 ± 315.8	0.876
Hb (g/L)	136.8 ± 10.8	134.8 ± 14.0	0.751

LRYGB, laparoscopic Roux-en-Y gastric bypass; *BMI*, body mass index; *HbA1c*, glycosylated hemoglobin; *T2DM*, type2 diabetes mellitus; *HOMA-IR*, insulin resistance index; *ALT*, alanine aminotransferase; *AST*, aspartate transaminase; *GGT*, glutamyl transpeptidase; *BUN*, blood urea nitrogen; *Cr*, creatinine; *UA*, uric acid; *TG*, triglyceride; *TCHO*, total cholesterol; *HDL*, high-density lipoprotein; *LDL*, low-density lipoprotein; *Ca*, serum calcium;*V-B12*, vitamin B_{12}; *Hb*, hemoglobin. *[a] There was a statistical difference before and after surgery

Table 2 Comparison of preoperative characteristics in patients with and without T2DM complete remission

Variables	Complete remission	No complete remission	*P* value (Rank sum test)
Sex (male/female)	71(33/38)	30(10/20)	0.222
Age (year)	44.3 ± 10.8	47.5 ± 11.4	0.135
Duration (year)	5.6 ± 4.1	9.6 ± 3.7	0.000[a]
Height (m)	1.66 ± 0.07	1.65 ± 0.07	0.646
Weight (kg)	83.8 ± 15.0	82.6 ± 16.9	0.715
BMI (kg/m^2)	30.0 ± 4.9	29.5 ± 5.4	0.667
Waistline (cm)	101.5 ± 11.8	103.5 ± 14.5	0.635
AST (U/L)	21.5 ± 8.4	22.6 ± 12.3	0.920
ALT (U/L	32.7 ± 19.1	30.1 ± 19.1	0.652
TCHO (mmol/L)	4.6 ± 0.8	5.0 ± 1.2	0.110
TG (mmol/L)	2.0 ± 1.6	2.3 ± 2.5	0.595
HDL (mmol/L)	1.1 ± 0.2	1.1 ± 0.3	0.704
LDL (mmol/L)	2.8 ± 0.7	3.1 ± 0.8	0.084
FPG (mmol/L)	7.4 ± 2.9	8.9 ± 2.9	0.100
C-peptide (ng/mL)	1.8 ± 0.9	1.2 ± 0.6	0.003[a]
Peak of C-peptide	2.9 ± 1.3	2.9 ± 1.3	0.789
FINS (uU/mL)	19.2 ± 10.3	22.1 ± 21.1	0.225
HbA1c (%)	7.9 ± 1.5	9.1 ± 1.3	0.000[a]
HOMA-IR	6.1 ± 4.1	8.0 ± 7.9	0.970
HOMA-β (%)	126.7 ± 86.6	77.3 ± 62.9	0.010[a]
UA (umol/L)	305.7 ± 107.3	309.2 ± 104.2	0.669
BUN (mmol/L)	5.2 ± 1.8	5.1 ± 1.5	0.140
Cr (μmol/L)	55.1 ± 13.3	47.6 ± 12.6	0.066
GGT (U/L)	30.2 ± 20.3	28.5 ± 15.4	0.661
Non-insulin/insulin (num)	71(43/28)	30(11/19)	0.028[a]
Weight loss (kg)	18.1 ± 0.9	16.6 ± 2.3	0.474
Blood loss (mL)	55.7 ± 28.9	75.2 ± 43.8	0.373
Hospital stay (day)	6.0 ± 2.8	6.3 ± 1.0	0.199
Operation time (h)	2.6 ± 0.8	2.6 ± 0.7	0.466

BMI, body mass index; *HbA1c*, glycosylated hemoglobin; *T2DM*, type2 diabetes mellitus; *HOMA-IR*, insulin resistance index; *ALT*, alanine aminotransferase; *AST*, aspartate transaminase; *GGT*, glutamyl transpeptidase; *BUN*, blood urea nitrogen; *Cr*, creatinine; *UA*, uric acid; *TG*, triglyceride; *TCHO*, total cholesterol; *HDL*, high-density lipoprotein; *LDL*, low-density lipoprotein; *Ca*, serum calcium; *V-B12*, vitamin B_{12}; *Hb*, hemoglobin.
[a] There was a statistical difference before and after surgery

One patient (1.0%) required a secondary surgery 34 h after the first surgery because of bleeding of the side-to-side anastomosis between the intestines. One patient (1.0%) had jejunojejunal anastomotic obstruction after LRYGB, and she underwent laparoscopic jejunojejunal anastomotic revision on the sixth day after surgery. After the second operation, she developed an abdominal infection and was eventually discharged successfully with culdocentesis and anti-infective treatment. Ninety-nine patients, excepting the 2 patients above, did not have early-stage complications after surgery (< 30 days). Six patients (7.8%) had incomplete intestinal obstructions and were treated conservatively by bowel rest or parenteral nutrition during the year following surgery. One patient (1.0%) received a repeated laparoscopic operation ascribed to the stricture of gastrojejunal anastomosis 6 weeks after the first surgery. Iron deficiency anemia appeared 9 months after the operation in one patient (1.0%) and was treated by ferrous preparation. Two patients (2.0%) presented with low body weight postoperatively. One patient's BMI decreased from 25.3 to 17.3 kg/m^2 6 months after surgery, and the other's BMI dropped from 23.4 to 17.2 kg/m^2 12 months after operation; their symptoms improved after treatment with enteral nutrition. The two patients failed to be regularly followed up after surgery.

Discussion

This study included 101 patients who underwent LRYGB for T2DM. One year after the operation, 71 patients (70.3%) had

Table 3 Stratification analysis of pre-op characteristics on T2DM remission post-op

Characteristics	*n*	Complete remission	No complete remission	*P* value
During (year)				0.001
< 9.5	71	60 (84.5%)	11 (15.5%)	
≥ 9.5	30	11 (36.7%)	19 (63.3%)	
HbA1c (%)				0.001
< 7.5	38	37 (97.4%)	1 (2.6%)	
≥ 7.5	63	45 (71.4%)	18 (28.6%)	
C-peptide (ng/mL)				0.004
< 1.2	39	26 (66.7%)	13 (33.3%)	
≥ 1.2	62	56 (90.3%)	6 (9.7%)	
History of medical therapy				0.032
Non-insulin	54	43 (79.6%)	11 (20.4%)	
Insulin	47	28 (59.6%)	19 (40.4%)	
BMI (kg/m^2)				0.441
< 27.5	38	25 (65.8%)	13 (34.2%)	
≥ 27.5	63	46 (73.0%)	17 (27.0%)	

complete remission of T2DM, which is consistent with previous reports. In 1995, Pories et al. [11] reported for the first time the long-term efficacy of GBP on T2DM with obesity: there were 121 T2DM and 150 patients with impaired glucose tolerance in the study, and the complete remission rate of diabetes mellitus was 82.9%. A meta-analysis [14] of 135,246 patients in 2009 also showed that the remission rate of T2DM was 80.3% after GBP surgery. In 2012, Mingrone et al. [2] published a prospective randomized controlled trial comparing surgical treatment and traditional medical treatment for T2DM; the study enrolled patients whose diabetes duration was more than 5 years, and the outcome showed that the complete remission rate of T2DM was 75%.

The current global guidelines regard BMI as an independent reference standard for surgical indication in T2DM for bariatric surgery [6–10]. However, according to this standard, the complete remission rate of T2DM after GBP varies greatly [2–5, 11, 22]. Therefore, whether BMI is an important factor affecting the efficacy of GBP in the treatment of T2DM has also been increasingly questioned by researchers [12–14].

China has a large T2DM patient population, and the average BMI of T2DM patients in China is only 25 kg/m^2. Reports of gastric bypass for T2DM patients with a BMI < 27.5 kg/m^2 are lacking. We hope GBP may benefit more T2DM patients. Thus, we operated on nonobese patients with T2DM, whose hyperglycemia was inadequately controlled despite optimal medical treatment by either oral or injectable medications (including insulin) and who simultaneously had hypertension, abnormal lipid metabolism, polycystic ovary syndrome or family history of diabetes.

The results of this study suggest that preoperative BMI may not be significantly associated with T2DM remission after LRYGB. The complete remission rate of T2DM in the BMI ≥27.5 kg/m^2 group (73.0%) was slightly higher than that in the BMI <27.5 kg/m^2 group (65.8%). However, the difference in remission rates between the two groups was not statistically significant. Logistic regression analysis also showed no significant relationship between BMI and remission of T2DM after GBP. In the meta-analysis [13] conducted earlier by our center, the results also showed that preoperative BMI

Table 4 The results of in-group verification using prognostic model of T2DM remission after LRYGB

Scores	Match the model (*n*)	Complete remission (*n*)	Remission rate (%)
4	17	17	100
3	26	23	88.4
2	32	22	68.8
1	16	8	50
0	10	1	10

The prognostic model T2DM remission after LRYGB include HbA1c level (0–1), fasting C-peptide (0–1), duration of T2DM (0–1), and medication therapy (0–1). HbA1c < 7.5%, duration < 9.5 years, C-peptide ≥ 1.2 ng/mL, absence of insulin therapy were 1 score respectively; otherwise 0 score. The range of scores of the model was from 0 to 4. The higher the score, the higher the diabetes remission rate. AUC of the model was 0.825 (95% CI, 0.741–0.910; $P = 0.001$)

may not be an independent prognostic factor for remission of T2DM. A prospective randomized controlled study of surgical treatment and traditional medical treatment of T2DM published by Mingrone et al. [2] also pointed out that BMI was not an important prognostic factor for remission of T2DM after bariatric surgery.

At present, some studies have reported other important factors affecting the remission of T2DM after bariatric surgery other than BMI. However, these results were not consistent due to differences in BMI, age, diabetes duration, preoperative HbA1c, FPG, C-peptide levels, hypoglycemic medications, different surgical procedures, major surgical parameters, and criteria for complete remission of T2DM in each study. In addition, most studies were based on patients with a BMI ≥ 35 kg/m^2 [15–22]. Our study retrospectively analyzed the clinical data from Chinese T2DM patients treated by LRYGB with a BMI of 23~51 kg/m^2. The results showed that patients in the T2DM complete remission group had a shorter diabetes duration, lower preoperative FPG and HbA1c, higher fasting C-peptide, higher HOMA-β index, and an absence of insulin therapy compared with the incomplete remission group and that the differences were statistically significant. Further logistic regression analysis showed that the duration of T2DM, preoperative HbA1c, preoperative fasting C-peptide, and history of medical therapy before surgery were independent prognostic factors affecting complete remission of T2DM after LRYGB. Our previous meta-analysis [13] also showed that preoperative fasting C-peptide levels are independent prognostic factors affecting remission of T2DM after bariatric surgery; the higher the preoperative fasting C-peptide and the lower the preoperative HbA1c and FPG were, the higher the remission rate of T2DM after bariatric surgery. Ana M. Ramos Leví et al. [17] reviewed 141 patients with diabetes out of 657 patients with bariatric surgery from a single-center in 2014. Their results also showed that diabetes duration, fasting C-peptide, and preoperative insulin use were independent prognostic factors. However, patients enrolled in the study received different bariatric procedures. In addition, diabetic remission criteria were defined as HbA1c < 6% and FPG < 5.56 mmol/L. Dixon JB et al. [15] studied 154 T2DM patients with obesity and considered fasting C-peptide and duration of diabetes to be independent factors affecting the remission of T2DM after GBP. In their study, 66 subjects underwent LRYGB, 88 underwent one anastomosis gastric bypass (OAGB), the average BMI was 37.2 (23 to 94) kg/m^2, and diabetic remission criteria were HbA1c < 6.0% for follow-up of 1 year. In 2011, Weijie Li et al. [18] also reported that HbA1c and C-peptide levels are independent factors affecting T2DM remission after bariatric surgery. Their group analyzed 205 T2DM patients with obesity who also received varying surgical procedures. The average preoperative C-peptide level of all patients was 5.3 ± 3.5 ng/mL, and diabetes remission criteria were FPG < 110 mg/dL and HbA1c < 6.0% followed up for 1 year.

Presently, studies from different aspects showed that a shorter duration of T2DM, lower HbA1c, higher fasting C-peptide, and the absence of insulin-based hypoglycemic medications resulted in a higher complete remission rate of T2DM after bariatric surgery [15, 25–28]. However, there was no ideal prognostic model for the evaluation of T2DM after LRYGB. In the stratified analysis of our study, the results showed that groups with HbA1c < 7.5%, disease duration < 9.5 years, C-peptide ≥ 1.2 ng/mL, and the absence of insulin therapy had higher rates of complete diabetes remission than those with HbA1c ≥ 7.5%, disease duration ≥ 9.5 years, C-peptide < 1.2 ng/mL, and insulin therapy, and the differences were statistically significant. Among the 101 patients enrolled in this study, patients with HbA1c < 7.5%, duration of T2DM < 9.5 years, C-peptide ≥ 1.2 ng/mL, and noninsulin-based medications had a 100% complete remission rate of T2DM after LRYGB. The complete remission rates were 88.4% when patients met any three of the indicators listed above. The results of our study offer a prognostic model for the selection of T2DM patients before GBP.

T2DM is a metabolic disease with insulin resistance or the progressive loss of beta cell function that is affected by many factors, including environmental and genetic factors [23, 29]. It is well-known that the longer the duration of T2DM is, the more severe the islet function damage will be. Due to the damage of islet function, blood glucose is difficult to control, which results in a higher HbA1c level, and most patients need to use large doses of insulin to control blood glucose [23]. We believe that the duration of T2DM, HbA1c level, fasting C-peptide level, and history of medical therapy may reflect the severity of T2DM to some degree. These findings also suggest that the remission of T2DM after GBP may be closely related to the preoperative severity of T2DM.

Of course, our study also had some limitations. This study was a single-center retrospective study with fewer patients enrolled, and the follow-up time of this study was shorter. In the future, we plan to conduct prospective, multicenter research in this area.

In conclusion, GBP is safe and effective for Chinese T2DM patients. The duration of T2DM, preoperative HbA1c level, fasting C-peptide level, and history of medical therapy before surgery may be important prognostic factors affecting the complete remission of T2DM after LRYGB. Patients with HbA1c < 7.5%, duration of T2DM < 9.5 years, fasting C-peptide ≥ 1.2 ng/mL, and absence of insulin-based hypoglycemic medications may have a higher complete remission rate of T2DM after GBP.

Author Contributions Rixing Bai and Maomin Song designed and supervised the study, Wenmao Yan collected and analyzed the data, and drafted the manuscript, Youguo Li, Jun Xu and Zhiqiang Zhong offered the technical or material support, Ying Xing, Yi Lin, Ming Yan and Maoming Song revised the manuscript for important intellectual content, all authors have read and approved the final version to be published.

Funding Information This study was supported by "Beijing Municipal Science and Technology Commission" (Grant No. Z161100000116068).

Compliance with Ethical Standards

All procedures performed in the study involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. All patients signed a written informed consent before LRYGB.

Conflict of Interest The authors declare that they have no conflict of interest.

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