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ORIGINAL CONTRIBUTIONS

Comparative Effectiveness of Different Bariatric Procedures in Super Morbid Obesity

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Abstract

Background Super obesity (BMI ≥ 50 kg/m^2) is associated with significant morbidity and mortality. The best procedure to treat super obesity is not completely established. Our aim was to compare the effectiveness of bariatric procedures (adjustable gastric band [AGB], Roux-en-Y gastric bypass [RYGB], sleeve gastrectomy [SG]) in super obesity.

Methods Retrospective observational study of super obese patients who underwent bariatric surgery. Data was assessed preoperatively and in the 1st and 2nd years of follow-up.

Results We evaluated 213 individuals, 77.9% female, age of 43.38 ± 11.49 years, and preoperative BMI of 54.53 ± 4.54 kg/m^2; 19 submitted to AGB, 127 to RYGB, and 67 to SG. In the pre-surgical assessment, there were no significant differences in age, anthropometric parameters, blood pressure, glycemic profile, and lipid profile between the three surgical groups. The percentage of excess weight loss (%EWL) in the 1st year was 67.58% in RYGB, 58.74% in SG, and 38.71% in AGB ($p < 0.001$), and the percentage of total weight loss (%TWL) was 36.29%, 31.59%, and 21.07%, respectively ($p < 0.001$). Two years after surgery ($n = 147$; follow-up rate of 69%), the %EWL and %TWL were significantly higher in the RYGB group ($p < 0.001$). RYGB had a higher success rate (%EWL ≥ 50% and %TWL ≥ 20%) in both years of follow-up ($p < 0.001$). In multiple linear regression, after adjusting for other covariates, RYGB was the only strong predictive factor of %EWL and %TWL ($p < 0.001$).

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Conclusion RYGB proved to be more effective in super obesity. The beneficial effects in weight loss were evident both 1 and 2 years after the procedure, regardless of pre-surgical anthropometric characteristics.

Keywords Super morbid obesity · Bariatric surgery · Weight loss · Gastric bypass · Adjustable gastric band · Sleeve gastrectomy

Introduction

Obesity is a major health problem and has nearly tripled since 1975, affecting more than 650 million adults worldwide. It is associated with several comorbidities, including type 2 diabetes mellitus (DM), hypertension, dyslipidemia, cardiovascular diseases, and cancer [1]. Super obesity is associated with a substantially increased risk of morbidity and mortality. A recent study with more than 9500 participants showed a trend of increasing risk of death with increasing level of BMI. Multivariable-adjusted (adjusted for race/ethnicity, education, alcohol intake, and physical activity level) hazard ratios (HR) for death for those with BMI of 50.0–54.9 kg/m^2 and 55.0–59.9 kg/m^2 were 3.48 (95% confidence interval [CI] 2.82–4.31) and 5.91 (95% CI 4.24–8.24), respectively. Compared with normal-weight BMI, super obesity was associated with up to 9.8 years of life lost [2].

Bariatric surgery is the most effective long-term therapy for weight loss, improvement of comorbidities and decreased mortality in morbid obesity. Currently, the most common bariatric procedures worldwide are sleeve gastrectomy (SG) and Roux-en-Y gastric bypass (RYGB), being performed in 46% and 40% of patients, respectively. Adjustable gastric banding (AGB) is performed in 7.4% and biliopancreatic diversion with duodenal switch (BPD/DS) only in 1.1% [3]. A recent meta-analysis suggested that RYGB is the more long-term effective procedure in morbid obesity, in comparison with SG and AGB [4]. However, the best surgical procedure to treat super obesity has been discussed, but there is no consensus [5].

The main aim of this study was to report the experience of a national reference center and to compare the effectiveness of different bariatric surgeries (AGB, RYGB, or SG) in patients with super obesity. The second aim was to assess predictive factors of weight loss after bariatric surgery.

Materials and Methods

Study Design and Participants

A retrospective observational cohort study was performed involving patients with super obesity submitted to bariatric surgery between January 2010 and June 2016 in our institution, a tertiary care academic hospital which is a reference center for bariatric surgery in Portugal. All patients were assessed before surgery by a multidisciplinary team consisting of an endocrinologist, a bariatric surgeon, a nutritionist, and a psychiatrist. To be a suitable candidate for surgery, patients must be between 18 and 65 years old, have a BMI ≥40 kg/m^2 (or ≥ 35 kg/m^2 and at least one obesity-related comorbidity) and be compliant with a dietary plan for at least 1 year. A total of 1820 patients underwent bariatric surgery during the study period. Only patients with preoperative BMI ≥ 50.0 kg/m^2 and at least 1 year of follow-up were included. Those submitted to revision surgery or with incomplete data were excluded. We analyzed 213 super obese patients, which were subdivided in three groups according to the type of bariatric surgery: AGB, RYGB, or SG. All procedures were performed according to standard technique (in RYGB, the biliary limb was measured to 70 cm and the alimentary limb to 150 cm).

Clinical Data Evaluated

Demographic (age, sex), anthropometric (height, weight, BMI, waist, and hip circumferences), clinical (blood pressure [BP]), and laboratory data (lipid profile, HbA1c, and fasting plasma glucose) were obtained preoperatively and at the 1st and 2nd years of follow-up. The presence of DM, dyslipidemia and hypertension and medication in use was also evaluated, as previously described [6].

BMI was defined as weight (kg)/height (m)^2, ideal body weight as that equivalent to a BMI of 25 kg/m^2 and excess weight (EW) as the difference between preoperative weight and ideal weight. The percentage of excess weight loss (%EWL) was calculated using the formula: [(initial weight − follow-up weight) / (initial weight − ideal weight)] × 100. The percentage of total weight loss (%TWL) was calculated by the formula: [(initial weight − follow-up weight)/initial weight] × 100 [7]. The success of bariatric surgery in terms of weight loss was defined as %EWL ≥ 50% [8] or %TWL ≥ 20% [9].

Statistical Analysis

Results are presented as mean ± standard deviation for continuous variables and as frequencies and percentages for categorical variables. Normal distribution of continuous variables was evaluated using the Kolmogorov-Smirnov test. Differences between the three groups of bariatric surgery were evaluated with chi-squared test for categorical variables and ANOVA test for continuous variables, followed by the Bonferroni test when findings were significant. The

comparison of baseline and follow-up was made by use of the McNemar test for categorical variables and paired sample *t* test for continuous samples. Pearson's correlation coefficient was used to assess association between continuous variables. Independent predictors of %EWL and %TWL were identified by simple and multiple linear regression models. A p value ≤ 0.05 was considered statistically significant. Statistical analyses were performed with IBM SPSS Statistics 20.0®.

Results

Baseline Population Characteristics

From the 213 patients with super obesity, 77.9% were female, with a mean age of 43.38 ± 11.49 years, mean preoperative weight of 142.92 ± 19.16 kg, and mean preoperative BMI of 54.53 ± 4.54 kg/m^2. Nineteen (8.9%) were submitted to AGB, 127 (59.6%) to RYGB, and 67 (31.5%) to SG. In the presurgical evaluation, there were no significant differences in age, height, weight, BMI, waist-to-hip ratio, BP, glycemic profile, and lipid profile between the three surgical procedures (Table 1). We found differences in sex distribution according to the type of surgery: 51.1% of men were submitted to SG while 65.1% of women underwent RYGB, leading to a greater proportion of female in the RYGB group than in the SG group (85% vs. 64%, respectively, $p = 0.004$).

Weight Loss and Metabolic Characteristics After Bariatric Surgery

After 1 year of follow-up (Table 2, Fig. 1), patients submitted to RYGB had a significantly lower mean body weight and BMI compared to those that underwent other procedures ($p < 0.001$). The BMI of patients in the SG group was lower than those in the AGB group ($p < 0.001$). The weight loss was significantly higher in patients submitted to RYGB and lower in those submitted to AGB (Table 2, Fig. 2). The %EWL 1 year after surgery was 67.58% in RYGB, 58.74% in SG, and 38.71% in AGB ($p < 0.001$) and the %TWL was 36.29%, 31.59%, and 21.07%, respectively ($p < 0.001$). There was a strong benefit of RYGB and a disadvantage of AGB, comparing with the other procedures, regarding rates of success in weight loss in the 1st year of follow-up (Table 2, Fig. 3). SG had intermediate rate of successful weight loss. The %EWL ≥ 50% occurred in 85.0% in RYGB, 74.6% in SG, and 15.8% in AGB ($p < 0.001$) and %TWL ≥ 20% was present in 98.4%; 92.5%, and 52.6%, respectively ($p < 0.001$). The majority of patients who reached a BMI < 30 kg/m^2 after surgery were submitted to RYGB: 18 (14.2%) and 23 (25.8%) patients in the 1st ($p = 0.041$) and 2nd years ($p = 0.016$), respectively. Only 5 patients in the SG group and none of the AGB group reached a BMI < 30 kg/m^2 in 2 years of follow-up.

Two years after surgery we assessed 147 patients (follow-up rate of 69%), 12 submitted to AGB, 89 to RYGB and 46 to SG. Those who underwent RYGB maintained a significantly lower mean weight and BMI and higher %EWL and %TWL comparing to the other groups ($p < 0.001$, Table 2, Figs. 1 and 2). This group had higher successful rates (Table 2, Fig. 3), both %EWL ≥ 50% (92.1% vs 69.6% in SG and 50.0% in AGB) and %TWL ≥ 20% (98.9% vs 87.0% in SG and 66.7% in AGB). Despite the benefit of SG comparing with AGB reported in the 1st year, in the 2nd year, there was only a trend to a better response in SG, but no significant differences were observed regarding weight, BMI, %EWL, %TWL, and success rate comparing to the AGB group.

RYGB was associated with lower total cholesterol ($p = 0.016$) and low-density lipoprotein cholesterol levels ($p = 0.001$) in the 1st postoperative year and SG was associated with a higher prevalence of dyslipidemia both in 1st ($p = 0.004$) and 2nd years of follow-up ($p = 0.001$). AGB had a lower effect in diastolic BP ($p = 0.026$) in the 1st year and in fasting plasma glucose in the 2nd year ($p = 0.002$). We did not find other statistically significant differences in metabolic parameters comparing the different bariatric surgeries (Table 3).

Predictors of Weight Loss After Bariatric Surgery

In univariate analysis (Tables 4A and 5A), younger age and RYGB was significantly associated with greater %EWL and %TWL in both years and preoperative BMI was negatively associated with %EWL in the 2nd year. Sex, height, weight, and waist-to-hip ratio were not associated with variation of EWL and TWL. In a multivariate linear model (Tables 4B and 5B), after simultaneous adjustment for relevant covariates (age, sex, height, weight, BMI, waist-to-hip ratio, and RYGB), only RYGB remained a strong positive predictive factor for %EWL and %TWL both in the 1st and 2nd years of follow-up. Super obese patients submitted to RYGB had, in average, an increase of 16% in EWL in the 1st year ($\beta = 15.581$, $p < 0.001$), 14% in EWL in the 2nd year ($\beta = 14.001$, $p < 0.001$), 9% in TWL in the 1st year ($\beta = 8.595$, $p < 0.001$), and 8% in TWL in the 2nd year ($\beta = 7.703$, $p < 0.001$).

Morbidity and Mortality

The mortality rate was 0% during the first 2 years of follow-up. The overall 30-day morbidity was 6.6% and there were no significant differences in overall complications between the three bariatric techniques ($p = 0.146$). Both postoperative minor and major complications occurred in 7 patients. Major complications included respiratory failure requiring intervention such as intubation

Table 1 Baseline clinical characteristics of the total study population and by bariatric surgery groups

	Total population (n = 213)	AGB (n = 19)	RYGB (n = 127)	SG (n = 67)	p value
Age, years	43.38 ± 11.49	47.32 ± 9.21	42.09 ± 10.67	44.70 ± 13.21	0.095
Sex, %					
Female	166 (77.9)	15 (78.9)	108 (85.0)	43 (64.2)	
Male	47 (22.1)	4 (21.1)	19 (15.0)	24 (35.8)	0.004*
Height, cm	161.70 ± 8.86	158.63 ± 7.24	161.50 ± 8.38	162.96 ± 9.96	0.158
Weight, kg	142.92 ± 19.16	139.56 ± 19.21	141.93 ± 17.67	145.77 ± 21.65	0.302
BMI, kg/m^2	54.53 ± 4.54	55.30 ± 5.08	54.32 ± 4.28	54.73 ± 4.89	0.623
Waist-to-hip ratio	0.95 ± 0.09	0.93 ± 0.07	0.94 ± 0.08	0.97 ± 0.09	0.104
Hypertension, %	144 (67.6)	15 (78.9)	80 (63.0)	49 (73.1)	0.197
Systolic BP, mmHg	137.86 ± 19.39	140.18 ± 24.74	138.35 ± 18.41	136.14 ± 19.59	0.704
Diastolic BP, mmHg	85.68 ± 13.50	84.41 ± 15.70	85.49 ± 12.04	86.47 ± 15.53	0.843
Dyslipidemia, %	98 (46.0)	10 (52.6)	51 (40.2)	37 (55.2)	0.119
TC, mg/dL	199.16 ± 39.86	219.37 ± 41.35	197.21 ± 39.29	196.77 ± 39.39	0.067
HDL, mg/dL	48.66 ± 11.05	51.37 ± 10.62	48.96 ± 11.58	47.02 ± 9.95	0.307
LDL, mg/dL	124.20 ± 31.36	135.21 ± 35.16	121.39 ± 30.30	126.10 ± 31.69	0.184
TG, mg/dL	142.27 ± 103.67	139.53 ± 58.77	146.76 ± 111.88	134.66 ± 81.94	0.756
Diabetes, %	78 (36.6)	5 (26.3)	48 (37.8)	25 (37.3)	0.675
FPG, mg/dL	105.68 ± 38.38	98.37 ± 29.30	106.61 ± 42.75	106.25 ± 30.38	0.683
HbA1c, %	6.055 ± 1.139	5.722 ± 0.607	6.187 ± 1.295	5.911 ± 0.901	0.135

Mean ± standard deviation; n (%)

AGB adjustable gastric banding, *RYGB* Roux-en-Y gastric bypass, *SG* sleeve gastrectomy, *BMI* body mass index, *BP* blood pressure, *TC* total cholesterol, *HDL* high-density lipoprotein cholesterol, *LDL* low-density lipoprotein cholesterol, *TG* triglycerides, *FPG* fasting plasma glucose, *HbA1c* glycated hemoglobin, * $p < 0.05$ for comparison between RYGB and SG

(n = 4), gastrointestinal hemorrhage requiring transfusion (n = 1), gastrointestinal hemorrhage requiring reoperation (n = 1) and acute pyelonephritis requiring surgery (n = 1).

Discussion

Our study proved that RYGB allowed significant higher weight loss effects than SG and AGB at 2 years of follow-up in super obesity. The benefits of RYGB were strongly evident in the 1st year after surgery and were maintained in the 2nd year of follow-up. In literature, we found an average %EWL in super obesity ranging from 47 to 73.4% in the 1st year after RYGB [8–19]; only one study [10] had a %EWL superior to our results. Two years after RYGB, our results are similar to those previously described (%EWL between 60 and 77.7% [8, 10–12, 15, 18, 20]. Considering success rates defined by %EWL ≥ 50%, our results are consistent with previous studies, which reported success rates between 82.3–94.7% at the 1st year and between 86.7–91.6% at the 2nd year [8, 10]. Regarding the evaluation of %TWL, our results at the 1st year were slightly better than those we found in literature (30.1–35.6% [9, 13, 15, 16, 21, 22]), but at the 2nd year were in the described interval (38.6–40.75% [15, 21]). Up to 98% of our sample in the RYGB group achieved %TWL ≥ 20%, being a higher success rate than previously reported [9]. Long-term studies [8, 11, 15, 16, 20, 23] have also shown the efficacy of RYGB in super obesity, despite a slight late weight regain. Five years after RYGB, several studies reported %EWL of 58–59.5% [8, 16, 23], %TWL of 30–38.3% [16, 23] and success rates (%EWL ≥ 50%) of 60–78.1% [8, 23]. Patients who completed ≥ 10 years of follow-up had a %EWL of 52.9–63.2% [11, 16, 20] and a %TWL of 34.7% [16, 20].

SG was originally developed as the initial procedure of a 2-stage bariatric surgery for high-risk patients, namely with BMI ≥ 50 kg/m^2 [24, 25]. Subsequent research evidenced it benefits as a stand-alone bariatric surgery in this population [12, 26, 27]. In the 1st year, the results of our super obese sample submitted to SG seem to be better than the majority of other studies (40.2–66.4% [10, 12–14, 27–29]. However, in the 2nd year, other studies reported a %EWL higher than 60% [10, 12, 28], but a success rate up to 52.2% [10].Our results regarding %TWL were similar to those reported by other authors [13, 22, 28]. The sustainability of weight loss on a long-term

Table 2 Comparison of anthropometric measures, weight loss and success rate between patients submitted to different bariatric surgeries

	Total population	AGB	RYGB	SG	*p* value
Weight, kg					
Preoperative ($n = 213$)	142.92 ± 19.16	139.56 ± 19.21	141.93 ± 17.67	145.77 ± 21.65	0.302
1st year ($n = 213$)	94.90 ± 17.92	110.12 ± 20.61	90.09 ± 14.28	99.71 ± 19.79	< 0.001*†
2nd year ($n = 147$)	90.83 ± 17.45	102.34 ± 20.65	86.10 ± 13.53	96.96 ± 20.20	< 0.001*†
BMI, kg/m^2					
Preoperative ($n = 213$)	54.53 ± 4.54	55.30 ± 5.08	54.32 ± 4.28	54.73 ± 4.89	0.623
1st year ($n = 213$)	36.24 ± 5.85	43.58 ± 6.20	34.52 ± 4.58	37.63 ± 6.06	< 0.001*†§
2nd year ($n = 147$)	35.17 ± 6.09	41.34 ± 8.02	33.22 ± 4.66	37.34 ± 6.29	< 0.001*†
%BMI < 30 kg/m^2, *n* (%)					
1st year ($n = 213$)	23 (10.8)	0	18 (14.2)	5 (7.5)	0.041*†§
2nd year ($n = 147$)	29 (19.7)	0	23 (25.8)	5 (10.9)	0.016*†§
Waist-to-hip ratio					
Preoperative ($n = 213$)	0.95 ± 0.09	0.93 ± 0.07	0.94 ± 0.08	0.97 ± 0.09	0.104
1st year ($n = 213$)	0.91 ± 0.08	0.86 ± 0.05	0.89 ± 0.08	0.94 ± 0.08	0.008*§
2nd year ($n = 147$)	0.89 ± 0.10	0.86 ± 0.08	0.87 ± 0.09	0.93 ± 0.11	0.010*§
%EWL					
1st year ($n = 213$)	62.22 ± 17.79	38.71 ± 17.72	67.58 ± 14.26	58.74 ± 17.78	< 0.001*†§
2nd year ($n = 147$)	66.40 ± 18.12	48.36 ± 22.27	72.19 ± 14.62	59.90 ± 18.15	< 0.001*†
%TWL					
1st year ($n = 213$)	33.45 ± 9.66	21.07 ± 9.69	36.29 ± 7.80	31.59 ± 9.43	< 0.001*†§
2nd year ($n = 147$)	35.76 ± 9.59	26.48 ± 11.65	38.71 ± 7.89	32.46 ± 9.60	< 0.001*†
%EWL ≥ 50, *n* (%)					
1st year ($n = 213$)	161 (75.6)	3 (15.8)	108 (85.0)	50 (74.6)	< 0.001†§
2nd year ($n = 147$)	120 (81.6)	6 (50.0)	82 (92.1)	32 (69.6)	< 0.001*†
%TWL ≥ 20, n (%)					
1st year ($n = 213$)	197 (92.5)	10 (52.6)	125 (98.4)	62 (92.5)	< 0.001*†§
2nd year ($n = 147$)	136 (92.5)	8 (66.7)	88 (98.9)	40 (87.0)	< 0.001*†

Mean ± standard deviation; *n* (%)

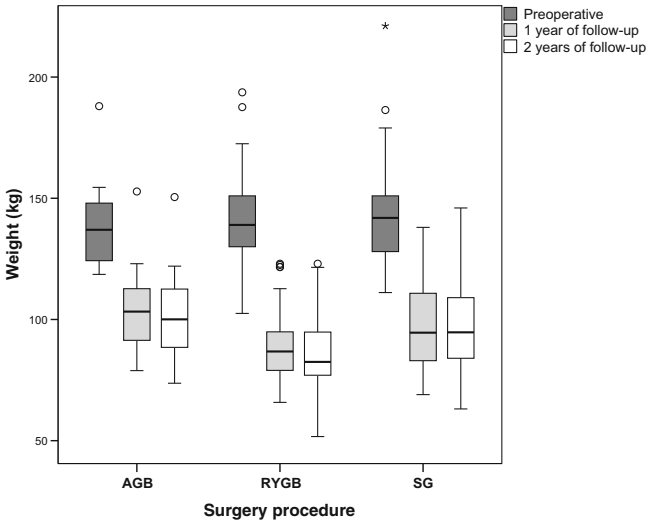
AGB adjustable gastric banding, *RYGB* Roux-en-Y gastric bypass, *SG* sleeve gastrectomy, *BMI* body mass index, *%EWL* percentage of excess weight loss, *%TWL* percentage of total weight loss, * $p < 0.05$ for comparison between RYGB and SG, † $p < 0.05$ for comparison between RYGB and AGB, § $p < 0.05$ for comparison between SG and AGB

follow-up remains a relevant topic in the bariatric field and has been evaluated by other authors. Despite a tendency toward weight regain, SG was associated with %EWL of 36.8–68% [26, 29–31] at 5 years of follow-up and a success rate of 54.05% in super obesity [30].

To our best knowledge, there are no randomized trials comparing in a head-to-head fashion the outcomes between RYGB and SG in patients with BMI ≥ 50 kg/m^2, but observational studies have addressed this issue [10, 12–14, 22]. Celio et al. compared the two procedures using the Bariatric Outcomes Longitudinal Database: 42119 patients who underwent RYGB and 8868 in the SG group [22]. In the 1st year, RYGB provided better weight loss than SG evaluating both %TWL and %EWL, but the authors did not report data after 1 year of follow-up. Likewise, smaller studies including super obese patients demonstrated that RYGB can achieve superior weight loss effects in comparison to SG [10, 13, 14]. On the other hand, Hong et al. studied 607 super obese patients with 3 years of follow-up and there were no significant differences in %EWL and change in BMI between different surgeries during follow-up [12]. However, this study has a dramatic decline in the follow-up data over time (follow-up rate less than 14% after 18 months).

Previous studies already showed that RYGB is clearly more effective than AGB in terms of weight loss [17–19]. The reported %EWL in patients submitted to RYGB was significantly higher than those underwent AGB, ranging from 52 to 73% and 31 to 46%, respectively. Our results are similar to these findings.

In recent reviews, BPD/DS is more effective than RYGB in long-term weight loss, but has significantly more



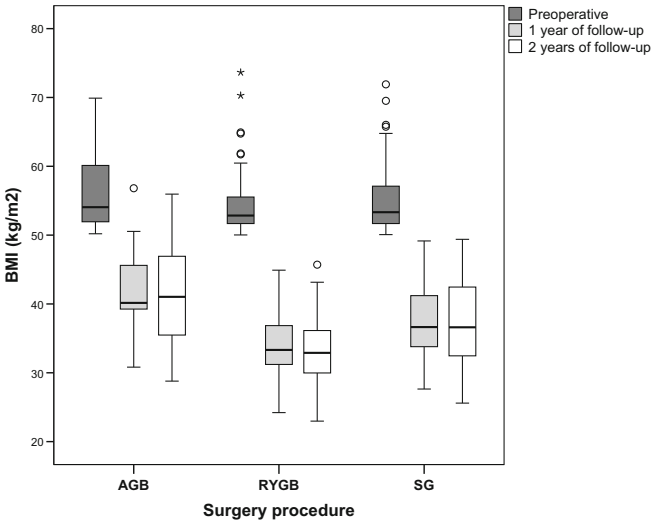
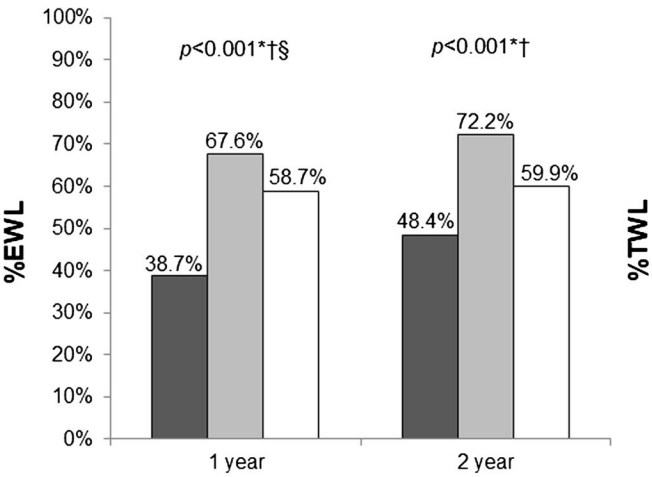


Fig. 1 Graphic evolution of weight and BMI according to the bariatric surgery. *n.s.* not significant, *AGB* adjustable gastric banding, *RYGB* Roux-en-Y gastric bypass, *SG* sleeve gastrectomy, *BMI* body mass index, * $p < 0.05$ for comparison between RYGB and SG, † $p < 0.05$ for comparison between RYGB and AGB, § $p < 0.05$ for comparison between SG and AGB

complications and slightly higher perioperative mortality [5, 32]. The authors concluded that current published literature is insufficient for recommending one type of bariatric surgery in this high-risk population [5]. Unfortunately, we cannot make any comparison with this technique because we do not perform BPD/DS in our hospital.

Super obesity has been associated to less weight loss [8, 11, 20]. Furthermore, these patients need to lose more weight to achieve a valid reduction in their mortality risk [2]. A systematic review including 115 studies ($n = 24{,}326$) identified potential preoperative predictors of weight loss after bariatric surgery [33]. Both preoperative higher BMI and super obesity were negatively associated with postoperative weight loss. Meta-analysis revealed that super obese patients lost in average near 10% less EWL compared to non-super obese. Even in multivariate analysis, several studies identified advanced age [9], hypertension [9], preoperative BMI [9, 13, 31, 33], and SG (comparing to RYGB) [13] as independent negative predictive factors for weight loss after surgery. Some aforementioned factors are similar to our results. Preoperative BMI had a negative association with %EWL, while younger age and underwent a RYGB were positive predictors in our univariate analyses (but statistical significance were not consistent in the different years of follow-up). After adjusting for age, sex, height, weight, BMI, and waist-to-hip ratio in a



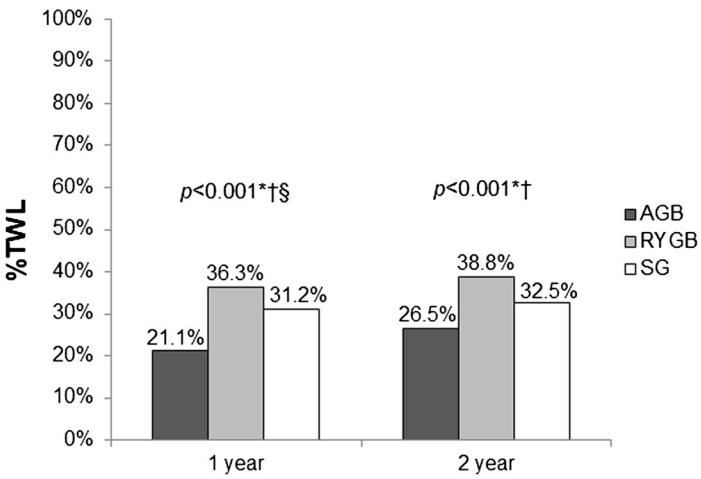


Fig. 2 Measurement of weight loss in the 1st and 2nd years of follow-up. *%EWL* percentage of excess weight loss, *%TWL* percentage of total weight loss, * $p < 0.05$ for comparison between RYGB and SG, † $p < 0.05$ for comparison between RYGB and AGB, § $p < 0.05$ for comparison between SG and AGB

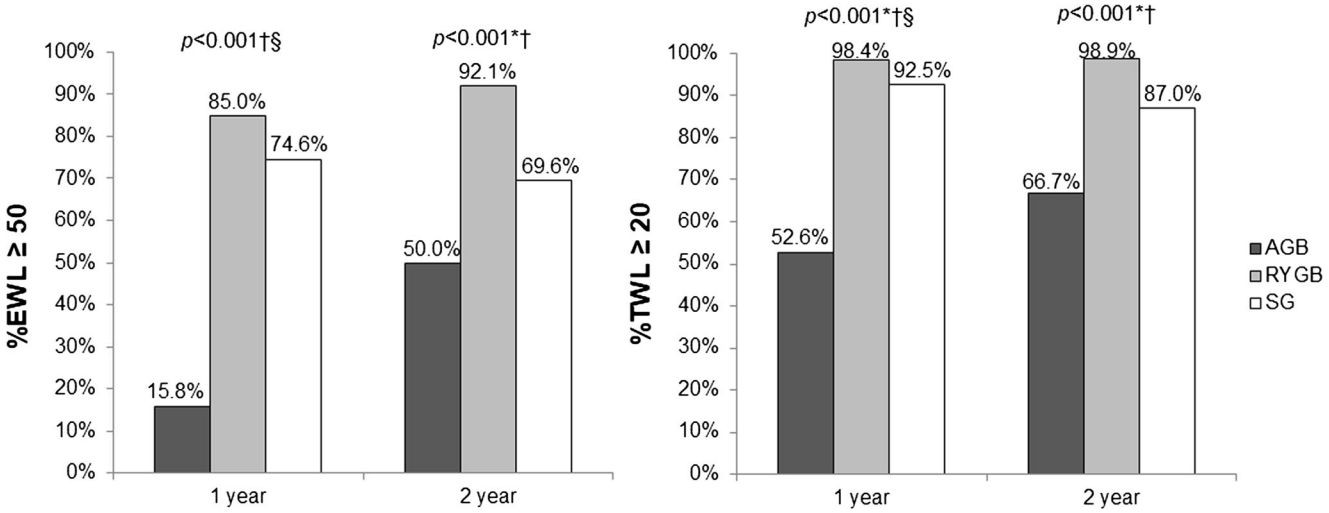


Fig. 3 Success of bariatric surgery in 1st and 2nd years of follow-up. *%EWL* percentage of excess weight loss, *%TWL* percentage of total weight loss, * $p < 0.05$ for comparison between RYGB and SG, † $p < 0.05$ for comparison between RYGB and AGB, § $p < 0.05$ for comparison between SG and AGB

multivariate regression model, RYGB was the only positive predictive factor for %EWL and %TWL in both years. In summary, RYGB was an independent predictor of weight loss even after adjusting for main demographic variables (sex and age) and baseline anthropometric parameters.

We observed significant decreases in the prevalence of DM, hypertension, and dyslipidemia after all bariatric surgeries. These comorbidities did not differ between groups on a statistically significant level both at baseline and over the follow-up. Despite a tendency to better control in almost all metabolic characteristics in the RYGB group, it did not reach statistical significance. Several authors evaluated the remission rate of DM, hypertension and dyslipidemia after bariatric surgery [8, 10–13, 16, 19, 21–23, 26–32, 34–36]. Some studies also found a comparable rate of resolution in some comorbidities with different bariatric surgeries [12, 32, 35]. Nonetheless, the improvement of these comorbidities during follow-up was not related to the %EWL and success rate of the bariatric surgery in this population, as already published [8, 21, 28, 31]. Indeed, numerous factors, rather than a single mechanism, are likely to mediate postoperative glycemic improvement [36, 37].

This study has some limitations. Although all patients have been counseled about eating behavior, dietetic changes, and physical activity both pre- and postoperatively, the adherence to counseling, which could influence weight loss, was not evaluated in our study. Moreover, demographic data was different between groups. Particularly, the AGB group had a small sample size. However, although we had a lower power to detect differences in this subgroup, we were able to show significant differences regarding weight loss and postoperative metabolic parameters in patients submitted to AGB in comparison with RYGB and SG. It is also important to note that near 30% of the patients were lost to follow-up at the 2nd year. Patients who experienced more satisfactory outcomes may be more likely to maintain the follow-up; therefore, we cannot preclude that our patients lost to follow-up presented a different weight loss evolution [38].

Notwithstanding these limitations, our study had several strengths. We compared in a head-to-head fashion the three types of bariatric surgery performed in patients with BMI ≥ 50 kg/m^2 in a tertiary center. There was no self-reported data, which can be inaccurate. No significant differences regarding mortality and morbidity were found between the three surgical groups. Furthermore, the baseline characteristics were equal between groups (unless, as mentioned previously, the differences in sex distribution). Unintentional selection bias resulting from patient selection of the surgical technique can be a limitation, because almost 80% of our sample was female and more than a half of male underwent SG. Of note, since sex was not a significant predictor of weight loss neither in the univariate nor in the multivariate analysis, differences in sex distribution seem to have little impact in the results.

Conclusion

The present study highlights RYGB as the best surgery to treat super obesity compared to SG and AGB, regardless of pre-surgical anthropometric characteristics. In our center, RYGB proved to have an average success rate near 92% in 2 years of follow-up. Weight loss effects were markedly

Table 3 Comparison of metabolic characteristics between patients submitted to different bariatric surgeries

	Total population	AGB	RYGB	SG	*p* value
Hypertension, %					
Preoperative (*n* = 213)	144 (67.6)	15 (78.9)	80 (63.0)	49 (73.1)	0.197
1st year (*n* = 213)	86 (40.4)	7 (36.8)	51 (40.2)	28 (41.8)	0.910
2nd year (*n* = 147)	59 (40.1)	7 (58.3)	31 (34.8)	21 (45.7)	0.194
Systolic BP, mmHg					
Preoperative (*n* = 213)	137.86 ± 19.39	140.18 ± 24.74	138.35 ± 18.41	136.14 ± 19.59	0.704
1st year (*n* = 21 l3)	125.87 ± 17.79	138.89 ± 30.19	124.41 ± 16.63	125.86 ± 15.57	0.068
2nd year (*n* = 147)	129.51 ± 20.60	127.67 ± 20.72	128.55 ± 22.10	131.74 ± 18.02	0.792
Diastolic BP, mmHg					
Preoperative (*n* = 213)	85.68 ± 13.50	84.41 ± 15.70	85.49 ± 12.04	86.47 ± 15.53	0.843
1st year (*n* = 213)	76.00 ± 10.51	85.00 ± 10.69	76.00 ± 10.19	74.00 ± 10.36	0.026§
2nd year (*n* = 147)	77.10 ± 12.36	86.00 ± 7.90	76.88 ± 12.25	75.96 ± 13.20	0.351
Dyslipidemia, %					
Preoperative (*n* = 213)	98 (46.0)	10 (52.6)	51 (40.2)	37 (55.2)	0.119
1st year (*n* = 213)	48 (22.5)	5 (26.3)	19 (15.0)	24 (35.8)	0.004*
2nd year (*n* = 147)	36 (24.5)	2 (16.7)	14 (15.7)	20 (43.5)	0.001*
TC, mg/dL					
Preoperative (*n* = 213)	199.16 ± 39.86	219.37 ± 41.35	197.21 ± 39.29	196.77 ± 39.39	0.067
1st year (*n* = 213)	181.81 ± 36.90	201.33 ± 35.11	175.82 ± 35.38	187.39 ± 37.98	0.016†
2nd year (*n* = 147)	182.43 ± 35.22	189.67 ± 26.22	178.91 ± 32.52	188.19 ± 41.88	0.343
HDL, mg/dL					
Preoperative (*n* = 213)	48.66 ± 11.05	51.37 ± 10.62	48.96 ± 11.58	47.02 ± 9.95	0.307
1st year (*n* = 213)	55.96 ± 11.60	56.50 ± 13.69	56.68 ± 11.64	54.46 ± 10.98	0.498
2nd year (*n* = 147)	61.38 ± 12.58	61.33 ± 10.95	61.56 ± 12.58	61.00 ± 13.26	0.977
LDL, mg/dL					
Preoperative (*n* = 213)	124.20 ± 31.36	135.21 ± 35.16	121.39 ± 30.30	126.10 ± 31.69	0.184
1st year (*n* = 213)	107.60 ± 32.60	129.13 ± 37.18	100.91 ± 30.25	114.00 ± 32.16	0.001†
2nd year (*n* = 147)	103.53 ± 27.94	108.11 ± 20.28	99.68 ± 27.69	111.15 ± 29.13	0.119
TG, mg/dL					
Preoperative (*n* = 213)	142.27 ± 103.67	139.53 ± 58.77	146.76 ± 111.88	134.66 ± 81.94	0.756
1st year (*n* = 213)	92.98 ± 106.13	106.13 ± 40.71	89.08 ± 33.20	96.68 ± 37.97	0.130
2nd year (*n* = 147)	91.21 ± 43.06	101.67 ± 32.70	88.55 ± 44.75	94.27 ± 41.99	0.606
Diabetes, %					
Preoperative (*n* = 213)	78 (36.6)	5 (26.3)	48 (37.8)	25 (37.3)	0.675
1st year (*n* = 213)	30 (14.1)	2 (10.5)	18 (14.2)	10 (14.9)	0.916
2nd year (*n* = 147)	18 (12.2)	2 (16.7)	7 (7.9)	9 (19.6)	0.130
FPG, mg/dL					
Preoperative (*n* = 213)	105.68 ± 38.38	98.37 ± 29.30	106.61 ± 42.75	106.25 ± 30.38	0.683
1st year (*n* = 213)	85.92 ± 11.15	90.63 ± 13.36	85.32 ± 10.45	85.78 ± 11.67	0.205
2nd year (*n* = 147)	87.22 ± 11.86	100.22 ± 21.03	86.62 ± 10.80	85.35 ± 9.33	0.002†§
HbA1c, %					
Preoperative (*n* = 213)	6.055 ± 1.139	5.722 ± 0.607	6.187 ± 1.295	5.911 ± 0.901	0.135
1st year (*n* = 213)	5.273 ± 0.457	5.181 ± 0.488	5.330 ± 0.446	5.191 ± 0.461	0.127
2nd year (*n* = 147)	5.267 ± 0.416	5.167 ± 0.424	5.307 ± 0.422	5.211 ± 0.403	0.395

Mean ± standard deviation; *n* (%)

AGB adjustable gastric banding, *RYGB* Roux-en-Y gastric bypass, *SG* sleeve gastrectomy, *BP* blood pressure, *TC* total cholesterol, *HDL* high-density lipoprotein cholesterol, *LDL* low-density lipoprotein cholesterol, *TG* triglycerides, *FPG* fasting plasma glucose, *HbA1c* glycated hemoglobin, * $p < 0.05$ for comparison between RYGB and SG, † $p < 0.05$ for comparison between RYGB and AGB, § $p < 0.05$ for comparison between SG and AGB

Table 4 Predictors of %EWL and %TWL at the 1st year of follow-up

	%EWL at 1st year		%TWL at 1st year	
	β (95% CI)	p value	β (95% CI)	p value
A. Univariate analysis				
Age, years	− 0.282 (− 0.489; − 0.075)	*0.008*	− 0.149 (− 0.262; − 0.037)	*0.009*
Sex (female)	3.439 (− 2.349;9.227)	0.243	1.659 (− 1.487;4.805)	0.300
Height, cm	0.175 (− 0.097;0.446)	0.206	0.069 (− 0.079;0.217)	0.360
Weight, kg	− 0.001 (− 0.127;0.125)	0.993	0.056 (− 0.012;0.125)	0.103
BMI, kg/m^2	− 0.414 (− 0.943;0.115)	0.125	0.229 (− 0.058;0.516)	0.117
Waist-to-hip ratio	− 12.532 (−47.644;22.580)	0.482	− 8.297 (− 27.606;11.013)	0.397
RYGB	13.265 (8.699;17.831)	< *0.001*	7.025 (4.535;9.514)	< *0.001*
B. Multivariate analysis				
Constant	− 303.370	0.282	− 143.860	0.348
Age, years	0.045 (− 0.230;0.321)	0.745	0.027 (− 0.123;0.177)	0.726
Sex (female)	2.715 (− 7.512;12.941)	0.600	1.625 (0.578;0.564)	0.564
Height, cm	2.313 (− 1.128;5.754)	0.186	0.957 (− 0.913; 2.828)	0.313
Weight, kg	− 1.092 (− 2.971;0.787)	0.253	− 0.426 (− 1.448;0.595)	0.411
BMI, kg/m^2	2.565 (− 2.246;7.376)	0.294	1.452 (− 1.163;4.067)	0.274
Waist-to-hip ratio	− 5.260 (− 41.923;31.403)	0.777	− 3.164 (− 23.097;16.768)	0.754
RYGB	15.581 (9.784;21.378)	< *0.001*	8.595 (5.443;11.747)	< *0.001*

Significant predictors are indicated by italics

%EWL percentage of excess weight loss, *%TWL* percentage of total weight loss, *CI* confidence interval, *BMI* body mass index, *RYGB* Roux-en-Y gastric bypass

evident in the 1st year, but additional benefits occurred during the 2nd year of follow-up. In multivariate analysis, RYGB was an independent predictive factor of %EWL and %TWL. Our results provide compelling support for

Table 5 Predictors of %EWL and %TWL at the 2nd year of follow-up

	%EWL at 2nd year		%TWL at 2nd year	
	β (95% CI)	p value	β (95% CI)	p value
A. Univariate analysis				
Age, years	− 0.473 (− 0.720;-0.226)	< *0.001*	− 0.257 (− 0.388;-0.126)	< *0.001*
Sex (female)	2.722 (− 5.153;10.597)	0.496	1.647 (− 2.521;5.815)	0.436
Height, cm	0.237 (− 0.120;0.595)	0.192	0.090 (− 0.100;0.280)	0.352
Weight, kg	− 0.055 (− 0.220;0.110)	0.512	0.036 (− 0.051;0.123)	0.414
BMI, kg/m^2	− 0.766 (− 1.377;-0.155)	*0.014*	0.031 (− 0.299;0.362)	0.851
Waist-to-hip ratio	− 9.479 (− 50.062;31.105)	0.644	− 6.841 (− 28.401;14.719)	0.531
RYGB	14.677 (9.113;20.240)	< *0.001*	7.488 (4.522;10.453)	< *0.001*
B. Multivariate analysis				
Constant	− 2.204	0.996	43.074	0.839
Age, years	− 0.276 (− 0.598;0.047)	0.093	− 0.146 (− 0.319;0.028)	0.098
Sex (female)	0.087 (− 12.303;12.477)	0.989	0.400 (− 6.257;7.056)	0.905
Height, cm	0.685 (− 4.214;5.584)	0.782	− 0.077 (− 2.709;2.555)	0.954
Weight, kg	− 0.335 (− 3.090;2.420)	0.810	0.079 (− 1.401;1.559)	0.916
BMI, kg/m^2	0.222 (− 6.663;7.106)	0.949	− 0.051 (− 3.750;3.647)	0.978
Waist-to-hip ratio	− 3.138 (− 44.001;37.725)	0.879	− 2.182 (− 24.135;19.771)	0.844
RYGB	14.001 (7.181;20.821)	< *0.001*	7.703 (4.039;11.366)	< *0.001*

Significant predictors are indicated by italics

%EWL percentage of excess weight loss, *%TWL* percentage of total weight loss, *CI* confidence interval, *BMI* body mass index, *RYGB* Roux-en-Y gastric bypass

choosing RYGB in super morbid obesity. Future efforts should focus on long-term follow-up studies.

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Compliance with Ethical Standards

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

Ethical Approval All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent For this type of study, formal consent is not required.

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