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REVIEW ARTICLE

Robotic Versus Laparoscopic Bariatric Surgery: a Systematic Review and Meta-Analysis

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Abstract We aim to summarize the available literature on patients treated with robotic bariatric surgery (RBS) or laparoscopic bariatric surgery (LBS) and compare the clinical outcomes between RBS and LBS. A systematic literature was conducted in accordance with the PRISMA guidelines. Thirty-four observational studies met our inclusion criteria, and 27 studies of 27,997 patients were included in the meta-analysis. There were no significant differences between RBS and LBS regarding overall postoperative complications, major complications, the length of hospital stay, reoperation, conversion, and mortality. Nevertheless, RBS was burdened by longer operative times and higher hospital costs when compared with LBS. On the contrary, the incidence of anastomotic leak was lower in RBS than in LBS. Further studies with a longer follow-up are recommended.

Keywords Bariatric surgery · Laparoscopic · Robotic · Robotic-assisted

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Introduction

Obesity is a growing problem in the world and is associated with highly elevated risks of adverse health outcomes. The NCD Risk Factor Collaboration revealed that between 1975 and 2014, the prevalence of obesity increased from 3.2 to 10.8 % in men and from 6.4 to 14.9 % in women in their pooled analysis of 1698 population-based studies including more than 19 million participants [1]. Bariatric surgery has been approved as an effective treatment that achieves dramatic and durable weight loss in obese patients [2].

Since the first laparoscopic Roux-en-Y gastric bypass (LRYGB) was reported in 1994, laparoscopic bariatric surgery (LBS) has become widely used for the treatment of morbid obesity because of shorter hospital stay, faster convalescence, and lower postoperative complication rates compared with open bariatric procedure [3, 4]. In order to overcome the technical disadvantages of laparoscopic surgery, including lack of three-dimensional (3D) imaging and loss of some freedom of motion, robotic surgical systems were introduced in 1997. Compared with traditional laparoscopy, robotic surgical system has been considered to achieve better postoperative quality and overcome some of the limitations of laparoscopic surgery. So robotic surgery is becoming more prevalent in the fields of gynecology and urology in the last decade. More recently, it has seen more use in the field of bariatric surgery; however, the benefit between robotic BS and laparoscopic BS was still in debate.

In this review, we aimed to determine whether robotic BS is superior to laparoscopic BS in terms of postoperative complications, operative times, the length of hospital stay, and economic parameters.

Materials and Methods

Study Design

A systematic review and meta-analysis was conducted according to predefined guidelines provided by the Cochrane Collaboration (2008) [5]. All data were reported according to Meta-analysis Of Observational Studies in Epidemiology statement [6].

Search Strategy

Two authors (Author 1, Author 2) independently searched published studies indexed in the MEDLINE, EMBASE, web of science and the Cochrane Central Register of Controlled Trials (CENTRAL) in The Cochrane Library. References of all selected studies were also examined. The following main search terms were used: robotic, laparoscopic, Roux-en-Y, gastric bypass, sleeve gastrectomy, gastroplasty, biliopancreatic diversion, adjustable gastric banding, and bariatric surgery. The latest date for this search was May 2016.

Inclusion and Exclusion Criteria

Two reviewers (Author 1, Author 2) independently screened all abstracts and selected studies in the meta-analysis if they met all of the following criteria: (1) randomized, controlled trials (RCTs) or observational studies including cohort, cross-sectional, and case-control studies; (2) written in the English language; (3) conducted on human subjects; (4) compared outcomes between the laparoscopic and robotic bariatric surgery; (5) If data of ongoing studies were published as updates, results of only the longest duration periods were included. For studies without the outcomes we needed, author(s) would be contacted via e-mail for more relevant information, if necessary. Exclusion criteria were (1) reviews, comments, case reports, abstracts, animal studies, and unpublished studies.

Primary Outcomes

The main outcome was the rate of overall complications, major complications (Grade 3 and 4 complications) and minor complications (Grade 1 and 2 complications) [7]. Other primary outcomes were adverse events including anastomotic leak, stricture or stenosis, gastrointestinal (GI) or abdominal bleeding, reoperation, mortality, operative time, and length of stay (LOS).

Secondary Outcomes

The secondary outcomes included conversion rate, 30-day readmission, volume of intraoperative bleeding, ICU stay, deep-vein thrombosis (DVT), ulcer, abscess, intestinal obstruction, wound infection, trocar side hernia, pneumonia, vomiting, diarrhea, dehydration, abdominal pain, and fever.

Data Extraction

Two investigators (Author 1, Author 2) independently reviewed abstracts of all citations. Data verifications between the two authors were performed to ensure reliability and completeness after all abstracts were reviewed. The inclusion criteria were applied to all identified studies independently. Different decisions were resolved by consensus.

Full texts of potentially relevant articles identified through other sources were retrieved. If multiple articles from the same study were searched, only the article with the longest follow-up period was included. Data with respect to research design, type of surgery, participant characteristics, duration of study, and outcomes were independently extracted. We contacted the authors for the primary reports of the unpublished data. If the authors did not reply, the available data were used for our analyses.

Methodological Quality Assessment

We used the nine-point Newcastle-Ottawa Scale to assess the study quality for all included observational studies. This scale evaluated a quality score calculated on three fundamental methodological criteria: study participants (0–4), adjustment for confounding (0–2), or ascertainment of the exposure or outcome of interest (0–3). We arbitrarily classified quality as high (score: 7–9) versus low (score: 0–3). We excluded studies from our meta-analysis if they had poor quality. Discrepant opinions between authors were resolved to reach a consensus.

Statistical Analysis

The data were pooled using REVMAN 5.0 software (The Nordic Cochrane Centre, Copenhagen, Denmark) and STATA/SE version 13 (Stata Corp, College Station, TX, USA). For each study, we calculated ORs with 95 % confidence intervals (CIs) for dichotomous data and standardized mean differences (SMDs) with 95 % CIs for continuous data. A random-effect model (DerSimonian-Laird method) was used when significant heterogeneity was detected between studies ($P < 0.10$; $I^2 > 50$ %). Otherwise, a fixed-effect model (Mantel-Haenszel test) was used. Subgroup analyses by type of robotic procedure (robotic-assisted, totally robotic) and type of bariatric surgery (RYGB, SG, AGB) were performed. To assess the stability of the results of the meta-analysis, sensitivity analysis was performed. Publication bias was assessed by the Egger's test and represented graphically by funnel plots. Egger's formal statistical test was performed only when the number of included studies was adequate (10 or more) and statistical significance was defined as $P < 0.1$.

Results

Description of Included Studies

After excluding duplicate results, the initial search included 1066 articles, 1032 articles were excluded because 970 were off the topic after scanning the title and/or the abstract, 38 were not RCT or observational studies, 10 had no laparoscopic comparison group, and 14 were conference abstracts. A total of 34 articles were included in our systematic review and 27 studies of 27,997 patients were included in the meta-analysis (Fig. 1). The characteristics are outlined in Table 1.

Quality Assessment of Included Studies

NOS evaluated the quality of the included studies. Total score ranged from 4 to 8. None of the studies had low quality (total score below 3) and excluded from the meta-analysis.

Overall Complications

Twenty-three trials reported the incidence of overall complications [8–30]. Meta-analysis revealed no significant difference in the incidence of overall complications between the TRRYGB and the LRYGB (OR 0.92, 95 % CI 0.73–1.16, $P = 0.49$), the RARYGB and the LRYGB (OR 0.99, 95 % CI 0.77–1.27, $P = 0.92$), the RASG and the LSG (OR 0.79, 95 % CI 0.49–1.29, $P = 0.35$), and RBS and the LBS (OR 0.93, 95 % CI 0.79–1.09, $P = 0.39$). There was no evidence of statistical heterogeneity ($I^2 = 25$ %) (Fig. 2).

Major and Minor Complications

Major complications were reported in 9 studies [8–11, 22, 23, 30–32] and minor complications in 7 studies [8–11, 22, 23, 31]. There was no significant difference in the incidence of major complications between the TRRYGB and the LRYGB (OR 1.00, 95 % CI 0.59–1.69, $P = 0.99$), the RARYGB and the LRYGB (OR 1.00, 95 % CI 0.69–1.45, $P = 1.00$), and the RBS and the LBS (OR 1.01, 95 % CI 0.74–1.36, $P = 0.97$). There was a low degree of heterogeneity between studies ($I^2 = 23$ %) (Fig. 3).

Likewise, we found no statistically significant difference in minor complications between RARYGB and the LRYGB (OR 1.00, 95 % CI 0.63–1.60, $P = 1.00$) and RBS and the LBS (OR 0.79, 95 % CI 0.59–1.05, $P = 0.11$); however, the minor complications rates were significantly lower after TRRYGB compared with LRYGB (OR 0.68, 95 % CI 0.46–0.98, $P = 0.04$) (Fig. 4).

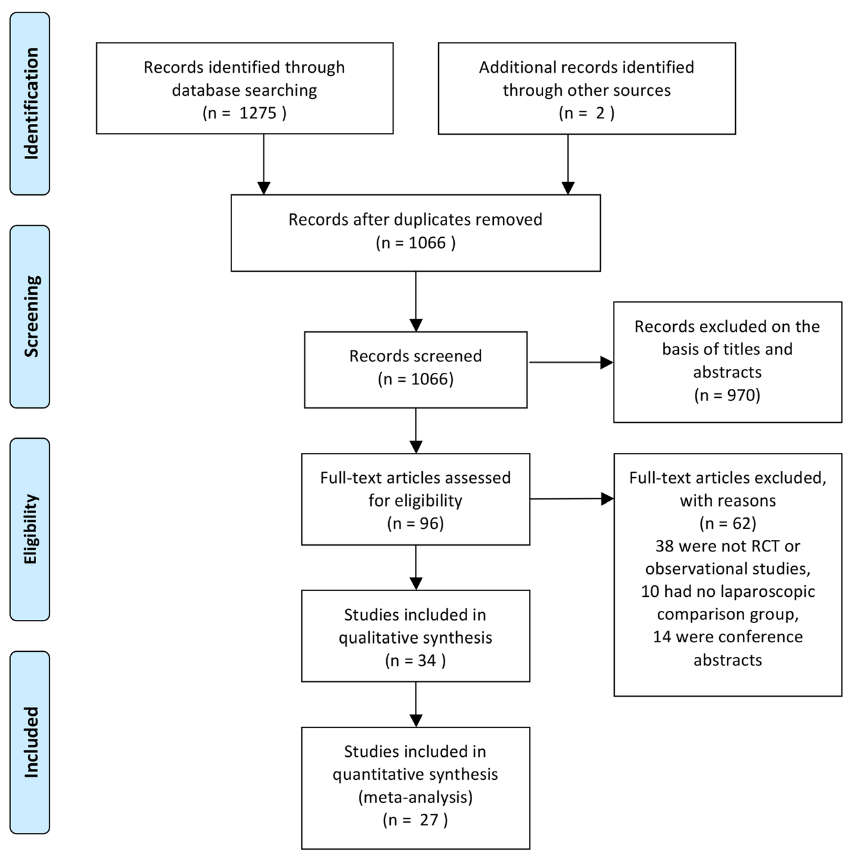

Fig. 1 Flow diagram of the selection process. *RCT* randomized controlled trial

Table 1 Characteristics of included studies

Study	Country	Design	Group	*N*	Age	Sex (female)	BMI	Prior surgery
RYGB								
Hubens 2008	Netherlands	Cohort	TRRYGB	45	42	8	44.2	4
			LRYGB	45	39	37	43.9	2
Mohr 2005	USA	Cohort	TRRYGB	10	38.5	10	45.6	
			LRYGB	10	45.5	10	43	
Myers 2013	USA	Cohort	RARYGB	100	45.7 ± 10	76	45.7 ± 6.3	
			LRYGB	100	47 ± 11	83	44.6 ± 5.7	
Park 2011	USA	Cohort	TRRYGB	105	42.2 ± 11	83	46.8 ± 8.4	
			LRYGB	195	43.9 ± 11	141	47.7 ± 9.4	
Sanchez 2005	USA	RCT	TRRYGB	25	43.3	23	45.5 ± 6.4	13
			LRYGB	25	44.4	22	43.4 ± 4.7	15
Benizri 2013	France	Cohort	TRRYGB LRYGB	100 100	41 ± 11	166	45 ± 6	
Wood 2014	USA	Cohort	TRRYGB	100	42.3 ± 10.3	85	50.1 ± 9.4	
			LRYGB	100	43.7 ± 9.7	15	48.1 ± 7.9	
Curet 2009	USA	Cohort	TRRYGB	21	46.5	19	45.6	
			LRYGB (stapled)	78	47.3	64	44.6	
			LRYGB (hand-sewn)	36	48.4	32	46.1	
Ayloo 2011	USA	Cohort	RARYGB	90	39 ± 9	78	48 ± 6	
			LRYGB	45	43 ± 8	42	46 ± 6	
Scozzari 2011	Italy	Cohort	RARYGB	110	42.6	83	46.7	
			LRYGB	423	41.1	318	47.3	68
Snyder 2010	Italy	Cohort	RARYGB	320	45 ± 10	197	49.1	
			LRYGB	356	42	285	50.4(34–88)	
Hagen 2012	Swizerland	Cohort	TRRYGB	143	42.6 ± 11.2	105	44.5 ± 5.3	
			LRYGB	323	41.5 ± 10.1	259	44.5 ± 5.3	
Ahmad 2015	USA	Cohort	RARYGB	172	47.3 ± 11.3	114	47.4 ± 7.1	
			LRYGB	173	45.8 ± 12.3	127	46.2 ± 6.0	
Buchs 2015	Switzerland	Cohort	TRRYGB	65	41 ± 11	39	53 ± 3.1	
			LRYGB	54	41 ± 10.5	38	55 ± 5.6	
Villamere 2015	USA	Cohort	RARYGB	1217	NR	962	NR	
			LRYGB	34,667	NR	27,288	NR	
Ayloo 2016	USA	Cohort	TRRYGB	61	39.7	56	43.9	
			LRYGB	46	43.2	43	47.1	28
			RARYGB	85	39.5	72	47.3	23
Lyn-Sue 2016	USA	Cohort	RRYGB LRYGB	25 25	41.7 43.4	NR	45.3 46.5	41
Moon 2016	USA	Cohort	RARYGB	64	45.9 ± 10	46	48.4 ± 7.9	
			LRYGB	206	45.0 ± 10.7	159	48.4 ± 8.1	
Smeenk 2016	Netherlands	Cohort	TRRYGB	100	39 ± 10.2	92	40 ± 2.66	
			LRYGB	100	42 ± 11.8	80	42 ± 4.75	35
Scozzari 2014	Italy	Cohort	RARYGB	48	45.3 ± 8.5	37	43.8 ± 4.5	36
			LRYGB	102	43.6 ± 10.7	75	49.2 ± 6.1	
Buchs 2014	Switzerland	Cohort	TRRYGB	388	43.8 ± 10.7	284	44 ± 5.2	
			LRYGB	389	42 ± 10.4	305	44.8 ± 6.2	
Parini 2006	Italy	Cohort	RARYGB	17	44	10	49.8	
			LRYGB	97	NR	NR	NR	
SG								
Kannan 2016	USA	Cohort	RASG	46	46	28	48.69 ± 9.59	
			LSG	57	46	32	52.73 ± 11.17	

Table 1 (continued)

Villamere 2015	USA	Cohort	RASG	957	NR	738	NR	
			LSG	18,694	NR	14,400	NR	
Elli 2015	USA	Cohort	RASG	105	41 ± 10.2	95	49.0 ± 7.05	
			LSG	304	41 ± 0.96	244	51.34 ± 8.95	
Schraibman 2014	Brazil	Cohort	RASG	16	43 ± 16	6	41.3 ± 4.5	
			LSG	32	46 ± 13	16	39.4 ± 3.8	
Vilallonga 2013	Spain	Cohort	RASG	100	44 ± 11	79	48 ± 8	
			LSG	100	43 ± 11	64	47 ± 6	
Romero 2013	USA	Cohort	RASG	134	43.0 ± 12.6	NR	45.0 ± 7.1	
			LSG	3148	40.7 ± 11.6	NR	43.6 ± 8.1	
Ayloo 2011	USA	Cohort	RASG	30	38 ± 9.1	29	57 ± 10.7	
			LSG	39	38 ± 10	35	56 ± 11.7	
AGB								
Edelson 2011	USA	Cohort	RAGB	287	45 ± 11.3	230	45.4 ± 5.5	
			LAGB	120	47 ± 11.2	89	45.1 ± 6.7	
Villamere 2015	USA	Cohort	RAGB	75	NR	57	NR	
			LAGB	3753	NR	2846	NR	
Study	Surgeon	Time period			T2DM	Hypertension	Dyslipidemia	OSA
RYGB								
Hubens 2008	Single	October 2004 and April 2006			19	19		17
					17	21		12
Mohr 2005	Single	July to September 2002						
Myers 2013	Single	October 2009 and September 2011			41	72		83
					40	60		65
Park 2011	Multiple	January 2007 and December 2009			38	60	55	57
					68	125	101	126
Sanchez 2005	Single	July 2004 to April 2005						
Benizri 2013	Two	January 2007 and December 2011						
Wood 2014	Single	NR			33	54	46	49
					32	56	56	39
Curet 2009	Multiple	1 July 2005 to 31 December 2005						
Ayloo 2011	Single	January 2006 to December 2009						
Scozzari 2011	Multiple	September 2006 and June 2009			21	57		23
Snyder 2010	Multiple	From 2003 to December 2008						
Hagen 2012	Multiple	June 1997 to July 2010						
Ahmad 2015	Single	January 2011 to October 2014						
Buchs 2015	Multiple	July 1997 to March 2014			18	24		25
					14	24		17
Villamere 2015	Multiple	October 2010 to February 2014						
Ayloo 2016	Single	January 2006 to May 2013			36.4 %	55.7 %		27.1 %
Lyn-Sue 2016	Single	January 2012 to January 2015			4	9	4	7
					10	15	8	9
Moon 2016	Single	January 1, 2012 to April 30, 2014						
Smeenk 2016	Two	November 2011 to January 2015			23	20	30	5
					27	23	23	13
Scozzari 2014	Two surgeon	November 2007 and June 2012			16	25		16
					27	41		39
Buchs 2014	Multiple	January 2003 to September 2013			81	135		106
					86	131		85
Parini 2006	Single	October 2000 to March 2004			4	13	1	5
					NR			
SG								
Kannan 2016	Multiple	February 2010 to February 2012		16		26	16	30
				17		27	20	39
Villamere 2015	Multiple	October 2010 to February 2014						
Elli 2015	Two	January 2008 to December 2013		47		48	28	24
				95		159	93	108
Schraibman 2014	Two	January 2011 to March 2013		3		5		3
				7		12		2
Vilallonga 2013	Multiple	September 2006 and November 2012		25		48	26	77
				27		46	33	80
Romero 2013	Multiple	September 2009 to August 2012		43		74	37	58
				NR				
Ayloo 2011	Single	September 2007 to February 2010		7		16	6	7

Table 1 (continued)

			10	17	4	12
AGB						
Edelson 2011	Two	December 2006 and June 2009	80	160	83	155
			40	80	40	62
Villamere 2015	Multiple	October 2010 to February 2014				

RYGB Roux-en-Y gastric bypass surgery, *SG* sleeve gastrectomy, *AGB* adjustable gastric banding, *RRYGB* robotic Roux-en-Y gastric bypass surgery, *TRRYGB* totally robotic Roux-en-Y gastric bypass surgery, *RARYGB* robotic-assisted Roux-en-Y gastric bypass surgery, *LRYGB* laparoscopic Roux-en-Y gastric bypass surgery, *RASG* robotic-assisted sleeve gastrectomy, *LSG* laparoscopic sleeve gastrectomy, *RAGB* robotic-assisted adjustable gastric banding, *LAGB* laparoscopic adjustable gastric banding, *RCT* randomized controlled trial, *BMI* body mass index, *NR* not reported, *T2DM* type 2 diabetes mellitus, *OSA* obstructive sleep apnea, *NR* not reported

Anastomotic Leak and Stricture, GI/Abdominal Bleeding

Anastomotic leak was reported in 19 studies [8–11, 13–19, 22–24, 27–29, 32, 33] (Fig. 5). There was no significant difference in the incidence of anastomotic leak between the RARYGB and the LRYGB (OR 1.00, 95 % CI 0.50–2.00, P = 1.00), the RASG and the LSG (OR 0.42, 95 % CI 0.12–1.53, P = 0.19). However, the anastomotic leak rates were significantly lower after RBS and TRRYGB compared with laparoscopic procedures

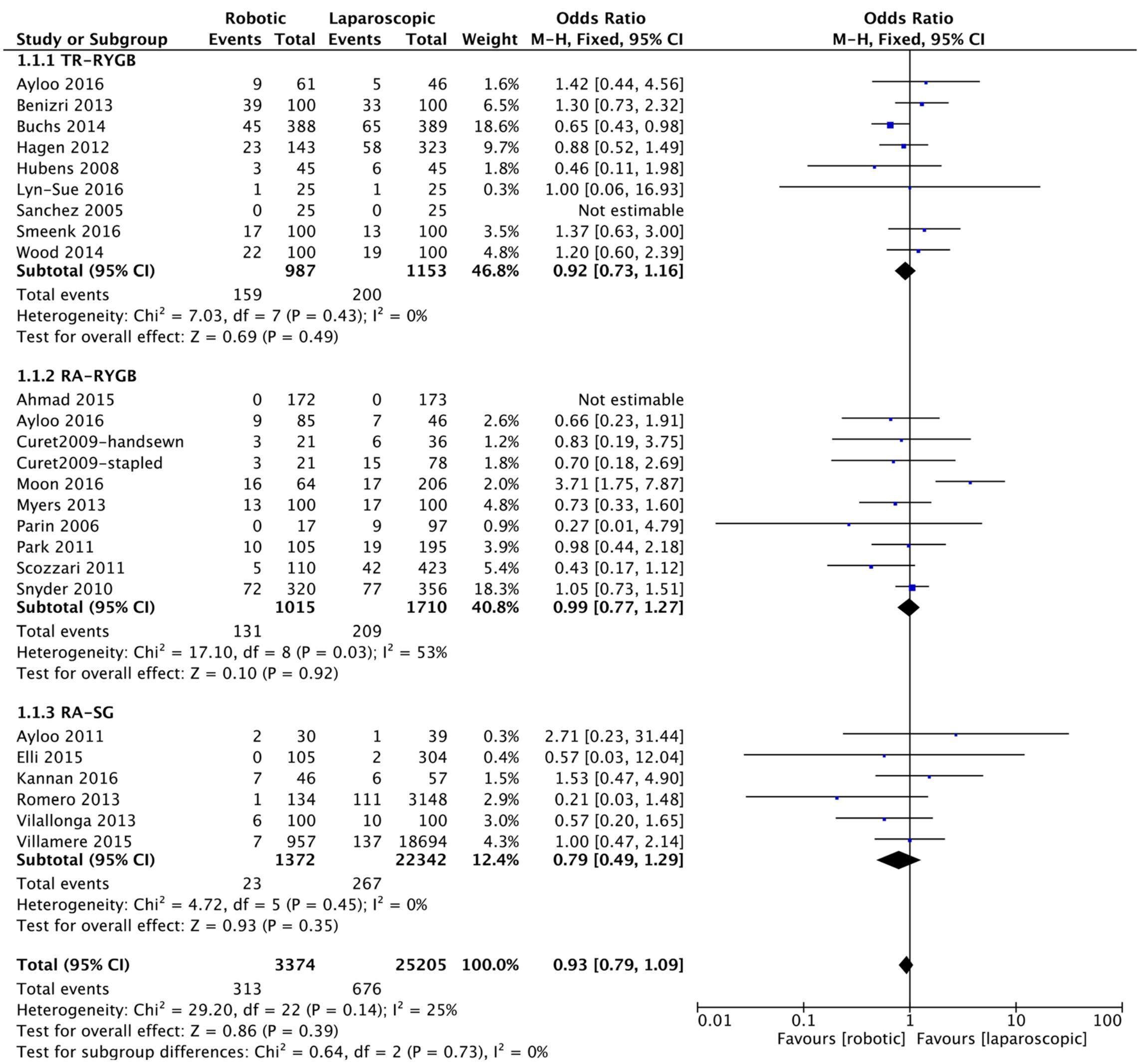

Fig. 2 Forest plot describing the differences in rates of overall complications between RBS and LBS. The subgroup analysis on studies performing TRRYGB, RARYGB, and RASG is presented. There was no difference in the incidence of overall complications between RBS and LBS. *RBS* robotic bariatric surgery, *LBS* laparoscopic bariatric surgery, *TRRYGB* totally robotic Roux-en-Y gastric bypass, *RARYGB* robotic-assisted Roux-en-Y gastric bypass, *RASG* robotic-assisted sleeve gastrectomy

Study or Subgroup	Robotic Events	Robotic Total	Laparoscopic Events	Laparoscopic Total	Weight	Odds Ratio M-H, Fixed, 95% CI
1.2.1 TR-RYGB						
Ayloo 2016	3	61	4	46	5.1%	0.54 [0.12, 2.56]
Benizri 2013	10	100	2	100	2.1%	5.44 [1.16, 25.52]
Buchs 2014	12	388	20	389	22.8%	0.59 [0.28, 1.22]
Mohr 2005	2	10	2	10	1.9%	1.00 [0.11, 8.95]
Smeenk 2016	3	100	1	100	1.1%	3.06 [0.31, 29.95]
Subtotal (95% CI)		**659**		**645**	**33.0%**	**1.00 [0.59, 1.69]**
Total events	30		29			
Heterogeneity: $Chi^2 = 8.17$, df = 4 (P = 0.09); $I^2 = 51\%$						
Test for overall effect: Z = 0.01 (P = 0.99)						
1.2.2 RA-RYGB						
Ahmad 2015	0	172	0	173		Not estimable
Ayloo 2016	2	85	4	46	6.0%	0.25 [0.04, 1.44]
Scozzari 2011	11	110	32	423	14.0%	1.36 [0.66, 2.79]
Snyder 2010	12	320	16	356	17.2%	0.83 [0.39, 1.78]
Villamere 2015	14	1217	368	34667	29.1%	1.08 [0.63, 1.86]
Subtotal (95% CI)		**1904**		**35665**	**66.2%**	**1.00 [0.69, 1.45]**
Total events	39		420			
Heterogeneity: $Chi^2 = 3.42$, df = 3 (P = 0.33); $I^2 = 12\%$						
Test for overall effect: Z = 0.00 (P = 1.00)						
1.2.3 RAGB						
Villamere 2015	0	75	16	3753	0.8%	1.50 [0.09, 25.24]
Subtotal (95% CI)		**75**		**3753**	**0.8%**	**1.50 [0.09, 25.24]**
Total events	0		16			
Heterogeneity: Not applicable						
Test for overall effect: Z = 0.28 (P = 0.78)						
Total (95% CI)		**2638**		**40063**	**100.0%**	**1.01 [0.74, 1.36]**
Total events	69		465			
Heterogeneity: $Chi^2 = 11.67$, df = 9 (P = 0.23); $I^2 = 23\%$						
Test for overall effect: Z = 0.03 (P = 0.97)						
Test for subgroup differences: $Chi^2 = 0.08$, df = 2 (P = 0.96), $I^2 = 0\%$						

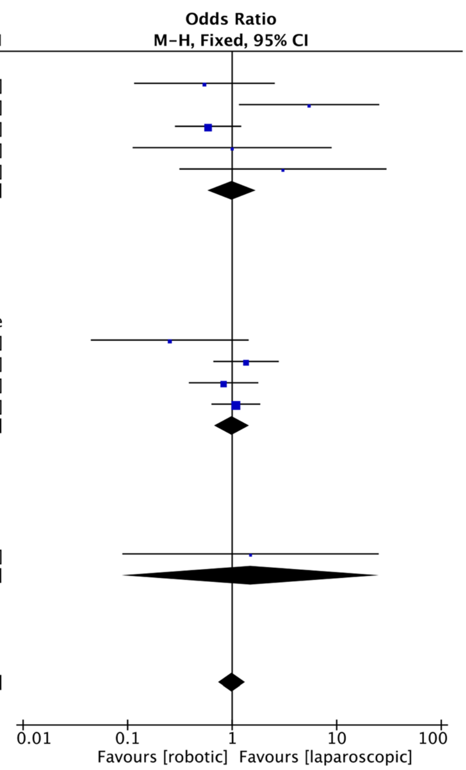

Fig. 3 Forest plot describing the differences in rates of major complications between RBS and LBS. The subgroup analysis on studies performing TRRYGB, RARYGB, and RAGB is presented. There was no difference in the incidence of major complications between RBS and LBS. *RBS* robotic bariatric surgery, *LBS* laparoscopic bariatric surgery, *TRRYGB* totally robotic Roux-en-Y gastric bypass, *RARYGB* robotic-assisted Roux-en-Y gastric bypass, *RAGB* robotic adjusted gastric banding

(OR 0.5, 95 % CI 0.3–0.81, *P* = 0.005; OR 0.22, 95 % CI 0.09–0.55, *P* = 0.001). There was no significant heterogeneity (I^2 = 46 %).

Anastomotic stricture was available for 16 studies [8, 10, 13–15, 17–19, 22–25, 28, 32, 34, 35] (Fig. 6) and GI/abdominal bleeding in 12 studies [10, 13, 14, 17–19, 22, 23,

Study or Subgroup	Robotic Events	Robotic Total	Laparoscopic Events	Laparoscopic Total	Weight	Odds Ratio M-H, Fixed, 95% CI
1.3.1 TR-RYGB						
Ayloo 2016	3	61	3	46	3.2%	0.74 [0.14, 3.85]
Benizri 2013	14	100	19	100	16.0%	0.69 [0.33, 1.48]
Buchs 2014	32	388	45	389	40.4%	0.69 [0.43, 1.11]
Mohr 2005	2	10	3	10	2.3%	0.58 [0.07, 4.56]
Smeenk 2016	2	100	4	100	3.8%	0.49 [0.09, 2.74]
Subtotal (95% CI)		**659**		**645**	**65.7%**	**0.68 [0.46, 0.98]**
Total events	53		74			
Heterogeneity: $Chi^2 = 0.18$, df = 4 (P = 1.00); $I^2 = 0\%$						
Test for overall effect: Z = 2.05 (P = 0.04)						
1.3.2 RA-RYGB						
Ahmad 2015	0	172	0	173		Not estimable
Ayloo 2016	6	85	3	46	3.5%	1.09 [0.26, 4.57]
Snyder 2010	33	320	37	356	30.7%	0.99 [0.60, 1.63]
Subtotal (95% CI)		**577**		**575**	**34.3%**	**1.00 [0.63, 1.60]**
Total events	39		40			
Heterogeneity: $Chi^2 = 0.01$, df = 1 (P = 0.90); $I^2 = 0\%$						
Test for overall effect: Z = 0.01 (P = 1.00)						
Total (95% CI)		**1236**		**1220**	**100.0%**	**0.79 [0.59, 1.05]**
Total events	92		114			
Heterogeneity: $Chi^2 = 1.83$, df = 6 (P = 0.94); $I^2 = 0\%$						
Test for overall effect: Z = 1.60 (P = 0.11)						
Test for subgroup differences: $Chi^2 = 1.65$, df = 1 (P = 0.20), $I^2 = 39.3\%$						

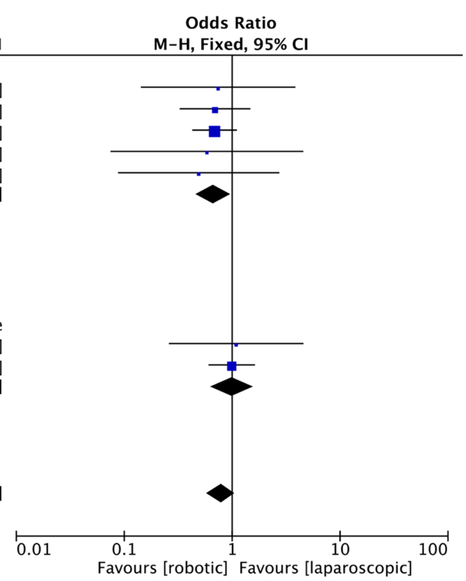

Fig. 4 Forest plot describing the differences in rates of minor complications between RBS and LBS. The subgroup analysis on studies performing TRRYGB and RARYGB is presented. There was no difference in the incidence of minor complications between RBS and LBS. But there was a significantly reduced number of minor complications associated with TRRYGB. *RBS* robotic bariatric surgery, *LBS* laparoscopic bariatric surgery, *TRRYGB* totally robotic Roux-en-Y gastric bypass, *RARYGB* robotic-assisted Roux-en-Y gastric bypass

Study or Subgroup	Robotic Events	Robotic Total	Laparoscopic Events	Laparoscopic Total	Weight	Odds Ratio M-H, Fixed, 95% CI
1.4.1 TR-RYGB						
Ayloo 2016	0	61	1	46	3.3%	0.25 [0.01, 6.19]
Benizri 2013	3	100	0	100	0.9%	7.22 [0.37, 141.52]
Buchs 2014	1	388	14	389	26.9%	0.07 [0.01, 0.53]
Hagen 2012	0	143	13	323	16.0%	0.08 [0.00, 1.36]
Hubens 2008	0	45	2	45	4.8%	0.19 [0.01, 4.10]
Lyn-Sue 2016	0	25	0	25		Not estimable
Smeenk 2016	0	100	0	100		Not estimable
Wood 2014	0	100	0	100		Not estimable
Subtotal (95% CI)		**962**		**1128**	**51.9%**	**0.22 [0.09, 0.55]**
Total events	4		30			
Heterogeneity: Chi² = 7.03, df = 4 (P = 0.13); I² = 43%						
Test for overall effect: Z = 3.27 (P = 0.001)						
1.4.2 RA-RYGB						
Ahmad 2015	0	172	0	173		Not estimable
Ayloo 2016	0	85	1	46	3.7%	0.18 [0.01, 4.44]
Moon 2016	5	64	1	206	0.8%	17.37 [1.99, 151.62]
Myers 2013	1	100	1	100	1.9%	1.00 [0.06, 16.21]
Parin 2006	0	17	1	97	0.9%	1.84 [0.07, 46.97]
Park 2011	2	105	4	195	5.3%	0.93 [0.17, 5.15]
Scozzari 2011	2	110	8	423	6.3%	0.96 [0.20, 4.59]
Snyder 2010	0	320	6	356	11.9%	0.08 [0.00, 1.50]
Subtotal (95% CI)		**973**		**1596**	**30.8%**	**1.00 [0.50, 2.00]**
Total events	10		22			
Heterogeneity: Chi² = 10.76, df = 6 (P = 0.10); I² = 44%						
Test for overall effect: Z = 0.00 (P = 1.00)						
1.4.3 RA-SG						
Kannan 2016	0	46	0	57		Not estimable
Romero 2013	0	134	62	3148	9.9%	0.18 [0.01, 2.98]
Vilallonga 2013	3	100	4	100	7.5%	0.74 [0.16, 3.41]
Subtotal (95% CI)		**280**		**3305**	**17.4%**	**0.42 [0.12, 1.53]**
Total events	3		66			
Heterogeneity: Chi² = 0.86, df = 1 (P = 0.35); I² = 0%						
Test for overall effect: Z = 1.31 (P = 0.19)						
1.4.4 RAGB						
Edelson 2011	0	287	0	120		Not estimable
Subtotal (95% CI)		**287**		**120**		**Not estimable**
Total events	0		0			
Heterogeneity: Not applicable						
Test for overall effect: Not applicable						
Total (95% CI)		**2502**		**6149**	**100.0%**	**0.50 [0.30, 0.81]**
Total events	17		118			
Heterogeneity: Chi² = 23.87, df = 13 (P = 0.03); I² = 46%						
Test for overall effect: Z = 2.79 (P = 0.005)						
Test for subgroup differences: Chi² = 6.86, df = 2 (P = 0.03), I² = 70.8%						

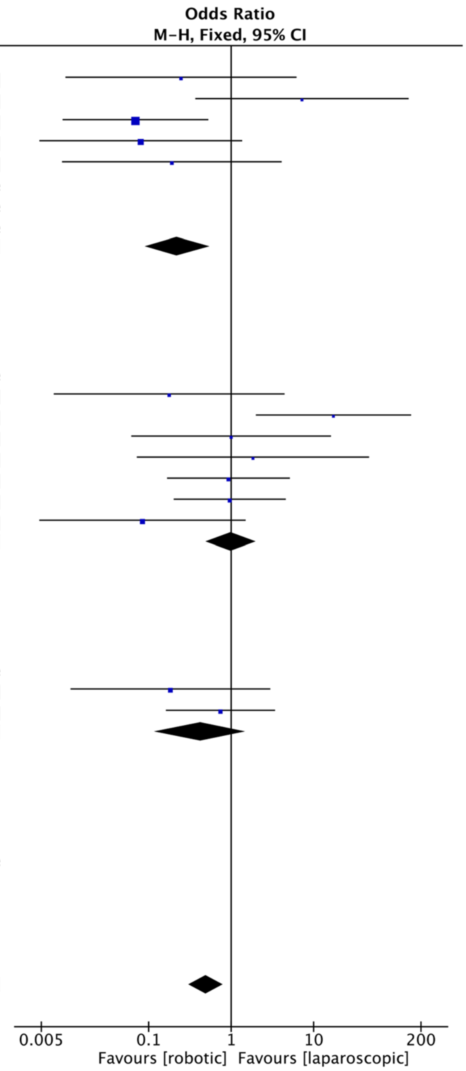

Fig. 5 Forest plot describing the differences in rates of anastomotic leak between RBS and LBS. The subgroup analysis on studies performing TRRYGB, RARYGB, and RASG are presented. There was a significantly reduction in the incidence of anastomotic leak associated with RBS. *RBS* robotic bariatric surgery, *LBS* laparoscopic bariatric surgery, *TRRYGB* totally robotic Roux-en-Y gastric bypass, *RARYGB* robotic-assisted Roux-en-Y gastric bypass, *RASG* robotic-assisted sleeve gastrectomy

28, 29, 34, 35]. The meta-analysis showed no difference between studies (TRRYGB versus LRYGB, RARYGB versus LRYGB, RASG versus LSG, and RBS versus LBS) in terms of the incidence of anastomotic leak and GI/abdominal bleeding, without evidence of statistical heterogeneity (I^2 = 34 %, I^2 = 0 %, respectively).

Reoperation, Readmission, Mortality, and Conversion

Reoperation was reported in 10 studies [8–11, 13, 16, 24, 25, 29, 33], readmission in 7 studies [16, 17, 24, 27, 30, 33, 34], mortality in 18 studies [8, 9, 12, 13, 15, 18, 22, 24–30, 32–35], and conversion in 12 studies [8–10, 13, 14, 19, 25, 27, 29, 33–35]. There was no significant difference in the incidence of reoperation, readmission, mortality, and conversion between studies, without evidence of statistical heterogeneity (I^2 = 66 %, I^2 = 0 %, I^2 = 0 %, I^2 = 46 %, respectively).

Operative Time and Length of Stay

The operative times were reported in 19 studies [8–11, 15, 17–20, 22, 24–26, 28, 29, 31–33, 36] and the length of stay in 19 studies [8–11, 13, 15, 16, 19–21, 24, 26–30, 33, 34, 36]. The meta-analysis revealed that there was an increased operative time after RBS, RARYGB, and RASG compared with laparoscopic procedures (SMD 0.61, 95 % CI 0.25–0.96, P < 0.0001; SMD 1.13, 95 % CI 0.31–1.95, P = 0.007; SMD 0.56, 95 % CI 0.29–0.83, P < 0.0001), respectively, although no significant difference was found between TRRYGB and LRYGB (SMD 0.24, 95 % CI −0.34–0.83,

Study or Subgroup	Robotic Events	Robotic Total	Laparoscopic Events	Laparoscopic Total	Weight	Odds Ratio M-H, Fixed, 95% CI
1.5.1 TR-RYGB						
Benizri 2013	8	100	0	100	0.9%	18.47 [1.05, 324.50]
Buchs 2015	0	65	0	54		Not estimable
Hagen 2012	0	143	22	323	25.6%	0.05 [0.00, 0.78]
Hubens 2008	2	45	2	45	3.6%	1.00 [0.13, 7.43]
Lyn-Sue 2016	1	25	1	25	1.8%	1.00 [0.06, 16.93]
Smeenk 2016	0	100	1	100	2.8%	0.33 [0.01, 8.20]
Wood 2014	9	100	7	100	11.8%	1.31 [0.47, 3.68]
Subtotal (95% CI)		**578**		**747**	**46.4%**	**0.83 [0.46, 1.50]**
Total events	20		33			
Heterogeneity: Chi² = 9.65, df = 5 (P = 0.09); I² = 48%						
Test for overall effect: Z = 0.61 (P = 0.54)						
1.5.2 RA-RYGB						
Ahmad 2015	0	172	0	173		Not estimable
Ayloo 2011	0	90	1	45	3.7%	0.16 [0.01, 4.10]
Myers 2013	6	100	2	100	3.5%	3.13 [0.62, 15.89]
Parin 2006	0	17	2	97	1.4%	1.09 [0.05, 23.72]
Park 2011	4	105	3	195	3.8%	2.53 [0.56, 11.55]
Scozzari 2011	3	110	33	423	24.6%	0.33 [0.10, 1.10]
Snyder 2010	3	320	8	356	13.9%	0.41 [0.11, 1.57]
Subtotal (95% CI)		**914**		**1389**	**50.9%**	**0.72 [0.40, 1.29]**
Total events	16		49			
Heterogeneity: Chi² = 8.95, df = 5 (P = 0.11); I² = 44%						
Test for overall effect: Z = 1.10 (P = 0.27)						
1.5.3 RA-SG						
Ayloo 2011	1	30	0	39	0.8%	4.02 [0.16, 102.15]
Romero 2013	0	134	12	3148	1.9%	0.93 [0.05, 15.84]
Subtotal (95% CI)		**164**		**3187**	**2.7%**	**1.82 [0.28, 11.70]**
Total events	1		12			
Heterogeneity: Chi² = 0.44, df = 1 (P = 0.51); I² = 0%						
Test for overall effect: Z = 0.63 (P = 0.53)						
Total (95% CI)		**1656**		**5323**	**100.0%**	**0.80 [0.53, 1.20]**
Total events	37		94			
Heterogeneity: Chi² = 19.67, df = 13 (P = 0.10); I² = 34%						
Test for overall effect: Z = 1.08 (P = 0.28)						
Test for subgroup differences: Chi² = 0.91, df = 2 (P = 0.64), I² = 0%						

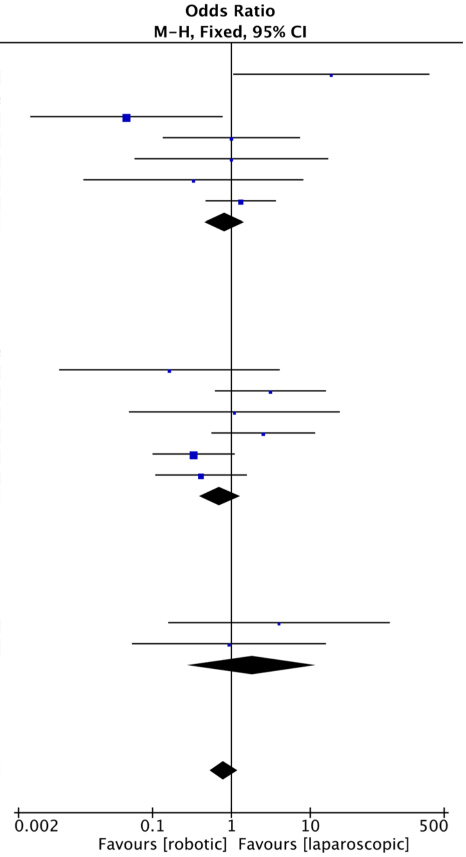

Fig. 6 Forest plot describing the differences in rates of anastomotic stricture between RBS and LBS. The subgroup analysis on studies performing TRRYGB, RARYGB, and RASG is presented. There was no difference in the incidence of anastomotic stricture between RBS and LBS. *RBS* robotic bariatric surgery, *LBS* laparoscopic bariatric surgery, *TRRYGB* totally robotic Roux-en-Y gastric bypass, *RARYGB* robotic-assisted Roux-en-Y gastric bypass, *RASG* robotic-assisted sleeve gastrectomy

$P = 0.42$). However, the studies showed considerable statistical heterogeneity ($I^2 = 96$ %).

There was no significant difference between studies in terms of the length of stay (SMD −0.02, 95 % CI −0.17–0.12, $P = 0.77$), with significant heterogeneity ($I^2 = 91$ %).

Other Outcomes

All other examined outcomes were not different between the RBS and the LBS (Table 2).

Economic Outcomes

The economic outcomes were reported in 6 studies [12–15, 30, 32]. Two studies reported surgical devices [14, 32], and four reported total hospital charges [12, 15, 30, 32], but only one study analysis the overall cost, including amortization of the costs to purchase the robotic system and the additional hospital costs generated in the management of the surgical complications [13]. The five studies suggested that not only the surgical devices but also the total hospital costs of the robotic procedures are more expensive than laparoscopic surgery [12, 14, 15, 30, 32]. However, Hagens et al. found that RRYGB can be cost effective because of a reduction of costly anastomotic complications after robotic procedure [13].

Sensitive Analysis and Publication Bias

The studies of the meta-analysis of the operative time and the length of stay showed considerable statistical heterogeneity. To assess the stability of the results, sensitivity analyses were conducted by excluding 1 study at a time. None of the results was significantly altered, indicating that our results were robust. Because publication bias could affect the results of meta-analyses, we attempted to evaluate this potential publication bias by using funnel plots analysis and Egger's test. Visual inspection of funnel plots for studies evaluating the primary outcomes suggested a symmetric distribution of studies around the effect size and the Egger's test confirmed the lack of publication bias in the incidence of overall complications ($P = 0.827$), anastomotic leak ($P = 0.828$), stricture ($P = 0.226$), and mortality ($P = 0.873$). There is also lack of publication bias in the operative time ($P = 0.224$) and the length of stay ($P = 0.427$). However, our meta-analysis results

Table 2 Pooled complication rates based on the reviewed studies directly comparing RBS with LBS

Outcomes	Overall analysis			Subgroup analysis on TRRYGB			Subgroup analysis on RARYGB			Subgroup analysis on RASG			Subgroup analysis on RAGB		
Categorical outcomes	*n*	OR (95%CI)	I^2, *P*	*n*	OR (95%CI)	I^2, *P*	*n*	OR (95%CI)	I^2, *P*	*n*	OR (95%CI)	I^2, *P*	*n*	OR (95%CI)	I^2, *P*
Mortality	22	1.12 (0.32, 3.90)	0 %, 0.86	6	0.55 (0.07, 4.14)	0 %, 0.55	8	1.25 (0.15, 10.46)	0 %, 0.99	6	3.60 (0.43, 30.02)	0 %, 0.94	2	NE	NA
Readmission	9	1.16 (0.87, 1.55)	19 %, 0.27	1	1.16 (0.40, 3.32)	NA	4	1.06 (0.72, 1.54)	14 %, 0.32	2	1.34 (0.72, 2.51)	50 %, 0.16	2	1.45 (0.60, 3.50)	69 %, 0.07
Reoperation	11	0.96 (0.58, 1.57)	66 %, 0.0005	5	0.66 (0.34, 1.27)	70 %, 0.02	3	2.82 (0.78, 10.18)	78 %, 0.03	2	1.11 (0.19, 6.33)	3 %, 0.31	1	1.26 (0.34, 4.75)	NA
Conversion	13	0.83 (0.47, 1.47)	0 %, 0.60	5	2.32 (0.92, 5.88)	0 %, 0.5	4	0.62 (0.06, 5.99)	NA	3	0.41 (0.04, 4.05)	3 %, 0.31	1	1.41 (0.01, 3.43)	NA
GI/abdominal bleeding	12	0.93 (0.53, 1.65)	46 %, 0.81	5	0.98 (0.52, 1.86)	69 %, 0.08	5	0.43 (0.15, 1.26)	0 %, 0.84	2	0.57 (0.15, 2.15)	0 %, 0.8	0	–	–
Intra-operation complications	7	1.10 (0.62, 1.96)	0 %, 0.56	5	1.10 (0.62, 1.96)	0 %, 0.56	1	NE	NA	1	NE	NA	0	–	–
Ulcer	8	1.0 (0.49, 2.12)	0 %, 0.64	4	1.22 (0.47, 3.15)	0 %, 0.6	4	0.76 (0.23, 2.48)	0 %, 0.39	0	–	–	0	–	–
Abscess/fistula	5	3.17 (0.63, 15.92)	60 %, 0.11	2	11.58 (0.63, 212.19)	NA	3	0.37 (0.02, 9.11)	NA	0	–	–	0	–	–
Intestinal obstruction	5	1.83 (0.57, 5.9)	0 %, 0.94	1	1 (0.06, 16.21)	NA	3	1.79 (0.43, 7.57)	0 %, 0.9	1	4.02 (0.16, 102.15)	NA	0	–	–
Wound infection	10	0.6 (0.26, 1.35)	0 %, 0.9	5	0.78 (0.25, 2.41)	0 %, 0.36	4	0.52 (0.14, 1.90)	0 %, 0.83	1	0.24 (0.01, 5.10)	NA	0	–	–
Ventral/trocar side hernia	2	0.77 (0.15, 3.89)	0 %, 0.53	1	0.33 (0.01, 8.20)	NA	1	1.11 (0.16, 7.95)	NA	0	–	–	0	–	–
Pneumonia	6	0.71 (0.36, 1.40)	12 %, 0.34	5	0.71 (0.36, 1.40)	12 %, 0.34	1	NE	NA	0	–	–	0	–	–
Nausea/vomiting	4	0.83 (0.44, 1.55)	0 %, 0.91	2	0.59 (0.10, 3.60)	0 %, 0.83	2	0.87 (0.44, 1.70)	0 %, 0.56	0	–	–	0	–	–
Dehydration	3	0.90 (0.33, 2.45)	0 %, 0.69	1	NE	NA	2	0.90 (0.33, 2.45)	0 %, 0.69	0	–	–	0	–	–
Diarrhea	2	1.07 (0.22, 5.35)	0 %, 0.95	1	1 (0.06, 16.21)	NA	1	NE	NA	0	–	–	0	–	–
DVT	7	2.22 (0.88, 4.56)	0 %, 0.95	4	2.10 (0.98, 4.52)	0 %, 0.88	2	3.23 (0.37, 28.33)	0 %, 0.56	1	NE	NA	0	–	–
Abdominal pain	3	1.40 (0.71, 2.46)	62 %, 0.07	2	0.36 (0.09, 1.46)	0 %, 0.36	1	2.44 (1.04, 5.73)	NA	0	–	–	0	–	–
Continuous outcomes	*n*	SMD (95%CI)	I^2, *P*	*n*	SMD (95%CI)	I^2, *P*	*n*	SMD (95%CI)	I^2, *P*	*n*	SMD (95%CI)	I^2, *P*	*n*	SMD (95%CI)	I^2, *P*
Estimated blood loss (ml)	5	0 (−0.13, 0.13)	0 %, 0.51	1	0.26 (−0.13, 0.64)	NA	3	−0.03 (−0.18, 0.11)	0 %, 0.52	1	−0.05 (−0.52, 0.43)	NA	0	–	–
ICU stay (days)	2	0.19 (−0.42, 0.81)	92 %, 0.0003	2	0.19 (−0.42, 0.81)	92 %, 0.0003	0	–	–	0	–	–	0	–	–

OR odds ratio, *SMD* standardized mean difference, *GI* gastrointestinal, *RBS* robotic bariatric surgery, *LBS* laparoscopic bariatric surgery, *TRRYGB* totally robotic Roux-en-Y gastric bypass, *RARYGB* robotic-assisted Roux-en-Y gastric bypass, *RASG* robotic-assisted sleeve gastrectomy, *RAGB* robotic adjusted gastric banding, *DVT* deep vein thrombosis, *ICU* intensive care unit, *NE* not estimable, *NA* not applicable of the incidence of major complications ($P = 0.012$), minor complications ($P = 0.021$), reoperation ($P = 0.015$), and conversion ($P = 0.023$) were influenced by publication bias, because statistically significant data are published more frequently than nonsignificant data. Publication bias was not calculated for the rest of the outcomes because less than 10 eligible studies were included in the analysis.

Discussion

It has been considered that LBS has been widely established as an effective treatment that achieves dramatic and durable weight loss in obese patients [37]. And at the same time, the application of laparoscopic techniques to morbidly obese patients adds some obstacles, such as lack of 3D imaging and increased abdominal wall torque on the ports. Therefore, robotic surgery systems had been considered to combine the advantages of minimally invasive surgery with the easier performance of open surgery since they were introduced in field of digestive surgery [38]. For the last decades, RBS has aroused interest among many general surgeons. However, compared with LBS, the advantage of RBS is not clear. In order to investigate the value and safety of RBS for morbidly obesity, we conducted this systematic review and meta-analysis.

There have been three earlier meta-analyses related to RRYGB [39–41]. Markar et al. reported a reduction in the incidence of anastomotic stricture in RRYGB compared with LRYGB, but this did not perform economic analysis and assess risk of bias [41]. A meta-analysis comparing RRYGB with LRYGB performed by Bailey et al. involved only 10 studies and did not perform subgroup analysis [39]. According to a recent meta-analysis, the result suggested comparable clinical outcomes between RRYGB and LRYGB, but a lack of the data of SG and AGB makes the result less reliable [40]. The present meta-analysis including 27 studies of 27,997 patients mainly compared the clinical outcomes between RBS and LBS, and refined subgroup analysis may produce reliable results.

Our result revealed that compared to conventional laparoscopy, although similar results were found regarding overall postoperative complications and hospital stay, RBS was burdened by longer operative times and greater hospital costs. However, RBS provided a real advantage of a lower incidence of anastomotic leak over LBS. In additions, robotic-assisted RYGB and SG generally took longer than the standard laparoscopic procedures, and TRRYGB decreased the incidences of minor complications and anastomotic leak than LRYGB.

Some recent studies have shown the difference between the learning curve for RBS and that of LBS. This has been reported to be 10 cases for RRYGB and 20 cases for RSG versus 70–100 cases for LRYGB or LSG [42–45]. In other words, it takes only a short period of time for the surgeon to learn how to use the robotic surgical system. So some experts considered that this shorter learning curve might result in shorter operative times [20, 31]. However, our result showed that LBS could be performed with shorter operative times than RBS, especially robotic-assisted RYGB and SG. Although the learning curve for RBS appears to be shorter than that for LBS, the addition of docking time and instrument exchange in robotic surgical procedure might have account for the longer operative times [46].

Concerning to economic outcomes, six studies compared costs between RBS and LBS [12–15, 30, 32], which came from different countries and used different costing techniques. Therefore, we could not combine cost estimates in our meta-analysis. Five of the six studies suggested higher hospital costs associated with the robotic versus laparoscopic approach [12, 14, 15, 30, 32]. The factors contributing to the increased hospital costs associated with robotic approach may include semi-disposable robotic instruments, increased length of operating room time, postoperative ICU stay, and hospitalization. Additionally, because of its initial purchase price and yearly maintenance fees, the robotic surgical procedure has been considered as expensive consumables [47]. The overall hospital costs per case should include the amortization costs of the robotic system [13, 48]. In addition, the postoperative complications, reoperation, and conversion may result in additional hospital costs. Understandably, high rates of postoperative complications, reoperation, and conversion have a negative impact on the overall costs. Hagen et al. reported a lower rate of anastomotic leak in RRYGB than LRYGB (0 versus. 4 %), leading to a cost reduction in the robotic cases [13]. Our meta-analysis found that the robotic procedure could decrease the incidence of costly anastomotic leak, which might result in some financial advantages. With regarding to the incidence of reoperation and conversion, although there is little difference between RBS and LBS, our result may be influenced by published bias that influenced by the fact that statistically significant data are published more frequently. If there is a lower incidence of postoperative complications in robotic procedure, the hospital cost per case can be minimized through increased robotic utilization, and additional hospital costs generated in the management of the surgical complications can be decreased significantly.

Except for surgical devices, use of the operating room, postoperative ICU stay, and hospitalization, the overall hospital costs should also include amortization costs of the robotic system (e.g., its initial purchase price and yearly maintenance fees) and the additional hospital costs generated in the management of the surgical complications, but most of studies included in our review did not mention this part. Whether RBS can be cost effective depending on balancing greater robotic overhead costs with the savings associated with avoiding stapling devices use and costly postoperative complications [13]. Well-designed and well-conducted RCT studies investigating postoperative complications and the overall cost are needed before adoption of a robotic approach to bariatric surgery.

The heterogeneity between the studies for operative time is statistically significant, which might be resulted from different definitions adopted for operative time by each surgical team and the operative surgeon's level of robotic and laparoscopic surgical experience. Additionally, patients with history of abdominal surgery might suffer from longer operative time.

With any new technology, it is crucial that surgeons and operating room teams who adopt robotics are appropriately trained in its safe execution. There are a number of established curriculums for training and there are several avenues for surgeons and other team members to obtain this training in the form of skills labs to introduce the robotic platform, surgical simulators, case observations, mini-fellowships, and wet labs. The first cases performed by novice robotic surgeons should be proctored by an experienced surgeon, and it is imperative that surgeons continue to use robotics regularly in their practice. This enables them and the surgical team to improve their skills and efficiency. In today's climate of efficiency, hybrid approaches or staged introduction can be a way to introduce robotics without significantly increasing operative times during the learning curve.

Despite a low utilization of robotic-assisted laparoscopic elective general and bariatric surgical procedures [30], the current as well as future proposed robotic platforms offer potential in the advancement of decreased incision, single incision, and incision-less (endoscopic and natural orifice) surgery. The continued integration of radiologic imaging and other adjuncts for augmented visualization to allow for creation of a real time operative map may be especially useful in complex revisional surgeries. The robotic platform provides superior visualization, increased degrees of movement, and ergonomic advantages, and with future innovations and research, we are likely to see even more widespread adoption of this tool in bariatric surgical procedures. In addition, the robotic approach not only improves the surgeon's performance but also makes the surgeon feel safer and more comfortable. Unfortunately, the surgeon's comfort and/or physical exhaustion is not addressed or even mentioned in most of the comparison studies between laparoscopy and robotic surgery, so further studies exploring these parameters are needed.

Our review has some strengths and limitations. Strengths included the comprehensive search method, data extraction, and study quality assessment made by two independent reviewers. There are also some limitations in our study. First, although comprehensive search strategies focused on laparoscopic bariatric surgery and robotic bariatric surgery was implemented, this review is subject to publication bias inevitably. Second, most of the included studies are observational reports and not blinded, which are of suboptimal quality and subject to selection bias. Finally, most of studies included in our study had follow-up periods of only 1–12 months. A study conducted by Scozzari et al. suggested a higher incidence of complications with longer follow-up [32]. Therefore, long-term outcomes such as anastomotic stricture may be underestimated for RBS and LBS.

This systematic review and meta-analysis demonstrates the need for additional studies comparing the RBS with the LBS. Large, randomized prospective studies with a longer follow-up are needed before we can definitively make conclusions regarding other important postoperative clinical outcomes (e.g., weight loss, the remission rate of T2DM, OSA, hypertension, dyslipidemia, etc.) and on the overall hospital costs.

Conclusions

Although similar results were found regarding overall postoperative complications and hospital stay, RBS was burdened by longer operative times and greater hospital costs. However, if the rate of postoperative complication had been considered as a primary and reasonable parameter for surgeons to evaluate when determining the efficacy of a new surgical technique designed to improve a preexisting procedure, RBS did lead to a technical improvement over LBS. The cost saving might occur in the robotic platform because of the decreased costly anastomotic leak, and further studies with a longer follow-up should be performed to explore postoperative complications and overall hospital costs.

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Compliance with Ethical Standards

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

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

Informed Consent Statement Informed consent was obtained from all individual participants included in the study.

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