Surgical Endoscopy (2019) 33:3558–3566
https://doi.org/10.1007/s00464-019-07000-9

REVIEW ARTICLE

The impact of robotic colorectal surgery in obese patients: a systematic review, meta-analysis, and meta-regression

Ian Jun Yan Wee[1] · Li-Jen Kuo[2] · James Chi-Yong Ngu[3]

Received: 4 December 2018 / Accepted: 19 July 2019 / Published online: 25 July 2019

Abstract

Background Robotic surgery (RS) may overcome the limitations of laparoscopic colorectal surgeries (LS) in obese patients, but remains less well studied. This systematic review and meta-analysis aims to evaluate the outcomes of obese patients who have undergone robotic colorectal surgery.

Methods This study was performed according to the PRISMA guidelines. A search was performed on Medline, EMBASE, and the Cochrane Library to identify relevant articles. Dichotomous and continuous outcomes were analyzed as risk ratio (RR) and mean difference (MD), respectively. All post-operative outcomes were within 30 days after surgery. The quality of studies was assessed using the Newcastle–Ottawa Scale. Meta-regression analysis was conducted to identify sources of heterogeneity.

Results Three studies totaling 262 subjects compared LS (45.0%) against RS (55.0%) in obese patients. The RS group had a significantly reduced length of hospital stay (LOS) (MD − 2.55 days, 95%CI − 3.13 to − 1.97 days, $P<0.00001$, $I^2=26\%$) and lower risk of re-admission (RR 0.42, 95%CI 0.19–0.92, $P=0.030$, $I^2=0\%$), however, the length of operative time was longer (MD 40.54 min, 95%CI 32.72–48.36 min, $P<0.00001$, $I^2=37\%$). Six studies totaling 761 subjects compared obese (40.5%) against non-obese (59.5%) patients who underwent RS. An increased operative time (MD 20.72 min, 95%CI 7.39–34.04 min, $P=0.002$, $I^2=0\%$) and risk of wound infection (RR 2.59, 95%CI 1.12–6.02, $P=0.030$, $I^2=0\%$) were noted in the former, with no differences in other intra- and post-operative outcomes. Meta-regression revealed that the pathology (rectal, colon, both) ($P=0.255$), age ($P=0.530$), gender ($P=0.279$), and continent that the study originated from ($P=0.583$) were not significant sources of heterogeneity for the risk of wound infection.

Conclusion Compared to laparoscopy, robotic surgery provides earlier recovery with shorter LOS and reduced re-admission rates for obese patients, without compromising on other operative outcomes. Among patients undergoing robotic colorectal surgery, obesity is associated with a longer operative duration and greater risk of wound infection.

Keywords Robotics · Laparoscopy · Obesity · Colorectal surgery

Minimally invasive colorectal surgery has gained widespread acceptance due to its superior short-term outcomes compared to open surgery [1–4]. However, the technical challenges of conventional laparoscopic surgery (LS) have been acknowledged, with obesity being one of the contributory factors [5–7]. Visceral obesity limits working space during laparoscopy due to increased tissue volume, making it more difficult to achieve adequate exposure. Retraction is also more challenging because fatty mesentery tends to tear and bleed more easily. This is aggravated by the greater amount of force required to support the weight of these bulky tissues. Such problems become compounded when operating in the confined space of a narrow pelvis during rectal surgery.

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00464-019-07000-9) contains supplementary material, which is available to authorized users.

✉ James Chi-Yong Ngu
james_ngu@cgh.com.sg

1 Yong Loo Lin School of Medicine, National University of Singapore, Singapore, Singapore

2 Division of Colorectal Surgery, Department of Surgery, Taipei Medical University Hospital, Taipei, Taiwan

3 Department of General Surgery, Changi General Hospital, 2 Simei Street 3, Singapore 529889, Singapore

Robotics was introduced to address the limitations of conventional laparoscopy, and the feasibility of robotic surgery (RS) in obese patients has been inferred from the results of earlier publications [8–10]. However, studies specifically investigating the benefits of robotics in this group of patients remain limited. Our objective was therefore to provide a contemporary review of the literature, and a meta-analysis to evaluate the impact of robotic colorectal surgery in obese patients.

Methods

This systematic review and meta-analysis was conducted in strict accordance to the preferred reporting items for systematic reviews and meta-analyses (PRISMA) statement guidelines [11]. As this was a meta-analysis of published studies, there were no human subjects involved. Hence, IRB approval and written consent were not required.

Literature search

An electronic search was performed on MEDLINE, EMBASE, and the Cochrane Library from date of inception to 30th August, 2018 to identify all published studies evaluating the safety and efficacy of robotic colorectal surgery in obese patients. A combination of 'MeSH' and non-'MeSH' search terms using Boolean operators was used in Medline: (robotic.m.p. OR ROBOTICS/OR robot-assisted.mp. OR robotic-assisted.mp.) AND (obesity.mp. OR OBESITY/ OR obese.mp. OR body mass index/OR BMI.mp.) AND (colorectal surgery.mp. OR colorectal surgery/OR rectal cancer.mp. OR rectal neoplasms/OR colorectal cancer.mp. OR colorectal neoplasms/). A manual search of the reference lists of included studies was performed to identify additional relevant studies.

Study selection and inclusion criteria

Two reviewers (IW, JN) screened the studies in an independent fashion for potential inclusion. In the first stage, the abstracts and titles were screened to include potentially relevant studies. Full-texts of these studies were subsequently retrieved and reviewed in their entirety to confirm inclusion. Conflicts were resolved by consensus.

Randomized (RCT) and non-randomized (non-RCT, cohort study, case–control study) studies that evaluated robotic colorectal surgery outcomes were screened. Only studies that exclusively compared obese and non-obese patients were included. The other group of studies reviewed included those that compared the outcomes between RS to LS or open surgery solely in obese patients. Studies of the following designs were excluded: those that evaluated the impact of obesity as secondary outcomes or subgroup analyses; single-arm; non-English language; case reports and case series; animal and laboratory studies; literature reviews; conference abstracts with no extractable data.

Comparisons

Two main comparisons were made (1) Robotic versus laparoscopic colorectal surgery for obese patients; (2) Obese versus non-obese patients undergoing robotic colorectal surgery.

Obesity definitions and data extraction

For simplification of statistical analysis, the obese arm included both obese and morbidly obese patients, while the non-obese arm included normal weight, and overweight patients. Most studies utilized the National Institutes of Health criteria: underweight (Body Mass Index, BMI $\leq$ 18.5 kg/m^2); normal weight (BMI of 18.6–24.9 kg/m^2); overweight (BMI of 25–29.9 kg/m^2); obese *I* (BMI of 30–34.9 kg/m^2); obese II (BMI of 35–39.9 kg/m^2); obese III (BMI of > 40 kg/m^2). One study measured visceral obesity (VFA) and defined obesity as having a VFA of equal to or greater than 130 cm^2 [12].

Primary outcomes of interest included intra-operative data: conversion, blood loss, and operative time. Secondary outcomes included 30-day post-operative data: length of hospital stay (LOS), anastomotic leak, re-operation, re-admission, wound infection, ileus, and pulmonary complications. Two authors (IW, JN) extracted the following data from each study independently: first author, year, type of publication, country, mean age, proportion of male gender, BMI, and oncologic parameters (use of neo-adjuvant chemotherapy, positive margins, mean lymph node harvested, and tumour size).

Quality assessment

For cohort studies, the Newcastle–Ottawa Scale (NOS) was employed to assess the quality of included studies against the maximum score of 9 points. It comprises aspects of patient selection, comparability of study groups, and outcome assessment. Publication bias was not assessed due to the lack of studies included in each outcome (less than 10) [13].

Statistical analysis

The risk ratio (RR) was calculated from each study and pooled using the Mantel–Haenszel method with 95% confidence intervals using Review Manager software (Revman 5.3, The Cochrane Collaboration). For continuous outcomes, mean differences (MD) were calculated and pooled using the inverse-variance method. Statistical heterogeneity was assessed using the I^2 statistic, where a value above 50% was deemed to be of substantial heterogeneity [14]. A random-effects meta-analysis was employed in such instances. To ensure that findings prevailed with better quality data, leave-one-out sensitivity analyses of exclusion were performed. Although bias and heterogeneity may arise from including both colon and rectal surgery in the same analysis, separate meta-analysis was not possible since the included studies did not stratify these results accordingly.

As such, mixed-effects meta-regression using the *metaprop* command in STATA was conducted to explore potential sources of heterogeneity, such as the type of pathology (rectal, colon, both), patient age, proportion of male gender, and continent. This was only performed when there was a sufficient number of studies (5 or more) in the specific outcome.

Results

Systematic search

The screening process is depicted in the PRISMA flow diagram (Fig. 1). A total of 9 retrospective cohort studies were included, of which one was conducted in Japan [12], one in Turkey [15], one in the United Kingdom [16], and six in the United States of America [9, 10, 17–20]. Three studies totaling 262 patients compared LS (118/262; 45.0%) against RS (144/262; 55.0%) in obese patients with rectal cancer [12, 16, 20]. The remaining 6 studies comprising 761 patients compared obese (308/761; 40.5%) against non-obese (453/761; 59.5%) patients who underwent RS for colon and rectal pathologies. Baseline and oncologic parameters are presented in Table 1. The overall risk of bias is low, since all studies scored 8 and above, out of 9 points on the NOS scale. A summary of baseline and oncologic parameters can be found in Table 1.

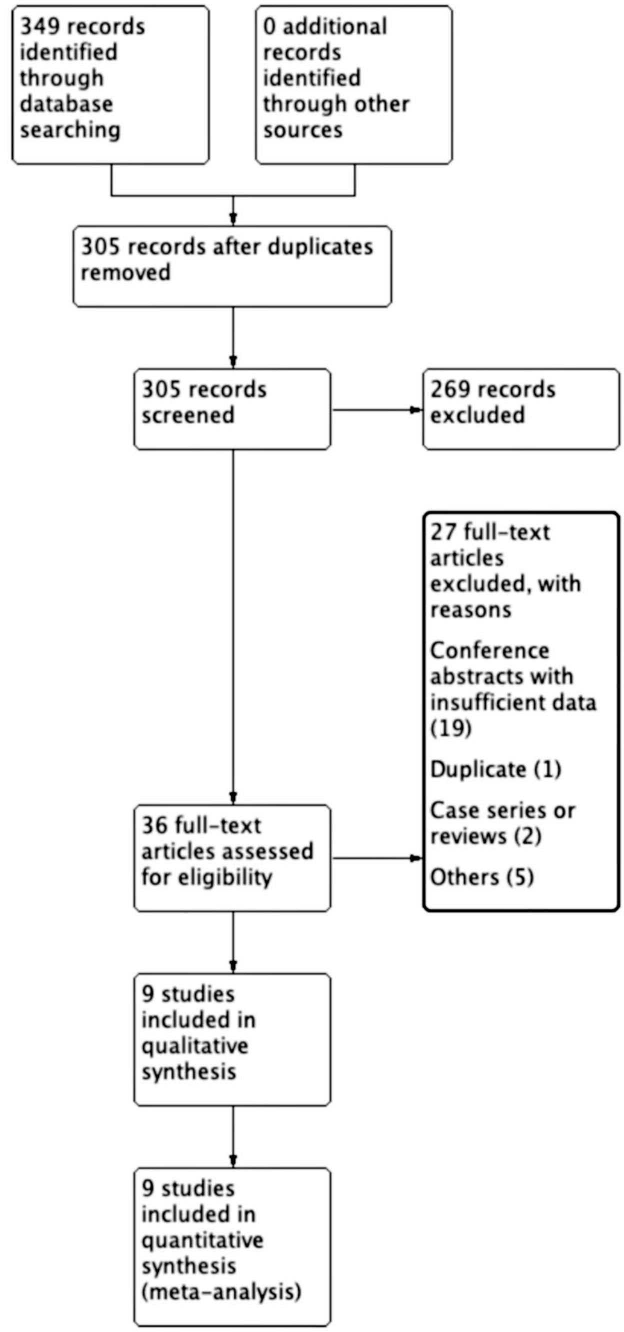

Fig. 1 PRISMA flow diagram

First comparison: RS versus LS in obese patients

Obese patients who underwent RS had a significantly reduced LOS (MD −2.55 days, 95%CI −3.13 to −1.97 days, $P<0.00001$, $I^2=26\%$) (Fig. 2), and lower risk of re-admission (RR 0.42, 95%CI 0.19–0.92, $P=0.030$, $I^2=0\%$) (Fig. 3). Of note, 2 of 3 studies employed an enhanced recovery after surgery (ERAS) protocol [16, 20]. The length of operative time was longer (MD 40.54 min, 95%CI 32.72–48.36 min, $P<0.00001$, $I^2=37\%$) (Fig. 4).

In terms of secondary outcomes, although there was a trend towards a reduced conversion rate in the RS group as compared to the LS group, this was not statistically significant (RR 0.19, 95%CI 0.03–1.05, $P=0.060$, $I^2=0\%$) (Supplementary Fig. 1). Other outcomes including the amount of blood loss (MD −30.71 mL, 95%CI −120.66 to 59.25 mL, $P=0.500$, $I^2=87\%$), risk of anastomotic leak (RR 1.65, 95%CI 0.26–10.55, $P=0.590$, $I^2=0\%$), and re-operation (RR 0.52, 95%CI 0.12–2.39, $P=0.380$,

Table 1 Baseline characteristics of included studies

First author, year	Country	da Vinci model	BMI cut-off (kg/m^2)	Pathological indication	Comparison	No.	Mean age ± S.D (years)	Male (%)	BMI (kg/m^2)	Chemo (%)	Positive margins (%)	Mean LN harvested ± S.D (n)	Tumour size (cm)
Gorgun, 2016	USA	NR	≥30	Rectal Ca	All OB, LAP versus ROB	27/29	60.3 ± 9.8/58.8 ± 10.7	59.3/75.9	35.2 ± 5.0/34.9 ± 7.2	51.9/65.5	NR	21.8 ± 9.6/25.5 ± 14.0	2.8 ± 2.2/2.1 ± 2.0
Panteleimonitis, 2018	UK and Portugal	Si and Xi	≥ 30	Rectal Ca	All OB, LAP versus ROB	61/63	67.3 ± NR/65.8 ± NR	67.2/63.5	32.0 ± 1.2/32.4 ± 1.7	23.0/38.1	NR	16.0 ± NR/17.0 ± NR	NR
Shiomi, 2016	Japan	NR	VFA ≥ 130 cm^2	Rectal Ca	All OB, LAP versus ROB	30/52	66.8 ± 9.8/64.0 ± 11.5	80.0/86.5	27.3 ± 4.0/27.6 ± 5.3	0.0/1.9	0.0/0.0	26.0 ± 11.3/32.3 ± 13.0	NR
Keller, 2016	USA	NR	≥30	Benign and malignant colorectal lesions	All ROB, OB versus NW	45/45	51.7 ± 11.4/51.9 ± 11.6	57.8/57.8	34.5 ± 4.2/25.1 ± 3.3	28.9/24.4	4.4/4.4	15.6 ± 9.5/17.9 ± 9.5	NR
Lagares-Garcia, 2016	USA	Si	≥30	Benign and malignant colorectal lesions	All ROB, OB versus NW	34/36	56.1 ± 11.6/64.6 ± 14.2	25.0/35.3	NR	NR	NR	NR	NR
Bayraktar, 2017	Turkey	Xi	≥30	Rectal Ca	All ROB, OB versus NW	30/71	61.0 ± 9.0/60.0 ± 11.0	63.0/65.0	32.0 ± 1.5/25.0 ± 3.0	23.0/39.0	NR	29.0 ± 15/26.0 ± 11.0	4.2 ± 2.5/4.2 ± 1.9
Harr, 2017	USA	NR	≥30	Benign and malignant colorectal lesions	All ROB, OB versus NW	108/108	57.1 ± 12.4/59.2 ± 11.3	50.0/50.0	36.2 ± 5.7/24.6 ± 3.2	NR	NR	NR	NR
Pai, 2017	USA	NR	≥30	Rectal Ca	All ROB, OB versus NW	33/68	57.7 ± 11.3/63.4 ± 10.5	54.5/66.2	33.8 ± 3.4/25.2 ± 3.2	87.9/67.6	9.1/2.9	15.9 ± 7.2/14.5 ± 7.5	NR
Duchalais, 2018	USA	Si and Xi	≥30	Benign and malignant colorectal lesions	All ROB, OB versus NW	58/125	59.0 ± 10.0/58.0 ± 13.0	69.0/69.0	NR	59.0/58.0	2.0/2.0	26.0 ± 11.0/27.0 ± 14.0	NR

PC prospective cohort, *LAP* laparoscopic, *ROB* robotic/robotic-assisted, *OB* obese, *NW* normal weight, *BMI* body mass index, *LN* lymph node, *NR* not reported. All parameters are reported as LAP/ROB or OB/NW

Study or Subgroup	Robotic Mean	Robotic SD	Robotic Total	Laparoscopic Mean	Laparoscopic SD	Laparoscopic Total	Weight	Mean Difference IV, Fixed, 95% CI
Gorgun 2016	6.4	4.2	29	8.4	4.4	27	6.7%	−2.00 [−4.26, 0.26]
Panteleimonitis 2018	6.3	0.9	63	9	2.3	61	88.6%	−2.70 [−3.32, −2.08]
Shiomi 2016	12.3	6.7	52	12.8	5.5	30	4.7%	−0.50 [−3.18, 2.18]
Total (95% CI)			**144**			**118**	**100.0%**	**−2.55 [−3.13, −1.97]**

Heterogeneity: Chi² = 2.70, df = 2 (P = 0.26); I² = 26%
Test for overall effect: Z = 8.58 (P < 0.00001)

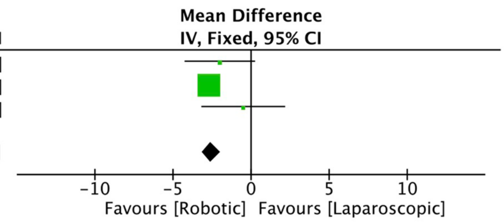

Fig. 2 Forest plot of length of hospital stay in comparison 1

Study or Subgroup	Robotic Events	Robotic Total	Laparoscopic Events	Laparoscopic Total	Weight	Risk Ratio M-H, Fixed, 95% CI
Gorgun 2016	4	29	6	27	33.8%	0.62 [0.20, 1.96]
Panteleimonitis 2018	4	63	12	61	66.2%	0.32 [0.11, 0.95]
Total (95% CI)		**92**		**88**	**100.0%**	**0.42 [0.19, 0.92]**
Total events	8		18			

Heterogeneity: Chi² = 0.67, df = 1 (P = 0.41); I² = 0%
Test for overall effect: Z = 2.16 (P = 0.03)

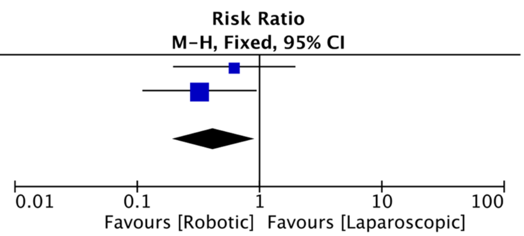

Fig. 3 Forest plot of re-admission rates in comparison 1

Study or Subgroup	Robotic Mean	Robotic SD	Robotic Total	Laparoscopic Mean	Laparoscopic SD	Laparoscopic Total	Weight	Mean Difference IV, Fixed, 95% CI
Gorgun 2016	329	102.2	29	294.6	81.1	29	2.7%	34.40 [−13.08, 81.88]
Panteleimonitis 2018	261	27.7	63	218.8	17.3	61	93.2%	42.20 [34.10, 50.30]
Shiomi 2016	275.5	98.7	52	268.8	78.2	30	4.1%	6.70 [−32.06, 45.46]
Total (95% CI)			**144**			**120**	**100.0%**	**40.54 [32.72, 48.36]**

Heterogeneity: Chi² = 3.15, df = 2 (P = 0.21); I² = 37%
Test for overall effect: Z = 10.16 (P < 0.00001)

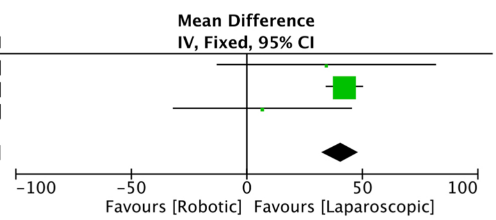

Fig. 4 Forest plot of length of operative time in comparison 1

Study or Subgroup	Obese Mean	Obese SD	Obese Total	Non-obese Mean	Non-obese SD	Non-obese Total	Weight	Mean Difference IV, Fixed, 95% CI
Bayraktar 2017	332	156	30	311	100	71	4.9%	21.00 [−39.48, 81.48]
Duchalais 2018	363	108	58	323	112	125	15.3%	40.00 [5.97, 74.03]
Harr 2017	282.4	120.5	108	272.7	115.4	108	17.9%	9.70 [−21.77, 41.17]
Keller 2016	255.3	63.6	45	252.8	70.2	45	23.2%	2.50 [−25.18, 30.18]
Pai 2017	367	58	33	335	84	68	22.5%	32.00 [3.89, 60.11]
Shiomi 2016	275.5	98.7	52	250.5	85.5	75	16.2%	25.00 [−8.08, 58.08]
Total (95% CI)			**326**			**492**	**100.0%**	**20.72 [7.39, 34.04]**

Heterogeneity: Chi² = 4.05, df = 5 (P = 0.54); I² = 0%
Test for overall effect: Z = 3.05 (P = 0.002)

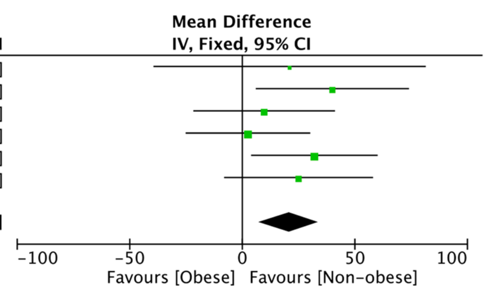

Fig. 5 Forest plot of length of operative time in comparison 2

$I^2 = 0\%$) were similar between both groups (Supplementary Figs. 2–4). Consistent findings were demonstrated in the sensitivity analysis.

Second comparison: obese versus non-obese for participants who underwent RS

An increased operative time was noted in the obese group as compared to the non-obese group (MD 20.72 min, 95%CI 7.39–34.04 min, $P = 0.002$, $I^2 = 0\%$) (Fig. 5). In addition, the obese group had a significantly increased risk of wound infections (RR 2.59, 95%CI 1.12–6.02,

$P=0.030$, $I^2=0\%$) (Fig. 6). However, there were no significant differences in other intra- and post-operative outcomes including the risk of conversion (RR 1.12, 95%CI 0.56–2.27, $P=0.740$, $I^2=0\%$), amount of blood loss (MD − 0.76 mL, 95%CI − 13.57 to 12.05 mL, $P=0.910$, $I^2=0\%$), LOS (MD 0.48 days, 95%CI − 0.33 to − 1.30 days, $P=0.240$, $I^2=74\%$), risk of ileus (RR 1.43, 95%CI 0.90–2.26, $P=0.130$, $I^2=41\%$), pulmonary complications (RR 1.57, 95%CI 0.36–6.84, $P=0.550$, $I^2=18\%$), anastomotic leak (RR 0.85, 95%CI 0.43–1.67, $P=0.630$, $I^2=0\%$), and re-admission rates (RR 1.20, 95%CI 0.71–2.05, $P=0.500$, $I^2=0\%$) (Supplementary Figs. 5–11). Consistent findings were demonstrated in the sensitivity analysis. A summary of outcomes can be found in Table 2.

Meta-regression analysis

A meta-regression analysis was performed to explore sources of heterogeneity in the risk of wound infection. The analysis revealed that the type of pathology (rectal, colon, both) ($P=0.255$), patient age ($P=0.530$), proportion of male gender ($P=0.279$), and continent ($P=0.583$) were not significant sources of heterogeneity.

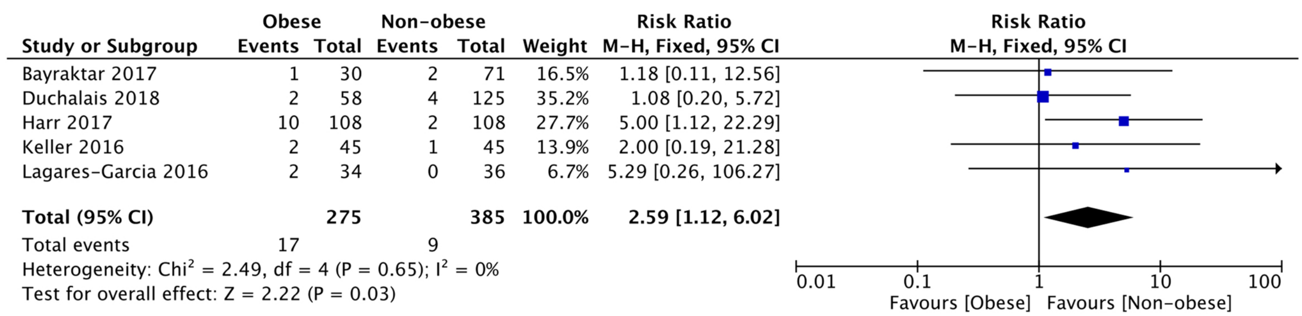

Fig. 6 Forest plot of wound infection rates in comparison 2

Table 2 Summary of outcomes

No.	Outcome	Studies/participants (*n*)	Effect estimate	*P* value	I^2 value (%)
Robotic versus laparoscopic for all obese patients					
1.	Conversion	3/262	RR 0.19, 95%CI 0.02–1.05	0.06	0
2.	Blood loss	2/262	MD − 30.71, 95%CI − 120.66 to 59.25	0.50	87
3.	Operative time	3/264	MD 40.54, 95%CI 32.72 to 48.36	**<0.00001**	37
4.	Length of hospital stay	3/262	MD − 2.55, 95%CI − 3.13 to − 1.97	**<0.00001**	26
5.	Anastomotic leak	3/262	RR 1.65, 95%CI 0.26–10.55	0.59	0
6.	Re-operation	2/180	RR 0.52, 95%CI 0.12–2.39	0.38	0
7.	Re-admission	2/180	RR 0.42, 95%CI 0.19–0.92	**0.03**	0
Obese versus non-obese for all robotic surgery					
1.	Conversion	7/888	RR 1.12, 95%CI 0.56–2.27	0.74	0
2.	Blood loss	6/287	MD − 0.76, 95%CI − 13.57 to 12.05	0.91	0
3.	Operative time	6/818	MD 20.72, 95%CI 7.39–34.04	**0.002**	0
4.	Length of hospital stay	7/888	MD 0.48, 95%CI − 0.33 to − 1.30	0.24	74
5.	Wound infection	5/660	RR 2.59, 95%CI 1.12–6.02	**0.03**	0
6.	Ileus	6/761	RR 1.43, 95%CI 0.90–2.26	0.13	41
7.	Pulmonary complications	2/284	RR 1.57, 95%CI 0.36–6.84	0.55	18
8.	Anastomotic leak	6/761	RR 0.85, 95%CI 0.43–1.67	0.63	0
9.	Re-admission	4/559	RR 1.20, 95%CI 0.71–2.05	0.50	0

Bold *P* values indicate statistical significance

RR relative risk, *MD* mean difference

Discussion

Obesity has been shown to be a significant risk factor for increased morbidity, conversion rate, and blood loss during conventional laparoscopic colorectal surgery [21, 22]. Given the rising prevalence of obesity throughout the world [23, 24], operative techniques need to be developed to ensure that surgical outcomes remain consistent with those reported in non-obese patients. In the landmark ROLARR trial, the odds of conversion in obese patients were significantly higher compared to underweight or normal weight patients (adjusted OR = 4.69 [95%CI 2.08–10.58]; $P < 0.001$), with RS showing a trend towards a lower conversion rate compared to LS in the obese group of patients (18.9% vs. 27.8%, adjusted OR = 0.583 [95%CI 0.212–1.602]; $P = 0.29$) [25]. A similar finding was demonstrated in the current meta-analysis. In addition, the results suggest that RS provides earlier recovery with shorter LOS and reduced re-admission rates, without compromising on other operative outcomes. This could be due to the earlier recovery of gastrointestinal function after RS, as well as the incorporation of ERAS pathways in 2 of 3 studies [16, 20, 26, 27]. Other outcomes including blood loss, anastomotic leak, and re-operation rates were comparable between the two minimally invasive approaches. Nonetheless, the small number of studies included in this systematic review highlights the paucity of evidence available [16, 20].

While RS was associated with a longer operative time, some authors have attributed this to the protracted docking time associated with the older robotic systems [16], which often involved complicated docking procedures and port placement configurations [28]. With the newer da Vinci Xi system, however, docking can be completed faster with the boom-mounted robotic arms and laser targeting system [28]. In addition, the multi-quadrant capabilities of the Xi also help to shorten the operative duration by reducing the need for re-docking or hybrid procedures [29]. Another argument in favour of RS would be that most surgeons in the included studies were experienced in LS but were still in their learning phase for RS [12, 16, 20], potentially introducing bias in favour of the LS group. The actual benefit of RS could therefore be greater than what has been reported in the current literature, especially when performed by experienced robotic surgeons.

Although the main focus of this systematic review was intra- and post-operative surgical outcomes, cost remains an important factor, especially since the length of operative time was longer with RS, and robotic instruments and accessories may cost more [30–32]. However, emerging evidence is demonstrating that robotics may be more cost-effective than laparoscopy and open resection if certain thresholds in quality of life, instrument costs, operating room time, and complication rates are achieved [32]. The other paramount consideration is oncological outcome. While current evidence suggests that RS is comparable to LS in terms of long-term oncological outcomes [18, 33–36], evidence pertaining to the obese population remains limited [16]. Since obesity was previously shown to be a risk factor for poorer oncological outcomes after surgery in other cancers such as prostate [37, 38], further research is warranted for colorectal cancer surgery in this group of patients.

Nonetheless, the results from this meta-analysis must be interpreted in the context of known limitations of retrospective cohort studies, such as selection and confounding bias. While the quality of studies were graded using the NOS tool, other residual confounders such as pathology, obesity-associated comorbidities, age, and gender, could not be accounted for using meta-regression analysis given the limited number of studies. Next, studies with pre-specified subgroups of obese patients [25] were excluded since outcomes reported may not be stratified according to the obese cohort. However, this may potentially result in a smaller sample size. Given the large number of meta-analyses performed in this study, there may also be an issue of multiple testing, which we have attempted to address by classifying complications into primary or secondary. While BMI is a commonly used method for defining obesity, other indices such as visceral fat measurements (VFA), waist and hip circumference, and waist-to-hip ratio may be more relevant when comparing surgical outcomes. Given the difference in fat distribution between Asian and Western populations, it might be more accurate to use the VFA for studies on the former [39]. In addition, as obesity was assessed on a dichotomous scale (30 kg/m^2), it was not possible to ascertain the extent of obesity at which surgery becomes more challenging. Conversely, patients who were underweight could also have been associated with poorer surgical outcomes [40], but given the lack of data, we were not able to stratify between normal and underweight patients in the non-obese group. Another potential bias would be heterogeneity in the types (benign vs. malignant) and location (rectal vs. colon) of disease conditions being studied, which may confound the overall outcomes and complication risks for obese patients. Unfortunately, subgroup analyses were not feasible as the data reported were not stratified according to these subgroups. Lastly, the lack of long-term follow-up data precluded the evaluation of oncologic outcomes.

Compliance with ethical standards

Disclosures Ian Jun Yan Wee, Li-Jen Kuo, and James Chi-Yong Ngu have no conflicts of interest or financial ties to disclose.

References

1. Nelson H, Sargent DJ, Wieand HS, Fleshman J, Anvari M, Stryker SJ et al (2004) A comparison of laparoscopically assisted and open colectomy for colon cancer. N Engl J Med 350(20):2050–2059
2. Bonjer HJ, Deijen CL, Abis GA, Cuesta MA, van der Pas MH, de Lange-de Klerk ES et al (2015) A randomized trial of laparoscopic versus open surgery for rectal cancer. N Engl J Med 372(14):1324–1332
3. Green BL, Marshall HC, Collinson F, Quirke P, Guillou P, Jayne DG et al (2013) Long-term follow-up of the Medical Research Council CLASICC trial of conventional versus laparoscopically assisted resection in colorectal cancer. Br J Surg 100(1):75–82
4. Delaney CP, Chang E, Senagore AJ, Broder M (2008) Clinical outcomes and resource utilization associated with laparoscopic and open colectomy using a large national database. Ann Surg 247(5):819–824
5. Denost Q, Quintane L, Buscail E, Martenot M, Laurent C, Rullier E (2013) Short- and long-term impact of body mass index on laparoscopic rectal cancer surgery. Colorectal Dis 15(4):463–469
6. Sarli L, Rollo A, Cecchini S, Regina G, Sansebastiano G, Marchesi F et al (2009) Impact of obesity on laparoscopic-assisted left colectomy in different stages of the learning curve. Surg Laparosc Endosc Percutaneous Tech 19(2):114–117
7. Scheidbach H, Benedix F, Hugel O, Kose D, Kockerling F, Lippert H (2008) Laparoscopic approach to colorectal procedures in the obese patient: risk factor or benefit? Obes Surg 18(1):66–70
8. Bayraktar O, Aytac E, Ozben V, Atasoy D, Bilgin IA, Erenler Bayraktar I et al (2018) Does robot overcome obesity-related limitations of minimally invasive rectal surgery for cancer? Surg Laparosc Endosc Percutaneous Tech 28(1):e8–e11
9. Duchalais E, Machairas N, Kelley SR, Landmann RG, Merchea A, Colibaseanu DT et al (2018) Does obesity impact postoperative outcomes following robotic-assisted surgery for rectal cancer? Surg Endosc 32(12):4886–4892
10. Harr JN, Luka S, Kankaria A, Juo Y, Agarwal S, Obias V (2016) Robotic-assisted colorectal surgery in obese patients: a case-matched series. Surg Endosc Other Interv Tech 31(7):2813–2819
11. Moher D, Liberati A, Tetzlaff J, Altman DG (2009) Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. BMJ Clin Res Ed 339:b2535
12. Shiomi A, Kinugasa Y, Yamaguchi T, Kagawa H, Yamakawa Y (2016) Robot-assisted versus laparoscopic surgery for lower rectal cancer: the impact of visceral obesity on surgical outcomes. Int J Colorectal Dis 31(10):1701–1710
13. Sterne JAC, Sutton AJ, Ioannidis JPA, Terrin N, Jones DR, Lau J et al (2011) Recommendations for examining and interpreting funnel plot asymmetry in meta-analyses of randomised controlled trials. BMJ Clin Res Ed 343:d4002
14. Higgins JPT GS (2011) Cochrane Handbook for Systematic Reviews of Interventions Version 5.1.0. The cochrane collaboration. www.handbook.cochrane.org. Accessed 30 Nov 2018
15. Bayraktar O, Aytaç E, Özben V, Atasoy D, Bilgin IA, Erenler Bayraktar İ, Baca B, Hamzaoğlu İ, Karahasanoğlu T (2018) Does robot overcome obesity-related limitations of minimally invasive rectal surgery for cancer? Surg Laparosc Endosc Percutaneous Tech 28(1):e8–e11
16. Panteleimonitis S, Pickering O, Abbas H, Harper M, Kandala N, Figueiredo N et al (2018) Robotic rectal cancer surgery in obese patients may lead to better short-term outcomes when compared to laparoscopy: a comparative propensity scored match study. Int J Colorectal Dis 33(8):1079–1086
17. Pai A, Alsabhan F, Park JJ, Melich G, Sulo S, Marecik SJ (2017) The impact of obesity on the perioperative, clinicopathologic, and oncologic outcomes of robot assisted total mesorectal excision for rectal cancer. Polski Prz Chir 89(4):23–28
18. Lagares-Garcia J, O'Connell A, Firilas A, Robinson CC, Dumas BP, Hagen ME (2016) The influence of body mass index on clinical short-term outcomes in robotic colorectal surgery. Int J Med Robot Comput Assist Surg 12(4):680–685
19. Keller DS, Madhoun N, Flores-Gonzalez JR, Ibarra S, Tahilramani R, Haas EM (2016) Effect of BMI on short-term outcomes with robotic-assisted laparoscopic surgery: a case-matched study. J Gastrointest Surg 20(3):488–493
20. Gorgun E, Ozben V, Costedio M, Stocchi L, Kalady M, Remzi F (2016) Robotic versus conventional laparoscopic rectal cancer surgery in obese patients. Colorectal Dis 18(11):1063–1071
21. Yang T, Wei M, He Y, Deng X, Wang Z (2015) Impact of visceral obesity on outcomes of laparoscopic colorectal surgery: a meta-analysis. ANZ J Surg 85(7–8):507–513
22. Bell S, Kong JC, Wale R, Staples M, Oliva K, Wilkins S et al (2018) The effect of increasing body mass index on laparoscopic surgery for colon and rectal cancer. Colorectal Dis 20(9):778–788
23. Hales CM, Fryar CD, Carroll MD, Freedman DS, Ogden CL (2018) Trends in obesity and severe obesity prevalence in US youth and adults by sex and age, 2007-2008 to 2015-2016. JAMA 319(16):1723–1725
24. Li XY, Jiang Y, Hu N, Li YC, Zhang M, Huang ZJ et al (2012) Prevalence and characteristic of overweight and obesity among adults in China, 2010. Zhonghua yu fang yi xue za zhi [Chin J Prev Med] 46(8):683–686
25. Jayne D, Pigazzi A, Marshall H, Croft J, Corrigan N, Copeland J et al (2017) Effect of robotic-assisted vs conventional laparoscopic surgery on risk of conversion to open laparotomy among patients undergoing resection for rectal cancer: the ROLARR randomized clinical trial. JAMA 318(16):1569–1580
26. Liao G, Zhao Z, Lin S, Li R, Yuan Y, Du S et al (2014) Robotic-assisted versus laparoscopic colorectal surgery: a meta-analysis of four randomized controlled trials. World J Surg Oncol 12:122
27. Kim CW, Kim CH, Baik SH (2014) Outcomes of robotic-assisted colorectal surgery compared with laparoscopic and open surgery: a systematic review. J Gastrointest Surg 18(4):816–830
28. Ngu JCTC, Koh DC (2017) The da Vinci Xi: a review of its capabilities, versatility, and potential role in robotic colorectal surgery. Robot Surg Res Rev 4:77–85
29. Ngu JC, Sim S, Yusof S, Ng CY (2017) Insight into the da Vinci(R) Xi-technical notes for single-docking left-sided colorectal procedures. Int J Med Robot MRCAS 13(4):1798
30. Childers CP, Maggard-Gibbons M (2018) Estimation of the acquisition and operating costs for robotic surgery. JAMA 320(8):835–836
31. Kim CW, Baik SH, Roh YH, Kang J, Hur H, Min BS et al (2015) Cost-effectiveness of robotic surgery for rectal cancer focusing on short-term outcomes: a propensity score-matching analysis. Medicine 94(22):e823
32. Simianu VV, Gaertner WB, Kuntz K, Kwaan MR, Lowry AC, Madoff RD et al (2019) Cost-effectiveness evaluation of laparoscopic versus robotic minimally invasive colectomy. Ann Surg; Publish Ahead of Print
33. Healy LA, Ryan AM, Sutton E, Younger K, Mehigan B, Stephens R et al (2010) Impact of obesity on surgical and oncological outcomes in the management of colorectal cancer. Int J Colorectal Dis 25(11):1293–1299
34. Ballian N, Yamane B, Leverson G, Harms B, Heise CP, Foley EF et al (2010) Body mass index does not affect postoperative morbidity and oncologic outcomes of total mesorectal excision for rectal adenocarcinoma. Ann Surg Oncol 17(6):1606–1613
35. Lim DR, Bae SU, Hur H, Min BS, Baik SH, Lee KY et al (2017) Long-term oncological outcomes of robotic versus laparoscopic total mesorectal excision of mid-low rectal cancer

following neoadjuvant chemoradiation therapy. Surg Endosc 31(4):1728–1737
36. Law WL, Foo DCC (2017) Comparison of short-term and oncologic outcomes of robotic and laparoscopic resection for mid- and distal rectal cancer. Surg Endosc 31(7):2798–2807
37. Ma J, Li H, Giovannucci E, Mucci L, Qiu W, Nguyen PL et al (2008) Prediagnostic body-mass index, plasma C-peptide concentration, and prostate cancer-specific mortality in men with prostate cancer: a long-term survival analysis. Lancet Oncol 9(11):1039–1047
38. Yu YD, Byun SS, Lee SE, Hong SK (2018) Impact of body mass index on oncological outcomes of prostate cancer patients after radical prostatectomy. Sci Rep 8(1):11962
39. Deurenberg P, Deurenberg-Yap M, Guricci S (2002) Asians are different from Caucasians and from each other in their body mass index/body fat per cent relationship. Obes Rev 3(3):141–146
40. Lopez-Jimenez F (2009) Speakable and unspeakable facts about BMI and mortality. Lancet (London, England) 373(9669):1055–1056