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RESEARCH

Comparison of SADI-S Versus SG in Chinese with Diabetes and BMI < 35 kg/m2:a Retrospective Study with Medium-Term Outcomes

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Abstract

Background As a modification of the duodenal switch (DS), the single-anastomotic ileo-ileal bypass combined with sleeve gastrectomy (SADI-S) has recently gained popularity and has been successfully employed for weight loss and the remission of type 2 diabetes mellitus (T2DM). However, current studies predominantly focus on patients with severe obesity.

Objectives In this study, we present the first comparison of single-anastomotic duodenoileal bypass combined with sleeve gastrectomy (SADI-S) and sleeve gastrectomy (SG) for the mid-term treatment of Chinese diabetic patients with a BMI < 35 kg/m2. This research provides comparative reports on the efficacy of these two surgical approaches.

Patients and Methods We included 53 diabetic patients with BMI < 35 kg/m^2 who underwent either SADI-S or SG and were followed for 2 years postoperatively. Demographic characteristics, weight loss, and nutritional and metabolic outcomes were analyzed at 3-month, 6-month, 1-year, and 2-year follow-up intervals. All surgeries were performed by the same surgeon at a single weight loss center in China between July 2015 and November 2022.

Results A total of 24 patients who underwent Single Anastomosis Duodenal-Ileal Bypass with Sleeve Gastrectomy (SADI-S) and 29 patients who underwent Sleeve Gastrectomy (SG) were included in our analysis. Comparative analysis of the baseline indicators between the two groups revealed no statistically significant differences (P > 0.05).Both patient groups completed a 2-year follow-up. In terms of weight loss, the SADI-S group demonstrated superior outcomes compared to the SG group, with better results in weight, BMI, and total weight loss percentage (%TWL) at the 2-year follow-up, and these differences were statistically significant (66.9 ± 7.9 vs. 61.2 ± 6.6, p = 0.007; 23.8 ± 2.0 vs. 21.7 ± 1.6, p = 0.000; 31.1% ± 6.3% vs. 24.4% ± 6.4%, p = 0.000). Regarding diabetes remission, the SADI-S group also outperformed the SG group (p = 0.000). Specifically, 91.8% of patients in the SADI-S group achieved complete remission of T2DM, compared to 41.4% in the SG group (p = 0.000). Furthermore, the SADI-S group showed significantly better results in the remission of hyperlipidemia compared to the SG group.However, there was no significant difference in hypertension relief between the SADI-S group and the SG group. Additionally, the incidence of postoperative hypozincemia was significantly higher in the SADI-S group compared to the SG group (p = 0.038). No significant differences were observed in other postoperative nutritional outcomes between the two groups.

Conclusion In Chinese diabetic patients with a BMI < 35 kg/m^2, both SADI-S and SG were effective in treating obese T2DM. However, compared with SG, primary SADI-S can achieve better weight loss and remission of obesity-related metabolic diseases.Additionally, the rates of postoperative nutritional deficiencies were found to be acceptable. Nonetheless, multicenter studies with larger sample sizes and longer follow-up periods are necessary to draw definitive conclusions.

Keywords SADI-S · SG,Type 2 diabetes mellitus (T2DM) · Obesity

Introduction

As the changes in modern lifestyle and eating habits, characterized by increased sedentary behavior and a rise in high-energy/high-fat diets, have contributed to a growing prevalence of obesity [1]. Obesity is associated with the

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development of various metabolic diseases, including type 2 diabetes mellitus (T2DM), hyperlipidemia, and hypertension (HTN), as well as cardiovascular disease (CVD). Obesity is a significant risk factor for the development of type 2 diabetes. Concurrently,both obesity and diabetes are increasingly prevalent in China.Recently, epidemiological research indicates that approximately 11% of the population in China is affected by diabetes. Currently, China has the highest number of diabetes patients globally and is among the countries experiencing the most significant increase in diabetes prevalence worldwide [2].The prevalence of young-onset diabetes in China is on the rise. Approximately 20% of diabetic patients in China and other regions of Asia receive their diagnosis before the age of 40 [3]. The increasing prevalence of obesity and associated metabolic diseases significantly impacts individuals' quality of life, places considerable strain on the healthcare system, and has emerged as a critical public health challenge in contemporary society.Traditional treatment measures are often insufficient in addressing obesity and its associated metabolic diseases. In contrast, bariatric surgery has emerged as an effective intervention for these conditions, gradually garnering increased attention and widespread acceptance [4, 5].

Currently, laparoscopic sleeve gastrectomy (LSG) and Roux-en-Y gastric bypass (RYGB) are the most frequently performed bariatric surgeries globally [6].To be more precise, SG has emerged as the most popular weight loss surgery globally, attributed to its simplicity and lower incidence of complications [6, 7]. In addition,Bariatric procedures, particularly BPD and its modified version BPD/DS, are recognized as the most effective treatment modalities for excessive obesity [8, 9]. However, their technical complexity and associated risks of both short and long term nutritional complications such as severe diarrhea and malnutrition result in these procedures accounting for less than 0.5% of all bariatric surgeries performed globally [10]. To simplify the BPD/DS procedure, Sanchez et al. initially proposed the combination of SADI-S, drawing on the surgical principles of BPD/DS [11]. Additionally, SADI-S is acknowledged by organizations such as the International Federation for the Surgery of Obesity and Metabolic Disorders (IFSO) and the American Society for Metabolic and Bariatric Surgery (ASMBS) as a safe bariatric surgical option [12]. It has been reported that SADI-S not only maintains the efficacy of BPD/DS in treating obesity and related metabolic diseases to a greater extent [13], but is also technically less challenging than BPD-DS.In addition, the incidence of surgical complications is lower in comparison to BPD-DS and RYGB [13–21].SADI-S is currently performed exclusively in cases of severe obesity or as a revision surgery following laparoscopic sleeve gastrectomy (LSG), adjustable gastric banding (LAGB), and Roux-en-Y gastric bypass (RYGB).The study by Cottam et al. also indicated that SADI-S resulted in greater relief of T2DM compared to Roux-en-Y gastric bypass (RYGB) [22]. In addition,Most individuals with type 2 diabetes in China exhibit a low body mass index (LBMI) while also presenting with abdominal obesity.Current research on SADI-S in the treatment of obesity and related metabolic diseases primarily targets individuals with severe obesity.However, there are few relevant reports on the SADI-S treatment for patients with T2DM who weigh less than 35 kg/m^2, and there is a lack of comparative studies with other bariatric surgeries.The minimum preoperative body mass index (BMI) as outlined in the Chinese guidelines for bariatric metabolic surgery is 27.5 kg/m^2. Consequently, this study retrospectively analyzed the clinical data of 53 patients with T2DM at our center from July 2015 to November 2022. It compared the efficacy, nutritional outcomes, and micronutrient deficiencies of primary SADI-S versus SG in treating Chinese patients with T2DM who had a BMI of less than 35 kg/m^2. The findings aim to provide valuable guidance for weight loss metabolic surgeons and their patients.

Patients and Methods

Patients

All participants underwent preoperative physical and laboratory examinations, along with multidisciplinary consultations.Additionally, information on preoperative metabolic disorders, including hypertension and hyperlipidaemia, was collected. Patients were followed up at 3, 6, 12, and 24 months postoperatively. The analysis encompassed preoperative characteristics, intraoperative and postoperative conditions, weight loss outcomes, changes in micronutrient and nutrient levels, as well as the remission of obesity-related metabolic diseases.

There were 22 males and 31 females, aged 42 (34–51) years.A comparison of the baseline indicators between two patient groups is shown in Table 1.

Inclusion and Exclusion Criteria

Inclusion Criteria (1) patients with T2DM having a BMI between 27.5 and 35 kg/m^2; (2) *patients who have undergone either primary SADI-S or primary SG;* (3) patients who are willing to undergo bariatric metabolic surgery and accept the potential adverse consequences associated with the procedure.

Exclusion Criteria (1) BMI of patients with T2DM $<$ 27.5 kg/m^2 or $\geq$ 35 kg/m^2; (2) patients undergoing revision or secondary surgery; (3) patient follow-up duration of less than 2 years; (4)) age $<$ 16 or $>$ 65 years old (5) patients with a history of drug abuse or ethanol addiction, those lacking comprehension, unable to comply with postoperative dietary

Table 1 Preoperative baseline characteristics of the two groups of patients

	SG($n=29$)	SADI-S($n=24$)	p
Gender (male/female), n	11/18	11/13	0.057
Mean age (years)	44.7 ± 10.6[c]	39.8 ± 11.4	0.108
Body weight (kg)	88.7 ± 9.9	92.3 ± 13.4	0.267
BMI (kg/mp^2)	31.5 ± 1.7	32.5 ± 2.1	0.061
FBG (mmol/L)	10.3 ± 2.8	10.1 ± 3.6	0.853
HbA1c (%)	8.7 ± 1.9	8.6 ± 1.7	0.977
OGTT (mmol/L)	17.6 ± 3.6	16.0 ± 3.8	0.117
Insulin (μIU/L)	33.3 ± 33.2	29.2 ± 18.0	0.588
Duration of T2D (years)	4.5(1.3–6.8)[a]	1.8(0.3–6)	0.217

SG Sleeve gastrectomy, *SADI-S* Single-anastomosis duodenal-ileal bypass with sleeve gastrectomy, *FPG* fasting plasma glucose, *OGTT* Oral Glucose Tolerance Test

[a]Median (ranges)

[c]Mean ± standard deviation

and lifestyle modifications, and those exhibiting poor adherence; (6) patients who are lost to follow-up after surgery.

Surgery' Main Points

See reference for details [20]*, the difference is that in this study cohort the common channel of SADI-S was extended to 350 cm.*

Observation Indicators and Evaluation Criteria

Observation Indicators

Perioperative conditions: duration of surgery, postoperative hospital stay, and postoperative complications; (2) Weight loss outcomes: weight, BMI, percentage of additional weight loss (%EWL), and percentage of total weight loss (%TWL); (3) T2DM remission: HbA1c and FPG; (4) Hypertension remission: systolic blood pressure (SBP) and diastolic blood pressure (DBP); (5) Hyperlipidaemia remission: total cholesterol(TC) and triglycerides(TG) (6) Nutritional outcome: total protein, albumin, haemoglobin, calcium, iron, zinc, vitamin D, vitamin B12 and folate.

Evaluation Criteria

The Evaluation Criteria is shown in Table 2.

Postoperative Management and Follow-up

Routine standardized care was administered postoperatively. On the first postoperative day, the patient was transferred from the intensive care unit to the general ward. The patient was encouraged to ambulate and to consume a small quantity of water. Routine upper gastrointestinal imaging was

Table 2 The evaluation criteria

Evaluation items	Evaluation criteria
T2DM diagnostic criteria [23]	FPG ≧7.0 mmol/L or oral glucose tolerance test 2 h blood glucose ≧11.1 mmol/L or glycated haemoglobin ≧6.5%
Postoperative complication	Clavien-Dindo grading [24]
T2DM in complete remission [25]	No need for glucose-lowering therapy postoperatively, and glycated haemoglobin < 6.0%
%TWL [26–28]	(Preoperative weight—postoperative weight)/preoperative weight × 100%
%EWL [27, 28]	(Preoperative weight—postoperative weight)/(preoperative weight—ideal weight) (ideal BMI = 23 kg/m^2)
Hypertension diagnostic criteria	Systolic blood pressure (SBP) ≥ 140 mmHg or diastolic blood pressure (DBP) ≥ 90 mmHg
Hyperlipidemia diagnostic criteria [29]	Total cholesterol ≥ 5.7 mmol/L or triglyceride ≥ 1.7 mmol/L
Hyperlipidemia complete remission	No need for oral medication after surgery, total cholesterol < 5.7 mmol/L and triglycerides < 1.7 mmol/L
Wasting Diagnostic criteria [30]	BMI < 18.5 kg/m2 with extreme loss of muscle and/or fat
Anemia	Haemoglobin (HGB) < 110 g/L
Hypoalbuminemia	Albumin < 35 g/L
Total protein deficiencies	Total protein < 62 g/L
Serum folate deficiency	Folic acid < 3.2 ng/mL
Serum vitamin B12 deficiency	Vitamin B12 < 180 pmol/L
Serum vitamin D deficiency	Vitamin D < 30 ng/mL
Serum calcium deficiency	Calcium < 2.1 mmol/L
Serum iron deficiency	Iron < 8.9 μmol/L
Serum zinc deficiency	Zinc < 11.1 μmol/L

conducted on the third postoperative day to assess for the presence of fistulae, stenosis, obstruction, and gastrointestinal peristalsis. If the results were normal, patients were permitted to begin a semi-liquid diet.If the patient has no obvious vomiting or discomfort, he will be discharged from the hospital in 3–4 days.

During hospitalization, the dietitian delivered nutritional education to the patients. Upon discharge, patients were instructed to adhere strictly to a diet comprising three progressive phases: clarified liquids, semi-solids, and solids. Each phase is designed to last a minimum of 2–3 weeks. To ensure sustained benefits, all patients were provided with prophylactic supplements of protein, vitamins, and micronutrients.Nutrient Supplement Plan: For the SADI-S group, the regimen includes 60 g to 160 g of whey protein powder (BY-HEALTH) per day, one tablet of Centrum multielement (Wyeth Pharmaceuticals) daily, 100 μg of vitamin B12 per day, 75 μg of vitamin B complex tablets per day, one tablet of Caltrate D (Wyeth Pharmaceuticals) per day, and one Vitamin AD soft capsule daily (which contains 10,000 IU of vitamin A and 1,000 IU of vitamin D). Additionally, the SADI-S group will take 0.5 mg of Methycobal (mecobalamine). For the SG group, the intake of whey protein powder (BY-HEALTH) is limited to 60 g to 90 g daily, without the supplementation of Vitamin AD soft capsules or Caltrate D, while the remainder of the regimen aligns with that of the SADI-S group.

All patients were monitored by surgeons and case managers through clinic visits, telephone consultations, or other methods, with relevant data collected throughout the process. Our follow-up protocol includes a minimum of three blood tests and imaging studies, such as color ultrasound, during the first year. Subsequently, patients undergo annual or more frequent blood tests, as necessary, to identify potential nutritional, vitamin, and micronutrient deficiencies.A total of 53 patients were monitored at 3, 6, 12, and 24 months postoperatively. The follow-up indicators included body weight, body mass index (BMI), percentage of excess weight loss (%EWL), percentage of total weight loss (%TWL), fasting blood glucose (FBG), glycosylated hemoglobin(HbA1c), systolic blood pressure (SBP), diastolic blood pressure (DBP), total protein (TP), albumin (ALB), triglycerides (TG), total cholesterol (TC), as well as various nutrients, including micronutrients, vitamins, and folic acid, in addition to postoperative complications. The follow-up period concluded in November 2024.

Statistical Methods

Statistical analysis was conducted using SPSS version 25.0. Measurement data that conformed to a normal distribution were expressed as mean ± standard deviation (Mean ± SD) and analyzed using the independent samples t-test. In contrast, measurements with a skewed distribution were reported as median (interquartile range) and analyzed using the Wilcoxon rank sum test. Categorical data were assessed using the chi-square test, with categorical variables presented as the number of cases and percentage (%). For categorical data that did not meet the assumptions of the chi-square test, the Fisher exact test was employed. A p-value of less than 0.05 was considered statistically significant.

Results

Surgical Outcomes and Complications

All 53 patients with T2DM successfully completed laparoscopic surgery, characterized by clear intraoperative vision and the absence of significant bleeding, conversion to laparotomy, or mortality. Additionally, blood loss during the procedure was minimal, with recorded levels of less than 50 mL.The SADI-S group exhibited an operative time of 172.6 ± 31 min and a postoperative hospitalization of 6 (5–6.8) d. In contrast, the SG group had an operative time of 113.1 ± 26.9 min and a postoperative hospitalization duration of 6 (6–7.8) d. In summary, the operation time for the SG group was significantly shorter than that for the SADI-S group ($P = 0.000$), while the postoperative hospitalization time was significantly longer for the SG group compared to the SADI-S group ($P = 0.038$).In terms of postoperative complications, gastric leakage occurred in one patient (4.2%) in the SADI-S group, classified as grade IIa according to the Clavien-Dindo classification. In contrast, bleeding was reported in one patient in the SG group, also categorized as grade IIa by Clavien-Dindo, resulting in a complication rate of 4.2%. Notably, there was no significant difference in the incidence of surgical complications between the two groups.Both patients recovered and were discharged following conservative treatment.

In terms of nutritional deficiencies, at one year postoperatively, neither group exhibited wasting, stenosis, hypoglycemia, hypotension, vitamin B12 deficiency, vitamin D deficiency, or folate deficiency. In the SADI-S group, hypozincemia was observed in 7 patients (29.2%), while only 1 patient (3.5%) in the SG group developed hypozincemia, with this difference being statistically significant ($p = 0.017$). At two years postoperatively, 6 patients (25%) in the SADI-S group and 1 patient (3.5%) in the SG group developed hypozincemia, again demonstrating a statistically significant difference ($p = 0.038$).The incidences of wasting,stenosis, hypoalbuminemia,anemia,gallbladder stones,hypoglycemia,hypotension, hypocalcemia, hypoferritinemia, vitamin B12 deficiency, vitamin D deficiency, and folic acid deficiency were not statistically significant in either group.In the SADI-S group, one patient experienced significant weight loss 24 months postoperatively, resulting in a low BMI of 17.72 kg/m2. However, follow-up assessments indicated that the patient had not adhered to the prescribed regular diet and vitamin supplementation.All nutritional complications are also shown in Table 3.

Weight Loss Outcome

Changes in body weight indicators are shown in Table 4 and Fig. 1. There was no significant difference in preoperative weight and BMI between the two groups. However, the SADI-S group exhibited a more pronounced trend of decreasing weight and BMI compared to the SG group (Fig. 1A, B). At three months postoperatively, no significant differences were observed in any weight-related indices between the SADI-S and SG groups (all $P > 0.05$). At six months postoperatively, the percentage of total weight loss (TWL%) was significantly higher in the SADI-S group than in the SG group ($P = 0.004$), while no significant differences were noted in other weight indicators ($P > 0.05$). At twelve months postoperatively, the weight, BMI, excess weight loss percentage (EWL%), and TWL% for the SADI-S and SG groups were 62.5 ± 6.8 vs. 66.1 ± 6.3, 22.1 ± 1.6 vs. 23.5 ± 1.9, 111.1% ± 19.4% vs. 93.8% ± 21.9%, and 31.8% ± 5.9% vs. 25% ± 6.9%, respectively.In conclusion, the

Table 4 Comparison of weight loss outcomes 2 year after surgery between the two groups

	SG(*n* = 29)	SADI-S (*n* = 24)	*p*
3mo Body weight (kg)	71.5 ± 8.9[c]	73.1 ± 10.5	0.555
3mo BMI(kg/m^2)	25.4 ± 1.8	25.9 ± 2.3	0.451
3mo %EWL	73.3 ± 17.2	74.0 ± 21.3	0.899
3mo %TWL	19.4 ± 4.7	20.7 ± 4.4	0.297
6mo Body weight (kg)	67.5 ± 7.1	66.3 ± 8.0	0.576
6mo BMI(kg/m^2)	24.1 ± 1.7	23.4 ± 1.8	0.218
6mo %EWL	89.3 ± 18.7	98.0 ± 21.0	0.117
6mo %TWL	23.6 ± 5.2	27.8 ± 4.8	0.004*
12mo Body weight (kg)	66.1 ± 6.3	62.5 ± 6.8	0.05*
12mo BMI(kg/m^2)	23.6 ± 1.9	22.1 ± 1.6	0.005*
12mo %EWL	93.8 ± 21.9	111.1 ± 19.4	0.004*
12mo %TWL	25.0 ± 6.9	31.8 ± 5.9	0.000*
24mo Body weight (kg)	66.9 ± 7.9	61.2 ± 6.6	0.007*
24mo BMI(kg/m^2)	23.8 ± 2.0	21.7 ± 1.6	0.000*
24mo %EWL	91.9 ± 22.1	115.6 ± 20.6	0.000*
24mo %TWL	24.4 ± 6.4	33.1 ± 6.3	0.000*

SG Sleeve gastrectomy, *SADI-S* Single-anastomosis duodenal-ileal bypass with sleeve gastrectomy, *BMI* Body mass index, *%EWL* Percentage of excess weight loss, *%TWL* Percentage of total weight loss

[c]Mean ± standard deviation

$p^* < 0.05$ was considered statistically significant

Table 3 Comparison of postoperative complications between the two groups

Complications/sequelae	SG (*n* = 29) Po-12mo SG (n = 29)	SADI-S (*n* = 24) Po-12mo SADI-S (n = 24)	*p*	SG (*n* = 29) Po-24mo SG (n = 29)	SADI-S (*n* = 24) Po-24mo SADI-S (n = 24)	*p*
Mortality	0(0)[b]	0(0)	-	0(0)	0(0)	-
Bleeding	1(3.4)	0(0)	1	1(3.4)	0(0)	1
Leakage	0(0)	1(4.2)	0.453	0(0)	1(4.2)	0.453
Reoperation	0(0)	0(0)	-	0(0)	0(0)	-
Stenosis	0(0)	0(0)	-	0(0)	0(0)	-
Emaciation	0(0)	0(0)	-	0(0)	1(4.2)	0.453
Hypoalbuminemia	0(0)	2(8.3)	0.2	0(0)	1(4.2)	0.453
Anemia	2(6.9)	3(12.5)	0.649	4(13.8)	3(12.5)	1
Cholelithiasis	9 (31.0)	12(50)	0.16	16(55.1)	16(66.7)	0.394
Hypoglycemia	0(0)	0(0)	-	0(0)	0(0)	-
Hypotension	1(3.4)	0(0)	1	0(0)	0(0)	-
Hypocalcaemia	1(3.4)	1(4.2)	1	3(10.3)	2(8.3)	1
Hypoferremia	1(3.4)	4(16.7)	1	4(13.8)	4(16.7)	1
Hypozincemia	1(3.4)	7(29.2)	0.017*	1(3.4)	6(25)	0.038*
Serum folate deficiency	0(0)	0(0)	-	0(0)	0(0)	-
Serum vitamin B12 deficiency	0(0)	0(0)	-	0 (0)	1(4.2)	0.453
Serum vitaminD deficiency	0(0)	0(0)	-	0 (0)	3(12.5)	0.086

SG Sleeve gastrectomy, *SADI-S* Single-anastomosis duodenal-ileal bypass with sleeve gastrectomy

[b]Number of cases (percentage)

$p^* < 0.05$ was considered statistically significant

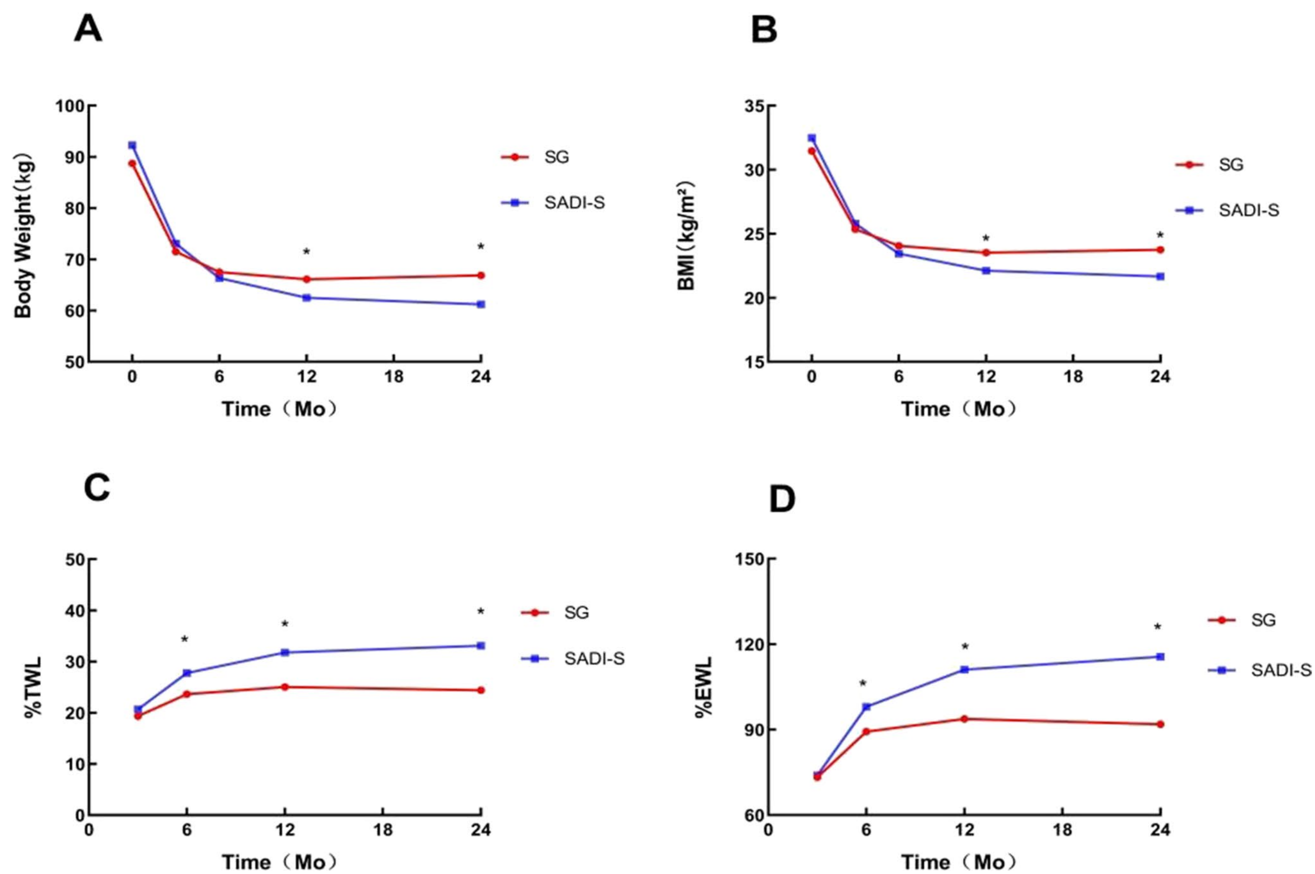

Fig. 1 Outcomes related to weight, BMI, %EWL, and %TWL were compared between the two groups at 3, 6, 12, and 24 months. SG,Sleeve gastrectomy;SADI-S,Single-anastomosis duodenal-ileal bypass with sleeve gastrectomy. * was considered statistically significant, *BMI* Body mass index, *%EWL* Percentage of excess weight loss, *%TWL* Percentage of total weight loss

SADI-S group demonstrated superior weight loss compared to the SG group, with all differences being statistically significant (P = 0.05, P = 0.005, P = 0.004, and P = 0.000). Furthermore, at 24 months postoperatively, the SADI-S group exhibited significantly better outcomes than the SG group in terms of weight, BMI, EWL%, and TWL%, with these differences also achieving statistical significance (P = 0.007, P = 0.000, P = 0.000, and P = 0.000).

Diabetes Outcomes

Table 5 presents the efficacy of diabetes management in the SADI-S and SG groups two years post-surgery. In the SADI-S group, 14 patients were treated with insulin, 3 patients received oral hypoglycemic medications, and the remaining 7 patients did not receive any form of drug or insulin treatment. Conversely, in the SG group, 17 patients were treated with insulin, 1 patient received oral hypoglycemic medications, while 5 patients did not undergo any drug or insulin therapy.In terms of diabetes efficacy, at 12 months postoperatively, the complete remission rates of Type 2 Diabetes Mellitus (T2DM) were 91.7% and 51.7% for the SADI-S and SG groups, respectively, with a p-value of 0.000. At the 24-month follow-up, 91.7% of patients in the SADI-S group and 41.4% of patients in the SG group achieved complete remission (p = 0.000). Additionally, HbA1c and FPG levels were significantly better in the SADI-S group compared to the SG group at both 12 and 24 months post-surgery, with statistically significant differences observed (p = 0.000, p = 0.022 and p = 0.000, p = 0.020, respectively).

Comorbidity Improvement and Resolution

The efficacy of metabolic disease in SADI-S and SG groups is shown in Table 5. In terms of comorbidity remission, at 12 months postoperatively, the remission rates for hyperlipidemia were 93.3% in the SADI-S group and 45.5% in the SG group, with a P value of 0.003. At the 24-month postoperative follow-up, 86.7% of patients in the SADI-S group and 50% of patients in the SG group had achieved complete remission (P = 0.022). Additionally, total cholesterol levels were significantly lower in the SADI-S group compared to

Table 5 Comparison of metabolic disease outcomes 2 years after between the two groups

	SG	SADI-S	*p*
12mo FBG(mmol/L)	5.9(5.3–6.8)[a]	5.4(4.9–5.9)	0.022*
12mo HbA1c (%)	6(5.6–6.7)	5.2(4.9–5.6)	0.000*
12mo T2DM CR	15(51.7%) [b]	22(91.7%)	0.000*
24mo FBG(mmol/L)	5.8(5.1–7.3)	5.2(4.9–5.6)	0.020*
24mo HbA1c (%)	6.2(5.7–6.6)	5.1(4.9–5.6)	0.000*
24mo T2DM CR	12(41.4%)	22(91.8%)	0.000*
12mo SBP(mmHg)	120.2 ± 13[c]	121.3 ± 14	0.763
12mo DBP(mmHg)	72.5 ± 8.1	76.1 ± 9.3	0.132
12mo Hypertension CR	15(88%)	12(83.3%)	1.000
24mo SBP(mmHg)	119.9 ± 9	117.5 ± 10.8	0.380
24mo DBP(mmHg)	74.2 ± 7.5	74.1 ± 7.8	0.982
24mo Hypertension CR	16(94.1%)	12(100%)	1.000
12mo TG(mmol/L)	1.1(0.9–1.4)	1.2(0.9–1.3)	0.789
12mo TC(mmol/L)	5.1 ± 1.2	3.8 ± 0.7	0.000*
12mo hyperlipidemia CR	10 (45.5%)	14 (93.3%)	0.003*
24mo TG(mmol/L)	1.2(0.8–1.4)	1.1(0.9–1.2)	0.228
24mo TC(mmol/L)	5.1 ± 1.1	4.1 ± 0.6	0.000*
24mo hyperlipidemia CR	11 (50%)	13(86.7%)	0.022*

SG Sleeve gastrectomy, *SADI-S* Single-anastomosis duodenal-ileal bypass with sleeve gastrectomy, *FPG* Fasting plasma glucose, *HbA1c* Glycated hemoglobin, *T2DM CR* Type 2 diabetes mellitus complete remission, *SBP* Systolic blood pressure, *DBP* Diastolic blood pressure, *TC* Total cholesterol, *TG* Triglyceride

$p^* < 0.05$ was considered statistically significant

[a] Median (ranges)

[b] Number of patients (percentage of patients)

[c] Mean ± standard deviation

Table 6 Comparison of nutrient outcomes 2 years after surgery between the two groups

	SG(*n* = 29)	SADI-S (*n* = 24)	*p*
12mo HGB (g/L)	138(129–147.5)[a]	129.5(120–137.5)	0.022*
12mo TP (g/L)	73(69.5–75.2)	70.4 (69.3–74.7)	0.148
12mo ALB (g/L)	43.8(41.9–46.1)	41.8(40.3–44.3)	0.038*
12mo VitD (ng/mL)	18.2 ± 7.7[c]	11.7 ± 5.1	0.001*
12mo VitB12 (pmol/L)	353(301.3–557.1)	451.6(346.1–641.4)	0.166
12mo FA (ng/mL)	32.8(17.3–45.3)	10.3(4.6–11.7)	0.000*
12mo Ca (mmol/L)	2.3 (2.3–2.4)	2.4(2.3–2.4)	0.078
12mo Fe (mmol/L)	18.6(15.3–20.6)	12.3 (9.7–16.2)	0.001*
12mo Zn (mmol/L)	14.2 ± 2.7	12.0 ± 1.9	0.001*
24mo HGB (g/L)	132(122–149.5)	130.5(120.3–139)	0.204
24mo TP (g/L)	72(70–76.6)	70.4(68.7–72.9)	0.043*
24mo ALB (g/L)	43.8(42.0–45.8)	41.3(39.3–42.5)	0.003*
24mo VitD (ng/mL)	18.7±7.6	10.2±5.3	0.000*
24mo VitB12 (pmol/L)	386.2(267.7–557.5)	406.3(290.7–627.0)	0.276
24mo FA (ng/mL)	28.2(18.5–39.0)	8.6(4.6–10.5)	0.000*
24mo Ca (mmol/L)	2.33(2.3–2.5)	2.4(2.3–2.5)	0.72
24mo Fe (mmol/L)	16.3 ± 5.2	12.0 ± 3.9	0.002*
24mo Zn (mmol/L)	13.9 ± 2.4	11.5 ± 1.8	0.000*

SG Sleeve gastrectomy, *SADI-S* Single-anastomosis duodenal-ileal bypass with sleeve gastrectomy, *ALB* Albumin, *TP* Total protein, *HGB* Hemoglobin, *FA* Folic acid, *Ca* Calcium, *Fe* Iron, *Zn* Zinc

[a] Median (ranges)

[c]Mean ± standard deviation

$p^* < 0.05$ was considered statistically significant

the SG group at both 12 and 24 months postoperatively, with statistically significant differences observed (P = 0.000 for both time points). However, there was no statistically significant difference between the two groups regarding total triglyceride levels.During the 1- and 2-year follow-up periods, the hypertension remission rates for the SADI-S and SG groups were 83.3% and 88%, and 100% and 94.1%, respectively. These differences were not statistically significant. Additionally, there were no significant differences observed between the two groups concerning systolic blood pressure and diastolic blood pressure.

Nutritional Outcomes

The nutritional status of the SADI-S and SG groups at 2 year after surgery is shown in Table 6.

At the one-year postoperative follow-up, hemoglobin, albumin, vitamin D, folic acid, iron ions, and zinc ions were significantly lower in the SADI-S group compared to the SG group, with statistically significant differences observed (P = 0.022, P = 0.038, P = 0.001, P = 0.000, P = 0.001, and P = 0.001). Conversely, no statistically significant differences were found between the two groups regarding total protein, vitamin B12, and calcium ions.At two years postoperatively, the levels of albumin, vitamin D, folic acid, iron ions, and zinc ions in the SADI-S group were 41.3(39.3–42.5), 10.2±5.3, 8.6(4.6–10.5),12.0 ± 3.9, and 11.5 ± 1.8, respectively. In comparison, the SG group exhibited levels of 43.8(42.0–45.8), 18.7±7.6,28.2(18.5–39.0), 16.3 ± 5.2, and 13.9 ± 2.4 These differences were statistically significant (P = 0.003, P = 0.000, P = 0.000, P = 0.002, P = 0.000). Additionally, at two years postoperatively, no significant differences were observed between the two groups regarding hemoglobin, total protein, vitamin B12, and calcium ions.

Discussion

SADI-S is a relatively new surgical technique that was enhanced by Sanchez-Pernaute and Torres et al. in 2007 [11]. Furthermore, the program has continued to evolve over time. Initially, the single-anastomotic duodeno-ileal bypass was performed using a 200 cm common channel, which posed a significant risk of nutritional deficiencies despite achieving a %EWL of approximately 100% [31]. To mitigate the complications associated with nutritional deficiencies, the length of the common channel has been increased to 250 cm [32] or 300 cm [33]. Although the safety and efficacy of SADI-S in managing severe obesity and diabetes have been well established [15, 34, 35], there is a paucity of studies addressing the treatment of diabetes in patients with a BMI < 35 kg/m^2.

In terms of weight loss effects, our study demonstrated that the SADI-S group achieved significantly greater weight loss compared to the SG group, which aligns with our previous findings [36]. Specifically, at 6, 12, and 24 months post-surgery, the %TWL for the SADI-S group was 27.8%, 31.8%, and 33.1%, respectively, all of which were significantly higher than those of the SG group (23.6%, 25.0%, and 24.4%).

Cottam et al. [22] compared the two-year outcomes of SADI-S and SG, revealing that at two years post-surgery, the %TWL for SADI-S was 36.8%, while SG was 25.6%. This indicates that SADI-S is more effective for weight loss and has significant advantages.Furthermore, their study revealed that the body weight index of the SG group recovered two years after surgery compared to one year post-surgery (%TWL: 27.1% vs. 25.6%, BMI: 31.8 kg/m^2 vs. 32.1 kg/m^2), while the body weight index in the SADI-S group exhibited a continuous downward trend. A review of weight regain after SG indicated that the weight recovery rate after SG ranged from 5.7% at two years to 75.6% at six years [37]. In contrast, some studies have suggested that SADI-S does not lead to weight regain within two years post-surgery [38], which aligns with our findings.Although these studies focused exclusively on clinically severe obese patients, our study also observed similar weight loss effects in individuals with T2DM who had a BMI of less than 35 kg/m^2.Currently, there is no direct or reliable evidence indicating that the Single Anastomosis Duodeno-ileal Bypass with Sleeve Gastrectomy (SADI-S) provides significant advantages over Sleeve Gastrectomy (SG) for patients with a BMI below 35 kg/m^2. However, recent literature [21, 22] suggests that for patients with clinically severe obesity, SADI-S outperforms both SG and RYGB in terms of weight loss.

This may be attributed to the distinct weight loss mechanisms of the SADI-S procedure compared to other surgical interventions.SADI-S not only restricts food intake through sleeve gastrectomy but also involves duodenoileal anastomosis, while preserving a longer segment of the small intestine to limit nutrient absorption.

Consequently,the impact of SADI-S on weight loss in patients with T2DM and a BMI of less than 35 kg/m^2 is significant, making it an ideal option for both patients and bariatric metabolic surgeons.

In terms of efficacy in treating diabetes, the complete remission rate for the SADI-S group at one year post-surgery was 91.7%, remaining at 91.7% two years post-surgery. In contrast, the SG group exhibited a complete remission rate of 51.7% at one year and 41.4% at two years post-surgery. These findings are consistent with our previous study [39], which also indicated that the complete remission rate of type 2 diabetes one year after SADI-S surgery was markedly superior to that of the SG group. Similarly, Cottam et al. [22] compared the complete response rates of SADI-S and RYGB for type 2 diabetes mellitus (T2DM) and found that the complete response rate for SADI-S was 90% (with an HbA1C of 6%), while the rate for RYGB was 69% ($P < 0.05$). This finding aligns with the T2DM remission rate observed in the SADI-S group in our study.In this study, the complete remission rate of type 2 diabetes mellitus (T2DM) two years after SADI-S treatment was found to be 91.7%, surpassing the 60–80% rates reported in previous studies [40, 41]. Several factors may account for this difference in effectiveness in treating T2DM: (1) The use of a smaller gastric tube (34 Fr) may facilitate better complete remission of T2DM by resulting in a reduced gastric capacity, in contrast to previous studies that employed larger gastric tubes ranging from 36 to 42 Fr. (2) Additionally, the patients with type 2 diabetes in this study had a shorter duration of the disease and exhibited milder symptoms.In our study, the complete remission rate of T2DM in the SG group two years post-surgery was 41.38% (12 out of 29 patients). This rate is higher than the 38.1% (33 out of 86 patients) reported by Salman et al. [42] two years after surgery. The observed difference in efficacy may be also attributed to the size of the gastric tube used; Salman et al. utilized a 36-Fr gastric tube, whereas our center employed a 32-Fr gastric tube. *Similarly, Tang* et al. [43] *noted that 2 years after surgery, a total of 50.0% of patients in the LSG group achieved complete remission of T2DM; in addition, Ma* et al. [44] *reported in a study with a BMI < 32.5 kg/m^2 that 24 months after SG, 18 of 49 patients (36.7%) achieved complete remission of diabetes mellitus. The authors suggest that the difference in efficacy may be related to the magnitude of BMI, with the larger the BMI, the relatively better the remission of diabetes after bariatric surgery.*In comparison to SG, SADI-S offers significant advantages in the treatment of T2DM, likely due to its comprehensive coverage of nearly all the remission mechanisms associated with the condition.Mechanically, similar to SG, it effectively reduces gastric capacity and caloric intake. However, SADI-S incorporates an additional duodenal-ileal diversion [16], which further decreases intestinal absorption. Additionally, the preservation of the pyloric valve aids in maintaining physiological gastric emptying rates, contributing to more stable blood sugar levels and potentially reducing the incidence of complications such as dumping syndrome and diarrhea.This argument may also elucidate the alleviation of hypertension and hyperlipidemia [45]. Nowday, the family of glucagon-like peptide-1 receptor agonists together with renal sodium/glucose co-transporter protein-2 inhibitors have attracted interest as potential therapeutic agents for patients with type 2 diabetes and obesity.*A 10-year long-term study by Mingrone* et al. [5] *showed that 15 (37.5%) of all patients treated surgically maintained diabetic remission throughout the 10-year period, compared with a 10-year remission rate of only 5.5% with pharmacologic therapy.Similarly, a 5-year study by Schauer* et al. [46] *showed that bariatric surgery combined with medication was more effective than medication alone in addressing diabetes.Clinicians and policy makers should ensure that metabolic surgery is appropriately considered in the management of patients with obesity and type 2 diabetes*.Consistent with the complete remission rate of T2DM observed in our study, 86.67% of patients attained complete remission of hyperlipidemia, while 100% of patients achieved complete remission of hypertension.

In the context of nutrition, substantial weight loss occurring shortly after bariatric metabolic surgery is accompanied by alterations in the body's nutrient levels,reflecting the body's intrinsic mechanisms for regulating metabolism. Consequently, a single nutritional index is insufficient to comprehensively assess the nutritional status of patients post-surgery. To address this, our center collected and analyzed various indicators—including hemoglobin (HGB), total protein (TP), albumin (ALB), folic acid(FA), trace elements, and several vitamins of two groups of patients 12 and 24 months following surgery. These indicator levels were utilized to evaluate the nutritional status of patients undergoing SADI-S and SG in the treatment of Chinese patients with T2DM and a BMI of less than 35 kg/m^2.

SADI-S is linked to a significant prevalence of postoperative nutritional deficiencies, primarily due to alterations in gastrointestinal anatomy and a reduced absorptive capacity.Specifically, hypoabsorption surgery is associated with increased fat malabsorption, which may subsequently lead to deficiencies in fat-soluble vitamins, particularly vitamin D, thereby affecting the body's calcium absorption.At the same time,hypoalbuminemia and various trace element deficiencies are common complications following bariatric surgery. On one hand, the results concerning nutrient deficiencies reported in the existing literature are often controversial and frequently contradictory.Reported nutritional outcomes for the SADI-S procedure vary significantly between different medical centers.In our center study reported that, two years after SADI-S surgery, the prevalence of hypoalbuminemia, anemia, hypocalcemia, hypoferremia, hypozincemia, vitamin D deficiency, vitamin B12 deficiency, and folic acid deficiency was 4.2%, 12.5%, 8.3%, 16.7%, 25%, 4.2%, 12.5%, and 0%, respectively.*In a recent review of SADI-S by Palmieri* et al. [17]*, it was noted that the total protein deficiency rate at mid-term follow-up after SADI-S was 23.4%, albumin deficiency was 6.8%, folate (vitamin B9) deficiency was 13.6%, vitamin B12 deficiency was 8.6%, and vitamin D deficiency was 34.3%*.In a separate study involving 286 patients,Zaveri et al. [18]. found that 7.3%, 8.6%, 5.3%, 0%, 23.8%, and 12.7% of patients exhibited reductions in calcium, total protein, albumin, vitamin B12, vitamin D, and zinc ion levels.On the other hand, Marincola et al. [47] reported mid-term (2 years) nutritional and metabolic outcomes following SADI-S surgery. In their study, 3% of patients developed anemia, while 1.5% experienced hypoalbuminemia. Additionally, hypoalbuminemia occurred in 4.5% of patients, and 31.8% developed postoperative vitamin D deficiency. Furthermore, 9.1% of patients experienced postoperative folic acid deficiency, and 3% developed hypokalemia. Notably, no patients were observed to develop postoperative hypocalcemia, hyponatremia, hyperglycemia, or reactive hypoglycemia.Similarly, Sanchez-Pernaute et al. [48] reported mid-term outcomes for 97 patients with T2DM following the SADI-S procedure. The study found that 34%, 13.7%, and 50% of patients experienced deficiencies in total protein, albumin, and vitamin D, respectively. Variations in outcomes among different centers may be attributed to several factors: (1) differences in common channels and gastric tubes; (2) variations in patient selection, as our center included patients with relatively low BMI; and (3) discrepancies in postoperative nutritional plans.Few studies clearly articulate the nutritional regimens employed when reporting their results. In our investigation, the limited instances of nutritional deficiencies observed were asymptomatic and identified through biochemical tests conducted during follow-up. Simultaneously, we employed stringent cutoffs to define nutrient deficiencies. While this approach facilitates early diagnosis and treatment of these conditions, it also leads to slightly higher prevalence rates than those reported by many authors.

In our center's study, the rates of hypoalbuminemia, anemia, hypocalcemia, hypoferremia, hypozincemia, vitamin D deficiency, vitamin B12 deficiency, and folic acid deficiency two years after sleeve gastrectomy (SG) surgery were 0% and 13.8%, 10.3%, 13.8%, 3.4%, 0%, 0%, and 0%, respectively.Similarly, in the study by Ledoux et al. [49], the incidence rates of postsurgical complications were assessed at both shortterm (1 year) and longterm (3 years) intervals following sleeve gastrectomy (SG). The rates for hypoalbuminemia were 3.9% and 3.6%, for anemia 3.6% and 7.2%, for vitamin B12 deficiency 7.5% and 7.2%, for vitamin D deficiency 54.6% and 65.8%, for hypocalcemia 1.8% and 5.4%, and for hypozincemia 32.2% and 45.1%, respectively.In summary, the variability observed among published series may be partly due to differences in patient selection and management regimens employed. In our study, however, the few cases of nutritional deficiencies were asymptomatic, and all patients returned to normal following prescribed treatment and improved nutritional intake.

Bariatric surgery can lead to significant nutritional and metabolic complications, necessitating careful patient selection and rigorous nutritional follow-up, particularly for individuals with a low body mass index (BMI < 35 kg/m^2). Current nutritional guidelines for malabsorptive procedures, such as biliopancreatic diversion with duodenal switch (BPD-DS) [50], recommend follow-up assessments at 3, 6, and 12 months during the first year, with at least annual evaluations thereafter.*Therefore, we believe that for bariatric surgery, it is important to prescribe specific diets and micronutrient supplementation to prevent the development of long-term severe micronutrient deficiencies*.

Although this is the first study to compare the effects of SADI-S and SG in the treatment of Chinese patients with T2DM and a BMI of less than 35 kg/m^2, the study has several limitations.First, the sample size of the study is limited, necessitating a larger volume of clinical data to objectively assess the two surgical procedures.Additionally, there is a notable absence of long-term follow-up results. Ensuring complete and regular follow-up after surgery is a critical concern, and an extended follow-up period is necessary to effectively compare the long-term efficacy and complications associated with the two surgical procedures.Finally,this study is retrospective in nature; therefore, future research should include randomized controlled trials to assess alternative treatment options and specific therapeutic interventions.We believe that the results of this study can serve as a valuable reference for the future treatment of low body mass index (BMI < 35 kg/m^2) diabetic patients and positively influence subsequent research.

Conclusions

In conclusion, both SADI-S and SG are effective in treating Chinese diabetic patients with a BMI of less than 35 kg/m^2.*Although the duration of surgery was longer in the SADI-S than in the SG group, SADI-S demonstrates superior weight loss and remission of obesity-related metabolic diseases.*In addition, the rates of postoperative nutrition and deficiencies were found to be acceptable. In summary, when compared to SG, SADIS emerges as a safe, effective, and feasible treatment option.However, careful consideration must be given to patient selection, postoperative follow-up, and nutritional monitoring. Furthermore, additional studies with a multicenter approach, larger sample sizes, and extended follow-up periods are necessary to establish definitive conclusions.

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Data Availability No datasets were generated or analysed during the current study.

Declarations

Ethics Approval All procedures conducted in this study involving human participants adhered to the ethical standards set forth by the institution and/or the National Research Council, as well as the 1964 Declaration of Helsinki and its subsequent amendments or equivalent ethical guidelines. The study, including all experimental methods, received approval from the Ethics Committee of the China-Japan Friendship Hospital of Jilin University.

Informed Consent Informed consent was obtained from all individuals included in this study.

Competing Interests The authors declare no competing interests.

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