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ORIGINAL RESEARCH

Analysis of Predictive Factors for the Efficacy of Modified Three-Port Laparoscopic Sleeve Gastrectomy in Treating Type 2 Diabetes Mellitus

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Objective: This retrospective cohort study identified predictors of treatment efficacy for modified three-port laparoscopic sleeve gastrectomy (TPLSG) in managing type 2 diabetes mellitus (T2DM).

Methods: We retrospectively analyzed clinical data from 187 T2DM patients who underwent modified TPLSG. Patients were categorized into effective group (those with satisfactory weight loss and diabetes remission/improvement) and ineffective group [those with insufficient weight loss and/or inadequate glycemic control (including patients meeting either or both criteria)]. After comparing baseline characteristics between groups, we performed *Logistic* regression analysis on significantly different variables to identify factors influencing treatment outcomes. A predictive nomogram was constructed and validated using calibration curves to assess the clinical value of these factors in predicting TPLSG efficacy for T2DM.

Results: This study conducted a total inclusion of 187 T2DM patients who were grouped according to whether they performed effective or ineffective after treatment with modified TPLSG. 131 were included in the effective group and 56 in the other group. In respects of baseline C-peptide level, duration of diabetes, baseline triacylglycerol (TG) level, baseline homeostasis model assessment of insulin resistance (HOMA-IR) and baseline glycated hemoglobin (HbAlc) levels, the two groups displayed statistical significance ($P < 0.05$). Covariance analysis and *Logistic* regression equations for above factors revealed that none of them were covariate ($VIF \leq 10$, tolerance ≥ 0.1) and all of them were influential factors leading to poor treatment effect after modified TPLSG, it was found that the mentioned factors boasted high application value in predicting the efficacy of patients after modified TPLSG by nomogram and calibration curves.

Conclusion: Baseline C-peptide level, duration of diabetes, baseline TG, baseline HOMA-IR, and baseline HbAlc level were all relevant factors affecting the treatment effect of patients with T2DM treated with modified TPLSG, which should be focused on and interfered in a targeted way in actual clinical practice.

Keywords: modified three-port laparoscopic sleeve gastrectomy, TPLSG, type 2 diabetes mellitus, C-peptide levels, insulin resistance index

Introduction

Type 2 diabetes mellitus (T2DM) is a common chronic metabolic disease with a complex pathogenesis that involves the interaction of poor lifestyle habits, environment, and genetic factors.[1] In the early stages of the disease, insulin resistance often appears, with symptoms being relatively subtle. Insulin resistance causes the body's cells to utilize insulin less efficiently than normal, reducing the ability to adapt to insulin responses. With the development of the disease, patients tend to manifest symptoms such as increased appetite, blurred vision, and numbness and tingling in the hands and feet, and ketoacidosis may occur in severe cases, posing a danger to life and health.[2] At present, the primary clinical treatment

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options for this disease include medication management, self-management education, and lifestyle modifications such as diet, exercise, and weight control. However, these methods cannot completely eliminate insulin resistance. Moreover, long-term use of hypoglycemic drugs will induce dependence and drug resistance, causing damage to liver and kidney function. Sasani N et al[3] believed that controlling appetite of patients with T2DM improved the blood glucose level of the body as evidenced by the performed reduction of weight as well as upgrade of the blood glucose level and insulin sensitivity by adjustment of the total calorie intake of the diet.

Zhang J et al[4] scholars concluded that sleeve gastrectomy (SG) was the most effective therapeutic option for T2DM because of its effective controlment of patient appetite. SG is a weight loss surgery that controls food intake of patients by removing most of the gastric structures, which improves the overall metabolic status by changing the physiological structure of the gastrointestinal tract to control appetite. However, it requires the use of multiple laparoscopic probes and causes more damage to the organism. It has been indicated that the modified three-port laparoscopic sleeve gastrectomy (TPLSG) possessed well-defined procedure and created smaller incision which helped in postoperative recovery.[5] The procedure only preserves the lesser curvature of the stomach, forming a three-dimensional "sleeve" gastric tube. The smaller volume of stomach after the operation reduces the secretion of hormones such as gastrin and gastric motility, prolonging the time that the food stayed in the stomach, which creates a continuous stimulation of the stomach wall that suppresses the appetite and further enhances the feeling of satiety. Avoiding fluctuations on blood glucose level caused by excessive intake of calories and sugar as well as keeping proper satiety make contributions to maintain insulin balance, promote the conversion of excess sugar into glycogen, and indirectly regulate symptoms of diabetes mellitus. Relevant studies have shown that SG can improve diabetic cardiomyopathy by reducing body weight, regulating lipid metabolism, and modulating inflammatory pathways, thereby protecting myocardial function. Currently, standard SG has been recognized as a safe and effective procedure in consensus statements. Compared to traditional gastric bypass surgery, TPLSG is simpler to perform, requires shorter operative time, and has no reported severe long-term complications.[6,7] However, in accordance with related study,[8] about 13% of T2DM patients manifested poor disease control after TPLSG with certain complications affecting the prognosis of patients. Therefore, it is of great significance to explore the influencing factors that lead to the poor efficacy of T2DM patients after modified TPLSG, which is conducive to improvement of the accuracy of preoperative assessment and postoperative prognosis, and shortening of the process of postoperative recovery.

Relevant studies indicate that C-peptide levels are closely associated with postoperative diabetes remission, and higher C-peptide levels may predict better surgical outcomes. Meanwhile, HbA1c, as the gold standard for long-term glycemic control, is strongly correlated with the risk of diabetic microvascular complications, aligning with current guidelines for the comprehensive management of T2DM. Additionally, insulin resistance markers such as homeostasis model assessment of insulin resistance (HOMA-IR) not only help predict complications like diabetic nephropathy but also provide a basis for disease stratification and personalized treatment.[9,10] However, current research on the combined predictive value of these factors for the efficacy of modified TPLSG in treating T2DM remains limited. Further in-depth studies in this direction is helpful to derive predictive factors, which are conducive clinical staff to identify patients at high risk in time and formulate appropriate interventions to ameliorate the clinical efficacy of the surgery. Therefore, this study selected 187 patients received modified TPLSG in our hospital as research subjects, observed the treatment effect of all patients after surgery, and explored the potential connection between the difference items and the poor treatment effect of T2DM after surgery from the analysis of the basic data of patients with different efficacy, thus providing substantial guidance and evidence-based medical arguments for clinical follow-up treatment plan of T2DM.

Information and Methods

Research Objects

Clinical data of 187 patients with T2DM treated by modified TPLSG surgery from December 2020 to December 2024 in our hospital were retrospectively analyzed. Based on therapeutic efficacy, with α=0.05, β=0.2 (80% statistical power), and an effect size of 0.3, the calculated minimum sample size requirement was n=128 cases. This study included n=187 cases, which meets the sample size requirement. The study was reviewed and approved by the Ethics Committee of

Anqing First People's Hospital Affiliated to Anhui Medical University (Approval No.: AQYY-YXLL-KJJKT-202215) with all procedures of this study conducted in accordance with the ethical standards of the *1964 Declaration of Helsinki* and its subsequent amendments. All patients or their family members were informed and provided signed consent.

Inclusion Criteria

(1) In conformity to the diagnostic criteria for T2DM in *Classification and Diagnosis of Diabetes: Standards of Medical Care in Diabetes-2020;*[11] (2) presence of insulin secretion, body mass index (BMI) ≥32.5 kg/m^2 or 27.5 kg/m^2 ≤BMI <32.5 kg/m^2, with two criteria for metabolic syndrome and indications for TPLSG treatment;[12] (3) aged from16 to 65; (4) duration of drug treatment ≥1 year; (5) complete clinical data and good compliance.

Exclusion Criteria

(1) Combined with secondary obesity or severe diabetes complications; (2) combined with hypothyroidism and other endocrine diseases; (3) combined with heart, lungs, and other main organs organic lesions or coagulation dysfunction; (4) previous history of weight-loss metabolic surgical treatments or dialysis treatments; (5) combined with gestational diabetes mellitus or immune system disorders; (6) combined with psychiatric disorders or a history of substance abuse; (7) received anticoagulant therapy prior to TPLSG treatment.

Modified TPLSG Method

Patients were directed to take lying split-leg position followed by general anesthesia tracheal intubation, sterilization, and draping. A 10~15mm curved incision was made above the umbilicus to establish a CO_2 pneumoperitoneum with pressure maintained at 12~15mmHg, and under the direct view of the laparoscope (Jiangsu Anmao Medical Technology Co., Ltd., TC200EN + TL300 + 26003AA), a 12mm laparoscopic trocar was inserted through the umbilicus at the lower edge of the umbilicus [Trocar, Yingtai (Suzhou) Medical Science and Technology Co., Ltd., Suzhou Medical Device Approval No. 20192021560] as the observation and main operation hole, and one 5-mm trocar was made symmetrically at the right and left rib margins below the midclavicular line as the secondary operation hole. Patients were taken head high left high position, left side tilt 15°, with left liver outer edge 1 cm using purse string, disposable urinary catheter suspension liver device. Gauze block with shadow line was chosen to lay flat on the Greater Omentum, fixed by its friction on the left side of the abdomen. 36F gastric correction tube was placed into the main operation hole to empty the gastric contents. After freeing the greater curvature at 3 ~5 cm from the pylorus to the cardia, gastroesophageal junction was cut open at the incision (His) angle. Along pylorus 5cm away to the cardia 1cm away of the support tube for the cutting marking line, a laparoscopic joint head cutting anastomosis was used to cut the stomach vertically in the lesser curvature, and then the remaining stomach was completely dissected vertically. After the creation of the gastric bursa was completed, the cutting anastomosis was used to transversely dissect the small intestine at the 100 cm level of the suspensory ligament of the duodenum (Trietz), and the distal part of the bursa was closed and anastomosed anteriorly to the colon. Absorbable barbed sutures were used to reinforce the incision margins with continuous sutures, hemostasis was achieved, and gauze was counted, then the gastric tube was removed, ensued with the removal of specimen after dilating the umbilical incision. Next, the liver suspension device was demolished, and the abdomen was closed layer by layer after puncture electrocoagulation stopping the hemorrhage.

Intervention Measures

During hospitalization, patients were advised to perform moderate-intensity aerobic exercises (such as brisk walking, swimming, or cycling) for at least 150 minutes per week, tailored to their individual condition. Health education was provided, covering topics including the etiology, pathogenesis, treatment methods, dietary control, and exercise rehabilitation of diabetes. To reinforce post-discharge health management, follow-up strategies such as telephone calls, distribution of contact cards, and the establishment of a follow-up database were implemented.

Assessment of Clinical Efficacy

① In terms of international common criteria of *Bariatric analysis and reporting outcome system (BAROS) applied to laparoscopic gastric banding patients*,[13] the percentage of excess weight loss (%EWL) = [(initial preoperative body mass) - (body mass on the day of postoperative follow-up)]/[(initial preoperative body mass) - (preoperative body mass index exceeding 23)]/ *100%. %EWL ≥ 50% represents good weight loss effect while %EWL <50 refers to insufficient weight loss effect or ineffective weight loss.

② In reference to the criteria of *Diagnosis and management of diabetes: synopsis of the 2016 American Diabetes Association Standards of Medical Care in Diabetes*[14] for evaluation of glycemic control. Cure: fasting blood glucose <5.5 mmol/L, Glycated Hemoglobin (HbAlc) <6%, no need for glucose-lowering medication; HbAlc <7%, no glucose-lowering medication; remission: fasting blood glucose decreased >1.39 mmol/L, HbAlc decreased >1%, partially improved; vitiation: glucose-lowering medication or insulin control was still needed after surgery, no change in each blood glucose index.

Inclusion criteria for the effective group: patients with good weight loss effect coupled with cured or alleviated blood sugar; inclusion criteria for the ineffective group: patients with insufficient or ineffective weight loss effect, patients with partially improved or ineffective blood sugar control, and patients with both of mentioned results.

Medical Data

Related information of patients was collected by reviewing medical data, ① clinical characteristics: gender, age, body mass index, history of smoking and drinking; ② disease characteristics: duration of diabetes mellitus, family history of diabetes mellitus, comorbid hypertension, comorbid hyperlipidemia; ③ laboratory indicators: fasting glucose, postprandial glucose, fasting insulin, baseline C-peptide, preoperative systolic blood pressure, preoperative diastolic blood pressure, and baseline triacylglycerol (TG), baseline HOMA-IR, baseline HbAlc.

Measurement of Laboratory Indicators

Before the operation, 5mL fasting elbow vein blood of patients was taken in the early morning, followed by separation of the serum by centrifugation for 15 min using automatic biochemical analyzer (Ningbo Hailshi Intelligent Manufacturing Co., Ltd.; model: Beckman Coulter Au5800) with a speed of 3000 r/min with placed in constant temperature box (Suzhou Novelty Measurement and Control Technology Co., Ltd). at −35°C for storage and examination. Enzyme-linked immunosorbent assay (Wuhan Aidi Antibiotech Co., Ltd) was used to determine fasting blood glucose, postprandial blood glucose, HbAlc level, TG and fasting insulin level in serum supernatant, and pulse-wave sphygmomanometer (Shenzhen Ruiguang Container Science and Technology Co., Ltd) was adopted to measure the preoperative systolic blood pressure and preoperative diastolic blood pressure level of patients. Fully automated chemiluminescence immunoassay analyzer (Abbott Architecti; model: i2000SR, USA) was applied to detect C-peptide levels, HOMA-IR = (fasting glucose water*fasting insulin)/22.5.

Observation Objects

(1) By observing the treatment effect situation of patients after modified TPLSG surgery, factors affecting the efficacy of modified TPLSG surgery for T2DM were analyzed according to difference items through multivariate linear regression with covariance analysis of the difference indexes of the single-factor analysis and multifactorial analysis of the indexes without covariance problems, then observed the influence of each index on the efficacy of modified TPLSG surgery.

(2) A nomogram was drawn to construct a predictive model of the influence of factors on poor treatment effect after modified TPLSG with the curve plotted for further validation.

Statistical Analysis

IBM SPSS 27.0 (IBMCorp., Armonk, N.Y., USA) statistical software and the χ^2 test was adopted for analysis of the data with the count data expressed as "n"; the normal distribution test was carried out by Shapiro–Wilk method for the measurement data, and those failed to conform to the normal distribution were expressed by median and interquartile spacing [M (P25, P75)], while conformed data were shown as mean ± standard deviation (SD) using the *t* test. $P < 0.05$ referred to statistical significance. To control for potential confounding factors, multicollinearity was assessed by variance inflation factor (VIF) and tolerance. Items differed between two groups were brought into *Logistic* regression equations to analyze the factors affecting poor effect after modified TPLSG surgery, with poor effect of modified TPLSG surgery as the dependent variable, clinical data as the independent variable, and P=0.05 as the criterion for gradual screening of variables.

Results

Comparison of Clinical Data Between the Two Groups of Patients

A total of 187 patients with T2DM were included in the study, and they were grouped according to the effectiveness of the modified TPLSG treatment. 131 patients with good weight loss and cured or relieved of blood glucose were enrolled into the effective group, while 56 patients with insufficient or ineffective weight loss and partially improved or ineffective blood glucose control were included in ineffective one. Compared with the ineffective group [8.00 (7.00,8.00) years, (8.73±0.94)%, 3.35 (3.10,3.60) ng/mL, 2.900 (2.50,3.10) mmoL/L, 4.200 (3.80,4.70)], the duration of 6.00 (6.00,7.00) years, baseline HbAlc level (7.42±0.86)%, baseline C-peptide level 4.10 (3.80,4.40) ng/mL, baseline TG level 2.400 (2.20,2.60) mmoL/ L, and baseline HOMA-IR level 3.700 (3.30,4.10) in the effective group with diabetes exhibited statistical differences (P<0.05, Table 1).

Table 1 Comparison of General Data

Indices		Effective group (n=131)	Ineffective group (n=56)	χ^2/t/z	*P*
Clinical feature					
Gender (cases)	Male	58	25	0.002	0.963
	Female	73	31		
Age (years)		56.00(52.00,60.00)	57.00(54.00,60.80)	0.552	0.581
Body mass index (kg/m^2)		29.50(28.10,32.40)	29.100(27.50,31.80)	1.281	0.202
Smoking history (cases)	Yes	30	15	0.324	0.569
	No	101	41		
Drinking history (cases)	Yes	49	25	0.860	0.354
	No	82	31		
Characteristics of the disease					
Duration of diabetes (years)		6.00(6.00,7.00)	8.00(7.00,8.00)	8.709	<0.001
Family medical history (cases)	Yes	25	17	2.963	0.907
	No	106	39		
Combined hypertension (cases)	Yes	39	18	0.104	0.747
	No	92	38		
Combined hyperlipidemia (cases)	Yes	56	26	0.216	0.642
	No	75	30		
Complications (cases)	Diabetic ketoacidosis	4	5	5.223	0.265
	Hyperglycemic hyperosmolar state	1	1		
	Diabetic retinopathy	24	14		
	Diabetic nephropathy	35	17		
	Diabetic neuropathy	25	6		
Laboratory indicators					
Fasting blood glucose (mmol/L)		7.81±0.91	7.93±0.96	0.812	0.418
Postprandial 2h blood glucose (mmol/L)		18.36±2.19	17.69±2.46	1.846	0.067
Fasting insulin (uIU/L)		8.31±1.29	8.16±1.45	0.701	0.484
Baseline HbAlc level (%)		7.42±0.86	8.73±0.94	9.276	<0.001
Baseline C-peptide level (ng/mL)		4.10(3.80,4.40)	3.35(3.10,3.60)	9.146	<0.001
Preoperative systolic blood pressure (mmHg)		123.00(118.00,131.00)	126.00(120.00,133.80)	1.552	0.122
Preoperative diastolic blood pressure (mmHg)		77.56±9.46	80.21±9.23	1.767	0.079
Baseline TG level (mmoL/L)		2.400(2.20,2.60)	2.900(2.50,3.10)	8.594	<0.001
Baseline HOMA-IR		3.700(3.30,4.10)	4.200(3.80,4.70)	6.394	<0.001

Abbreviations: TG, triacylglycerol; HOMA-IR, homeostasis model assessment of insulin resistance; HbAlc, glycated hemoglobin.

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Covariance Analysis

The treatment effect of patients after modified TPLSG was assigned as dependent variable, where effective treatment in patients after modified TPLSG was 0 and ineffective treatment represented 1. Baseline C-peptide level, duration of diabetes mellitus, baseline TG, baseline HOMA-IR, and baseline HbAlc level were taken as independent variables. The mentioned independent variables were all measured values. Covariance analysis of the indicators of variance from the univariate analysis revealed that there was no covariance between baseline C-peptide level, duration of diabetes, baseline TG, baseline HOMA-IR, and baseline HbAlc level (VIF ≤ 10, tolerance ≥ 0.1), suggesting that the above indicators could be analyzed by including them in a logistic regression model, details are expressed in Table 2.

Multifactorial Logistic Regression Analysis Affecting Treatment Effect After Modified TPLSG

As shown in Table 3, the difference items were calculated by *Logistic* regression equation, and the results of baseline C-peptide level, duration of diabetes, baseline TG, baseline HOMA-IR, and baseline HbAlc level were the influencing factors of poor treatment effect after modified TPLSG, indicating that the above factors could be included in the construction of the model of improved TPLSG postoperative efficacy.

Nomogram and Calibration Curve for Prediction of Treatment Effect After Modified TPLSG

As displayed in Figures 1 and 2, nomogram and calibration curves were plotted based on the above results, and it was found that the baseline C-peptide level, diabetes duration, baseline TG, baseline HOMA-IR, and baseline HbAlc levels were of high value in predicting the treatment effect of the patients received modified TPLSG. In addition, the calibration curves were similar to the standard ones, which expressed that nomogram rendered better ability of consistency and prediction with high accuracy performed by the model.

Table 2 Analysis of Covariance

Terms	VIF value	Tolerance
Baseline C-peptide levels	1.210	0.827
Diabetes duration	1.192	0.839
Baseline TG Levels	1.169	0.855
Baseline HOMA-IR	1.117	0.895
Baseline HbAlc Levels	1.143	0.875

Abbreviations: TG, triacylglycerol; HOMA-IR, homeostasis model assessment of insulin resistance; HbAlc, glycated hemoglobin; VIF, variance inflation factor.

Table 3 Multifactorial Logistic Regression Analysis Affecting Treatment Effect After Modified TPLSG

Factors	*B* value	SE	WaldX^2	*P*	*OR* value	*OR* value 95% *CI*
Baseline C-peptide level	1.684	0.266	39.988	<0.001	5.387	3.196 ~ 9.079
Course of diabetes	1.583	0.258	37.554	<0.001	4.868	2.934 ~ 8.076
Baseline TG level	2.849	0.520	30.051	<0.001	17.269	6.236 ~ 47.821
Baseline HOMA-IR	1.978	0.381	26.962	<0.001	7.230	3.426 ~ 15.254
Baseline HbAlc level	1.582	0.246	41.278	<0.001	4.862	3.001 ~ 7.877

Abbreviations: TPLSG, three-port laparoscopic sleeve gastrectomy; TG, triacylglycerol; HOMA-IR, homeostasis model assessment of insulin resistance; HbAlc, glycated hemoglobin.

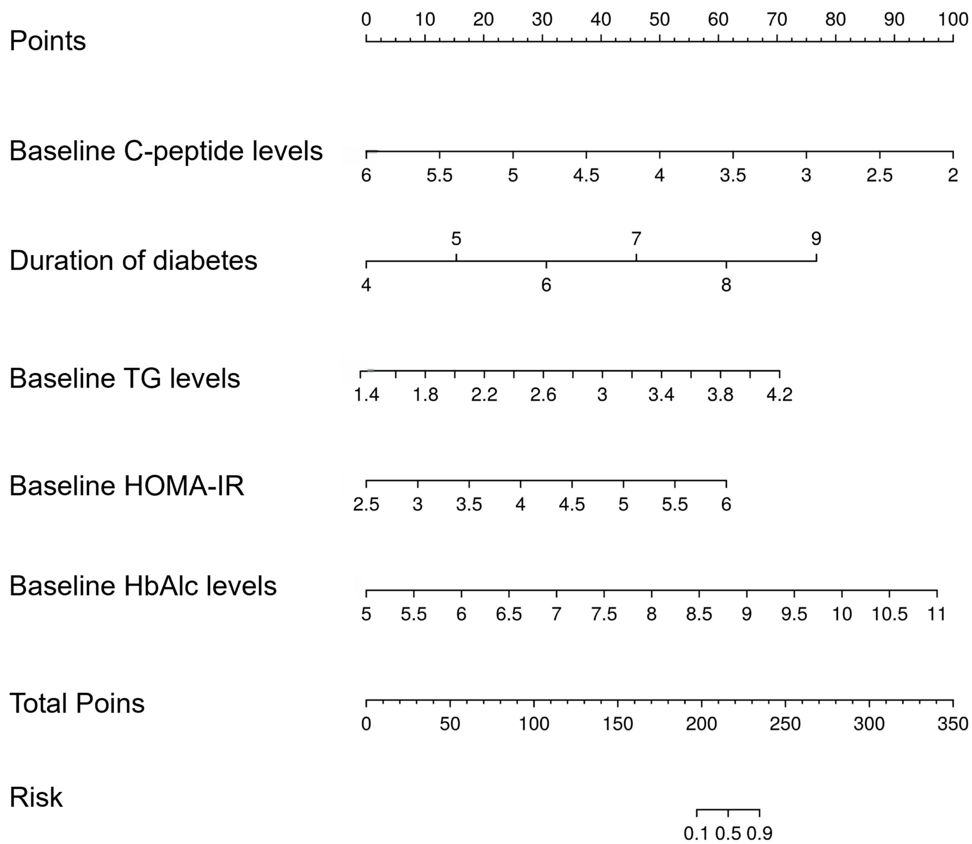

Figure 1 Nomogram predicted patient outcomes after modified TPLSG.
Abbreviations: TG, triacylglycerol; HOMA-IR, homeostasis model assessment of insulin resistance; HbAlc, glycated hemoglobin; TPLSG, three-port laparoscopic sleeve gastrectomy.

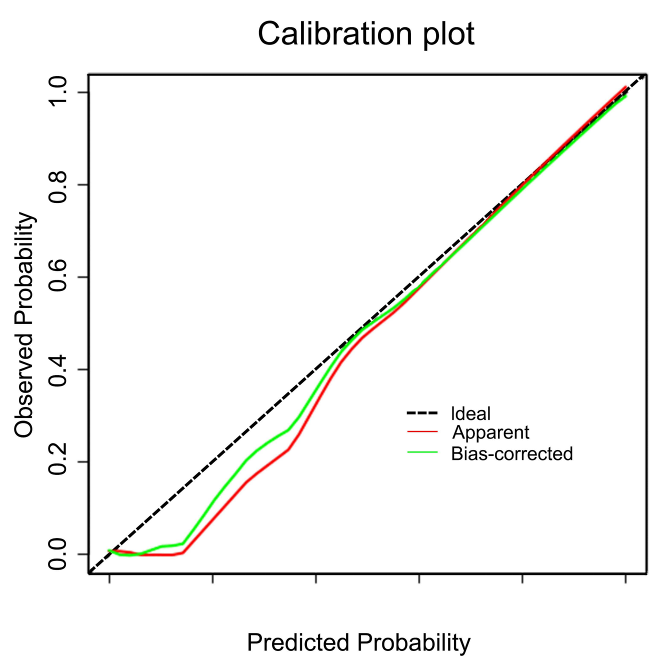

Figure 2 Calibration curve for predicting patient outcome after modified TPLSG.
Abbreviation: TPLSG, three-port laparoscopic sleeve gastrectomy.

Discussion

Relevant data has found that from 2000 to 2017, the morbidity of T2DM rose from 2.8% to 8.4%, showing an uptrend year by year, which is expected to reach about 9.9% by 2045.[15] Sakran N et al[16] concluded that TPLSG was considered as a comfortable and effective alternative in diabetes treatment, which helped to enhance postoperative recovery and quality of life surgery of patients while there still existed poor treatment manifestations in some patients. Therefore, preoperative prediction of relevant factors affecting patients could provide favorable support for clinical development of targeted interventions. A total of 187 patients with T2DM were enrolled in this study, of which 131 experienced effective treatment and included in the effective group, while the other 5 were included in the ineffective group for ineffective treatment impacts. There was statistical significance between the two groups when it comes to the baseline C-peptide level, diabetes duration, baseline TG, baseline HOMA-IR, and baseline HbAlc level ($P < 0.05$); Covariance analysis and *Logistic* regression equations for the above factors revealed that none of them were covariate ($VIF \leq 10$, tolerance ≥ 0.1) and all of them were influential factors for poor treatment effect after modified TPLSG. The AUC values of the above factors and the value of predicting treatment effect after modified TPLSG were found to be high by nomogram and calibration curves. Besides, calibration curves were similar to the standard curves with high model accuracy.

C-peptide is a cleavage product of proinsulin, typically released during insulin synthesis. It serves not only as a marker of insulin production, but also reflects the functional status of pancreatic β-cells and insulin secretion capacity. Furthermore, C-peptide can bind to G protein-coupled receptors (GPCRs) on cell membranes, activating calcium-dependent signaling pathways to stimulate insulin secretion from β-cells. Additionally, through MAPK pathway activation, it enhances the insulin-secreting capability of β-cells. Relevant studies have pointed out that less deterioration of pancreatic islet β-cell function can improve the surgical treatment outcome as much as possible, but a dysfunction of β-cell function may affect the T2DM remission process.[17] With the rise of C-peptide level, the damaged condition of pancreatic islet β-cells is effectively controlled, and the T2DM tends to improve.[18] In this study, the baseline C-peptide level in the effective group was higher than that in the ineffective group ($P < 0.05$), meaning that elevated C-peptide levels were effective in predicting improved efficacy after modified TPLSG.[19] Studies indicate that C-peptide exhibits synergistic effects with insulin in lowering blood glucose and improving microcirculation. Higher baseline C-peptide levels suggest better residual islet function in patients, which may provide a physiological foundation for enhanced postoperative metabolic outcomes.[20] A systematic retrospective analysis showed that stem cell therapy for T2DM patients resulted in a significant increase in C-peptide levels with an obvious improvement, indicating that the rise in C-peptide level could reflect the effectiveness of the treatment for T2DM patients, which was consistent with the results of this study. Therefore, the observation of the trend of C-peptide level could provide guidance for clinical evaluation of the effectiveness of T2DM treatment program.[21]

Research has revealed that under the impact of long-term hyperglycemia and insulin resistance, pancreatic β-cells needed to secrete more insulin to maintain glucose homeostasis, which led to long-term overwork of β-cells and accelerated their functional decline. When patients were in a long-term hyperglycemic environment, inflammation, fatty acids and other factors might directly damage β-cells, prompting apoptosis or functional decompensation.[22] Results of this study manifested that the duration of diabetes mellitus registered lower in the effective group compared to the other one, thus suggesting that longer duration of T2DM brought about worse treatment effect to patients received the modified TPLSG. A cohort study implied a linear negative correlation between diabetes duration and surgical remission rate, ie, a longer duration of diabetes led to the lower the likelihood of complete remission after surgery, which was similar to our results.[23] In addition, relevant studies also confirmed that with the gradual prolongation of T2DM and deterioration of pancreatic islet β-cell function, the recovery process after modified TPLSG might be hindered to some extent.[24,25] Thereby, preoperative focus on and targeted measures for patients with longer duration of diabetes mellitus may further improve the treatment effect after modified TPLSG surgery and enhance the prognosis quality.

In patients with T2DM, blood glucose tends to fluctuate and alternate between hyperglycemia and hypoglycemia. When blood glucose levels improved by treatment, the fluctuation of blood glucose decreases with gradual stable blood glucose levels, leading to a reduction in average concentration of blood glucose and a decrease in the level of HbA1c. In this study, the HbA1c level of the effective group registered lower than that of the ineffective group ($P < 0.05$), indicating that the reduction of HbA1c concentration could reflect the long-term stabilization of blood glucose of patients and the effective improvement of their condition, which was an important manifestation of effectiveness of treatment. According to a cross-sectional study, body mass index and HbA1c levels of patients were reformed within 10 months after treatment with TPLSG, while modified TPLSG surgery was able to upgrade insulin sensitivity and metabolic status of patients by reducing body weight, gastric volume, and part of the gastric acid secretion, with a significant reduction in HbA1c levels, which was in line with the results obtained in this study.[26] Such being the case, monitoring of HbA1c levels could provide a reference for clinical prediction of the efficacy of modified TPLSG.

Insulin resistance is one of the cores of the pathogenesis of T2DM, which mainly refers to the weakening of the role of insulin in target tissues, leading to more insulin secretion to overcome and maintain normal blood glucose levels. Thus, it is able to reflect the improvement of therapeutic efficacy by observation of the status of insulin resistance in patients. In the light of relevant studies, TG is a common lipid component with its elevated level usually associated with insulin resistance; whereas HOMA-IR may reflect the degree of diminished response of body tissues to insulin.[27,28] Previous studies have indicated that higher HOMA-IR indicates more severe insulin resistance and more insulin secretion to maintain normal blood glucose.[29] While the HOMA-IR value is reduced, the insulin utilization efficiency of patients is significantly improved with effective alleviated insulin resistance. Therefore, patients with better efficacy of modified TPLSG tended to register lower HOMA-IR. In the results of this study, the HOMA-IR value of effective group was lower than that of ineffective group, conforming to the above results. A study investigating the predictive value of HOMA-IR for gestational diabetes mellitus (GDM) development during early pregnancy found that HOMA-IR served as a moderate predictor in normal-weight women. However, in overweight/obese groups, the optimal HOMA-IR cutoff value was higher, while its predictive value was relatively lower for advanced maternal age. Our current study demonstrates that HOMA-IR exhibits higher predictive value in T2DM patients, thereby supplementing existing knowledge about HOMA-IR's differential predictive capacity across distinct diabetic populations.[30] This proposed that close attention to patients with higher HOMA-IR values could facilitate the development of appropriate intervention to improve the efficacy of modified TPLSG.

Patients with T2DM are often combined with metabolic disorders such as abnormal lipid metabolism with elevated TG exhibited, and high TG levels are usually closely associated with insulin resistance. According to relevant studies, obese patients are often accompanied by insulin resistance and glucose metabolism abnormalities. Abnormal elevation of TG level of body may cause lipid metabolism disorders, while modified TPLSG can limit food intake, reduce body fat storage, control the increased accumulation of TG and improve the overall lipid metabolism by gastric capacity reduction.[31] Therefore, decreased TG level reforms lipid metabolism and alleviates insulin resistance, thus performing better surgical efficacy. The data in this study also showed that the TG level in the effective group was lower than that in the other group ($P < 0.05$), denoting that patients with lower TG levels had better efficacy after modified TPLSG surgery, which was consistent with the results of above study. Therefore, higher TG levels can act as an important risk factor for predicting the efficacy of modified TPLSG, which needs much focus of clinical practitioners to improve surgical outcomes and prognostic recovery. Column line graphs are a tool for transforming complex statistical predictive models into an easy-to-understand graphical representation, which is now widely used in the medical field. In this study, we integrated clinical information of patients through column-line diagrams, enrolled continuous variables and analyzed the relevant determinants affecting treatment effects, and generated a prediction model for the effects of treatment with modified TPLSG, which enabled physicians to conduct more accurate treatment impacts and formulate targeted interventions to improve treatment efficacy. Moreover, developing personalized nutritional intervention plans based on these factors may improve glycemic control and reduce wound infection rates. Considering the need for long-term post-operative management, metabolic surgery patients may require extended medical support and follow-up to ensure sustained therapeutic efficacy, maintain glucose control and weight management. Through behavioral modifications, complications can be effectively controlled, facilitating patients' return to normal daily life.

However, there are still some shortcomings in this study: (1) As a single-center retrospective study, this research has inherent limitations in terms of spatiotemporal sample selection and cohort size. Furthermore, dynamic factors such as medication adherence and dietary variations could not be fully quantified through medical records alone. These constraints may introduce potential confounding factors and information bias, potentially affecting the accuracy and comparability of the study findings. (2) Our subjects are all from the same region, so the corresponding results may not be applicable to populations from other cultural backgrounds and regions, which may affect the generalizability of the predictors for clinical promotion and application. (3) No external validation of the predictors has been performed, limiting the ability of generalization for results in different data sets. Therefore, a sophisticated multicenter research plan will be subsequently developed for the validity of the results via more data to make our findings cover a wider group of people. We specifically recommend: (1) conducting multicenter cohort studies to verify the predictive model's generalizability in larger samples; (2) designing intervention trials with adjusted baseline cholesterol levels to test mechanistic hypotheses; and (3) investigating the clinical significance of predictive factors for long-term therapeutic outcomes. These approaches will collectively strengthen the evidence base and facilitate clinical translation of the findings. Despite the mentioned limitations, it still provides new ideas for the study of factors contributing to the poor outcome of T2DM patients received modified TPLSG. In addition, considering that some patients still have poor metabolic control after surgery, future research needs to combine quality of life scales (such as SF-36 or BAROS system) to evaluate the impact of postoperative rehabilitation guidance on long-term outcomes, and explore personalized intervention strategies based on predictive models.

In summary, the relevant factors associated with suboptimal therapeutic outcomes in T2DM patients following modified TPLSG include baseline C-peptide levels, duration of diabetes mellitus, baseline TG, baseline HOMA-IR, and baseline HbAlc levels. We recommend incorporating these parameters into routine clinical monitoring protocols and developing a dynamic risk assessment model that integrates these biomarkers with morphological characteristics. Furthermore, patients should be guided in self-monitoring with established rapid feedback mechanisms to enable clinicians to formulate personalized long-term rehabilitation plans, thereby improving sustained therapeutic efficacy and promoting prognostic recovery.

Data Sharing Statement

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising, or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors declare no competing interests.

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