Obesity Surgery (2021) 31:4877–4884
https://doi.org/10.1007/s11695-021-05658-6

ORIGINAL CONTRIBUTIONS

Effect of Roux-en-Y Gastric Bypass with Different Lengths of Biliopancreatic and Alimentary Limbs for Patients with Type 2 Diabetes Mellitus and a BMI < 35 kg/m^2: 5-Year Outcomes in Chinese Patients

Xiang Gao[1] · Liyong Zhu[1] · Guohui Wang[1] · Weizheng Li[1] · Zhi Song[1] · Shaihong Zhu[1] · Pengzhou Li[1]

Received: 5 January 2021 / Revised: 7 August 2021 / Accepted: 11 August 2021 / Published online: 17 August 2021

Abstract

Purpose There have been no definite conclusions about the biliopancreatic limb (BPL) and alimentary limb (AL) lengths in Roux-en-Y gastric bypass (RYGB) operations for different populations and BMIs. Western scholars have performed many studies on the lengths of the BPL and AL in patients with a BMI ≥ 35 kg/m^2. However, for diabetic Chinese patients with BMI < 35 kg/m^2, few people have compared the effects of different BPL and AL lengths on patient prognosis.

Patients and Methods Clinical data were collected prospectively and analyzed retrospectively for 87 patients with type 2 diabetes (T2DM) who underwent RYGB with a BPL of 50 cm and an AL of 50 cm (BPL50/AL50) or with a BPL of 100 cm and an AL of 100 cm (BPL100/AL100) and who were followed up for 5 years.

Results The cohort included 42 patients in the BPL50/AL50 group and 45 patients in the BPL100/AL100 group. At 5 years, there were significant differences in BMI, total weight loss (TWL%), glycosylated hemoglobin, and homeostasis model assessment insulin resistance between BPL50/AL50 and BPL100/AL100 ($P < 0.05$). Diabetes remission rate of the BPL100/AL100 group was significantly higher than that of the BPL50/AL50 group. Diabetes remission at 1 year after surgery correlated with the length limb (BPL + AL), duration of diabetes and TWL%. There was no difference in complications between BPL50/AL50 and BPL100/AL100.

Conclusions RYGB with BPL100/AL100 is a safe and effective treatment for diabetic patients with a BMI < 35 kg/m^2 and offers significant improvement in weight loss and glycemic control.

Keywords Roux-en-Y gastric bypass · Body Mass Index · Obesity · Type 2 diabetes

Introduction

Obesity and type 2 diabetes (T2DM) are global public health issues. The incidence of obesity increased from 7% in 1980 to 12.5% in 2015 [1]. Roux-en-Y gastric bypass (RYGB) is currently still the most effective treatment for obesity and T2DM [2]. However, the optimal lengths of the biliopancreatic limb (BPL) and alimentary limb (AL) in RYGB remain controversial. Currently, bariatric surgeons determine the lengths of BPL and AL based on the patient's body mass index (BMI) and islet cell function, combined with clinical experience [3].

Brolin reported for the first time in 1992 that the length of the AL can affect weight loss after RYGB [4]. To date, many studies have focused on limb length; the length of AL has ranged from 50 to 150 cm, and the length of the BPL has ranged from 50 to 200 cm. The BMI of patients in similar studies has been greater than 50 kg/m^2, while little attention has been paid to Asian populations with BMI less than 35 kg/m^2 [5–7]. To date, many studies have shown that increasing Roux limb length can improve weight loss after gastric bypass, especially in patients with BMI > 50 kg/m^2. A study of the effect of BPL lengths by Kraljevic et al. confirmed that a long BPL results in better weight loss [8]. In addition, Kaska et al. reported that an increased BPL length of 100–150 cm has a better antidiabetic effect in

✉ Pengzhou Li
602223@csu.edu.cn

[1] Department of General Surgery, Third Xiangya Hospital, Central South University, Changsha 410013, China

RYGB compared with a shorter BPL of 50–75 cm after 24 months [9]. A clinical trial showed that RYGB with a long BPL (200 cm) and short AL (50 cm) is effective in achieving complete control of T2DM in patients with BMIs between 30 and 35 kg/m^2 [10]. More recently, the literature has offered contradictory findings that RYGB with a 120-cm BPL does not achieve greater weight loss or remission of comorbidities than RYGB with a 70-cm BPL [11]. In reviewing the literature, no data were found on the constant lengths of the BPL and AL, and few studies have reported long-term effects of different BPL or AL lengths in Chinese T2DM patients with BMI less than 35 kg/m^2. In the past, different limb lengths for RYGB have been used in our center, based on the available literature and the characteristics of Chinese T2DM patients: BPL 50 cm with AL 50 cm or RYGB with BPL 100 cm and AL 100 cm. The aim of this cohort study was to compare the efficacy of RYGB surgeries with two different lengths of the BPL and AL for T2DM patients with BMI < 35 kg/m^2.

Patients and Methods

In the early stage, Chinese diabetic patients are characterized by low BMI and abdominal obesity, so we correspondingly reduced the length of the BPL and AL to 50 cm, to avoid the occurrence of short-bowel syndrome. However, after years of observation and research, we found that setting the lengths of the BPL and AL is set to 100 cm is more appropriate. Thus, we performed a retrospective analysis of a prospectively collected database. Patients who underwent primary laparoscopic RYGB surgery were included in our research. Patients were operated on between January 2008 and December 2014. This study was approved by the local ethics committee. All of the patients signed informed consent after fully understanding the risks and benefits of the surgery.

The inclusion criteria included the following: (1) age > 18 years old and < 65 years old; (2) BMI less than 35 kg/m^2; (3) diagnosis of diabetes according to American Diabetes Association 2018 diagnostic criteria [12]; (4) oral glucose tolerance test, fasting C-peptide greater than 1 ng/mL, and C-peptide twice the basic C-peptide level after 120 min, and (5) T2DM duration < 15 years. The exclusion criteria were as follows: (1) other bariatric surgeries, revisional RYGB surgery or gastrointestinal surgery; (2) diagnoses of type 1 diabetes; (3) carcinoma; and (4) drug or alcohol dependence. Patients were selected from our prospectively populated clinical computerized database, which has been in use since 2008. Pre-, intra-, and postoperative data were collected by research personnel. Postoperative follow-up visits were offered to all patients after 3, 6, 12, and 24 months and annually thereafter. All of the patients routinely required ingestion of compound nutrients (Glory Feel, Multivitamin), one capsule per day. Nutritional information was collected.

Surgical Methods

All of the patients underwent laparoscopic RYGB by the same team of surgical experts. We performed RYGB surgery with two different lengths of the BPL and AL. For LRYGB, four trocars were placed, constructing a small gastric pouch of approximately 30 mL using a linear stapler. The lengths of the BPL and AL were measured using hand-over-hand methods without stretching along the mesentery margin. The lengths of the BPL and Roux limb were 100 cm. The BPL and Roux limb lengths were 50 cm. Gastrojejunostomy was created by a staple technique with an anastomosis 1.5–2.0 cm in diameter, and the mesenteric and Petersen defects were closed.

Anthropometric Evaluations and Biochemical Examinations

Total weight loss (TWL%) was calculated as follows: (weight at each time point – initial weight)/initial weight × 100. Insulin resistance was measured by the homeostasis model assessment of insulin resistance (HOMA-IR) using the following formula: HOMA-IR = fasting plasma insulin (FINS) × fasting plasma glucose (FPG)/22.5. Diabetes complete remission was defined as an HbA1c level < 6.0% with a fasting glucose concentration < 5.6 mmol/L for 1 year or more without active pharmacological intervention. Partial remission was defined as HbA1c < 6.5% and fasting glucose concentration (5.6–6.9 mmol/L) for 1 year without antidiabetic medication. Improvement was defined as a reduction in HbA1c ≥ 1%. T2DM recurrence was defined as glycosylated hemoglobin > 6.5% or the need for medication after the remission of diabetes.

Statistical Analysis

All of the data were analyzed with IBM SPSS software, version 22.0 for Windows. Continuous variables that followed a normal distribution were expressed as the means and standard deviations. Qualitative variables were expressed as the numbers and percentages of cases. Comparison of qualitative variables was performed with the chi-square test or Fisher's exact probability test in cases with fewer than 5 observations in the cell. Continuous variables were compared with the *t* test or the paired *t* test. Multivariate analysis was performed for preoperative clinical characteristics to determine predictors of T2DM remission. A two-tailed $P < 0.05$ was considered statistically significant.

Results

In total, 87 patients underwent primary RYGB. Among them, 42 (48.3%) patients received BPL50/AL50 RYGB, including 22 women and 20 men; 45 (51.7%) patients received BPL100/AL100 RYGB, including 25 women and 20 men. The BMIs of the BPL50/AL50 RYGB and BPL100/AL100 RYGB groups were 29.12 ± 3.64 kg/m^2 and 30.40 ± 3.41 kg/m^2 ($P > 0.05$), and their waist circumferences were 98.21 ± 12.12 cm and 97.32 ± 13.21 cm, respectively. There were no significant differences in age, sex, smoking, diabetes duration, antidiabetic therapy, or *H. pylori* infection at baseline (Table 1).

Table 2 summarizes the changes in WC, WHR (waist-hip ratio), fasting plasma glucose (FPG), glycosylated hemoglobin (HbA1c), HOMA-IR, lipid metabolic profiles, and nutrition data at 5 years. The HbA1c of the two groups showed significant decreases at 3 months, 6 months, and 1 year, but at 3 months, 2 years and 5 years, the decrease in HbA1c was greater in the BL100/AL100 group than in the other groups and was statistically significant (Fig. 1). Compared with the baseline, the FPG of the two groups decreased significantly at 3 months and 1 year. At 3 months, 1 year, and 5 years, the FPG of the BPL100/AL100 group decreased more than that of the BPL50/AL50 group.

The remission rate of diabetes at different times is shown in Table 3. We observed that the total remission rate with BPL100/AL100 RYGB was significantly higher than that with BPL50/AL50 RYGB in different periods ($P < 0.05$). In the third and fourth years, the complete remission rates of the BPL100/AL100 group were significantly higher than those in the BPL50/AL50 group, which were 34.1% and 30.8%, respectively. Patients are stratified according to the ABCD scoring system in Table 4. The results suggest that the higher that the score is, the higher that the diabetes remission rate is. The recurrence rate of diabetes after 5 years in the BPL50/AL50 group was 27%, and that in the BPL100/AL100 group was 21%.

Further univariate analysis demonstrated that T2DM was more likely to resolve in individuals with younger age, higher BMI, higher TWL% and longer lengths of limbs (BPL + AL). ($P = 0.025$, 0.048, 0.038, and 0.016, respectively.) On multivariate analysis, TWL%, duration of diabetes and lengths of limbs was statistically significant ($P = 0.043$, 0.025, and 0.047), indicating that T2DM was more likely to be resolved in individuals with higher

Table 1 Characteristics of patients in the BPL50/AL50 and BPL100/AL100 groups at baseline

	BPL50/AL50	BPL100/AL100	*P*
Number	42	45	–
Age (years)	42.5 ± 6.8	41.3 ± 5.8	0.16
Sex (female)	22(52.4%)	25(55.6%)	0.77
BMI	29.12 ± 3.64	30.40 ± 3.41	0.31
Waist (cm)	98.21 ± 12.12	97.32 ± 13.21	0.08
FPG (mmol/L)	8.36 ± 2.24	8.73 ± 2.06	0.19
HOMA-IR	9.45 ± 1.34	9.10 ± 0.98	0.39
HbA1c (%)	8.58 ± 2.16	9.01 ± 1.08	0.11
TG (mmol/L)	2.56 ± 1.50	2.89 ± 1.91	0.23
TC (mmol/L)	4.39 ± 1.18	4.73 ± 1.01	0.77
HDL (mmol/L)	1.06 ± 0.28	1.08 ± 0.25	0.06
LDL (mmol/L)	2.50 ± 1.01	2.53 ± 0.74	0.43
Duration of T2DM (year)	5.3 ± 3.8	6.1 ± 3.7	0.25
Smoking	8(19.0%)	15(33.3%)	0.13
Oral antidiabetic drugs	31(73.8%)	29(64.4%)	0.35
Insulin treatment	11(26.2%)	15(33.3%)	0.47
H. pylori infection	19(45.2%)	23(51.1%)	0.58
Folate (< 4.6 ng/mL)	5(11.9%)	4(8.9%)	0.73
Vitamin B12 (< 211 pg/mL)	1(2.4%)	1(2.2%)	0.96
Iron (< 11.6 μmol/L for men, < 9.0 μmol/L for women)	3(7.1%)	3(6.7%)	0.93

BMI body mass index, *HbA1c* glycosylated hemoglobin, *FPG* fasting plasma glucose, *HOMA-IR* homeostasis model assessment insulin resistance, *TG* triglyceride, *TC* total cholesterol, *HDL* high-density lipoprotein, *LDL* low-density lipoprotein

Table 2 Comparison of the BPL50/AL50 and BPL100/AL100 groups on clinical variables at 5 years

	BPL50/AL50	BPL100/AL100	*P*
Follow-up	38	40	
BMI (kg/m^2)	27.12 ± 3.11	27.08 ± 3.01	0.00
Waist (cm)	94.66 ± 10.33	93.18 ± 9.57	0.04
WHR	0.96 ± 0.12	0.95 ± 0.14	0.07
TWL%	10.9 ± 3.7	23.4 ± 5.8	0.00
HbA1c (%)	7.86 ± 1.61	7.07 ± 1.91	0.01
FPG (mmol/L)	7.54 ± 2.72	7.01 ± 2.05	0.02
HOMA-IR	5.81 ± 1.22	4.58 ± 0.78	0.00
TG (mmol/L)	2.47 ± 3.98	1.79 ± 1.52	0.04
TC (mmol/L)	4.34 ± 2.11	4.38 ± 0.81	0.06
HDL (mmol/L)	1.12 ± 0.36	1.22 ± 0.36	0.21
LDL (mmol/L)	2.51 ± 0.69	2.47 ± 0.64	0.04
Folate (< 4.6 ng/mL)	1(2.5%)	2(5.0%)	0.59
Vitamin B12 (< 211 pg/mL)	3(7.9%)	6(15.8%)	0.29
Iron (< 11.6 μmol/L for men, < 9.0 μmol/L for women)	3(7.9%)	4(10.0%)	0.75

BMI body mass index, *WHR* waist-hip ratio, *TWL* total weight loss, *HbA1c* glycosylated hemoglobin, *FPG* fasting plasma glucose, *HOMA-IR* homeostasis model assessment insulin resistance, *TG* triglyceride, *TC* total cholesterol, *HDL* high-density lipoprotein, *LDL* low-density lipoprotein

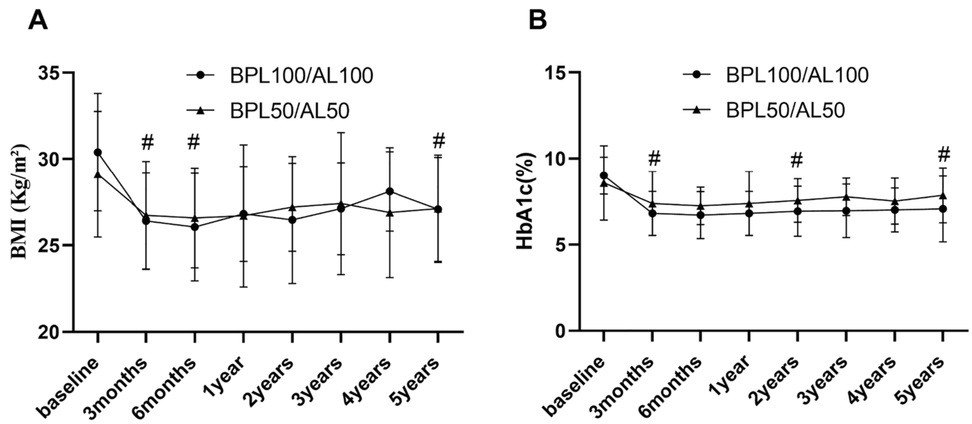

Fig. 1 Mean changes in BMI and HbA1c from baseline to 5 years. Shown are body-mass index (BMI, the weight in kilograms divided by the square of the height in meters) (**A**) and the mean glycated hemoglobin levels (**B**). # *P* values < 0.05 for the comparison between the BPL50/AL50 and BPL100/AL100 groups

Table 3 Remission of type 2 diabetes mellitus between the two groups

		1 year	2 years	3 years	4 years	5 years
Follow-up	BPL50/AL50	42	40	39	40	38
	BPL100/BPL100	42	43	41	39	40
Complete remission	BPL50/AL50	10(23.8%)	7(17.5%)	5(12.8%) *	5(12.5%) *	4(10.5%)
	BPL100/BPL100	15(35.7%)	14(32.6%)	14(34.1%)	12(30.8%)	11(27.5%)
Partial remission	BPL50/AL50	8(19.0%)	6(15.0%)	4(10.3%)	3(7.5%)	3(7.9%)
	BPL100/BPL100	10(23.8%)	8(18.6%)	7(17.1%)	5(12.8%)	4(10.0%)
Improvement	BPL50/AL50	7(16.7%)	6(15.0%)	6(15.4%)	3(7.5%)	2(5.3%)
	BPL100/BPL100	10(23.8%)	9(20.9%)	10(24.4%)	8(20.5%)	7(17.5%)
Total	BPL50/AL50	25(59.5%) *	19(47.5%) *	15(38.5%) *	11(27.5%) *	9(23.7%) *
	BPL100/BPL100	35(83.3%)	31(72.1%)	31(75.6%)	25(64.1%)	22(55.0%)

[*] $P < 0.05$ compared with BPL100/AL100

Table 4 T2DM remission rate at 1 year according to the preoperative ABCD scoring system

ABCD score		*N*	Complete remission	Partial remission	Improvement
0–3	BPL50/AL50	5	0	0	1(20.0%)
	BPL100/BPL100	5	1(20.0%)	1(20.0%)	1(20.0%)
4–6	BPL50/AL50	19	3(15.8%)	4(21.0%)	2(10.5%)
	BPL100/BPL100	17	3(17.6%)	3(17.6%)	4(23.5%)
7–10	BPL50/AL50	18	7(38.9%)	4(22.2%)	4(22.2%)
	BPL100/BPL100	20	11(50.0%)	6(30%)	5(25.0%)

TWL%, longer duration of diabetes and longer lengths of limbs (BPL + AL) (Table 5).

Complications

In general, there was no significant difference in nutritional status between the two groups (Table 2, $P > 0.05$). No patients died after surgery. In the BPL50/AL50 group, one patient had bleeding due to poor anastomosis of the linear cutting staple. The bleeding was successfully stopped under the endoscopy, and the patient was discharged without further incident. Two patients required revision surgery due to poor postoperative glycemic control. In the BPL100/AL100 group, one patient was readmitted to the hospital with vomiting. No patients suffered from a pulmonary embolism after surgery. The early complication and late complication rates were similar in the BPL50/AL50 and BPL100/AL100 groups.

Discussion

Gastric bypass surgery has proved to be one of the most reliable and effective methods for treating morbidly obese patients [13, 14]. In Chinese patients, T2DM is characterized

Table 5 The associations between diabetes remission at 1 year and clinical parameters

	P values (univariate)	*P* values (multivariate)
Age	0.025	0.149
BMI	0.048	0.057
TWL%	0.038	0.043
HbA1c (%)	0.056	0.398
FPG (mmol/L)	0.078	0.146
C-peptide (ng/mL)	0.365	0.158
Duration of diabetes	0.063	0.025
Waist (cm)	0.234	0.343
HOMA-IR	0.234	0.125
Length of limb	0.016	0.047

BMI body mass index, *TWL* total weight loss, *FPG* fasting plasma glucose, *HOMA-IR* homeostasis model assessment insulin resistance

primarily by a lower BMI (mean BMI 25 kg/m^2) and worse islet function with central obesity, compared to Caucasian individuals [15, 16]. Because populations differences lead to differences in the pathological characteristics of diabetes, there can also be differences in treatment methods. By making a small stomach pouch of 20 to 30 mL and bypassing the gastric remnants, proximal duodenum, and jejunum; these anatomical changes will further cause the secretion of intestinal hormones and intestinal bacteria composition changes, in turn leading to improved metabolism. Therefore, Western countries have made many improvements to RYGB surgery based on the characteristics of the population, such as lengthening the AL or BPL or even both. In contrast, there has not been much exploration of the optimization of these parameters in the East Asian population, which is characterized by a low BMI.

According to our study, both BPL50/AL50 and BPL100/AL100 decreased BMI significantly at 3 months, 6 months, and 1 year, but over the long term, the BPL50/AL50 group showed poorer results than the BPL100/AL100 group. Similarly, a systematic review of 8 studies also stated that long Roux limbs might result in greater weight loss after surgery for patients with BMI > 50 kg/m^2 [17]. Compared with the BPL50/AL50 group, the BPL100/AL100 group bypassed more of the jejunum, leading to early malabsorption of nutrients, in turn causing a significant early loss of weight. However, in the long-term, the weight loss effect decreased. The length of the AL also affects postoperative weight loss. The results of this study also showed that the weight loss of the BPL50/AL50 group was significantly lower than that of the BPL100/AL100 group at 5 years, and there was a difference compared with the preoperative values. Therefore, many suggestions for the AL length have been made in previous studies [5, 6, 18]. Among them, a study reported that, compared with a short AL of 100 cm, a long AL of 150 cm resulted in no difference in weight loss after 5 years. Of course, BPL length is also an important factor in weight loss. Smelt et al. reported that patients with a longer BPL achieved significantly greater %TWL than those with a shorter BPL at 2 years postoperatively (35.6 ± 8.6 versus 31.6 ± 7.5) [19]. Boerboom et al. reported that a long BPL and a short AL result in more weight loss, and they explained that a longer BPL might be the more obvious hindgut effect produced. The postprandial glucagon-like peptide-1 (GLP-1) response increases, decreasingly appetite and gastrointestinal motility and ultimately leading to greater weight loss [20].

In the current study, both the BPL50/AL50 and BPL100/AL100 groups had better glycemic control in the early stage than in the later stage. The total remission rate of diabetes in the BPL50/AL50 group was significantly lower than that in the BPL100/AL100 group during different periods. The total remission rates of T2DM observed in our patients who underwent RYGB with a 100-cm long BPL and 100-cm AL were 83.3% at 1 year, 72.1% at 2 years, 75.6% at 3 years, 64.1% at 4 years and 55.0% at 5 years, which are lower than those previously reported in a clinical study of diabetes patients with BMI > 35 kg/m^2 who underwent RYGB with a 200-cm BPL and a 120-cm AL [21]. Similarly, a prospective study showed that in patients with diabetes with BMI between 30 and 34.9 kg/m^2 who underwent RYGB with a BPL of 200 cm and an AL of 50 cm, a complete remission rate of 92.2% was observed [22]. The complete remission rates were lower than those in several previous studies. A single-center, randomized, controlled trial performed by Mingrone et al. reported that the partial remission rate was 75% at 2 years, 37% at 5 years and 25% at 10 years [23, 24]. Lee et al. reported that complete remission was achieved in 57% at 1 year and 55% at 2 years after gastric bypass in patients with BMI < 35 kg/m^2 [25]. A randomized, controlled trial reported that the remission (partial or complete) rate was 60% at 1 year, 45% at 2 years, 40% at 3 years, 30% at 4 years, and 30% at 5 years after RYGB in T2DM patients with BMI of 30 to 40 kg/m^2 [26]. It can be understood from our results that the overall diabetes remission rate in the BPL100/AL100 group dropped from 83% at 1 year to 55% at 5 years, which is also a downward trend. Although the remission rate in the third year was higher than that in the second year, there was no significant difference between the two. In addition, the difference in remission rate could be related to the differences in the lengths of the BPL and AL. The BPL/AL length was 75/100 cm in Mingrone G et al.'s study and 80/120 cm in Lee et al.'s study. This finding also indicated that the antidiabetic mechanisms of RYGB depend on the lengths of the BPL and AL. Patrício found that a long biliopancreatic limb (200 cm) was associated with higher fasting and postprandial GLP-1 and lower postprandial insulin/C-peptide and GIP levels compared the classical RYGB procedure [27].

It is well known that the mechanism by which RYGB improves metabolism is through restriction of nutrient intake and nutrient malabsorption. Insulin resistance is one of the main pathological mechanisms of T2DM. However, once beta cell failure occurs, insulin secretion is no longer sufficient to compensate for insulin resistance, and insulin resistance will manifest. For the East Asian population, the rapid failure of insulin function is the most prominent manifestation of diabetes [16]. Currently, there are two main hypotheses to explain the improvement in T2DM individuals following RYGB. The foregut theory states that the exclusion of the duodenum and the proximal jejunum reduces food stimulation, thereby reducing the release of anti-incretin; glucose-dependent insulinotropic polypeptide (GIP) is considered to be the main anti-incretin hormone secreted by the foregut, and GIP can inhibit gastric emptying. The hindgut theory states that food directly enters the terminal ileum after redirection so that the terminal ileum secretes GLP-1, which increases the release of incretin and better controls glucose metabolism [28]. Studies have reported that the density of incretin in cells at 200 cm of the duodenal angle is significantly different from that of the proximal small intestine mucosa [29]. As food quickly enters the distal small intestine, it stimulates the rapid secretion of GLP-1, thereby achieving glycemic control. In conclusion, BPL and AL are also major elements in diabetes remission. Nora et al. reported that a long BPL (200 cm) was also associated with a higher T2DM remission rate (73% vs 55%, $P < 0.05$) than a standard BPL (84 ± 2 cm) [30]. A prospective study reported that patients who underwent gastric bypass with a 200-cm BPL had 92.7% and 100% diabetes remission rates at 1 year and 3 years, respectively [21]. In the results of multivariate analysis, higher TWL%, longer duration of diabetes and longer lengths of limbs (BPL + AL) were statistically significantly different. TWL% and duration of diabetes has been consistently recognized as independent predictors of postoperative T2DM remission [31–33]. In RYGB surgery, the longer that the length of the BPL and AL are that are excluded, the faster that food will reach the distal end of the small intestine, limiting the absorption of food, and the greater that the postoperative weight loss. This finding also verifies the effects of BPL and AL lengths on the diabetes remission rate.

In addition to the improvement of glycemic control, the lipid profiles of the two groups were improved to a certain extent. Our current results are consistent with previously published data [34], and both studies indicate an improvement in lipid profiles after RYGB. A paired study that matched age, sex, BMI, and excess weight loss showed that RYGB could significantly reduce TC and LDL levels. However, the article did not describe the lengths of the AL and BPL in detail. Conversely, the patients that the authors included had BMI greater than 35 kg/m^2 [35]. Compared with their study, there was no difference between our two groups in sex, age, or BMI, but our research results showed that the TG and LDL levels of the two groups significantly decreased after 5 years, and those of the BPL100/AL100 group decreased more significantly. This outcome also reflects the influence of BMI and the lengths of the BPL and AL on lipid metabolism.

In our current study, there were no significant differences in early or late complications between the two groups, and there were no deaths or malnutrition events. One possible explanation for these findings is intestinal adaptation, which is a change in the structure and function of the intestinal epithelium after bowel resection or malabsorption surgery; the corresponding channel protein expression is upregulated, thereby compensating for malnutrition caused by bowel resection, but this compensation is limited [36]. Although extending limb length will have a positive effect on glycemic control, diabetes relief, and lipid profiles, it does not mean that we can excessively increase the lengths of the limbs because the lack of postoperative nutrients has always been an unavoidable problem for gastric bypass surgery [37, 38]. In particular, for limb lengths greater than 200 cm, the lack of nutrients after surgery is particularly obvious. Gasteyger et al. stated that the incidence of calcium and vitamin D deficiency increased significantly with the length of the Roux-en-Y limb [39]. Similar to our results, Inabnet reported calcium, iron, folate, vitamin B12, and vitamin D levels in patients in the short limb group (BPL 50 cm, AL 100 cm) and in the long limb group (BPL 100 cm, AL 150 cm) that were not significantly different from those at 3 to 12 months [40]. This outcome shows that extending the length of the limb to a certain extent might not result in a lack of nutrients. Of course, routine supplementation after surgery is also indispensable. The risk of postoperative nutritional deficiency requires further long-term monitoring. A major strength of the current study was having assessed the impact of BPL and AL lengths on T2DM metabolic improvement at 5 years for patients with BMI < 35 kg/m^2.

Conclusions

The efficacy of gastric bypass surgeries with BPL100/AL100 is more stable and obvious for diabetic patients with BMI < 35 kg/m^2 compared with that with BPL50/AL50, and BPL100/AL100 offers significant improvements in weight loss, glycemic control and lipid profiles.

Funding This study was funded The New Xiangya Talent Project of the Third Xiangya Hospital of Central South University (JY201708).

Declarations

Ethical Approval and Consent to Participate All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

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

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