OBES SURG (2011) 21:1458–1468
DOI 10.1007/s11695-011-0390-5

REVIEW

A Review of Studies Comparing Three Laparoscopic Procedures in Bariatric Surgery: Sleeve Gastrectomy, Roux-en-Y Gastric Bypass and Adjustable Gastric Banding

Juan Victor A. Franco · Pablo Adrian Ruiz · Mariano Palermo · Michel Gagner

Published online: 1 April 2011

Abstract Obesity is a major worldwide problem in public health, reaching epidemic proportions in many countries, especially in urbanized regions. Bariatric procedures have been shown to be more effective in the management of morbid obesity, compared to medical treatments in terms of weight loss and its sustainability. The two most commonly performed procedures are laparoscopic Roux-en-Y gastric bypass (LRYGB), laparoscopic adjustable gastric banding (LAGB), and the novel laparoscopic sleeve gastrectomy (LSG). The MEDLINE database (cutoff date September 2010), LILACS, and the Cochrane Library were searched using the key words "gastric bypass," "sleeve gastrectomy," and "gastric banding." Only studies that compared at least two of the laparoscopic procedures were included. Reviews and meta-analysis, editorial letters or comments, case reports, animal or in vitro studies, comparisons with medical treatment, comparisons with open (non-laparoscopic) procedures were excluded. Most studies indicated that LRYGB and LSG could be more effective achieving weight loss than LAGB. However, LAGB seems to be a safer procedure with frequent, but less severe, long-term complications. Although not uniformly reported, a resolution of obesity-related comorbidities was achieved with most bariatric procedures. The three procedures have acceptable efficacy and safety. We believe that patients should be informed in detail on the advantages and disadvantages of each available procedure, possibly in several interviews and always accompanied by a specialized interdisciplinary team, warranting long-term follow-up.

Keywords Laparoscopic Roux-en-Y gastric bypass · Laparoscopic adjustable gastric banding · Laparoscopic sleeve gastrectomy

M. Palermo (✉) · M. Gagner (✉)
Department of Surgery, Mount Sinai Medical Center,
4300 Alton Road,
Miami Beach, FL 33140, USA
e-mail: palermomd@msn.com

M. Gagner
e-mail: gagner.michel@gmail.com

J. V. A. Franco · P. A. Ruiz · M. Palermo
Department of Surgery, University of Buenos Aires (UBA),
Buenos Aires, Argentina

Introduction

Obesity is one of the major epidemics of the twenty-first century. Over two thirds of adults in the United States are overweight or obese, and over one third are obese, according to data from the National Health and Nutrition Examination Survey. The prevalence of obesity in the USA continues to be high, exceeding 30% in most sex and age groups. Prevalence estimates in European countries varies widely from country to country, with higher prevalence in central, eastern, and southern Europe. In most cases, the prevalence of obesity appeared lower in European countries than in USA [1]. As the Centers for Disease Control and Prevention states, American society has become "obesogenic," characterized by environments that promote increased food intake, unhealthy food and physical inactivity. In Latin America, the data is scarce, and estimates range from a prevalence of 9.9% to 37.5% [2]. In our region, it is associated with urbanity, lower socioeconomic and education level. Obesity and its comorbidities increase global health expenditures and accentuate inequity in health.

Obesity is well-known to be closely related to much comorbidity: coronary heart disease and stroke, hypertension (HT), insulin resistance (IR), type 2 diabetes mellitus (T2DM), hyperlipidemia (HL), obstructive sleep apnea (OSA), muscular and joint pain, degenerative osteoarthritis, many types of cancer and psychiatric disorders such as depression and eating disorders. The repercussion of obesity and its related disorders does not only lead to a reduction in life expectancy, but also to the development of severe physical and psychosocial impairment, i.e., a reduction in quality of life.

According the National Institutes of Health Consensus Development Program in March 1991 [3], potential candidates for bariatric surgery are those whose body mass index (BMI) exceeds 40 kg/m^2. Those with BMI >35 and <40 may also be considered for surgery if they present high-risk comorbid conditions such as life-threatening cardiopulmonary problems (e.g., severe sleep apnea, Pickwickian syndrome, and obesity-related cardiomyopathy) or severe diabetes mellitus. The recommended procedures at the time were Roux-en-Y gastric bypass and vertical-banded gastroplasty. The latter has fallen out of use because of its lack of success at weight loss and high rate of complications. Other bariatric procedures such as biliopancreatic diversion with or without duodenal switch (BPD/DS) are rarely performed nowadays because of its unacceptable high rate of macronutrient deficiency, among other complications. The aim of this study was to compare these three surgical procedures for obesity and compare his efficacy, safety, insulin resistance, and the surgical technique.

Methods

We performed bibliographic searches in PubMed (Medline), The Cochrane Library, and LILACS using their search engines. The cutoff date was September 3, 2010. The keywords used were "gastric bypass," "sleeve gastrectomy," and "gastric banding" in combination of pairs, obtaining 151, 529, and 93 results in PubMed. The results were screened including those who compared at least two of the three surgical procedures in terms of efficacy or safety as defined below. We have also included studies comparing differences in insulin resistance. We excluded reviews and meta-analysis, editorial letters or comments, case reports, animal or in vitro studies, comparisons with medical treatment, comparisons with open (non-laparoscopic) procedures. The results found in the Cochrane Library were duplicates from those found in PubMed. No results matching our inclusion and exclusion criteria were found using LILACS. The meta-analysis, editorial letters and reviews were taken into account for bibliographic references and discussion of findings. Multiple publications referring to the same series of patients (*kin relationships*) were analyzed altogether to avoid a duplication of data.

Efficacy was assessed using the percentage of excess weight loss (%EWL) and the resolution or improvement of comorbidities, evaluating the sustainability of these results. The %EWL was calculated as 100%×(preoperative weight− postoperative weight)/excess preoperative weight; the latter is usually defined by the Metropolitan Life Insurance Company tables (1983) or the weight for a BMI of 25 kg/m^2. Safety will be considered in terms of perioperative, early (<30 days), and late (>30 days) postoperative complications (re-intervention, sepsis, small bowel perforation, etc.) and management, absolute mortality and procedure-related mortality. Statistical significance was interpreted considering a P value <0.05. Met analytic techniques were not used because of the significant heterogeneity in the study design, outcome definitions, and their assessment methods.

Surgical Procedures

Laparoscopic Roux-en-Y gastric bypass (LRYGB) was first reported by Alan Wittgrove and Wesley Clark in 1994 [4], and it is both a restrictive and malabsorptive irreversible procedure and the most commonly performed in USA. A 15 to 30-mL gastric pouch is created and isolated from the distal stomach by applications of a linear stapler in most of the studies. The jejunum is divided 50 to 100 cm distal to the ligament of Treitz, and the distal limb is connected to the gastric pouch, creating an alimentary Roux limb. The proximal bowel segment or biliopancreatic limb is connected to the alimentary limb through a jejunojejunostomy 100 to 150 cm distal to the gastrojejunostomy. It presents a long learning curve and must be performed by surgeons with advanced laparoscopic or specific laparoscopic–bariatric surgery training. Another technique denominated "mini gastric bypass," involves transecting the proximal stomach into a long gastric tube and then performing a distal gastrojejunostomy 200 cm beyond the ligament of Treitz. Unless specified, all the studies performed LRYGB.

Laparoscopic adjustable gastric banding (LAGB), first reported in 1994 by Belachew and colleagues [5], is a purely restrictive reversible procedure, the most often performed in Europe and Australia, and increasingly considered in the USA since the approval of the Lap-Band® (Inamed, Allergan, Santa Barbara, CA) by the FDA in 2001. Most of the studies used the pars flaccida technique instead of the perigastric technique in order to reduce band slippage when placing the device. A per-oral balloon is inflated to calibrate the adjustment of the device creating a 15–25-ml gastric pouch. In general, American studies have used the Lap-Band® system, and other studies have also used a Swedish adjustable gastric band (Obtech® and Ethicon Endo-Surgery®) [6–8], and others, the Heliogast Band ® (Helioscopie, Vienne cedex, France) [9] and Soft Gastric Band ® (Agency for Medical Innovation, Gotzis, Austria) [9, 10]. The device was typically adjusted from 6 to 8 weeks after surgery according to the clinical assessment and in every visit thereafter, along with the usual care. This technique presents a shorter learning curve than the LRYGB and it can be performed by general surgeons.

The novel laparoscopic sleeve gastrectomy (LSG) was first described in 1988 by Hess [11] and Marceau [12] during the procedure of DS, commonly used as the first step of RYGB or BPD/DS, and since 1993 by Johnston [13] in an isolated form. It is a restrictive irreversible procedure. A gastric sleeve tube is created with the firings of a linear stapler commencing close to the pylorus following up to the incisura angularis. A nasogastric tube of 34 to 46 French is passed to guide and adjust the size of the gastric tube. Bougies, from 32 to 60 French, have been used in various studies. Factors that may affect weight loss and resolution of comorbidities after LSG are dissection of the entire gastric fundus, bougie size, antral resection, and ethnicity. LSG presents a shorter learning curve than LRYGB.

Results

Randomized Controlled Trials

Nguyen et al. [14] compared LRYGB to LAGB, randomizing 250 patients, 125 for each group at the beginning, although 14 from the LRYGB group and 39 from the LAGB group were excluded from the analysis after randomization because they were unwilling to undergo the assigned procedure. At 4 years postoperative, follow-up data were available for 83.1% patients from the LRYGB group and for 93.3% patients from the LAGB group. The baseline characteristics indicated a higher mean BMI and a lower mean age in the LRYGB group. A statistically significant higher %EWL was found in the LRYGB group compared to the LAGB at 1, 2, 3, and 4 years after surgery (Table 1). A subgroup analysis of patients with an initial BMI <50 kg/m^2 and >50 kg/m^2 presented better weight loss in the former group. In spite of a higher baseline BMI, at 4 years postoperative the mean BMI was significantly lower in the LRYGB group compared to the LAGB. The weight loss failure (%EWL <20%) was reported in 16.7% of LAGB patients and none in the LRYGB group. Early major complications (Table 2) were reported in seven patients in the LRYGB group (two postoperative gastrointestinal hemorrhages and five postoperative bowel obstructions) and in two patients in the LAGB group (one postoperative obstruction and one renal insufficiency). Early non-surgical complications were more frequent in the LRYGB group. Late major complications were reported in 29 patients from the LRYGB group (17 anastomotic stricture requiring endoscopic dilation, two internal hernias, three ventral hernias, two marginal ulcers, two abdominal pains requiring laparoscopy, one bowel obstruction, one peripheral neuropathy, and one patient died because of alcohol and drugs abuse) and in ten patients from the LAGB group (three port revisions, two band slippages, two band obstructions, one band erosion, and two failures of weight loss requiring conversion to LSG). Late non-surgical complications were reported in 15 patients from the LRYGB group (nine margin ulcers at the gastrojejunal anastomosis, two gastrointestinal bleeding, and three severe iron deficiency) and none from the LAGB group. The quality of life was measured by the validated 36-item health survey SF-36 questionnaire [15], reporting at 1 month after surgery an improvement in five of eight domains for the LRYGB group and an improvement in one of eight health domains for the LAGB group. At 1 year postoperative, they reported similar improvements with no significant differences between both groups. Methodologically, this is the largest randomized study, specifying sample size calculation, randomization method, detailed surgical technique, postoperative care, and with the greatest follow-up rates.

Himpens et al. [9] compared LAGB to LSG randomizing 40 patients for each treatment group. They did not specify how they did the randomization, and 34 patients from the LAGB group and 32 patients from the LSG group reached the 3-year follow-up. This study reported a statistical significance more on weight loss and reduced BMI and higher %EWL (57.7% vs. 48%) at 1 and 3 years with LSG compared to LAGB (Table 1). Insufficient weight loss was observed in two patients in both groups and was treated by conversion into LRYGB for the LAGB group and into duodenal switch for the LSG group. Non-surgical complications for LAGB included shoulder pain, frequent vomiting, and poor choice of alimentation. In LSG, they were less frequent, but also included gastric pain and deficiency of minerals. Early postoperative complications (Table 2) requiring re-operation were reported in two patients of the LSG and none in the LAGB group: an intraperitoneal bleeding and a gastric ischemia. Late complications requiring re-operation were registered in seven patients from the LAGB group and none in the LSG group; most of all, the procedures were specific, as disconnection of the port, pouch dilation and gastric erosion. The number of complications requiring re-operation was higher after LAGB compared to LSG, for most of them the procedures were specific. Though, the severity of the complications was higher after LSG compared to LAGB. Two patients had band removal, five patients in the LAGB group and two in the LSG group were converted to LRYGB or DS due to a complication or insufficient weight loss.

Angrisani et al. [16] compared LAGB to LRYGB, from a total of 51 patients; randomizing 27 for the LAGB group and

Table 1 Randomized studies

Author	Location	No. of patients	%EWL						
			1 m	6 m	12 m	2 years	3 years	4 years	5 years
Nguyen et al. [14]	USA	111 LRYGB 86 LAGB	N/A	N/A	36.5 LAGB 64.3 LRYGB	41.8 LAGB 68.9 LRYGB	41.5 LAGB 67.5 LRYGB	45.4 LAGB 68.4 LRYGB	N/A
Himpens et al. [9]	Belgium	40 LAGB 40 LSG	N/A	N/A	41.4 LAGB 57.7 LSG	N/A	48 LAGB 66 LSG	N/A	N/A
Angrisani et al. [16]	Italy	27 LAGB 24 LRYGB	N/A	N/A	34.7 LAGB 51.3 LRYGB	N/A	47.3 LAGB 67.3 LRYGB	N/A	47.5 LAGB 66.6 LRYGB
Karamanakos et al. [17]	Greece	16 LSG 16 LRYGB	18.2 LSG[a] 20.5 LRYGB[a]	55.5 LSG 50.2 LRYGB	69.7 LSG* 60.5 LRYGB*	N/A	N/A	N/A	N/A
Langer et al [10]	Austria	10 LAGB 10 LSG	16.7 LAGB 29.8 LSG	28.7 LAGB 61.4 LSG	N/A	N/A	N/A	N/A	N/A
Peterli et al. [18]	Switzerland	14 LSG 13 LRYGB	N/A	N/A	N/A	N/A	N/A	N/A	N/A

All differences are statistically significant ($p<0.05$). Peterli used %EBL as efficacy (not included in this table)

N/A does not apply

*$p \geq 0.05$, without statistical significance

[a] Without report on statistical significance

24 for the LRYGB, with a 5-year follow-up. Eight patients were excluded after randomization due to refusal to undergo the procedure (five LRYGB and three LAGB) and another patient was lost to follow-up in the LAGB group. The data were not examined on an intention to treat analysis. The study reported at 5 years after surgery that patients in the LRYGB had a significantly lower weight, BMI, and a significant greater %EWL compared to the LAGB group. Weight loss failure (BMI >35 kg/m^2 at 5 years) was significantly higher in the LAGB group (Table 1). At 5 years time, all patients had resolved, though not defined, their baseline obese-related comorbidities. The mean operative time and the mean hospital stay were significantly longer for patients in the LRYGB group compared to the LAGB group. Early complications (Table 2) requiring re-operation, within the first 30 days after surgery, were reported in two patients of the LRYGB group and none in the LAGB group: one posterior pouch leak and one jejunal perforation. Late

Table 2 Randomized studies: complications requiring a re-operation rate in RCTs

Author	Mortality	Conversion to laparotomy	Early complications requiring re-operation			Late complications requiring re-operation		
			LRYGB	LAGB	LSG	LRYGB	LAGB	LSG
Nguyen et al. [14]	1 LRYGB[a] 0 LAGB	0 LRYGB 0 LAGB	1 Gastrointestinal hemorrhage 5 Bowel obstruction	1 Postoperative obstruction	N/A	17 Anastomotic stricture[b] 2 Internal hernia 3 Ventral hernia 2 Marginal ulcer 2 Abdominal pain 1 Bowel obstruction	3 Port revision 2 Band slippage 2 Band obstruction 2 Weight loss failure requiring conversion to LSG 1 Band erosion	N/A
Himpens et al. [6]	Not reported	Not reported	N/A	0	1 Intraperitoneal bleeding 1 Gastric ischemia	N/A	3 Disconnection of the port 3 Pouch dilation 1 Gastric erosion	0
Angrisani et al. [16]	0 LAGB 0 LRYGB	0 LAGB 1 LRYGB (leak)	1 Posterior pouch leak 1 Jejunal perforation	0	N/A	1 Small bowel obstruction, internal hernia	2 Pouch dilation 2 Inadequate weight loss requiring conversion	N/A

Langer and Karamanakos did not report these variables. Peterli only reported that no patient in both groups had converted to laparotomy

[a] One patient died due to alcohol/drug abuse, not related to the procedure

[b] Required endoscopic dilation

complications requiring re-operation occurred in four patients from the LAGB group and in one patient from LRYGB group: two gastric pouch dilations and two band removals because of inadequate weight loss, and one small bowel obstruction because of an internal hernia, respectively. Surgical complications requiring re-operation were more frequent in the LAGB group, all were closely related to the procedure, and they were not as severe as the ones in the LRYGB group, where there were more early complications compared to the LAGB group.

Karamanakos et al. [17] compared LRYGB to LSG, randomizing 16 patients in each treatment group, with a postoperative follow-up time of 12 months without any patient loss. They studied the change in fasting and postprandial levels in ghrelin and peptide YY (PYY). Patients in the LSG group were younger. There was no report on peri- and postoperative complications. Initially (1 and 6 months), %EWL was greater in the LSG group, but after 12 months, no significant difference in weight loss and BMI was found (Table 1). For comorbidities, both procedures obtained a significant reduction in glucose and triglyceride levels, with no significant difference between both groups. T2DM was resolved in the two diabetic patients in the LRYGB group. Neither group presented a significant reduction in total and LDL cholesterol levels. Fasting ghrelin concentrations decreased significantly 12 months after surgery in the LSG group but not in the LRYGB group. Both groups had a significant increase in PYY levels at 12 months. Two subgroups of six patients in each group were studied for postprandial suppression of ghrelin and increase in PYY. Only the LSG group achieved a significant suppression of ghrelin from fasting levels, whereas a significant increase in PYY was found in both groups. Appetite was evaluated by a visual analogue scale, validated for evaluating cancer-induced cachexia. A significant decrease in appetite was found in both groups, although patients from the LRYGB group experienced a gradual regain of appetite during the follow-up time. The authors conclude that these differences in appetite and % EWL could partially be explained by changes in ghrelin and PYY in both procedures. Methodologically, it was a very small sample, with low power to detect further difference in these variables, and there was no analysis of correlation of these variables.

Langer et al. [10] compared LSG and LAGB, randomizing ten patients in each treatment group. They studied the change in plasma ghrelin levels. They did not specify the method of randomization, and no patient was reported to be lost to follow-up. The patient demographics were similar in both groups, except for a higher proportion of super obese patients in the LSG group, defined as having a BMI >50 kg/m^2. The results reported significantly higher %EWL 6 months after LSG compared with the LAGB (Table 1). The results of the ghrelin levels demonstrate a significant decrease at 1 day and at 6 months after LSG compared with the preoperative levels. In the LAGB group, there was no difference in the ghrelin levels at day 1 after surgery, although 6 months after surgery there was a significant increase in ghrelin levels. The authors conclude that these differences in %EWL could partially be explained by changes in ghrelin. Methodologically, it was a very small sample, with low power to detect further differences in these variables, and there was no analysis of correlation of these variables.

Peterli et al. [18] compared LSG and LRYGB, randomizing 13 in the LSG group and 14 in the LRYGB group. There was a 3-month follow-up, and no patient was reported to be lost at follow-up. They studied the improvement in glucose metabolism, measuring insulin and glucagon-like-1 peptide (GLP-1) levels, subsequently glucose, PYY, and ghrelin levels. The patient demographics were similar between both groups, except for three patients in the LSG group with T2DM and none in the LRYGB group, and all patients but one from the LSG group had a homeostasis model assessment of insulin resistance (HOMA-IR) higher than the normal limit. After meal induction, a postprandial response before surgery was attenuated for insulin, defective for GLP-1, did not significantly increase for PYY, and did not significantly decrease for ghrelin in both groups with no statistical difference between them. The results at 3 months postoperatively were reported. Both procedures reported a significant decrease in weight and BMI (Table 1), with no statistical difference between the two groups. The fasting insulin, PYY, and ghrelin levels were significantly decreased in both groups compared to preoperative levels, with no difference between the two groups. Postoperatively, there was a significant increase in postprandial insulin, GLP-1 levels, and PYY levels in both groups at 1 week and at 3 months after surgery. At week 1, there was a higher postprandial GLP-1 response in the LRYGB group, but at 3 months the LSG group had similar values. At week 1 and 3 months after surgery there was a significant decrease in fasting and postprandial ghrelin levels in both groups, with a higher postprandial suppression of ghrelin levels after meal intake in the LSG group (*P* value not reported). Two of three diabetic patients resolved their condition with no need for medication. Methodologically, it was a very small sample, with low power to detect further differences in these variables, and there was no analysis of correlation of these variables.

Efficacy

%EWL We found ten comparative studies [6–8, 19–25] evaluating this variable, being mostly a descriptive,

retrospective series with asymmetric distribution of patients (see Table 2). Most studies had heavier patients in the LRYGB group, but the reverse was found in the study by Jan et al. [20, 21]. The reason for this finding was that some groups considered that patients with greater BMI would benefit more from LRYGB, whereas Jan considered that because of the higher surgical risk of these patients, they would be candidates for a simpler procedure, such as LAGB. Sex was distributed unevenly in most groups, with men usually in the heavier group.

In all series, LRYGB had higher %EWL compared to LAGB throughout the duration of the follow-up time. Jan and Kim [22] have reported no statistical difference in the long-term follow-up (5 and 2 years, respectively), but the follow-up rates were very low or not published. The results for LSG were heterogeneous and were hard to interpret due to the lack of published data in terms of statistical significance. The results were similar or superior to those found for LRYGB. Lakdawala [6] reviewed a series using different bougie sizes when creating the sleeve, but this detail has not been uniformly published. In a study analyzing the distribution of %EWL of LAGB and LRYGB patients, Bessler et al. [26] found that while LRYGB patients had a one-peak normal distribution of results at 2 and 3 years follow-up, LAGB patients had a two- or three-peak distribution, denoting subgroups of patients with better, but mostly worse outcomes than those represented by the mean %EWL. This indicates that the interpretation of the mean±standard deviation and its statistical significance might be inadequate when estimating the results of LAGB.

The results from Lee [24] and Wong [8] must be interpreted carefully since Asian people have different surgical consensus (Asia-Pacific Bariatric Surgery Group consensus, BMI >37 kg/m^2 or BMI >32 kg/m^2 with comorbidities) because of the higher percent of visceral fat and cardiovascular risk at the same BMI compared to their western counterparts, therefore results are difficult to extrapolate. Wong described “mini gastric bypass” but did not specify to how many patients this procedure was performed.

A study by Mognol et al. [27] (not included in the table) analyzed the effects of LRYGB and LAGB in the super obese (BMI >50 kg/m^2). Their results were consistent with a %EWL of 73% (LRYGB) vs. 46% (LAGB) and a higher percentage of patients with a BMI < 35 kg/m^2. The pattern of complications was similar to other studies (see below).

One study [28] compared changes in body composition after LSG, LRYGB, LAGB, and BPD/DS, but unfortunately the postoperative measurement was at different times after these procedures. The study suggests, though, that the lowest postoperative percentage of body fat (excluding BPD/DS) were achieved with LRYGB and LSG, with higher percentages in patients following LAGB.

Only one of the studies [19] specified that they have excluded patients with band removal or conversion from LAGB to LRYGB; the rest do not provide data on how they have analyzed these subjects. The most important limitation of all these studies has been the lack of long-term follow-up. It cannot be stated that the initial results will be sustainable over time unless long-term data can be retrieved and analyzed. If the loss to follow-up was not uniform among the groups, differences could be attributed to different after care programs, loss of patients who have sustained weight loss, or loss of patients who have sought an alternative care after treatment failure. Even if the loss was uniform in all treatment groups, the analysis would lose power when the population size decreases, so statistically significant differences would be difficult to detect as describes Table 3.

Resolution of Comorbidities

There was no uniform definition of how patients were identified as having obesity-related comorbidities. Moreover, definitions of “resolution” or “improvement, better/control” were also heterogeneous. However, most studies indicate that bariatric procedures improve or resolve many of the obesity-related comorbidities [7, 8, 22, 23, 25]: hypertension (HT), insulin resistance (IR), type 2 diabetes mellitus (T2DM), hyperlipidemia (HL), obstructive sleep apnea (OSA), and muscular and joint pain. Most of these studies [7, 23, 25] also indicated better results with LRYGB compared to LAGB, whereas little data is available on LSG.

Safety

Overall, bariatric surgery appeared very safe compared to other laparoscopic abdominal procedures (Tables 4). Mortality in most cases is less than 1% and the incidence of adverse outcomes related to the patient’s characteristics, center’s volume, surgeons’ skills, surgical technique, the learning curve, and peri- and postoperative care. Conversion rates were also low in most groups, with a higher incidence in LRYGB. Many of the patients underwent concomitant procedures, the most common one being cholecystectomy and hiatal hernia repair (when found) (Tables 5).

LRYGB All the groups reported longer operative time and hospital stay for LRYGB. Blood loss has been variable and minimal. Most series report a high incidence of early complications such as bleeding, perforation, or leakage, which require immediate resolution, and some of them are life threatening. Late complications, such as anastomotic stenosis, are usually less frequent, milder, and can be

Table 3 Percentage of weight loss

Author	Location	Design	No. of patients	Mean %EWL (follow-up percentage)				
				6 m	12 m	2 years	3 years	5 years
Biertho et al. [6]	Switzerland (LAGB)	Retrospective	805 LAGB	22 LAGB (97%)	33 LAGB (97%)	N/A	N/A	N/A
	USA (LRYGB)	Case series	456 LRYGB	52 LRYGB (88%)	67 LRYGB (57%)			
Boza et al. [7]	Chile	Retrospective	62 LAGB	57.9 LAGB	65.5 LAGB	61.3 LAGB	61.4 LAGB	59.1 LAGB (91.5%)
		Case series	91 LRYGB	86.7 LRYGB	99.9 LRYGB	102.6 LRYGB	92.1 LRYGB	92.9 LRYGB (73.6%)
Christou and Efthimiou [19]	Canada	Retrospective	149 LAGB	31.4 LAGB (98%)	42.8 LAGB (73%)	49.6 LAGB (66%)	58.6 LAGB (72%)	61.0 LAGB (80%)
		Case series	886 LRYGB	54.8 LRYGB (97%)	70.4 LRYGB (83%)	78.8 LRYGB (62%)	79.2 LRYGB (62%)	75.2 LRYGB (67%)
Jan et al. [20, 21]	United States	Retrospective	406 LAGB	25.6 LAGB (84%)	34.0 LAGB (65%)	38.6 LAGB (25%)	39.3 LAGB (9%)	49 LAGB (1%)*
		Case series	492 LRYGB	49.3 LRYGB (60%)	64.9 LRYGB (48%)	67.4 LRYGB (21%)	66 LRYGB (10%)	58.6 LRYGB (1%)*
Kim et al. [22]	United States	Retrospective Case series	160 LAGB 232 LRYGB	24.6 LAGB 49.0 LRYGB	34.4 LAGB 63.5 LRYGB	47.5 LAGB* 68.0 LRYGB*	N/A	N/A
Lakdawala et al. [6]	India	Retrospective Matched cases	50 LSG 50 LRYGB	50.8LSG[a] 41.7 LRYGB[a]	76.1 LSG[a] 62.2 LRYGB[a]	N/A	N/A	N/A
Lee et al. [31]	Korea	Retrospective Case series	51 LAGB 25 LRYGB	32.7 LAGB 68.2 LRYGB	46.8 LAGB 76.9 LRYGB	55.1 LAGB 79.7 LRYGB	63.3 LAGB 85.5 LRYGB	N/A
Weber et al. [25]	Swizerland	Retrospective Matched cases	103 LAGB 103 LRYGB	24.9 LAGB 44.0 LRYGB	35.1 LAGB 54.8 LRYGB	42.1 LAGB 54.0 LRYGB	N/A	N/A
Wong et al. [8]	China	Retrospective Case series	57 LAGB 30 LSG	27 LAGB (79%)[a] 63 LSG (53%)[a]	31 LAGB (84%)[a] 65 LSG (63%)[a]	34 LAGB (47%)[a] 51 LSG (7%)[a]	N/A	N/A
			7 LRYGB	54 LRYGB (100%)[a]	70 LRYGB (86%)[a]	61 LRYGB (71%)[a]		

All differences are statistically significant ($p<0.05$)

N/A does not apply

*$p>0.05$, without significance

[a] Without report on statistical significance

resolved with endoscopic therapy if necessary. Most studies described an intraoperative technique to verify indemnity of intracorporeal sutures, e.g., methylene blue administration; nevertheless, anastomosis bleeding, or leakage was still one of the most frequent complications in the LRYGB. Kinking and obstruction of the Roux limb was associated with retrocolic alimentary limbs compared to antecolic limbs (3.7% vs. 0.3%, $p<0.05$). Internal hernia was frequent in those centers where mesenteric defects were not routinely closed. Marginal ulcer and gastritis were managed with proton pump inhibitors.

LAGB Most complications derived from the device itself. Compared to LRYGB, early complications were infrequent, but late complication rates were much higher, usually requiring revision surgery. Band slippage was frequent and sometimes could be resolved by repositioning but mostly by removal. It has been associated with the perigastric placement of the band and with the advent of the pars flaccida approach, the incidence was reduced (28.7% vs. 4.7%). Port migration, infection, or skin irritation was very frequent and required replacement and/or repositioning. Chronic band intolerance, usually recorded as gastric pouch dilation, and inadequate weight loss (not defined by authors) lead to revision surgery with band removal and in most cases, conversion to another bariatric procedure (LRYGB, LSG, BPD/DS). Some of these were open.

LSG Data comparing complications of LSG are scarce, reporting only dietary intolerance, stoma stenosis, and common complications of the other two procedures (e.g., wound infection, etc.).

Insulin Resistance

Many studies have analyzed changes in insulin, fasting glucose, GLP-1 (incretin) levels, together with the HOMA-IR.

Ballantyne [29, 30] analyzed these changes in patients undergoing LRYGB and LAGB. A significant decrease in

Table 4 Perioperative, early, and late complications related to the procedures

Author	No. of patients	Perioperative mortality	Conversion to laparotomy	Complications				
				% Patients global	Early (<30 days)	Late (>30 days)	Re-operation early+late	Band removal (conversion)
Biertho et al. [6]	805 LAGB 456 LRYGB	0 LAGB 2 LRYGB	3% LAGB 2% LRYGB	Not reported	14 LAGB* 19 LRYGB*	74 LAGB 37 LRYGB	0 (Early) 8 (Early)	18 Band removal (LRYGB or LBPD)
Boza et al. [7]	62 LAGB	0 LAGB	0% LAGB	Not reported	1 (1.6%) LAGB*	17 (27.4%) LAGB	4+9 LAGB	7 Band removal (4 LSG, 3 LRYGB)
	91 LRYGB	0 LRYGB	8% LRYGB		12 (14.2%) LRYGB*	33 (36.2%) LRYGB	1+15 LRYGB[a]	
Christou and Efthimiou [19]	149 LAGB	0 LAGB	0% LAGB	23.5% LAGB*	11 LAGB	24 LAGB	0+23*	16 Band removal (13 LRYGB) 6 LRYGB revisions (distal bypass)
	886 LRYGB	3 LRYGB	<1% LRYGB	15.2% LRYGB*	74 LRYGB	27 LRYGB	22+27*[a]	
Jan et al. [20, 21]	406 LAGB 492 LRYGB	1 LAGB 1 LRYGB	<1% LAGB <1% LRYGB	24% LAGB* 32% LRYGB*	32 LAGB 73 LRYGB	77 LAGB 115 LRYGB	67 LAGB 82 LRYGB[a]	24 Band removal (4 LBPD, 1 LRYGB, 1 LSG)
Kim et al. [22]	160 LAGB 232 LRYGB	0 LAGB 0 LRYGB	Not reported	4.3% LAGB 5.6% LRYGB	0.63% LAGB* 5.2% LRYGB*	3.7% LAGB* 0.43% LRYGB*	No significant difference	Not reported
Lakdawala et al. [6]	50 LSG 50 LRYGB	0 LSG 0 LSG	Not reported	2 LSG 3 LRYGB	Not reported	Not reported	1 1	Not reported
Lee et al. [31]	51 LAGB 25 LRYGB	0 LAGB 0 LRYGB	0% LAGB* 8.3% LRYGB*	11% LAGB* 32% LRYGB*	Not reported	Not reported	3 LAGB 4 LRYGB	Not reported
Weber et al. [25]	103 LAGB 103 LRYGB	0 LAGB 1 LRYGB	0% LAGB <1% LRYGB	Not reported	18 LAGB 21 LRYGB	45 LAGB* 14 LRYGB*	1+26* LAGB 7*+4 LRYGB[a]	17 Band removal and conversion to LRYGB
Wong et al. [8]	57 LAGB 30 LSG	0 LAGB 0 LSG	Not reported	5 LAGB 3 LSG	Not reported	Not reported	3 LAGB 0 LSG[a]	2 Band removal (1 open RYGB)
	7 LRYGB	0 LRYGB		4 LRYGB			2 LRYGB	

In Biertho "early" was defined by appearance in the first week that required a prolongation of the hospitalization and "late" after the first week

LBPD Laparoscopic Biliopancreatic Diversion

*$p<0.05$, statistically significant difference

[a] Some patients required therapeutic endoscopic interventions

fasting glucose, insulin, and HOMA-IR levels was found in both groups. A change in HOMA-IR directly correlated with weight loss in the long-term. Preoperative HOMA-IR was found to be an important predictor of change in HOMA-IR in the short-term. A greater decrease in HOMA-IR was found in the LRYGB group, especially when comparing the non-diabetic patients in both groups. Lee [31] and Abbatini [32] found similar results, the latter including an LSG group that achieved lower levels of HOMA-IR. Lee used the "mini gastric bypass" technique in all their bypass patients.

Korner [33, 34] studied postprandial levels of insulin, glucose, and GLP-1 among patients in the LRYGB and

Table 5 Most common complications

	LAGB	LRYGB
Early	Gastric perforation	Staple line bleeding
	Band or port site infection	Anastomotic leak or bleed
	Band obstruction	Bowel injury or obstruction
	Malposition	Pouch dilation
	Stoma obstruction with perforation	
Late	Acute gastric prolapse/band slippage	Internal hernia
	Band erosion, dysfunction, leak, etc.	Adhesive bowel obstruction
	Chronic band slippage/pouch dilation	Anastomotic stenosis, leak, or fistula
	Port rotation or leak, skin irritation	Marginal ulcer/gastritis and stenosis
	Explantation	Incisional hernia
	Esophageal dilation	Nutrient deficiency
Common to both	Wound infection, incisional hernia, symptomatic cholelithiasis, nausea/vomiting, intra-abdominal bleeding, pulmonary embolism	

LAGB groups. The patients in the LRYGB group had a greater postprandial insulin and GLP-1 peak with a greater glucose excursion. The GLP-1 and insulin levels significantly correlated. Interestingly, the HOMA levels correlated with the EWL, except at 12 weeks in the LRYGB group. Rodieux [35] found similar results, reporting a higher postprandial increase of glucose oxidation and a decrease of lipid oxidation, both well-known to be insulin-related. These results are in concordance to those found in the randomized controlled trials (RCT) by Peterli (see above)

The current proposed mechanisms for changes in insulin resistance are postoperatively restricted caloric intake (mainly in the short run) associated with a decreased appetite, changes in nutrient flow (LRYGB, bypassing duodenum), changes in bowel hormones (e.g., ghrelin, GLP-1), and changes in body weight and composition (mainly in the long run).

Discussion

Bariatric surgery has been shown to be more effective than the medical treatment of obesity, with a consistent weight loss and resolution of obesity-related comorbidities [36, 37].

LRYGB and LSG were consistently more effective in achieving weight loss compared to LAGB. These results are in concordance with previous revisions [36–39]. Besides the well-known restrictive (LAGB, LSG, LRYGB) and malabsorptive (LRYGB) mechanisms, further hypotheses were developed to explain the difference in %EWL among the bariatric procedures. Ghrelin is an intestinal peptide produced by the oxyntic glands of the stomach fundus. It stimulates feeding, increases body weight, and decreases fat use. In lean subjects, higher levels are detected before meal initiation, with a postprandial suppression. Postprandial suppression is usually lacking in obese subjects. Some studies [33, 40, 41] indicated that subjects who underwent LAGB had higher levels of ghrelin, while in LRYG and LSG groups a significant decrease was found. It must be highlighted that the majority of studies had short-term follow-up (12 to 18 months) and studies with longer follow-up had usually lower follow-up rates, rendering their results difficult to interpret. It is difficult to interpret results with patients lost at follow-up (see above).

A resolution of comorbidities should be a major endpoint in these studies. However, the uniformity in their definitions and strict follow-up are necessary to be able to make such comparisons. A study by Parikh [42] reported a similar resolution of diabetes following LAGB and LRYGB, but a 3-year follow-up was of 65% in each treatment group. Omana [43] reported a higher resolution of diabetes, hypertension, and hyperlipidemia following LSG compared to LAGB, but 1 year follow-up data were 45.9% and 62.1%, respectively.

As it was previously described, short-term complications are usually more frequent among LRYGB, and are usually more severe and present in the immediate postoperative period, whereas long term complications are usually more frequent following LAGB. They are usually device-related and with variable reintervention rates. This conclusion is consistent with previous reviews [38]. Data on LSG are limited, but we found a low incidence of complications in most studies.

This pattern of complications among patients undergoing LAGB or LRYGB explains why LAGB can be easily performed as an outpatient procedure. Sasse [44] informed that less than 3% of the patients undergoing LRYGB were referred to their ambulatory surgery center, whereas almost one forth of LAGB procedures was carried out in this location.

Besides these variables, further studies comparing utility and economic variables are needed. An increase in the quality of life (evaluated by SF-36) was found with both LAGB and LRYGB in one study [45], but a change in the Quality-Adjusted Life Year (QALY) was not calculated. This quantification is particularly useful in cost-effectiveness analyses. Both the LAGB and LSG have been found to be cost-effective, with incremental cost-effectiveness ratios below USD 25.000 per gained QALY [46, 47].

A broader consensus is needed when collecting and reporting data in bariatric surgery. Among key issues, the following could serve as a guideline (adapted from Treadwell [48]); authors should state reasons for patient exclusion, refusal to undergo randomized procedure, and crossing over among groups; collection criteria must be defined before the beginning of the study; authors should report an overlap of publications referring to the same patients; analyses should be performed on an intention to treat basis; the follow-up rate must be carefully informed to differentiate from "right censoring" (data collected from patients shortly before the study concluded); a careful explanation should be made about the study size calculation and predictive power of the sample; and comparisons should be made only between concurrent series of comparable patients.

The limitations of our review were that we chose to include only studies comparing at least two of the laparoscopic procedures. A single procedure case series could have provided higher rates of long-term follow-up, with better information about long-term efficacy and safety. We have not included studies about open bariatric surgery. We are not certain if long-term data following these procedures could have been extrapolated to those performed under laparoscopic approach. We did not perform meta-analyses due to heterogeneity among studies.

Conclusions

Each laparoscopic bariatric procedure has a singular pattern of complications and efficacy, measured as excess weight loss or resolution of comorbidities. Most studies indicated that LRYGB and LSG could be more effective achieving weight loss than LAGB. However, LAGB seems to be a safer procedure with frequent, but less severe, long-term complications. The selection of the adequate bariatric procedure should be customized to patient preferences with the support of an interdisciplinary team, preferably in a specialized high-volume bariatric surgery center. Further studies with long-term follow-up rates are needed.

Conflicts of Interest None of the authors have a conflict of interest.

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