Endokrynologia Polska
DOI: 10.5603/EP.2017.0004
Tom/Volume 68; Numer/Number 1/2017
ISSN 0423–104X

Remission of type 2 diabetes mellitus after bariatric surgery — comparison between procedures

Remisja cukrzycy typu 2 po leczeniu bariatrycznym — porównanie różnych procedur

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Abstract

Introduction: We aimed to assess the mid-term type 2 diabetes mellitus recovery patterns in morbidly obese patients by comparing some relevant physiological parameters of patients of bariatric surgery between two types of surgical procedures: mixed (roux-en-Y gastric bypass and biliopancreatic diversion) and restrictive (sleeve gastrectomy).
Material and methods: This is a prospective and observational study of co-morbid, type 2 diabetes mellitus evolution in 49 morbidly obese patients: 37 underwent mixed surgery procedures and 12 a restrictive surgery procedure. We recorded weight, height, body mass index, and glycaemic, lipid, and nutritional blood parameters, prior to procedure, as well as six and twelve months post-operatively. In addition, we tested for differences in patient recovery and investigated predictive factors in diabetes remission.
Results: Both glycaemic and lipid profiles diminished significantly to healthy levels by 6 and 12 months post intervention. Type 2 diabetes mellitus showed remission in more than 80% of patients of both types of surgical procedures, with no difference between them. Baseline body mass index, glycated haemoglobin, and insulin intake, among others, were shown to be valuable predictors of diabetes remission one year after the intervention.
Conclusions: The choice of the type of surgical procedure did not significantly affect the remission rate of type 2 diabetes mellitus in morbidly obese patients. **(Endokrynol Pol 2017; 68 (1): 18–25)**

Key words: *type 2 diabetes mellitus; bariatric surgery; gastric bypass; biliopancreatic diversion; sleeve gastrectomy*

Streszczenie

Wstęp: Badanie przeprowadzono w celu oceny wpływu zastosowanej terapii na remisję cukrzycy typu 2 o średnio długim czasie trwania u chorych z otyłością olbrzymią poprzez porównanie istotnych parametrów fizjologicznych między grupami wydzielonymi w zależności od typu przeprowadzonego zabiegu: grupa mieszana (ominięcie żołądkowo-jelitowe typu Y-Roux i wyłączenie żółciowo-trzustkowe) i grupa poddana zabiegom restrykcyjnym (mankietowa resekcja żołądka).
Materiał i metody: Do prospektywnego badania obserwacyjnego dotyczącego wpływu zastosowanej terapii na cukrzycę typu 2 włączono 49 chorych z otyłością olbrzymią: u 37 chorych wykonano zabiegi typu restrykcyjno-wyłączającego lub wyłączającego (grupa mieszana), a u 12 — zabiegi restrykcyjne. U wszystkich chorych określono masę ciała, wzrost, wskaźnik masy ciała oraz oznaczono we krwi parametry glikemiczne, lipidowe i dotyczące stanu odżywienia przed zabiegiem, a następnie 6 i 12 miesięcy po zabiegu. Ponadto wykonano badania mające na celu stwierdzenie różnic w przebiegu pooperacyjnym oraz oceniono czynniki predykcyjne remisji cukrzycy.
Wyniki: Stwierdzono poprawę profilu glikemii i stężeń lipidów 6 i 12 miesięcy po zabiegu. Remisja cukrzycy typu 2wystąpiła u ponad 80% wszystkich chorych, przy czym nie odnotowano różnicy w zależności od typu zabiegu. Czynnikami predykcyjnymi remisji cukrzycy rok po zabiegu były między innymi wyjściowe wartości wskaźnika masy ciała i hemoglobiny glikowanej oraz stosowana dawka insuliny.
Wnioski: Typ zabiegu bariatrycznego nie wpływał istotnie na częstość remisji cukrzycy typu 2 u chorych z otyłością olbrzymią. **(Endokrynol Pol 2017; 68 (1): 18–25)**

Słowa kluczowe: *cukrzyca typu 2; leczenie bariatryczne; ominięcie żołądkowo-jelitowe; wyłączenie żółciowo-trzustkowe; mankietowa resekcja żołądka*

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Introduction

Obesity is considered a significant risk factor in the development of type 2 diabetes mellitus [1]. According to International Diabetes Federation (IDF) data, in 2010 the worldwide prevalence was estimated at 8.3% of the adult population, and in 2030 it is expected to rise to 9.9% [1]. A high proportion of these patients also suffer from diseases related to type 2 diabetes mellitus, such as micro- and/or macro vascular disease [2].

A large number of observational studies have demonstrated that bariatric surgery, originally conceived as a weight-reduction therapy, has a huge impact on glycaemic control in obese-patients with type 2 diabetes mellitus [3, 4], even achieving a long-term complete remission, and an improvement in quality of life [5]. Also, it has a positive cost-benefit economic balance [6]. Moreover, a prospective study by Mingrone et al. [7] has recently demonstrated that medical therapy, combined with bariatric surgery, controls glycaemic levels in more patients than medical therapy itself. In light of these findings, the Centres for Medicare and Medicaid Service (CMS), the American Diabetes Association (ADA), and IDF position statement [8] endorse bariatric surgery as the most effective treatment for obesity and several associated co-morbidities, such as type 2 diabetes mellitus [3].

There have been large-scale trials focusing on the remission or reversal of type 2 diabetes mellitus in patients who have undergone bariatric surgery, independent of weight loss and/or caloric restriction [3]. Thus, there is enough evidence in the literature showing that Roux-en-Y gastric bypass (RYGB) and biliopancreatic diversion (BPD) can promote early amelioration of glucose control, independent of weight loss [9]. A common factor of both operations is the early arrival of a meal at the terminal ileum, and this subsequently gives rise to a recovery in the glycaemic metabolism and to resolution of type 2 diabetes mellitus [10].

However, the alternative technique of laparoscopic sleeve gastrectomy (LSG), a more recent restrictive technique, could be less effective in the treatment of obese patients with type 2 diabetes mellitus, compared with the other two mixed procedures, because its pathogenic mechanisms for glycaemic control are less understood.

In this work, we seek to find out the short- and mid-term effectiveness of one restrictive technique (LSG) in type 2 diabetes mellitus improvement, weight loss, and related co-morbidities progress, in comparison with two mixed procedures (RYGB and BPD), after one year of follow-up [11]. Furthermore, we try to identify reliable clinical baseline predictors of the likelihood of type 2 diabetes mellitus remission after these different surgical procedures.

Material and methods

Patients

Between 2008 and 2012 we prospectively and observationally studied 49 patients diagnosed with type 2 diabetes mellitus, with an average duration of 6.5 ± ± 2.5 years (29.0% men and 71.0% women, average age 49.0 ± 10.0 years). Type 2 diabetes mellitus was biochemically ascertained by HbA1c of ≥ 7.0% (53 mmol/mol). We randomly assigned 37 patients to mixed and 12 to restrictive bariatric surgery procedures. Progress of all patients after surgery was controlled by a multidisciplinary team at the Surgery and Nutrition Unit, Endocrinology and Surgery Department, Clinic Hospital San Cecilio (Granada, Spain), as previously described. Four weeks before surgery, patients followed a hypocaloric diet with 800 Kcal/day and 56 g protein/day intake. After the operation, multivitamin and mineral supplements were prescribed in patients who underwent the mixed procedures, to minimise micronutrient deficiency [12]. Patients were candidates for general anaesthetic and were able to understand the options necessary to comply with the requirement of each intervention program. Non-pregnant and non-lactating female patients had to agree to use a reliable method of contraception for two years. All patients agreed written informed consent to undergo surgical procedures and to participate in this study.

Surgical procedures

We conducted three different bariatric techniques grouped in two types of surgical procedures: mixed and restrictive. Mixed procedures have a restrictive and malabsorptive action. Biliopancreatic diversion Scopinaro and Roux-en-Y Gastric Bypass, which we performed as mixed procedures, are described below.

Biliopancreatic diversion Scopinaro technique

At 2.5 m from the ileo-caecal valve, the small bowel was transected and its distal extreme was anastomosed to the remaining stomach. At 50 cm proximal to the ileo-caecal valve, the proximal end of the ileum was anastomosed to the bowel in an end-to-side fashion, incorporating the remaining small bowel conveying the biliopancreatic juice and excluded from food transit [13].

Roux-en-Y Gastric Bypass technique

A small gastric pouch was fashioned (30 cc) and a 150-cm-long antecolic alimentary limb was carried out. A gastro-jejunal anastomosis was created using linear stapling in line with the Lonroth technique. A side-to-side jejuno-jejunal anastomosis was carried out, 30 cm from the angle of Treitz and using linear stapling. The mesenteric defect was sealed using non-absorbable stitches. Drainage was systematic [11].

As a restrictive procedure, we conducted laparoscopic sleeve gastrectomy, which is described below.

Laparoscopic sleeve gastrectomy technique

A 37-French tube was employed to calibrate the sleeve gastrectomy. The gastric section started 6 cm from the pylorus. Buttress material was applied (Duet®) to strengthen the staple line. Drainage was systematic [11].

Clinical evaluation

Weight (kg) and height (m) were measured using a manual stadiometer scale, to the nearest 100 g and 1 mm, respectively. With these data, we calculated the body mass index (BMI), as weight divided by height in metres squared (kg/m^2). Changes in preoperative and postoperative BMI levels were expressed as a percentage of excess BMI lost (EBL%) [14]. We also studied the evolution of other co-morbidities (hypertension, hyperlipidaemia, obstructive sleep apnoea, and gastroesophageal reflux) one year after both types of surgical interventions. We recorded those prior to and six and twelve months post-surgical intervention.

Laboratory analyses

We used the glucose oxidase method (Beckman) to measure fasting plasma glucose, and microparticle enzyme immunoassay (Abbott) to measure plasma insulin, with a sensitivity of 1 μU per millilitre and an intra assay coefficient of a variation of 6.6%.

We measured serum glycated haemoglobin levels by high-performance liquid chromatography (normal range 3.5 to 6.5%), and used standard enzymatic assays to measure total cholesterol, high-density lipoprotein (HDL) cholesterol, and triglycerides. We used the Friedewald formula to calculate low-density lipoprotein (LDL) cholesterol.

We conducted a colorimetric enzymatic test for a direct quantitative determination of serum triglycerides. We used the reactive Roche Cholesterol liquid R1 in an automatic analyser Roche/Hitachi 917. The upper normality limit was established as 150 mg/dL.

We used an immunoturbidimetric test to quantitatively determine serum GPT, in Roche automatic chemical analysers. We measured the ultraviolet spectrometry of the enzyme product after adding α-ketoglutarate and L-alanine. The upper normality limits were 41 UI/L in men and 31 UI/L in women.

We determined serum GOT quantitatively by means of ultraviolet spectrometry of the enzyme product, after adding α-ketoglutarate and L-aspartate. The upper normality limit was 37 UI/L for men and 31 UI/L for women.

We conducted in vitro colorimetric enzymatic tests to quantitatively determine serum GGT. We used R1 (buffer tris-hydroxymethyl-aminomethane) and R2 (buffer acetate) Roche reactives. The measurement interval was 0.05–20 μKat/L. 10–66 U/L for men and 5–39 U/L for women were considered normal values.

Type 2 diabetes mellitus remission criteria

Following ADA recommendations [15], we assumed partial type 2 diabetes mellitus remission when fasting glucose levels in plasma were 100–125 mg/dL (5.6–6.9 mmol/L) and HbA1c levels were under 6.5% (48 mmol/mol), suppressing the hypoglycaemic treatment. Complete type 2 diabetes mellitus remission required fasting glucose levels in plasma under 100 mg/dL (5.6 mmol/L) and HbA1c levels under 6.0% (42 mmol/ /mol), suppressing the hypoglycaemic treatment.

Statistical analyses

Data are expressed as mean ± SD. Data for categorical variables were presented as percentages. A Kolmogorov-Smirnov test confirmed that our data residuals fitted a normal distribution. A Levene test confirmed the homoscedasticity criterion. Therefore, we performed parametric statistics [16]. We contrasted the surgery data using a general linear model of ordinary least squares, by analysing several standard and repeated measure ANOVAs, to test for temporal differences in EBL%, blood glucose levels, HbA1c, hypoglycaemic treatment, and lipid profile.

Subsequently, we performed a backward stepwise linear discriminant analysis, including all the baseline parameters measured, to try to discern the a priori likelihood of patients to recover, or not, after the operation. A p-value < 0.05 was considered significant (two-tailed). Data was recorded and analysed using Statistica 7.0 software (Tulsa, OK, 70104, USA).

Results

The baseline parameters showed no statistical differences between mixed and restrictive surgical groups (Table I) as a result of the randomly-assigned type of surgery, except for a minimal statistical difference in HbA1c when we compared DBP and RYGB.

Weight loss

One year after surgery, the EBL% of patients who underwent BPD & RYGB was 71.7%, and 77.7% for LSG (Table II), with no significant differences between types of surgical procedures ($p > 0.3$).

Glycaemic control

Over time, there was a significant general trend to decrease glycaemic levels ($p < 0.01$). Patients who underwent mixed surgery procedures, showed basal values of 185.2 ± 80.1 mg/dL (10.3 ± 4.4 mmol/L), and

Table I. *Baseline Characteristics of the study population**
Tabela I. *Wyjściowa charakterystyka badanej populacji**

Variable	Whole population	BPD(N = 20) & RYGB(N = 17)	LSG	P Value**
	(N = 49)	(N = 37)	(N = 12)	
Male sex (n)	14	10	4	0.67
Age (years)	49.0 ± 10.0	48.4 ± 9.6	51.0 ± 11.4	0.43
Weight [kg]	133.5 ± 24.5	135.2 ± 25.0	128.4 ± 23.3	0.41
Height [cm]	163.0 ± 9.9	162.7 ± 10.1	163.8 ± 9.4	0.73
Body-mass index [kg/m^2]	50.2 ± 7.9	51.0 ± 8.3	47.7 ± 6.4	0.21
Fasting glucose [mmol/L]	10.5 ± 5.0	10.3 ± 4.4	11.1 ± 6.5	0.61
Glycated haemoglobin % (mmol/mol)	7.4 ± 1.6 (57.4 ± 17.89)	7.1 ± 1.4 (54.1 ± 15.1)	8.3 ± 2.1 (67.2 ± 22.63)	0.03
Diabetes duration (years)	6.5±2.5	6.1±2.3	6.7±2.8	0.83
Cholesterol [mmol/L]				
Total	4.9 ± 1.1	4.9 ± 1.1	4.7 ± 0.9	0.57
High-density lipoprotein	1.0 ± 0.2	1.0 ± 0.2	1.1 ± 0.3	0.60
Low-density lipoprotein	2.8 ± 0.8	2.8 ± 0.8	2.7 ± 0.7	0.78
Triglycerides [mmol/L]	2.4 ± 1.9	2.5 ± 2.2	2.0 ± 0.7	0.47
Transaminases [units/L]				
Glutamic-oxaloacetic transaminase	33.0 ± 40.9	36.1 ± 46.4	23.7 ± 12.2	0.37
Glutamic-pyruvic transaminase	39.7 ± 39.8	42.6 ± 44.2	31.0 ± 20.8	0.39
Gamma-glutamyl transferase	54.1 ± 54.5	53.7 ± 56.9	55.7 ± 48.4	0.91

BPD biliopancreatic diversion, RYGB Roux-en-Y gastric bypass, LSG laparoscopy sleeve gastrectomy. *Plus-minus values are means ±SD. To convert the values for glucose to milligrams per decilitre, divide by 0.05551. To convert the values for cholesterol to milligrams per decilitre, divide by 0.02586. To convert the values for triglycerides to milligrams per decilitre, divide by 0.01129. ** P values are between both groups of surgical procedures

Table II. *Actual values 1 year after the surgery in the study population**
Tabela II. *Rzeczywiste wartości rok po zabiegu w badanej populacji**

Variable	Whole population	BPD(N = 20) & RYGB (N = 17)	LSG	P Value**
	(N = 49)	(N = 37)	(N = 12)	
Weight [kg]	85.6 ± 15.5	87.5 ± 16.5	80.0 ± 10.6	0.14
Excess weight loss (%)	61.8 ± 14.4	60.6 ± 11.7	65.6 ± 20.8	0.30
Body-mass index [kg/m2]	32.3 ± 5.5	33.1 ± 5.5	30.0 ± 4.9	0.10
Excess body-mass index loss (%)	73.2 ± 17.5	71.7 ± 15.6	77.7 ± 22.5	0.30
Fasting glucose [mmol/L]	4.7 ± 1.0	4.7 ± 1.0	5.0 ± 0.7	0.36
Glycated haemoglobin % (mmol/mol)	4.8 ± 0.8 (29 ± 9.23)	4.8 ± 0.7 (29 ± 8.04)	4.9 ± 1.2 (30.1 ± 12.57)	0.61
Cholesterol [mmol/L]				
Total	3.7 ± 1.0	3.4 ± 0.7	4.6 ± 1.3	0.001
High-density lipoprotein	1.2 ± 0.3	1.1 ± 0.3	1.4 ± 0.3	0.002
Low-density lipoprotein	1.9 ± 0.8	1.8 ± 0.5	2.5 ± 1.1	0.002
Triglycerides [mmol/L]	1.3 ± 0.6	1.3 ± 0.5	1.4 ± 0.8	0.61
Transaminases [units/L]				
Glutamic-oxaloacetic transaminase	28.8 ± 37.1	30.9 ± 42.4	22.3 ± 9.4	0.49
Glutamic-pyruvic transaminase	27.7 ± 33.1	31.3 ± 37.3	16.4 ± 6.1	0.18
Gamma-glutamyl transferase	28.6 ± 25.9	26.4 ± 25.7	35.7 ± 26.4	0,28

BPD biliopancreatic diversion, RYGB Roux-en-Y gastric bypass, LSG laparoscopy sleeve gastrectomy. *Plus-minus values are means ±SD. To convert the values for glucose to milligrams per decilitre, divide by 0.05551. To convert the values for cholesterol to milligrams per decilitre, divide by 0.02586. To convert the values for triglycerides to milligrams per decilitre, divide by 0.01129. **P values are between both groups of surgical procedures

values of 99.1 ± 31.6 mg/dL (5.5 ± 1.8 mmol/L) and 81.4 ± 21.9 mg/dL (4.7 ± 1.0 mmol/L), after 6 and 12 months of follow-up, respectively. In turn, patients who underwent restrictive surgery procedure had basal blood glucose levels of 200.5 ± 117.1 mg/dL (11.1 ± 6.5 mmol/L), and levels of 95.2 ± 22.5mg/dL (5.3 ± 1.3 mmol/L) and 89.2 ± 12.7 mg/dL (5.0 ± 0.7 mmol/L), 6 and 12 months after the operation, respectively. Glycaemic levels at each moment of the study showed no significant differences between types of surgical procedures ($p > 0.3$).

One year after the intervention, the average percentage of glycated haemoglobin for both types of surgical procedures (4.8 ± 0.7% (29 ± 8.04 mmol/mol) for BPD & RYGB and 4.9 ± 1.2% (30.1 ± 12.57 mmol/mol) for LSG) was lower than the average for the six months post intervention (5.3 ± 0.7% (34 ± 7.87 mmol/mol) for BPD & RYGB and 6.1 ± 1.0% (43 ± 10.93 mmol/mol) for LSG) and the mean baseline (7.1 ± 1.4% (54.1 ± 15.1 mmol/mol) for BPD & RYGB and 8.3 ± 2.1% (67.2 ± 22.63) for LSG), significantly ($p < 0.01$), and with no significant differences between types of surgical procedures ($p > 0.05$).

Regarding the baseline medical treatment, 6.1% of patients were treated only with insulin therapy, 79.6% were treated only with oral hypoglycaemic agents, and 14.3% had both treatments. One year after the intervention, only 2.0% had insulin treatment, 8.2% took oral agents only, 6.1% had both treatments, and 83.7% had no pharmacological treatment.

Comparing the average daily dose of insulin (units/day), according to the type of surgical procedure, baseline values, 6, and 12 months after-surgery, were 67 ± 25.4, 14 ± 13.1, and 10.8 ± 13.1, respectively, for patients who underwent BPD & RYGB, and 51.6 ± 26.1, 11.2 ± 16.4, and 3.2 ± 7.2, respectively, for patients who underwent LSG. The high value of the variances may be due to the lack of insulin dose in many patients at 6 and 12 months. The treatment showed a clear tendency to reduce over time ($p < 0.01$), until suspension, in most cases. However, the type of surgery had no significant effect ($p > 0.2$).

The baseline, 6, and 12 months after surgery average daily doses of oral hypoglycaemic agents (mg/day), were 1624.6 ± 591.1, 180.4 ± 502.2 and 140.6 ± 436.1, respectively for patients who had undergone BPD & RYGB, and 1704.7 ± 602.3, 188.9 ± 374.8 and 377.8 ± ± 749.6, respectively, for patients who had undergone LSG. The high value of the variances is probably due to the high number of patients not treated with insulin at six and 12 months of follow-up. The reduction of the medication dose between baseline and six months post-surgery was significant ($p < 0.01$), but with no differences between six and 12 months after surgery ($p = 0.2$) or the type of surgical procedure ($p > 0.05$).

Lipid profile

LDL changed over time significantly ($p < 0.001$), being higher in LSG than BPD & RYGB patients ($p < 0.001$). HDL also changed over time ($p < 0.001$), with a similar pattern between types of surgical procedures ($p = 0.002$). Total cholesterol changed over time too ($p < 0.001$), also being higher in LSG than BPD & RYGB patients ($p < 0.001$).

One year after surgery, the total cholesterol levels were normalised in 97.3% of the mixed and in 75.0% of the restrictive surgical procedures ($p < 0.01$). HDL levels were normalised in 40.5% of patients who underwent mixed surgical procedures and in 66.7% of patients who underwent restrictive surgical procedures ($p < 0.01$). LDL was normalised at 83.8% and in 75.0% of patients in the respective types of surgical procedures ($p < 0.01$). Triglycerides were normalised in 86.5% and 91.7%, respectively ($p > 0.6$).

Co-morbidity resolution

Other obesity-associated co-morbidities also diminished in incidence after both types of surgical procedures, with no significant differences between them ($p > 0.05$). Hypertension, hyperlipidaemia, obstructive sleep apnoea, and gastroesophageal reflux were resolved in 41.0%, 48.0%, 39.0%, and 55.0% of patients, respectively.

Type 2 diabetes mellitus remission

One year after the intervention 5.4% of patients who underwent mixed procedures and 0.0% of patients who underwent restrictive technique achieved partial type 2 diabetes mellitus remission, with no significant differences between them ($p > 0.05$).

In turn, 78.4% of patients who underwent mixed procedures and 83.3% of patients who underwent restrictive technique achieved complete type 2 diabetes mellitus remission one year after the operation, with no significant influence on the remission rate of type 2 diabetes mellitus ($p > 0.05$), as shown in Table III.

Predictive baseline parameters

Several clinical baseline parameters were able to significantly predict the a priori likelihood of a patient recovering from type 2 diabetes mellitus, one year after

Table III. *Development of type 2 diabetes in the study population**

Tabela III. *Rozwój cukrzycy typu 2 w badanej populacji**

	Whole population	BPD (N = 20) & RYGB (N = 17)	LSG
	(N = 49)	(N = 37)	(N = 12)
Complete remission n (%)			
Six months	28 (57.1)	21 (56.8)	7 (58.3)
Twelve months	39 (79.6)	29 (78.4)	10 (83.3)
Partial remission n (%)			
Six months	10 (20.4)	8 (21.6)	2 (16.7)
Twelve months	2 (4.1)	2 (5.4)	0 (0.0)
Without remission nº (%)			
Six months	11 (22.4)	8 (21.6)	3 (25.0)
Twelve months	8 (16.3)	6 (16.2)	2 (16.7)

BPD — biliopancreatic diversion, RYGB — Roux-en-Y gastric bypass, LSG — laparoscopy sleeve gastrectomy. *Partial and complete remission criteria are based on the recommendations of the American Diabetes Association the intervention ($p < 0.001$). Type 2 diabetes mellitus patients who met remission criteria one year after the interventions had lower BMI, HbA1c, insulin and oral hypoglycaemic intake, HDL, and triglyceride levels than patients who did not (Table IV).

Discussion

Our study shows that mixed and restrictive types of surgical procedures are effective in reducing the EBL%, without significant differences between them; similar results can be found in several recent studies [17, 18].

We only found differences between types of surgical procedures in the evolution of the lipid parameters, except for the triglycerides, which were similar in both groups. The decrease in LDL, HDL, and total cholesterol levels was significant only in patients who underwent BPD & RYGB. In fact, Benetti et al. [19] found that malabsorptive techniques are highly effective in reducing the lipid profile because the absorption of lipids seems to be lowered, which matches with our results because mixed techniques have a malabsorptive component [20]. They also note that variation in cholesterol, HDL and LDL (including sterol) synthesis, catabolism, and absorption is independent of glycaemic control and insulin resistance.

Bariatric surgery is also effective in improving other obesity-associated co-morbidities. Independently of the technique used, many patients suffering from several co-morbidities such as hypertension, hyperlipidaemia, obstructive sleep apnoea, and gastroesophageal reflux recovered one year after the intervention, as previously detected in several works [21, 22]. Furthermore, other risk factors associated with obesity, such as nephropathy [23], have been described to have a lower incidence in treated patients.

Both technique groups were also equally effective in the reduction of glycaemia and HbA1c levels, with a gradual decrease, significantly greater over time, until reaching normal levels 12 months after operation, in most patients. The decline in glycated haemoglobin was higher at six than at 12 months, which suggests a rapid recovery towards normality, but with no differences between types of surgical procedures. Hypoglycaemic treatment decreased drastically after the intervention, stopping 60% after six months in both groups of surgeries. In fact, other authors have found a similar treatment-decrease trend, after a deliberate weight loss, in patients with type 2 diabetes mellitus [24]. The lack of differences between mixed and restrictive techniques suggests that the surgical technique used does not affect the fall in patient blood glucose levels and, therefore, in oral hypoglycaemic and/or insulin treatment reduction, since the lower the levels of glucose, the lower the antidiabetic requirements of the patient. In fact, surgery leads to a decrease in treatment dose and to suspension in many cases. Findings by a number of researchers support our result that different bariatric procedures have a similar effect in type 2 diabetes mellitus remission [9, 11, 25–29]. Contrastingly, other studies show improved type 2 diabetes mellitus remission in patients who underwent gastric bypass compared to patients who underwent other surgical techniques [30, 31]. Nonetheless, these articles focus on non-obese or non-morbidly obese patients, whilst the patients described in our work, as well as other works with comparable results, were morbidly obese, which could influence the outcome of different bariatric surgery procedures in type 2 diabetes mellitus remission. Consequently, further research investigating the differential antidiabetic effects of bariatric procedure on patients with disparate degrees of obesity would be welcome and could help us to understand the mechanisms underlying surgical remission of type 2 diabetes mellitus.

Table IV. *Baseline predictors for T2DM remission one year after bariatric surgery**

Tabela IV. *Wyjściowe czynniki predykcyjne remisji cukrzycy typu 2 rok po operacji bariatrycznej**

Variable	Complete remission	Partial remission	Standardised Coefficients
Body-mass index [kg/m^2]	46.3	56.0	–9.3
Glycated haemoglobin % [mmol/mol]	8.5 (69.4)	8.7 (71.6)	–37.8
Insulin [units/day]	57.2	62.5	17.0
Oral hypoglycaemic agents [mg/day]	996.7	2152.0	–18.7
High-density lipoprotein [mmol/L]	1.0	1.1	–26.5
Triglycerides [mmol/L]	2.2	4.6	–6.4

*Average Discriminant Analysis. The standardised discriminant function coefficients provide the formula applicable to a new patient's baseline factors. A negative result indicates that the patient should be classified in the complete remission group and is expected to recover completely; if the result is positive, the patient should be classified in the partial remission group ($p < 0.0001$; n as in Table III)

A meta-analysis [3] showed an overall rate of remission of hyperglycaemia of 78% among several bariatric techniques, higher than 80% for DBP (95%), and 80% for RYGB. After one year, our results showed complete remission of 78% when we used mixed surgery procedures and 83% with restrictive surgery procedure, without significant differences between them.

Certain studies have put forward the idea that some bariatric procedures may, in fact, enhance diabetes control through alterations in circulating gut hormones [32], aside from weight loss. Saeidi et al.

[33] recently suggested that the exposure of the Roux limb to undigested nutrients, brought about by the reorganisation of the intestinal glucose metabolism, causes the gut to become a key factor in the disposal of glucose, enhancing the glycaemic control. In addition, patients with type 2 diabetes mellitus, who had undergone RYGB in a randomised, controlled study, were shown to have greater glycaemic control than patients who had only followed a diet with an equivalent weight loss [34]. In that trial, circulating amino acids and acyl carnitines were also shown to drop after RYGB but not following intervention through diet. Following alterations to the normal course of the enterohepatic circulation of bile, Kohli et al. [35] were able to demonstrate the advantages of changes in the bile acids, such as glucose tolerance improvements, insulin sensitivity, and steatosis of the liver. Although these results largely explained glucose regulation when adopting malabsorptive techniques, they did not explain type 2 diabetes mellitus remission upon implementation of the restrictive procedures. For example, in LSG, mechanisms for gastric emptying and normal digestion are maintained, to some degree, so that there might be less of an adaptive hypertrophy response. Our conclusions produced comparable advantages with different types of bariatric procedures. They suggest that acute restriction in calories rather than gut hypertrophy is a key factor in diabetes remission, at least in the early postoperative phase before significant weight loss has resulted.

In turn, a recent study of type 2 diabetes mellitus evolution one year after surgery [11] concluded that some baseline parameters could work as predictors of the development of the disease. In our case, some of the baseline predictors of the patient outcome coincide with their results, specifically BMI and glycated haemoglobin. All in all, the baseline BMI, glycated haemoglobin, insulin and oral hypoglycaemic agent intake, HDL, and triglycerides were capable of discerning the a priori likelihood of a patient to recover from type 2 diabetes mellitus a year after intervention, with all those values being lower in patients whose probability of recovery was higher.

Conclusions

In conclusion, both types of surgical procedures obtained similar type 2 diabetes mellitus remission rates, suggesting a high efficiency of both and making neither procedure preferable to the other. Both were seen to assist in the control of the diabetes and co-morbidities. Identifying the mechanisms that underlie these remarkable outcomes could help guide the development of conservative approaches or replace quite invasive surgeries. Therefore, the technique used may depend on the surgeon's discretion, without compromising the patient's recovery prospects because the results, in terms of weight loss, glycaemic control, and diabetes remission, seem not to differ between techniques. The LSG appears to be an effective technique with similar results to the other surgical techniques analysed, with the advantage of being less invasive and traumatic to the patient because of its surgical approach, as well as involving a lower economical cost [36].

There is still a variety of unexplained and uncertain factors as regards surgical treatment of type 2 diabetes mellitus. However, the processes underlying the antidiabetic effect are starting to become more apparent in the emerging data, as well as disputing established beliefs [37]. To support our conclusions, additional animal model investigations or randomised controlled tests are required.

Acknowledgements

The Authors would like to thank the personnel of the Clinic Hospital "San Cecilio" (Granada, Spain) for their constant support and the patients for participating in this study. We also thank Ruth Martín for improving the English. Francisco Javier Zamora Camacho was partly supported by a Ramón Areces Foundation postdoctoral fellowship and Juan de la Cierva-Formación postdoctoral fellowship by the Spanish government.

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