

# Robotic versus Laparoscopic Sleeve Gastrectomy for Morbid Obesity: a Systematic Review and Meta-analysis

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**Abstract** We aim to review the available literature on obese patients treated with robotic or laparoscopic sleeve gastrectomy, in order to compare the clinical outcomes and intraoperative parameters of the two methods. A systematic literature search was performed in PubMed, Cochrane Library and EBSCOhost databases, in accordance with the PRISMA guidelines. Sixteen studies met the inclusion criteria incorporating 29,787 patients. Robotic sleeve gastrectomy (RSG) technique showed significantly higher mean operative time and increased length of hospital stay. Post-operative incidence of leakage, wound infection and bleeding, along with weight reduction, were comparable. The majority of the studies assessing charges found increased cost in RSG population. Well-designed, randomized controlled studies, comparing RSG to laparoscopic sleeve gastrectomy (LSG), are necessary to assess further their clinical outcomes and cost-effectiveness.

**Keywords** Sleeve gastrectomy · Robotic · Laparoscopic · Obesity

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## Introduction

Obesity is a rising morbid condition, while bariatric surgery continues to be the main therapeutic mode for a high rate of sustainable weight loss [1]. A stand-alone bariatric procedure that is increasingly performed is the laparoscopic sleeve gastrectomy (LSG) [2]. In fact, LSG was the most frequent bariatric procedure in the USA in 2013 [3]. However, the need for fewer complication rate, smaller hospital stay and better cosmetic results has led to the introduction in use of robotic technology in bariatric surgery.

Robotic sleeve gastrectomy (RSG), using the da Vinci Surgical System (Intuitive Surgical, Sunnyvale, CA, USA), has been proposed as an alternative approach to conventional LSG. RSG offers to operators certain advantages, such as improved control, through enhanced wrist movement and articulation, and visualization [4]. As the number of studies assessing the feasibility of RSG increases, it is necessary to examine whether the results between the two techniques are at least equivalent. The purpose of this study is to summarize the existing evidence comparing the surgical outcomes of LSG and RSG.

## Materials and Methods

### Search Strategy and Articles Selection

The present study was conducted in accordance with the protocol agreed by all authors and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses [5]. PubMed database, Cochrane Library and EBSCOhost were searched (last search: May 30, 2016) using the following terms in every possible combination: “robotic,” “robot-assisted,” “robotically,” “da vinci,” “robotic-assisted,” “laparoscopic,” and “sleeve

gastrectomy.” Inclusion criteria were (1) original reports with  $\geq 10$  patients, (2) written in the English language, (3) published from 2010 to 2016, (4) conducted on human subjects and (5) reporting outcomes of LSG or RSG on obese patients. Two independent reviewers (VST, DEM) extracted the data from the included studies. Any discrepancies between the investigators about the inclusion or exclusion of studies were discussed with the guarantor author (DZ) in order to include articles that best matched the criteria, until consensus was reached. Moreover, the reference lists of all included articles were assessed for additional potentially eligible studies.

### Data Extraction

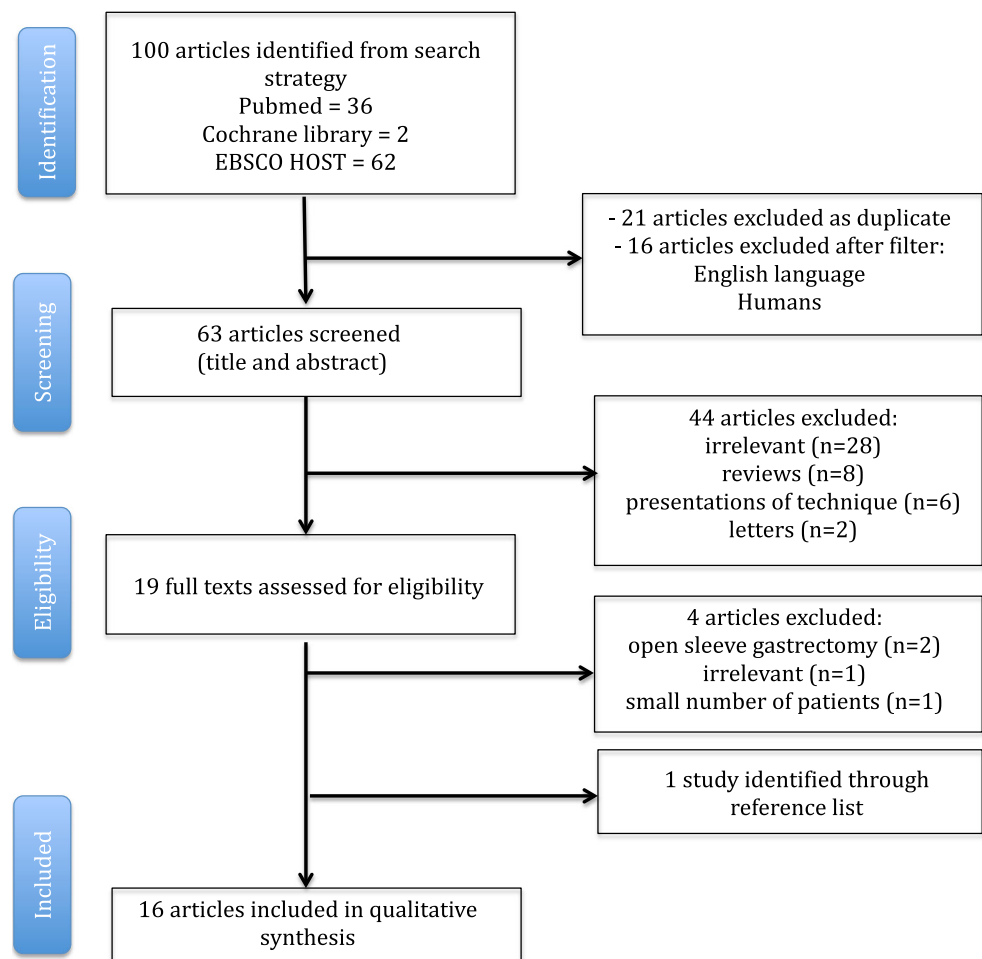
For each eligible study, data were extracted relative to demographics (number of patients, mean age, sex, comorbidities, preoperative body mass index (BMI)) and to the intraoperative parameters and outcomes (mean operative time; length of hospital stay; bougie diameter; conversion rate; intraoperative and post-operative complications; charges; BMI after 1, 6 and 12 months and % excess weight loss (%EWL) after 1, 6 and

12 months). Moreover, categorical outcomes were  $2 \times 2$  tabulated, referring patients presenting the outcome and patients free of the outcome, separately for the LSG and RSG groups. Regarding continuous outcomes, we extracted the mean, the standard deviation and the number of patients. In cases that standard deviation was not available, it was calculated using the available data.

### Statistical Analysis

Regarding the categorical outcomes, the odds ratio (OR) and 95% confidence interval (CI) were calculated, based on the extracted data, by means of fixed-effects model (Mantel-Haenszel statistical method), where the number of studies providing data was sufficient.  $OR < 1$  denoted that outcome was more frequent in the RSG group. Continuous outcomes were evaluated by means of weighted mean difference (WMD) with its 95% CI, using fixed-effects and random-effects (inverse variance statistical method) models, appropriately to calculate pooled effect estimates. In cases where  $WMD < 0$ , values in the RSG group were higher. Between-

**Fig. 1** Robotic vs laparoscopic sleeve gastrectomy flow diagram



**Table 1** Characteristics of the studies that were finally included in the systematic review and meta-analysis

Study, ID, year	Journal	Country	Time period	Type of comparison	Type of study	Patients, <i>n</i>		Female, <i>n</i> (%)		Mean age (range)		Mean preoperative BMI (range) (kg/m <sup>2</sup> )		Stars in Ottawa <sup>a</sup>
						LSG	RSG	LSG	RSG	LSG	RSG	LSG	RSG	
Alexandrou, 2015 [8]	The American Journal of Surgery	Greece	1/2004–7/2008	LSG	R	25	N/A	18 (72%)	N/A	41.3 ± 2.4	N/A	55.5 ± 1.7	N/A	5
Alexandrou, 2015 [9]	Obesity Surgery	Greece	6/2012–8/2014	LSG	R	100	N/A	79 (79%)	N/A	50.3 ± 7.6	N/A	38.8 ± 11.1	N/A	5
Alfieri, 2016 [10]	Surgical Endoscopy	USA	2008–2012	LSG vs RSG	R	7690	118	6015 (78.22%)	89 (75.42%)	N/A	N/A	N/A	N/A	7
Ayloo, 2011 [11]	Journal of Laparoendoscopic & Advanced Surgical Techniques	USA	9/2007–2/2010	LSG vs RSG	P	39	30	35 (89.7%)	29 (96.7%)	38 ± 10	38 ± 9.1	56 ± 11.7	57 ± 10.7	7
Bhatia, 2014 [12]	Journal of the Society of Laparoendoscopic Surgeons	India	5/2012–10/2013	RSG	R	N/A	35	N/A	15 (42.9%)	N/A	41.8 ± 10.4	N/A	48.17 ± 11.7	5
Diamantis, 2011 [13]	Obesity Surgery	Greece	11/2008–5/2009	RSG	P	N/A	19	N/A	17 (89.5%)	N/A	39.4 ± 10.9	N/A	48.2 ± 8.2	5
Ecker, 2015 [14]	Surgery for Obesity and Related Diseases	USA	9/2011–4/2014	RSG	R	N/A	411	N/A	307 (74.6%)	N/A	43.6 ± 11.2	N/A	48.7	6
Elfi, 2015 [15]	Obesity Surgery	USA	1/2008–12/2013	LSG vs RSG	R	304	105	244 (80.3%)	95 (90.5%)	41 (SD = 0.96)	41 (SD = 10.2)	51.34 (SD = 8.95)	49.0 (SD = 7.05)	9
Kanman, 2016 [16]	Surgery for Obesity and Related Diseases	USA	2/2010–2/2012	LSG vs RSG	R	57	46	32 (56.1%)	28 (60.9%)	46	46	52.73 ± 11.17	48.69 ± 9.59	9
Moon, 2016 [17]	Obesity Surgery	USA	6/2008–12/2014	LSG vs RSG	R	378	267	293 (77.5%)	189 (70.8%)	44.1 ± 11.5 (range, 19–71)	43.4 ± 11.9 (range, 19–71)	45.2 ± 7.6 (range, 33.8–83.2)	46.7 ± 7.7 (range, 34.4–71.9)	8
Pepper, 2016 [18]	Obesity Surgery	USA	6/2012–8/2014	LSG vs RSG	R	14	14	10 (71.4%)	12 (85.7%)	18	17	48	43	5
Romero, 2013 [19]	Obesity Surgery	USA	9/2009–8/2012	RSG	R	N/A	134	N/A	89 (66.4%)	N/A	43 ± 12.6	N/A	45 ± 7.1	5
Schraibman, 2014 [20]	Obesity Surgery	Brazil	1/2011–3/2013	LSG vs RSG	P	32	16	16 (50.0%)	6 (37.5%)	46 (SD = 13)	43 (SD = 16)	39.4 (SD = 3.8)	41.3 (SD = 4.5)	9
Vilallonga, 2013 [21]	Obesity Surgery	Spain	9/2006–11/2012	LSG vs RSG	P	100	100	64 (64%)	79 (79%)	43 (SD = 11)	44 (SD = 11)	47 (SD = 6)	48 (SD = 8)	9
Villanere, 2015 [22]	Surgical Endoscopy	USA	10/2010–2/2014	LSG vs RSG	R	18,694	957	14,400 (77.0%)	738 (77.1%)	N/A	N/A	N/A	N/A	5
Zacharoulis, 2012 [23]	Obesity Surgery	Greece	8/2006–8/2010	LSG	P	102	N/A	N/A	N/A	40 (range, 18–62)	N/A	45.4 (range, 35–61)	N/A	6

The first author of every study, along with the year of publication; the journals; the country of origin; the time period of the study; the comparison of techniques; the study design; the number of participants; the number of female patients, along with the mean age and mean preoperative body mass index (BMI) and the number of stars according to the Newcastle-Ottawa Quality Assessment Scale

N/A not available, R retrospective, P prospective, LSG laparoscopic sleeve gastrectomy, RSG robotic sleeve gastrectomy

<sup>a</sup>The Newcastle-Ottawa Scale (NOS) for assessing the quality of non-randomized studies. Every study is judged on three perspectives: the selection, the comparability and the ascertainment of the exposure of the study groups. The highest quality studies are awarded up to nine stars

**Table 2** Summary of the assessment of comorbidities of patients treated with laparoscopic sleeve gastrectomy (LSG) and robotic sleeve gastrectomy (RSG)

Comorbidities	LSG, <i>n</i> (%)	RSG, <i>n</i> (%)
Dyslipidemia	93 (0.33%)	222 (9.86%)
Sleep apnea	272 (0.98%)	480 (21.31%)
Diabetes mellitus	181 (0.66%)	374 (16.61%)
Hypertension	327 (1.19%)	518 (23%)

study heterogeneity was assessed through Cochran's Q statistic and by estimating [6].

### Quality and Publication Bias Assessment

The Newcastle-Ottawa Quality Assessment Scale (NOS) [7] was used as an assessment tool to evaluate non-randomized control trials (RCTs). The scale's range varies from zero to nine stars, and studies with a score equal to or higher than five were considered to have adequate methodological quality to be included. There were no RCTs in the literature to be included. Two reviewers (VST, DEM) rated the studies independently, and final decision was reached by consensus.

The existence of publication bias could not be evaluated using the Egger's formal statistical test [8], because the number of the included in the analysis studies was not adequate (less than ten), thus compromising substantially the power of the test.

## Results

### Article Selection and Patient Demographics

The flow diagram of the search of the literature is shown in Fig. 1. The characteristics of the included studies are summarized in Table 1. Sixteen studies were included in the qualitative synthesis [10–25]. The study design was retrospective in 9 [9–12, 15–20, 22, 23] and prospective in 4 studies [12, 14, 21, 22]. The included studies were conducted in the USA [11, 12, 16–21, 23], Greece [9, 10, 14, 24], Spain [22], India [13] and Brazil [21] and were published between 2011 and 2016. The RSG sample size ranged from 14 to 957 patients. The total sample size was 29,787; 27,535 patients treated with LSG and 2252 patients treated with RSG. Preoperative mean BMI was  $\geq 30$  kg/m<sup>2</sup> in all included patients.

The most frequent comorbidities in patients undergoing LSG and RSG are presented in Table 2. The most prevalent comorbidity was hypertension ( $n = 327$ , 1.19% for the LSG group;  $n = 518$ , 23% for the RSG group). Other frequent comorbidities were diabetes mellitus ( $n = 181$ , 0.66% for the LSG group;  $n = 374$ , 16.61% for the RSG group), sleep apnea

( $n = 272$ , 0.98% for the LSG group;  $n = 480$ , 21.31% for the RSG group) and dyslipidemia ( $n = 93$ , 0.33% for the LSG group;  $n = 222$ , 9.86% for the RSG group). Further analysis of most frequent comorbidities is shown in Table 4. There were no significant differences.

### Bougie Diameter

The use of bougie was assessed in this study (Table 3). Bougie was used in the following diameters: 32F [21, 22], 34F [18, 19], 36F [16, 24], 38F [13, 16, 17, 20] and 40F [12, 16]. In four studies [9, 10, 14, 15] (25%), we used endoscopes equivalent to 29F and 30F.

### Mean Operative Time

Mean operative time ranged from 84.18 to 138 min for the LSG and from 95.5 to 148 min for the RSG (Table 3). Mean operative time was significantly greater in the RSG group (WMD  $-20.66$  ( $-23.45$ ,  $-17.88$ );  $p < 0.0001$ ) as shown in Table 4 and Fig. 2.

### Length of Hospital Stay

The length of hospital stay ranged from  $1.7 \pm 1.8$  to  $4 \pm 3$  days for the RSG group, while it ranged from  $1.2 \pm 0.5$  to 5.9 (4–13) days for the LSG group (Table 3). According to our analysis shown in Table 4 and Fig. 2, the length of hospital was greater in the RSG group (WMD  $-0.25$  ( $-0.30$ ,  $-0.20$ );  $p < 0.0001$ ).

### Conversions

Conversion rate in the RSG group was 0% in all studies measured, as shown in Table 3. In the LSG group, the number of conversions was zero in three studies [10, 19, 21], one in two studies [12, 17] and two in one study [24], with the conversion rate ranging from 0 to 2.5%.

### Complications

The most prevalent post-operative complications are shown in Table 4. The risk of post-operative leakage was comparable between the two groups (OR 1.28 (CI 0.54, 3.03);  $p = 0.57$ ). The frequency of wound infection was nearly similar (4.19 (0.20, 89.46);  $p = 0.36$ ). Moreover, the risk of bleeding was similar for the LSG and RSG groups (1.76 (0.38, 8.09);  $p = 0.47$ ). The rate of other complications reported was not significantly different (0.93 (0.51, 1.69);  $p = 0.81$ ).

**Table 3** Summary of the assessment of the intraoperative parameters and outcomes of every study that was included in the systematic review and meta-analysis

Study ID, year	Bougie diameter (F)	Length of hospital stay (days)		Mean operative time (min)		Conversion rate (%)		Charges (\$)		%EWL (1 month)	
		LSG	RSG	LSG	RSG	LSG	RSG	LSG	RSG	LSG	RSG
Alexandrou, 2015 [9]	Endoscope equivalent to 29F bougie	4.5 (4–16)	N/A	115.5 (90–150)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Alexandrou, 2015 [10]	Endoscope equivalent to 29F bougie	N/A	N/A	114	N/A	0	N/A	N/A	N/A	N/A	N/A
Altieri, 2016 [11]	N/A	2.33 ± 1.75	2.37 ± 0.91	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Ayloo, 2011 [12]	40F	2.4 ± 0.4	2.6 ± 1.2	114 ± 28	135 ± 28	1 (2.5%)	0	N/A	N/A	N/A	N/A
Bhatia, 2014 [13]	38F	N/A	3.4 ± 0.8	N/A	116.3 ± 24.7	N/A	0	N/A	N/A	N/A	N/A
Diamantis, 2011 [14]	Endoscope equivalent to 29F bougie	N/A	4	N/A	95.5 ± 11.5	N/A	0	4730 <sup>b</sup>	5130 <sup>b</sup>	N/A	15.5 ± 8.6% (4–29.3)
Ecker, 2015 [15]	Endoscopes equivalent to 29F and 30F bougie	N/A	3	N/A	96.4 ± 24.9	N/A	N/A	N/A	Excessive cost of \$364,69 (p < .01)	N/A	N/A
Elli, 2015 [16]	36F, 38F, 40F	3.07 (SD = 4.17)	2.44 (SD = 0.746)	84.18 (SD = 23.83)	110.6 (SD = 48.27)	N/A	0	N/A	N/A	29	29.49
Kannan, 2016 [17]	LSG: 38F bougie RSG: 38F bougie	4.6 ± 0.9	4.2 ± 0.9	121	110	1	0	N/A	N/A	N/A	N/A
Moon, 2016 [18]	34F	1.2 ± 0.5	1.7 ± 1.8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Pepper, 2016 [19]	34F	75.9 <sup>a</sup> (73, 96)	69.6 <sup>a</sup> (55, 74)	99.5 (90, 106)	131.5 (114, 145)	0	0	49,498 (4551, 54,929)	56,646 (52,530, 62,445)	18 (16.4, 21.6)	18 (16.6, 21.2)
Romero, 2013 [20]	38F	N/A	2.2 ± 0.6 (2–7)	N/A	106.6 ± 48.8	N/A	0	N/A	N/A	N/A	17.8
Schraibman, 2014 [21]	32F	3	3	138	148	0	0	30,748.5 <sup>c</sup>	47,858.0 <sup>c</sup>	N/A	N/A
Vilallonga, 2013 [22]	32F	3 ± 5	4 ± 3	96	108	N/A	N/A	N/A	N/A	N/A	N/A
Villamere, 2015 [23]	N/A	2.06	2.45	N/A	N/A	N/A	N/A	8795	10,556	N/A	N/A
Zacharoulis, 2012 [24]	36F	5.9 (4–13)	N/A	92 (50–240)	N/A	2 (1.96%)	N/A	N/A	N/A	N/A	N/A
Study ID, year	%EWL (6 months)	%EWL (12 months)		BMI after 1 month		BMI after 6 months		BMI after 12 months		LSG	RSG
		LSG	RSG	LSG	RSG	LSG	RSG	LSG	RSG		
Alexandrou, 2015 [9]	N/A	N/A	65.26 ± 6.1%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Alexandrou, 2015 [10]	52.1%	N/A	67.3%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Altieri, 2016 [11]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Ayloo, 2011 [12]	N/A	N/A	N/A	49 ± 10.4	48 ± 8.9	46 ± 10.4	41.5 ± 8.7	43 ± 10.4	39 ± 8.8	N/A	N/A
Bhatia, 2014 [13]	N/A	Obese: 43.4 ± 8.6 Super obese: 41.5 ± 10.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Diamantis, 2011 [14]	N/A	44.1 ± 13.2% (17–63.5)	N/A	65.5 ± 25.6% (17–100)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Ecker, 2015 [15]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Elli, 2015 [16]	42.6	44.52	52.23	48.89	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Kannan, 2016 [17]	34.0 ± 16.5	39.0 ± 12.0	48.0 ± 28.2	57.0 ± 20.4	N/A	N/A	N/A	38.4 ± 8.8	42.2 ± 11.0	35.4 ± 8.7	35.4 ± 8.7
Moon, 2016 [18]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Pepper, 2016 [19]	N/A	N/A	N/A	N/A	40	N/A	N/A	N/A	N/A	N/A	N/A
Romero, 2013 [20]	N/A	47	N/A	57.2	N/A	41.5	35.5	N/A	N/A	N/A	35.3

**Table 3** (continued)

Study ID, year	%EWL (6 months)		%EWL (12 months)		BMI after 1 month		BMI after 6 months		BMI after 12 months	
	LSG	RSG	LSG	RSG	LSG	RSG	LSG	RSG	LSG	RSG
Schraubman, 2014 [21]	N/A	N/A	N/A	N/A	N/A	N/A	31.04	31.28	29.21	27.14
Vilallonga, 2013 [22]	67	66	N/A	N/A	N/A	N/A	N/A	N/A	33 (SD = 2)	32 (SD = 7)
Villamere, 2015 [23]	N/A	N/A	N/A	N/R	N/A	N/A	N/A	N/A	N/A	N/A
Zacharoulis, 2012 [24]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

The bougie diameter, the mean hospital stay, the mean operative time, the conversion rate, the charges and the % excess weight loss (%EWL) in 1, 6 and 12 months along with the body mass index (BMI) in 1, 6 and 12 months are demonstrated where available

F French, N/A not available, LSG laparoscopic sleeve gastrectomy, RSG robotic sleeve gastrectomy

<sup>a</sup> Expressed in hours

<sup>b</sup> Expressed in euros

<sup>c</sup> Expressed in reals

**Table 4** Summary of the analysis of the categorical and continuous outcomes

Categorical outcomes	OR (95% CI)	Heterogeneity	
		I <sup>2</sup>	p
Dyslipidemia	1.12 (0.81, 1.56)	0%	0.49
Sleep apnea	1.10 (0.79, 1.53)	0%	0.56
Diabetes mellitus	1.00 (0.78, 1.28)	0%	0.98
Hypertension	1.07 (0.86, 1.34)	0%	0.54
Leaks	1.28 (0.54, 3.03)	0%	0.57
Wound infection	4.19 (0.20, 89.46)	N/A	0.36
Bleeding	1.76 (0.38, 8.09)	0%	0.47
Other complications	0.93 (0.51, 1.69)	0%	0.81
Continuous outcomes	WMD (95% CI)	I <sup>2</sup>	p
Operative time	-20.66 (-23.45, -17.88)	92%	<0.0001
Length of hospital stay	-0.25 (-0.30, -0.20)	91%	<0.0001

LSG laparoscopic sleeve gastrectomy, RSG robotic sleeve gastrectomy, OR odds ratio, WMD weighted mean difference, CI confidence interval

### %EWL and Post-Operative BMI

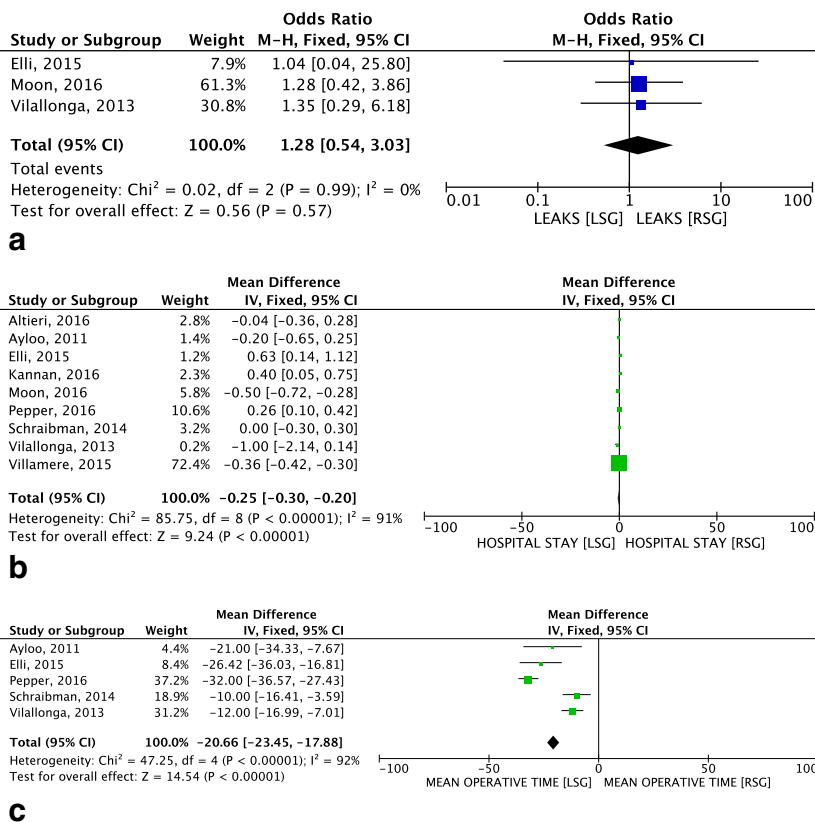
In our study, we examined the post-operative %EWL and BMI after 1, 6 and 12 months. %EWL ranged between 18 and 29 after 1 month, between 34 and 67 after 6 months and between 48 and 67.3 after 12 months for the LSG group. In addition, %EWL for the RSG group ranged between 15.5 and 29.49 after 1 month, 39 and 66 after 6 months and between 48.89 and 65.5 after 12 months. BMI was calculated from 43 to 49 after 1 month, from 31.04 to 46 after 6 months and from 29.21 to 43 after 12 months for the LSG group. On the other hand, BMI ranged between 40 and 48 after 1 month, 31.28 and 41.5 after 6 months and between 27.14 and 39 after 12 months for the RSG group. Further meta-analysis was not performed due to the lack of comparative data.

### Cost

Charges were assessed in five studies (Table 3). Four (80%) [15, 19, 21, 23] of them demonstrated significantly higher charges for the RSG procedure. The mean charges ranged between 4730 € and 49,498 reals for the LSG and between 5130 € and 56,646 reals for the RSG group. In one study [15], which compared LSG with RSG, the mean charges had a mean difference of \$364.69 ( $p < 0.01$ ). Pepper et al. [19] showed higher median total ( $p = 0.037$ ) and perioperative cost ( $p = 0.001$ ) for the RSG group. Schraubman et al. [21], also, found significantly higher cost for the RSG group ( $p < 0.001$ ). In addition, Villamere et al. [23] showed significantly higher charges for the RSG group ( $p < 0.05$ ). Diamantis et al. [14] found a difference of 400 € (4730 € for LSG and 5130 € for RSG), but they did not include in their analysis original



**Fig. 2** Forest plot describing the differences in **a** incidence of leaks, **b** length of hospital stay and **c** mean operative time between robotic and standard laparoscopic sleeve gastrectomy. **a** Incidence of leaks was not significantly different between the robotic and the standard laparoscopic group. **b** Length of hospital stay was significantly greater in robotic than in standard laparoscopic sleeve gastrectomy. **c** Mean operative time was significantly greater in robotic than in standard laparoscopic sleeve gastrectomy



purchase and maintenance costs. Meta-analysis was not performed due to lack of data.

**Publication Bias**

Publication bias was not calculated for the outcomes because of the small number of the studies that were included.

**Discussion**

This meta-analysis identified 16 articles describing LSG and RSG as two alternative bariatric procedures, measuring the patients’ outcomes and published between 2011 and 2016. No similar systematic review was identified through literature search. The articles included in this study bring us closer to linking the implementation of either method with improved standards of safety, efficiency and cost-effectiveness.

The present study demonstrates that RSG and LSG are well-tolerated, feasible and effective surgical approaches. The rate of comorbidities was evaluated for the LSG group and was relatively low. It may be related with lower mean BMI and rate of metabolic syndrome in the LSG population. According to previous studies [25], robot-assisted procedures are associated with greater mean operative time, due to the

increased setup time. This is in accordance with our outcomes. In fact, in our study, mean operative time was significantly greater in the RSG group. Mean length of hospital stay was, also, significantly greater in the RSG group. However, Kannan et al. [17] showed that the RSG group had shorter hospital stay (p = 0.01) but with limited clinical impact. Moreover, both techniques are associated with small and comparable rates of complications and conversions, being significantly safe. Since stapling phase, in both groups, is not robotic, it would be interesting to examine the technique of oversewing or buttressing. However, the available data were not sufficient to address this technical aspect.

Leaks and hemorrhage are the main risks of bariatric procedures, due to the long stapled lines and gastrointestinal anastomosis. According to our findings, the incidence of leaks and hemorrhage were comparable between the two groups. No significant differences were reported.

From the studies included, two [15, 18] referred %EWL after 1 month in the LSG group and three [13, 15, 18] in the RSG group, four [9, 15, 16, 21] referred %EWL after 6 months in the LSG and six [12, 13, 15, 16, 19, 21] in the RSG group, four [8, 9, 15, 16] referred %EWL after 12 months in the LSG and four [13, 15, 16, 19] in the RSG group. The %EWL was comparable between the two methods and also comparable to previous meta-analysis of sleeve gastrectomy as a primary

procedure [26]. In fact, in that study, published in 2009, the %EWL ranged between 36 and 85 [25].

Cost was also assessed in this study but was not further analyzed due to lack of available data. Five studies [14, 15, 19, 21, 23] analyzed the charges in the LSG group and five studies [14, 15, 19, 21, 23] in the RSG group. Total charges were approximately ranged from \$8795 to 49,498 for LSG and from \$10,556 to 56,646 for RSG [19, 23] in the USA, 4730 € for LSG and 5130 € for RSG in Greece [14] and 30,748.5 reals for LSG and 47,858.0 reals for RSG in Brazil [21]. Significantly higher charges for the RSG group were shown in four out of five (80%) studies [15, 19, 21, 23]. In only one study [14] that the difference was not significant. However, in this study, the purchase and maintenance charges were not included in the analysis [14]. The greater charges associated with robot-assisted surgery are primarily due to the initial cost of acquiring the robotic system and the semidisposable instruments [27].

This meta-analysis demonstrates the need for additional studies comparing LSG with the RSG. Ideally, these would be randomized controlled studies, with prospective design and longer follow-up. For rare events, such as conversions and mortality, a large sample is needed. The studies included offer specific linkage to patient outcomes, complication and weight loss.

The limitations of this systematic review and meta-analysis reflect the limitations of the studies included. Five studies [12, 14, 21, 22, 24] (31.25%) were prospective. There were no randomized controlled studies between the comparative studies included, thus posing a certain limitation in this study. The majority of the studies included [10–13, 16–21, 23] were retrospective (68.75%).

On the other hand, the strengths of this study are (1) the clear data extraction protocol, (2) the well-specified inclusion-exclusion criteria, (3) the search in three different databases, (4) the quality assessment of the included studies and (5) the detailed presentation of the results of data extraction and analysis.

## Conclusion

This meta-analysis identified 16 unique peer-reviewed studies of LSG and RSG procedures with patient outcome data. These studies suggest that LSG and RSG are associated with comparable clinical outcomes, complications and %EWL. Mean operative time and length of hospital stay were significantly greater in the RSG group. The majority of studies showed significantly higher charges for RSG. These results should be interpreted with caution due to the lack of randomized controlled studies. Future studies with greater clarity in significant outcomes, as the %EWL, complications and charges are

necessary to demonstrate the differences in efficacy between LSG and RSG.

## Compliance with Ethical Standards

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

**Ethical Approval** This article does not contain any studies with human participants or animals performed by any of the authors.

**Informed Consent** Does not apply.

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