Asian Journal of Surgery (2019) 42, 589–598

Available online at www.sciencedirect.com

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journal homepage: www.e-asianjournalsurgery.com

REVIEW ARTICLE

Short-term outcomes of robotic-assisted right colectomy compared with laparoscopic surgery: A systematic review and meta-analysis

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Received 28 August 2018; received in revised form 27 October 2018; accepted 2 November 2018
Available online 30 November 2018

KEYWORDS
Robotic-assisted;
Laparoscopic;
Right colectomy;
Systematic review;
Meta-analysis

Abstract To assess the clinical efficacy and safety of robotic-assisted right colectomy (RRC) with conventional laparoscopic right colectomy (LRC) by performing a systematic review and meta-analysis of the published studies. All published literature for comparative studies reporting preoperative outcomes of RRC and LRC were searched. We searched the databases included Cochrane Library of Clinical Comparative Trials, MEDLINE, Embase, Web of Science and Chinese Biomedical Database (CBM) from 1973 to 2018. The censor date was up to January 2018. Operative time, estimated blood loss, length of hospital stay, conversion rates to open surgery, postoperative complications, and related outcomes were evaluated. All calculations and statistical tests were performed using Stata 12.0 software. A total of 7769 patients with colon cancer enrolled in 13 trials were divided into a study group ($n = 674$) and a control group ($n = 7095$). Meta-analysis suggested significantly greater length of hospital stay in the LRC group [MD = −0.85; 95% CI: −1.07 to −0.63; $P < 0.00001$]. Robotic surgery was also associated with a significantly lower complication rate [OR = 0.73; 95% CI: 0.52 to 1.01; $P = 0.05$]. There were statistically significant differences between the groups in estimated blood loss [MD = −16.89; 95% CI: −24.80 to −8.98; $P < 0.00001$] and the rate of intraoperative conversion to open surgery [OR = 0.34, 95% CI: 0.15 to 0.75; $P = 0.008$)], but these differences were not clinically relevant. The recovery of bowel function in two groups is no significant differences [MD = −0.58, 95% CI: −0.96 to −0.20, $P = 0.0008$]. However, operation times [MD = 43.61, 95% CI: 39.11 to 48.10, $P < 0.00001$] were longer for RRC than for LRC. Compared to LRC, RRC

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https://doi.org/10.1016/j.asjsur.2018.11.002

was associated with reduced estimated blood loss, reduced postoperative complications, longer operation times. Recovery of bowel function and other perioperative outcomes were equivalent between the two surgeries.

1. Introduction

Robotic surgery has developed rapidly in various disciplines in recent years.[1] There are many advantages of this method, including precision and flexibility as well as remote control, which cannot be achieved with traditional open surgery or laparoscopic surgery.[2] Therefore, robotic surgery is the direction that minimally invasive surgery is moving towards.[3] Currently, the field of robotic surgery is gradually expanding, so it is very important for research and clinical studies to systematically analyse the relevant situation and the research hotspot of robotic surgery comprehensively and intuitively.[4]

Bibliometrics involves analysing written publications and studying the metrological characteristics of the literature using mathematical and statistical methods to describe, evaluate and predict the status of science and technology or trends in development. Multivariate statistics and social network analysis are the most advanced methods in scientific metrology. Massive amounts of data from the scientific literature can be transformed into visual images by cluster analysis, strategic coordinate maps and social network knowledge maps. From personal experience, it is difficult to obtain the overall picture of emerging scientific research as well as the structural characteristics and development trends with intuition alone.

We summarized the growing discipline of robotic colorectal surgery from a bibliometric perspective. In analysing the characteristics and trends of related topics, we used multivariate statistics and visualization to reveal the main research themes and development trends in recent years. We found that robotic colorectal surgery-related research is mainly concentrated in the rectal field. After examining other colorectal diseases, we were convinced that a meta-analysis of the short-term outcomes of robotic-assisted right colectomy (RRC) compared to those of laparoscopic right colectomy (LRC) in cases of right colon cancer was necessary.[5]

Since Weber et al first reported the use of robotic colectomy surgery in 2002,[6] more and more surgeons have been willing to use this technology.[7] Studies have revealed the feasibility and safety of both RRC and LRC. There are 13 studies[8–20] with a full list of author information at the end of an article comparing the outcomes of RRC against those for standard LRC, but no meta-analyses have compared and integrated the results of these studies. The objective of this meta-analysis was to compare the safety and efficacy of RRC with those of conventional LRC.

2. Materials and methods

2.1. Inclusion criteria

All the publications retrieved from the search were reviewed carefully to determine eligibility based on the inclusion criteria. Studies were included if: 1) they compared RRC with conventional LRC; 2) they included >15 patients in each study group; and 3) they investigated objective clinical outcome measures via standardized questionnaires. In the event that data duplication was observed, more recent studies or studies with larger sample sizes were given preference and earlier, smaller studies were excluded. We also manually searched the abstracts published at major international conferences. A manual search of the bibliographies of relevant articles was also carried out to identify trials for possible inclusion. There was no language restriction except that abstracts not written in English were excluded. Reference lists of all retrieved articles were manually searched for additional studies.

2.2. Exclusion criteria

Abstracts, letters, editorials, expert opinions, reviews without original data, case reports, and studies lacking control groups were excluded. The following types of studies or data were also excluded: (1) studies that reported on colorectal surgery but did not contain a distinct group of colon surgery patients; (2) studies where the outcomes and parameters of patients were not clearly reported; (3) studies for which it was impossible to extract the appropriate data from the published results; and (4) studies for which there was an overlap between authors or centres in the published literature.

2.3. Selection of studies

We searched Cochrane Library of Clinical Comparative Trials, MEDLINE, Embase, Web of Science, Chinese Biomedical Literature Database (CBM) and the da Vinci surgery system database (www.davincisurgerydatabase.com) for relevant content published from 1973 to 2018. The censor date was January 2018. The search terms were "Robotic/robotic assisted", "right colectomy" AND/OR "laparoscopic". The search also included all of the MeSH terms. No search restrictions were imposed. The reference lists of all retrieved articles were reviewed for further identification of potentially relevant studies.

Review articles were also obtained to identify other possible studies.

2.4. Data extraction and management

Two reviewers independently assessed the eligibility of each trial. According to the inclusion and exclusion criteria, the two researchers checked the results of the study and determined whether it should be included in the analysis by reading the title, abstract and full text.

Author names, year of publication, the countries patients were from, sample size, operation time, estimated blood loss, length of hospital stay, rates of conversion to open surgery, postoperative complications, and related outcomes were recorded. Two reviewers independently extracted the data from each study.

2.5. Statistical analysis

We used Stata software (version 12.0; Stata Corp LP, College Station, TX, United States) to perform calculations and statistical tests. Continuous variables were pooled using the mean difference (MD). Dichotomous data were analysed using the odds ratio (OR) for the pooled effect. The pooled effect adopts interval estimation and hypothesis testing. The interval estimation used a 95% confidence interval (95% CI), and the hypothesis testing used Q statistics. Values of $I^2 \geq 50\%$ indicated substantial heterogeneity. The fixed-effects model was used if there was no significant heterogeneity between the trials. Otherwise, the random-effects model was used. If there was obvious heterogeneity between the trials, only the descriptive analysis was carried out. A statistically significant difference existed if $P < 0.05$. Forest plots were used to represent a single study and its pooled hazard ratio (HR) and risk ratio (RR). A funnel plot was used to assess publication bias.

The meta-analysis was performed using Review Manager software, version 5.2, provided by the Cochrane Collaboration (The Nordic Cochrane Centre, Copenhagen, Denmark). We analysed dichotomous variables using estimation of the OR with a 95% CI and analysed continuous variables using a weighted MD with a 95% CI.

Values of the Higgins I^2 statistic that were <25, 25–50, and >50% were defined as low, moderate, and high heterogeneity, respectively. A fixed-effects model was used for studies with low or moderate statistical heterogeneity, and a random-effects model was used for studies with high statistical heterogeneity. The following groups and subgroups of patients were analysed: 1. Right side colectomy: patients who underwent caecectomy or right hemicolectomy; 2. Left side colectomy: patients who underwent left hemi-colectomy or sigmoidectomy; 3. Sigmoidectomy: patients who underwent only sigmoid colon resection; 4. Colectomy: patients who underwent caecectomy, right hemicolectomy, left hemicolectomy, sigmoidectomy, other (total, multiple, not specified), or ostomy. Values of $P < 0.05$ were considered statistically significant. Sensitivity analyses were performed to determine if modifying the inclusion criteria for this meta-analysis affected the final results. An estimate of potential publication bias was made using a funnel plot in which the OR for each study was plotted against its logarithm.

3. Results

3.1. Results of the search

According to the retrieval strategy and data collection methods, 4848 relevant articles were retrieved. We removed 4670 articles by reading the title and abstract and 178 articles were included preliminarily. The 158 articles due to lack of right colectomy trials were eliminated and 20 articles may conforming to criteria. After reading the full text according to the criteria and filtered data integrity, 13 trials and a total of 7769 patients were included eventually. The details are listed in Fig. 1.

3.2. Included studies

3.2.1. General characteristics

Our study included one randomized controlled trials (RCT), 5 prospective not randomized (PNR) trials and 7 retrospective(R) trials. All of the trials were researched in Korea, Italy, USA and France. The publication time was from 2007 to 2016. The details are listed in Table 1.

3.2.2. Types of participants

A total of 7769 cases were included in the 13 trials.[8–20] The maximum number of cases in a single trial[10] was 6780, and the minimum number of cases was 28. There were 4097 male patients and 3672 female patients. There were no statistically significant differences in these variables between the study group and the control group. The details are listed in Tables 1 and 2.

3.2.3. Operating time

The operating time was reported in 12 studies,[8–12,14–20] and 9 of the studies[9,10,12,14–17,19,20] indicated that operating times were longer in the RRC group. The 3 studies[8,11,18] were showed no difference in operating time between the two approaches. In this study, undocking time was not included in the operation time. Because of the high heterogeneity ($I^2 = 92\%$) among these studies, a random effects model was used for the meta-analysis. The results show that the RRC group had a significantly longer operating time than the LRC group (MD = 43.61; 95% CI: 39.11, to 48.10; $P < 0.00001$). An analysis excluding the data from the study by Deutsch et al still showed that the RRC group had significantly longer operation times than the LRC group (MD = 57.83; 95% CI: 51.88 to 63.78; $P < 0.00001$), and the study heterogeneity remained high ($I^2 = 92\%$; Fig. 2).

3.2.4. Length of hospital stay

The length of hospital stay was reported in 10 studies.[9–11,14–20] The results of the meta-analysis showed that the LRC group had a significantly longer length of hospital stay than the RRC group (MD = −0.85; 95% CI: −1.07 to −0.63; $P < 0.00001$), with high study heterogeneity ($I^2 = 52\%$; Fig. 3).

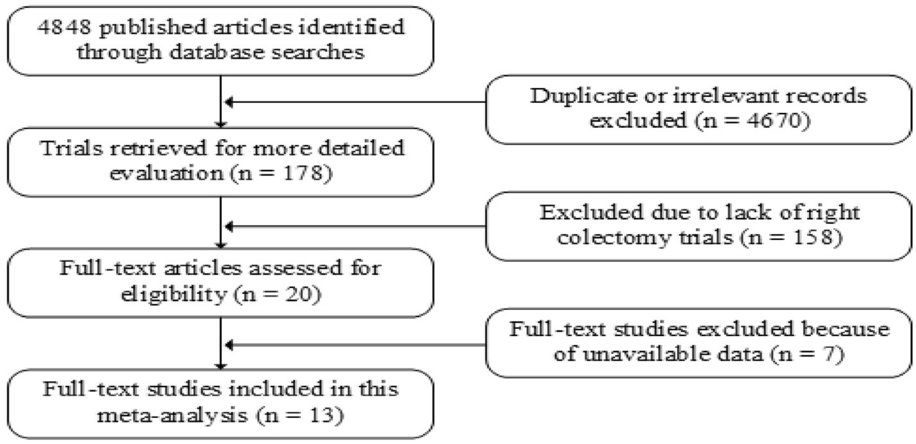

Figure 1 Flow chart of the trial selection process.

3.2.5. Conversion to open surgery and estimated blood loss

The rate of conversion to open surgery was reported in 9 studies.[8,11–14,16,17,19,20] The results of the meta-analysis showed that the RRC group had a significantly lower conversion to open surgery than the LRC group (OR = 0.34, 95% CI: 0.15 to 0.75; P = 0.008), with low study heterogeneity (I^2 = 0%). The estimated intraoperative blood loss was reported in 8 studies.[8,11,14,16–20] The results of the meta-analysis showed that intraoperative estimated blood loss was significantly lower in patients from the RRC group than in patients who underwent LRC (MD = −16.89; 95% CI: −24.80 to −8.98; P < 0.00001), and low study heterogeneity was observed (I^2 = 35%; Figs. 4 and 5).

3.2.6. Time to bowel function recovery

Time to bowel function recovery was reported in 4 studies.[11,15,17,18] The results of the meta-analysis showed that bowel function recovered no difference between the

Table 1 Baseline characteristics.

Study	Year	Country	Total	Group	Patients	age	Mean MBI	Sex (M/F)	Study type	Anastomosis
Kang *et al*[8]	2016	Korea	63	RRC	20	66.0 ± 9.6	23.5 ± 2.4	9/11	R	Extracorporeal
				LRC	43	65.7 ± 13.2	23.0 ± 3.0	22/21		
Ferrara *et al*[9]	2016	Italy	28	RRC	13	66.1 ± 12.6	21.7 ± 2.5	7/6	R	Intracorporeal
				LRC	15	65.4 ± 11.2	22.6 ± 3.8	7/8		
Dolejs *et al*[10]	2017	USA	6780	RRC	259	65.3 ± 5.6	24.5 ± 2.7	126/133	R	Intracorporeal
				LRC	6521	63.7 ± 1.2	23.8 ± 2.0	3482/3039		
de'Angelis *et al*[11]	2016	France	80	RRC	30	71 ± 8.5	26.43 ± 3.21	15/15	R	Extracorporeal
				LRC	50	71.1 ± 12.92	25.26 ± 4.19	19/31		
Trastulli *et al*[12]	2015	Italy	142	RRC	102	68.8 ± 11.6	25.6 ± 3.8	56/46	R	Extracorporeal
				LRC	40	71.5 ± 10.3	26.6 ± 4	25/15		
Guerrieri *et al*[13]	2015	Italy	29	RRC	18	74 ± 6	26 ± 2	9/9	R	Intracorporeal
				LRC	11	65 ± 10	26 ± 3	9/2		
Casillas *et al*[14]	2014	US	162	RRC	52	65 ± 12	26.9 (25.6–28.3)	25/27	PNR	Extracorporeal
				LRC	110	71 ± 12	27.0 (26.1–28.1)	69/41		
Morpurgo *et al*[15]	2013	Italy	96	RRC	48	68 ± 8	25 ± 3.5	27/21	PNR	Intracorporeal
				LRC	48	74 ± 11	28 ± 4	16/32		
Lujan *et al*[16]	2013	US	47	RRC	22	71.88 ± 9.0	31.44 ± 6.02	8/14	PNR	Intracorporeal
				LRC	25	72.6 ± 11.1	27.88 ± 6.1	10/15		and Extracorporeal
Park *et al*[17]	2012	Korea	70	RRC	35	62.8 ± 10.5	24.4 ± 2.5	14/21	RCT	Intracorporeal
				LRC	35	66.5 ± 11 · 4	23.8 ± 2.7	16/19		and Extracorporeal
Deutsch *et al*[18]	2012	US	65	RRC	18	65.2 ± 12	25 ± 3.8	6/12	R	Extracorporeal
				LRC	47	70.8 ± 14.6	28 ± 6.5	22/25		
deSouza *et al*[19]	2010	US	175	RRC	40	71.35 ± 14.	27.33 ± 5.22	22/18	PNR	Extracorporeal
				LRC	135	65.32 ± 18	26.57 ± 6.39	62/73		
Rawlings *et al*[20]	2007	US	32	RRC	17	64.6 ± 11.7	25.7 ± 4.3	8/9	R	Intracorporeal
				LRC	15	63.1 ± 17.5	28.3 ± 6.4	6/9		

RRC, robotic right colectomy; LRC, laparoscopic right colectomy; PNR, prospective not randomized; R, retrospective; RCT, randomized controlled trial.

Table 2 Comparison of characteristics between RRC and LRC.

Characteristics	No of studies	RRC	LRC	MD/OR (95%CI)	P value
No. of patients	13	674	7095	Null	P = 0.76
Gender (M/F)	13	302/372	3765/3330	Null	P = 0.54
Age, years	13	65 ± 13.5	66 ± 10.6	Null	P = 0.21
BMI	13	22.6 ± 2.2	20.5 ± 7.5	Null	P = 0.19
Intraoperative outcomes					
Operative time (minutes)	12	200.61 ± 84.50	134.11 ± 72.63	43.61 [39.11, 48.10]	P < 0.00001
Blood loss (mL)	8	77.33 ± 106.51	78.49 ± 108.18	−16.89 [−24.80, −8.98]	P < 0.0001
Conversion to open surgery	9	8/336	26/464	0.34 [0.15, 0.75]	P = 0.008
Postoperative outcomes					
Hospital stay (days)	10	4.67 ± 3.23	4.16 ± 3.14	−0.85 [−1.07, −0.63]	P < 0.00001
Total complication	11	85/402	148/559	0.73 [0.52, 1.01]	P = 0.05
Anastomosis leakage	8	11/564	156/6894	0.79 [0.42, 1.50]	P = 0.48
Postoperative ileus	8	40/543	665/6971	0.96 [0.68, 1.36]	P = 0.81
Wound infection	8	15/578	14/6957	0.68 [0.34, 1.34]	P = 0.26
Time to first flatus (d)	4	2.44 ± 0.99	2.93 ± 1.57	−0.25 [−0.44, −0.06]	P = 0.01
Time to soft diet resumed (d)	3	3.57 ± 1.59	4.06 ± 2.02	−0.55 [−0.82, −0.29]	P < 0.00001
Total hospital cost (US$)	3	11602.78 ± 3047.42	9768 ± 1657.20	2581.00 [2579.05, 2582.94]	P < 0.00001

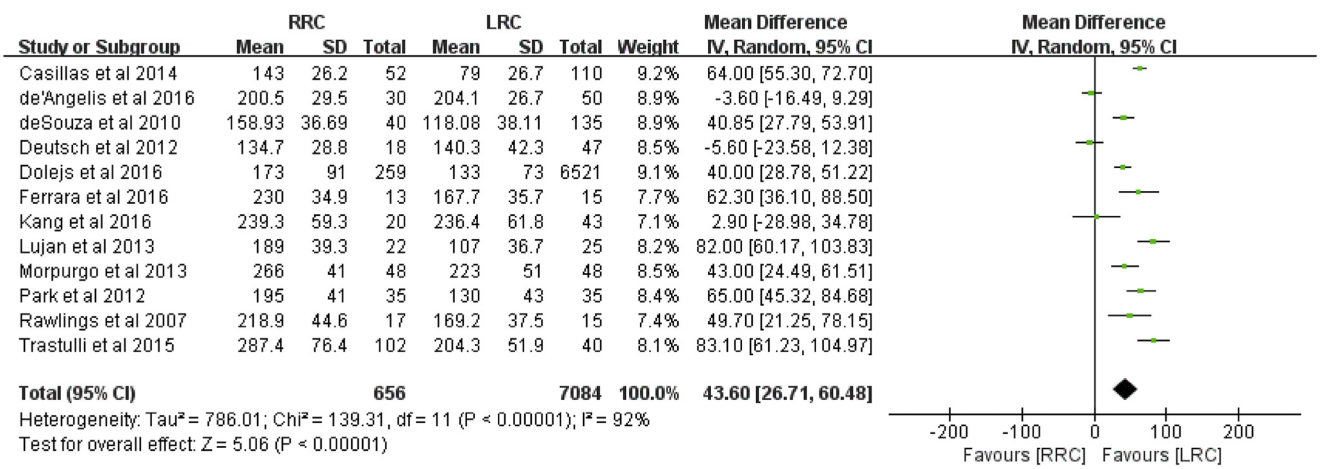

Figure 2 Forest plot of operating time.

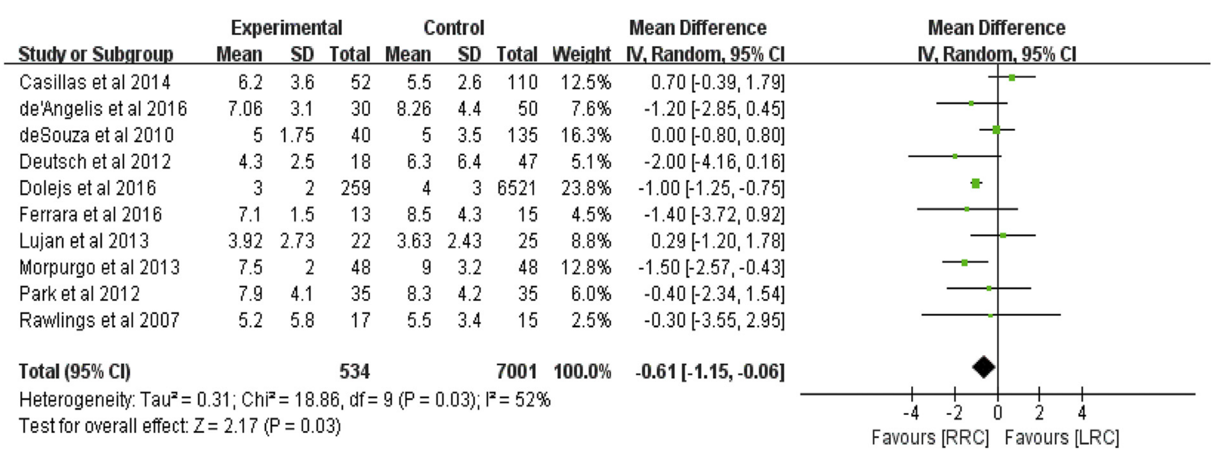

Figure 3 Forest plot of Length of hospital stay.

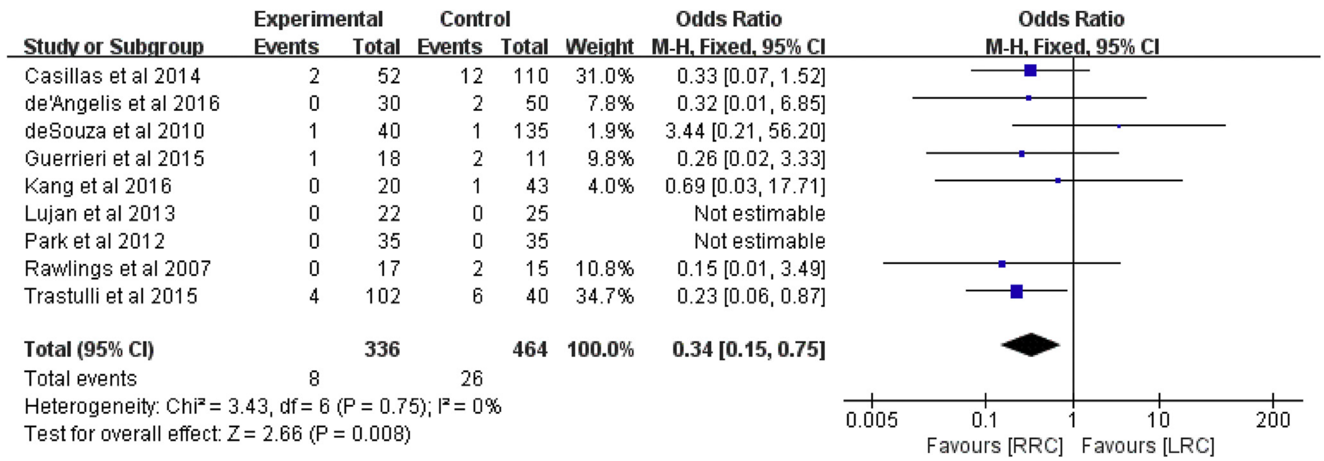

Figure 4 Forest plot of conversion to open surgery.

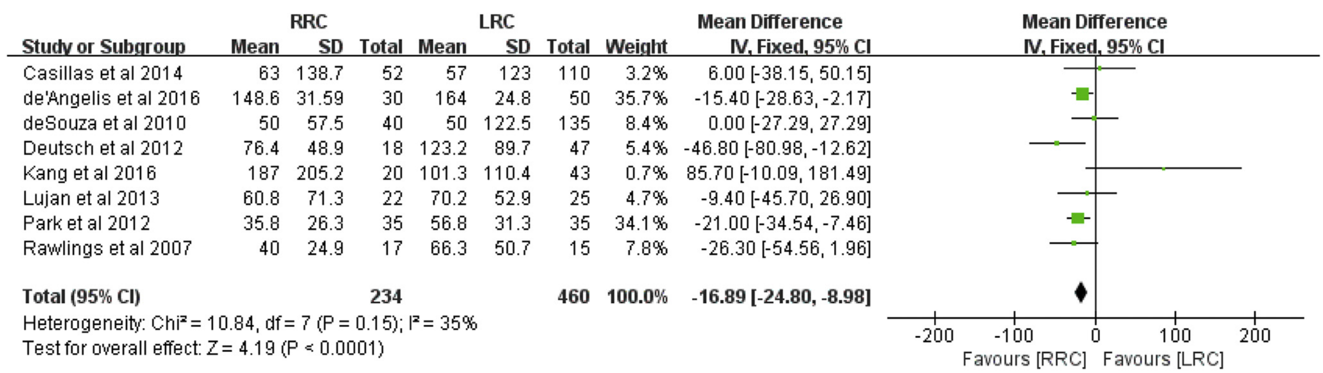

Figure 5 Forest plot of estimated blood loss.

RRC and LRC. (MD = −0.25; 95% CI: −0.44 to −0.06; $P < 0.0001$) with high study heterogeneity ($I^2 = 86\%$ Fig. 6).

3.2.7. Overall postoperative complications

Overall postoperative complications were reported in 11 studies.[8,11–20] The results of the meta-analysis showed that the rate of overall complications in the RRC group was significantly lower than that in the LRC group (OR = 0.73; 95% CI: 0.52 to 1.01; P = 0.05) and that there was no study heterogeneity ($I^2 = 1\%$). In terms of postoperative ileus, the meta-analysis shows no difference between the two groups (OR = 0.96; 95% CI: 0.68 to 1.36; P = 0.81), with no heterogeneity ($I^2 = 0\%$). The meta-analysis also showed no difference between the two groups in terms of anastomosis leakage (OR = 0.79; 95% CI: 0.42 to 1.50; P = 0.48) and postoperative bleeding (MD = 0.97; 95% CI: 0.37 to 2.57; P = 0.95), with low heterogeneity observed for both outcomes ($I^2 = 21\%$ and 2%, respectively; Fig. 7).

4. Discussion

Since first being described in 1991, laparoscopic colorectal surgery has evolved rapidly in recent years.[21–24] Currently, most colorectal procedures are performed laparoscopically.[25,26] Several studies show that laparoscopic colorectal surgery is associated with better short-term outcomes than open surgery, and the benefits include smaller incisions, reduced postoperative pain and reduced duration of ileus

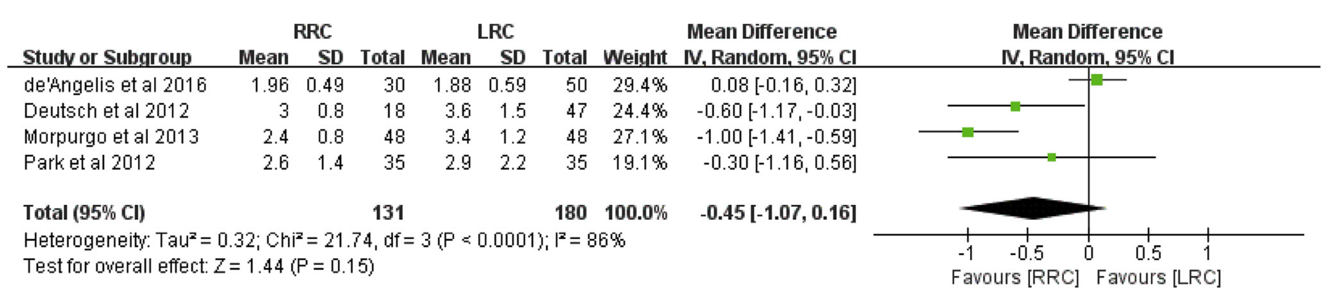

Figure 6 Forest plot of time to bowel function recovery.

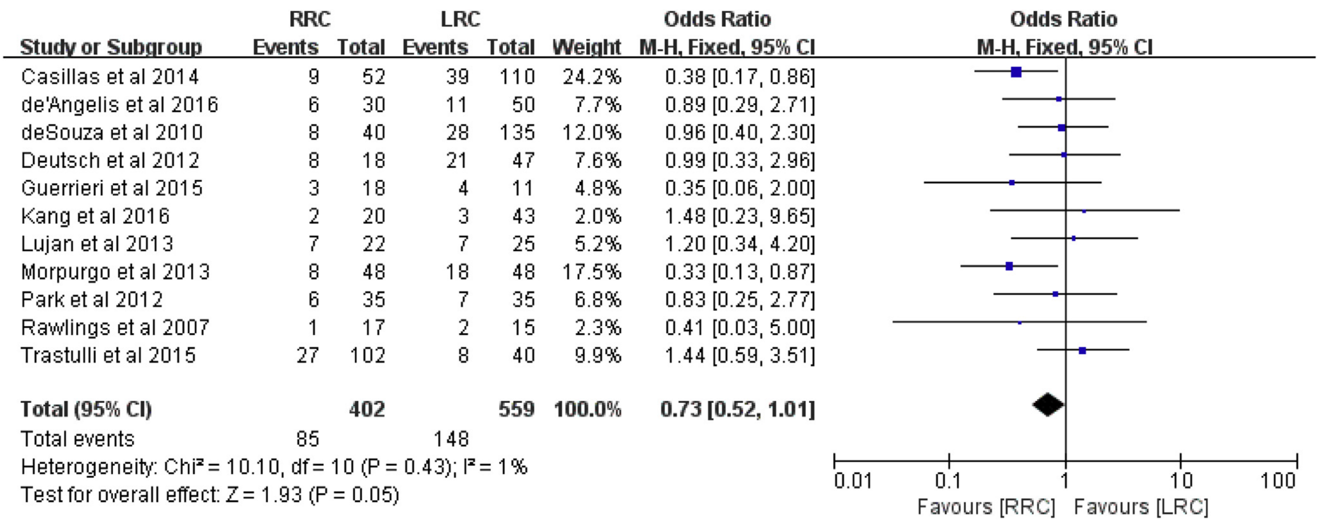

Figure 7 Forest plot of overall postoperative complications.

as well as faster postoperative recovery and a shorter hospital stay.[2–4,6,27–33] However, the laparoscopic approach has several limitations, such as tremor, loss of a three-dimensional view, inability to perform high-precision suturing, poor ergonomics, fixed tips, and limited movement dexterity.

The da Vinci surgical system has been developed to overcome such difficulties and has become increasingly popular in colorectal surgery.[7,34–37] The system is equipped with a three-dimensional high-definition camera and is capable of physiological tremor filtration. Furthermore, it enables three extra degrees of movement by using articulated instruments. Therefore, it can minimize the risk of injury to vessels and nerve structures as well as provide oncological resection capabilities. Furthermore, the surgical system can also decrease the learning curve for laparoscopic surgery. However, there are also limitations to this system, such as loss of haptic feedback, the limited range of movement of the robotic arms and the fact that it is time consuming and high-cost. The limited intracorporeal range of motion is a major drawback in colectomy when operating in a large operative field.[38–40]

To date, several studies have compared the safety and efficacy of NRCTs using meta-analyses, which might be a good method for surgical trials since most of the available evidence in surgery is derived from non-randomized studies. However, selection bias exists in these studies because most of the studies are not randomized and because preoperative characteristics are not consistent across some of the studies. High study heterogeneity may prevent meta-analysis results from being useful. However, factors other than the surgical approach impact these outcomes.[41–46] This meta-analysis indicates the apparent feasibility of RRC. The pooled results of the seven studies showed that RRC led to longer operation times, lower estimated blood loss, shorter hospital stays, lower overall rates of postoperative complications, but no significantly difference in bowel function recovery than LRC.[47–49]

A long operation time was widely reported for robotic colorectal surgery. Many factors influence operation times, and these factors include setup time, docking time, learning curve, and the type of anastomosis. In terms of right colectomy, either a hybrid technique or repositioning of the robotic cart is required. Multiple dockings of the robotic cart and the creation of a proper surgical field are also time-consuming.[50,51] The setup time was excluded from all the seven studies included in the meta-analysis. Operation time was reported to be longer in the RRC group than in the LRC group in most of the studies, except for the study by Deutsch et al.[33,52,53] This meta-analysis indicates that the operation time in patients from the RRC group was significantly longer than that for patients in the LRC group. The heterogeneity of the operation time between these approaches was very high ($I^2 = 90\%$). The reasons for this high heterogeneity of operating time are threefold. First, different diseases of the right-side colon, such as cancer, diverticulitis, polyps, Crohn's disease, and so on, were included in different studies. Furthermore, some studies included both benign and malignant diseases, and some included only right-side colon cancer.[54–56]

Second, the anastomosis techniques were different among the studies, as shown in Table 1. Third, the learning curve for RRC procedures was slower than that for LRC procedures. Therefore, the operating surgeon was relatively inexperienced in RRC procedures. However, clinical and oncological outcomes improve significantly in laparoscopic surgery with increasing experience. Robotic-assisted intracorporeal anastomosis was compared with extracorporeal anastomosis in the study by Morpurgo et al.[57–59] Anastomotic complications were observed in patients in the LRC group with extracorporeal anastomosis, while none were observed in the RRC group. Additionally, the extracorporeal anastomosis group had a significantly higher risk of incisional hernia than the intracorporeal anastomosis group. In our meta-analysis, there were significantly fewer overall complications in the RRC group, which can be explained by the older age of the patients in the LRC group. A good field of vision and precise movements may minimize the risk of tissue injuries and ultimately lead to fewer complications. However, in terms of the postoperative ileus, anastomotic leakage, and postoperative bleeding outcomes, this meta-analysis showed no differences between the two groups. More advanced studies are still needed to verify this conclusion.[60,61]

A major drawback of robotic rectal surgery is its high cost. In this study, cost was not taken into account when performing the comparison because only two studies provided relevant data. In those two studies, total costs were significantly higher for RRC than for LRC. Baek et al reported that the total cost of robotic surgery was approximately 1.5 times higher than that of laparoscopic surgery. A recent systematic review also showed that robot-assisted laparoscopic resections had significantly higher costs and longer operation times than traditional laparoscopic resections, without any measurable benefits from robot-assisted surgery.[62–64]

Several limitations exist in the present meta-analysis. First, the studies included in this meta-analysis consisted of one RCT and six NRCTs, and NRCTs can bias the interpretation of results despite the use of quality scores. Second, the included studies had a relatively limited number of patients, and it was difficult to perform subgroup analyses. Third, this meta-analysis could not account for problems caused by confounding factors that were inherent in the included studies. Finally, it was impossible to match the characteristics of the patients in most of the studies, and heterogeneity exists between the two groups.[65–68]

In conclusion, this meta-analysis suggests that RRC has longer operation times, lower estimated blood losses, shorter hospital stays, lower overall rates of postoperative complications than LRC. Other clinical and oncological outcomes appear to be equivalent between the two intervention types. Future well-designed prospective RCTs are required to better define this technique.

Funding

This study was supported by the Longyuan Youth Innovative Talent Support Project. The Talent Innovation and Entrepreneurship Projects of Lanzhou (2016-RC-56). Gansu Province Natural Science Fund (145RJZA117). Research on da Vinci surgery system database creation. (www.davincisurgerydatabase.com 16GSSY2-2).

Contributions

Hui Cai provide article ideas, Shixun Ma, Yan Chen and Yifeng Chen performed the data analysis and wrote the main manuscript. Yufeng Lu assisted in the screening of articles Tiankang Guo, Xiongfei Yang and Jinhui Tian guided statistical methods. All authors reviewed the manuscript.

Competing interests

The authors declare no competing interests.

Acknowledgements

Thanks for the guidance from Dr. Tian Jinhui from the Evidence-Based Medicine Center of Lanzhou University.

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