Comparison of short-term outcomes of robotic-assisted and laparoscopic-assisted D2 gastrectomy for gastric cancer: a meta-analysis

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Abstract

Aim: The aim of the study was to compare the outcomes of robot-assisted (RAGD2) and laparoscopy-assisted gastrectomy with D2 lymphadenectomy (LAGD2) for patients with gastric cancer.
Material and methods: Relevant articles published up to September 2020 were searched. The weighted mean difference (WMD) was used to pool continuous variables, while risk ratio (RR) was calculated for dichotomous outcomes.
Results: RAGD2 required a longer operating time (WMD = 29.78, 95% confidence interval (CI): 15.97–43.59) and had less operative blood loss (WMD = −31.93, 95% CI: −44.03 to −19.83), shorter time to first flatus (WMD = −0.13, 95% CI: −0.22 to −0.04), shorter time to liquid diet (WMD = −0.20, 95% CI: −0.28 to 0.12), and fewer severe complications (RR = 0.62, 95% CI: 0.43–0.90) and overall complications (RR = 0.75, 95% CI: 0.62–0.91) than LAGD2.
Conclusions: RAGD2 could be beneficial in reducing operative blood loss and postoperative complications relative to LAGD2.

Key words: robot-assisted gastrectomy, laparoscopy-assisted gastrectomy, meta-analysis.

Introduction

Gastric cancer is one of the most common causes of cancer-related death affecting 13.5/100,000 people worldwide. The incidence of the disease varies widely between different areas, having the highest prevalence in East Asian countries [1]. Gastric cancer in China accounts for 42.5% of the global incidence and 45.0% of deaths [2]. In recent years, the worldwide incidence of gastric cancer has been decreasing, but it remains a serious health problem worldwide.

Currently, surgery is recommended as the primary treatment for patients with gastric cancer. Compared with conventional open surgery, laparoscopic surgery has been shown to have many advantages, such as mitigation of postoperative pain, early recovery of gastrointestinal function, and early return to normal activity [3, 4]. For surgeons, two-dimensional (2D) laparoscopy limits depth perception, which increases strain when working in a three-dimensional space. Three-dimensional (3D) laparoscopy has been introduced [5]. Meanwhile, the technology is limited when completion of lymph node dissection occurred. Although laparoscopic gastrectomy has been widely accepted as a treatment for early gastric cancer, the application of laparoscopic D2 lymphadenectomy remains controversial [6]. Recently, robotic systems have been developed [7, 8]. Multiple retrospective studies comparing 2D laparoscopy with 3D laparos-

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copy and robotic surgery have been published. However, most outcome indicators remain controversial, such as operation time, postoperative hospital stay, and postoperative complications. For example, Lee *et al.* reported that robotic surgery may be related to less blood loss than conventional laparoscopic surgery in gastric cancer patients [9]. Nevertheless, the study reported by Cui *et al.* [10] showed that laparoscopy-assisted gastrectomy with D2 lymphadenectomy (LAGD2) presented more harvested lymph nodes, shorter postoperative hospital stay, and lower operative cost than robot-assisted gastrectomy with D2 lymphadenectomy (RAGD2). Accordingly, it is necessary to synthesize the latest research results through meta-analysis to assess surgical outcomes after RAGD2 and LAGD2.

Aim

This meta-analysis was performed to compare the clinical efficacy and postoperative complications of RAGD2 versus LAGD2 for gastric cancer. Based on the pooled data, we demonstrated that RAGD2 could be beneficial in reducing operative blood loss and postoperative complications relative to LAGD2.

Material and methods

Selection strategy

The meta-analysis was performed based on the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines [11]. The eligible studies were identified by searching databases including PubMed, Embase, Cochrane Library, CNKI, Wanfang, and CQVIP for studies published up to September 1, 2020. The combination of the following terms was used: "robot", "robotic", "laparoscopic", "laparoscope", "laparoscopy", "gastric carcinoma", "stomach carcinoma", "gastric cancer", "stomach cancer", "gastric tumor", "stomach tumor", "gastric neoplasms", "stomach neoplasms", "D2", and "extended lymphadenectomy". The enrolled studies were selected without any language limitations. Moreover, print-out literature was searched through manual retrieval, and the references of the included articles were further checked to identify more relevant papers.

Study selection

Randomized controlled trials (RCTs), non-randomized clinical studies, and cohort studies were included in this meta-analysis if (1) the study investigated the short-term outcomes of RAGD2 versus LAGD2 (lymphatic dissection, including total gastrectomy, distal gastrectomy, and proximal gastrectomy); (2) gastric cancer was diagnosed by gastroscopy or pathology, and the patients had not received preoperative radiotherapy and/or chemotherapy; and (3) the article reported at least one short-term outcome, such as surgery-related outcomes or postoperative complications.

Studies were excluded if: (1) the study included patients who underwent D2, D1 + α/β gastrectomy, or there were no independent data for D2; (2) the study only included subjects who underwent RAGD2 or LAGD2; and (3) the study included incomplete data or the full text could not be obtained. Furthermore, if duplicate data were found, we only included the study that provided more detailed information.

Data extraction and quality assessment

Two investigators independently extracted the following information: the name of the first author, year of publication, baseline characteristics of included subjects (such as sample size, type of research, age, sex, body mass index (BMI), and TNM stage), and outcome data. If disagreements occurred during data extraction and quality assessment, the two investigators would discuss the matter until they reached an agreement.

The quality of RCTs was assessed based on the Cochrane Collaboration's tool [12], and the methodological quality of the cohort studies was evaluated using the Newcastle-Ottawa scale (NOS) [13]. The NOS includes nine items with scales ranging from 0 to 9, with 7–9 indicating high quality, 4–6 scores indicating intermediate quality, and < 4 indicating low quality.

Statistical analysis

Continuous variables included operating time, operative blood loss, number of retrieved lymph nodes, time to first flatus, time to liquid diet, and postoperative length of stay. These data were pooled using the weighted mean difference (WMD) with a 95% confidence interval (CI). The outcomes of categorical variables such as postoperative complications and death were meta-analyzed using the risk ratio (RR) and 95% CI. Heterogeneity was calculated based on Cochran's Q and I^2 tests [14]. Significant heterogeneity was defined among the included studies when $p < 0.05$ and/or $I^2 > 50\%$; in such cases, the random

effects model was used. Otherwise, the fixed-effects model was selected ($p > 0.05$, $I^2 < 50\%$). Furthermore, the sensitivity of the results was calculated by omitting one study each time. The Egger test was used to assess potential publication bias. All statistical analyses were conducted using RevMan 5.3 (The Cochrane Collaboration, Oxford, UK) and Stata 11.0 (StataCorp LP, College Station, Texas, USA).

Results

Literature search

Figure 1 shows a detailed flowchart of the literature selection. A total of 79, 105, 7, 33, 42, and 7 articles were retrieved from the PubMed, Embase, Cochrane Library, CNKI, Wanfang, and CQVIP databases, respectively. After removing duplicate articles, 194 remained. We then reviewed the titles and abstracts, and 173 articles were eliminated. After reading the full text, nine of the remaining 21 articles were excluded. Manual searches failed to find studies that could be included in the analysis. Finally, 12 articles were included in this meta-analysis [9, 10, 15–24].

Characteristics of the enrolled studies

As shown in Table I, 3176 subjects (1339 patients in the RAGD2 group and 1837 patients in the LAGD2 group) were included in this meta-analysis. All included studies were retrospective cohort studies published between 2010 and 2020. These studies were conducted in China, South Korea, and Italy. The included sample sizes ranged from 70 to 570. The average age of the study subjects was 53.6–71 years old. Except for the study by Lee *et al.* [9], no significant difference in age was found between the two groups in the remaining studies. In addition, similar baseline information, such as BMI, ASA grade, tumor size, and TNM staging, in the two groups were reported in each article. All included studies had an NOS score of 5–8, and the methodological quality was medium or high.

Results of meta-analysis

Clinical efficacy

Six variables were analyzed: operating time, operative blood loss, number of retrieved lymph nodes, time to first flatus, time to liquid diet, and postoperative length of stay. Obvious heterogeneity occurred among the included studies for the above indicators
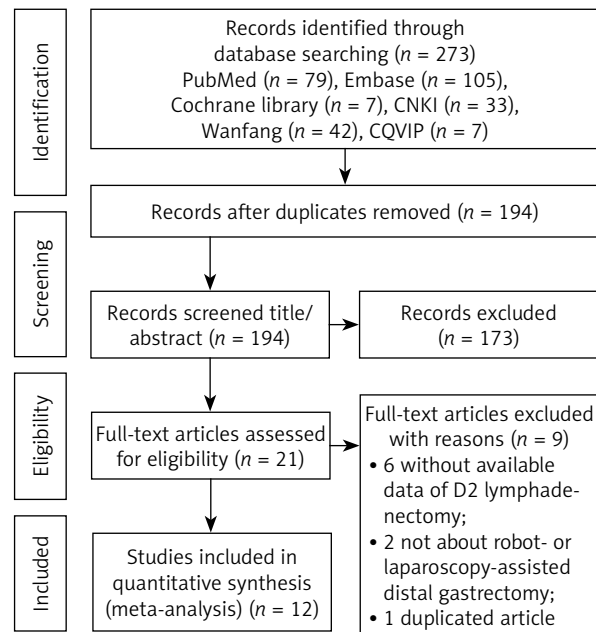
Figure 1. Flow chart of literature screening. Relevant literature in the PubMed, Embase, Cochrane library, CNKI, Wanfang, and CQVIP databases was identified using the designated search terms. After screening the titles, abstracts, and full texts, 12 eligible studies were finally included in this meta-analysis

($p < 0.05$, $I^2 > 50\%$); therefore, the random effects model was selected.

In total, 12 studies reported data on operating time, and the results showed that RAGD2 was significantly longer than LAGD2 (WMD = 29.78 min, 95% CI: 15.97–43.59; $p < 0.0001$, Figure 2 A). Except for the study by Cui *et al.* [10], all studies reported a difference in operating blood loss between the two groups. The pooled data showed that the operating blood loss for RAGD2 was significantly less than that for LAGD2 (WMD = –31.93 ml, 95% CI: –44.03 to –19.83; $p < 0.00001$, Figure 2 B).

In total, 11 articles [3, 10, 15–18, 20–24] reported the difference in the number of retrieved lymph nodes, and the combined results indicated that the difference between the two groups was not statistically significant (WMD = 1.65, 95% CI: –0.14 to 3.44; $p = 0.07$, Figure 2 C). Eight [10, 16–19, 21, 23, 24] and seven studies [15, 16, 18–20, 23, 24] reported the difference in time to first flatus and time to liquid diet, respectively. The results showed that time to first flatus (WMD = –0.13 days, 95% CI: –0.22 to –0.04; $p = 0.005$, Figure 2D) and time to liquid

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Table I. Characteristics of 12 studies included in this meta-analysis

Study (country)	Duration	Groups	N	M/F	Age [years]	BMI [kg/m²]	ASA, I/II/III	Tumor size [cm]	TNM stage, I/II/III	Type of resection
Cui, H 2020 (China)	2016.01–2019.12	RAG	187	122/65	59.0 ±10.5	24.1 ±3.0	4/162/21	3.5 ±2.4	81/47/59	Distal gastrectomy
		LAG	344	250/94	57.2 ±11.9	23.8 ±3.4	5/304/35	3.3 ±2.0	151/89/104	
Hu, SD 2017 (China)	2014.12–2016.06	RAG	39	28/11	59.41 ±12.34	NR	NR	NR	7/13/19	NR
		LAG	39	20/19	56.72 ±12.47	NR	NR	NR	10/7/22	
Lee, J 2015 (Korea)	2003–2010	RAG	133	85/48	53.6 ±13.2	23.2 ±2.7	NR	NR	101/15/17	Distal gastrectomy
		LAG	267	154/113	59.2 ±11.7 *	23.7 ±2.8	NR	NR	218/32/17	
Li, SY 2018 (China)	2015.05–2017.05	RAG	50	35/15	65.6 ±8.3	24.3 ±2.1	NR	NR	NR	Distal gastrectomy
		LAG	56	39/17	66.0 ±7.4	24.6 ±2.4	NR	NR	NR	
Liu, ZL 2020 (China)	2014.10–2018.08	RAG	108	262/109	61 ±4	23.0 ±2.1	NR	NR	60/99/212	NR
		LAG	263								
Pugliese, R 2010 (Italy)	2000.06–2009.10	RAG	18	7/11	65.7 (45–82)	28.8 (21–40)	7/42/21	2.2 ±0.8	50/8/9/3	Distal gastrectomy
		LAG	52	36/16	71 (41–86)						
Shen, XQ 2018 (China)	2016.09–2017.09	RAG	65	49/16	58 ±10	22.9 ±2.6	12/42/11	NR	9/19/37	Distal or total gastrectomy
		LAG	97	67/30	59 ±10	22.4 ±2.9	15/66/16	NR	14/22/61	
Wang, WJ 2019 (China)	2016.01–2018.05	RAG	223	183/40	57.7 ±10.9	22.1 ±3.5	115/77/31	5.0 ±1.9	53/83/87	Distal or total gastrectomy
		LAG	223	180/43	57.4 ±11.1	22.2 ±3.4	112/79/32	5.1 ±2.2	54/84/85	
Xue, YG 2016 (China)	2012.02–2014.05	RAG	35	26/9	59.2 ±9.6	24.6 ±2.9	NR	4.5 ±1.8	6/8/21	Distal gastrectomy
		LAG	35	25/10	56.2 ±14.1	23.4 ±2.3	NR	4.2 ±1.9	5/13/17	
Ye, SP 2019 (China)	2015.06–2018.10	RAG	99	58/41	58.7 ±6.7	23.9 (17.3–28.6)	52/40/7	4.76 ±1.27	2/54/43	Total gastrectomy
		LAG	106	55/51	59.0 ±7.3	23.9 (19.9–28.3)	53/44/9	4.70 ±1.24	3/51/52	
Ye, SP 2020 (China)	2014.12–2019.11	RAG	285	189/96	57.1 ±8.3	24.4 ±2.3	168/102/15	4.84 ±1.31	7/149/129	Distal gastrectomy
		LAG	285	186/99	57.0 ±8.6	24.5 ±2.2	161/111/13	4.86 ±1.31	4/146/135	
Zhang, XL 2012 (China)	2009.01–2011.12	RAG	97	66/31	56.1 ±5.8	22.5 ±3.6	NR	NR	23/22/52	Proximal, distal or total gastrectomy
		LAG	70	49/21	54.8 ±4.9	21.7 ±2.1	NR	NR	8/17/45	

*ASA – American Society of Anesthesiologists classification, BMI – body mass index, M – male, F – female, NR – not reported. *Significant difference between two groups.*

diet (WMD = –0.20 days, 95% CI: –0.28 to –0.12; $p < 0.00001$, Figure 2 E) were significantly shorter for RAGD2 than for LAGD2. Furthermore, no significant difference was found in the postoperative length of stay between the two groups (WMD = –0.21 days, 95% CI: –0.88 to 0.47; $p = 0.55$, Figure 2 F).

A

Study or subgroup	RAG Mean	SD	Total	LAG Mean	SD	Total	Weight (%)	Mean difference IV, random, 95% CI
Cui H 2020	225.8	48.3	187	230.8	49.5	344	8.7	−5.00 [−13.68, 3.68]
Hu SD 2017	227.87	47.56	39	194.24	58.49	39	7.2	33.63 [9.97, 57.29]
Lee J 2015	217.5	37.8	133	171	52.4	267	8.7	46.50 [37.51. 55.49]
Li SY 2018	160.4	20.2	50	185.6	15.1	56	8.9	−25.20 [−32.05, −18.35]
Liu ZL 2020	269	32	108	205	30	263	8.8	64.00 [56.96, 71.04]
Pugliese R 2010	344	62	18	235	23	52	6.4	109.00 [79.68, 138.32]
Shen XQ 2018	236.4	45	65	224.6	44.8	97	8.3	11.80 [−2.31, 25.91]
Wang WJ 2019	242.3	33.5	223	238.4	37.8	223	8.9	3.90 [−2.73, 10.53]
Xue YG 2016	222.1	7.6	35	173.1	21.4	35	8.8	49.00 [41.48, 56.52]
Ye SP 2019	203.9	13.6	99	183.6	12.1	106	9.0	20.30 [16.77, 23.83]
Ye SP 2020	186	12	285	147	9	285	9.0	39.00 [37.26, 40.74]
Zhang XL 2012	272.3	46.1	97	240.3	89.1	70	7.3	32.00 [9.20, 54.80]
Total (95% CI)			**1339**			**1837**	**100.0**	**29.78 [15.97, 43.59]**

Heterogeneity: $\tau^2 = 548.57$; $\chi^2 = 653.76$, d$f = 11$ ($p < 0.00001$); $I^2 = 98\%$
Test for overall effect: $Z = 4.23$ ($p < 0.0001$)

Favours (RAG)   Favours (LAG)

B

Study or subgroup	RAG Mean	SD	Total	LAG Mean	SD	Total	Weight (%)	Mean difference IV, random, 95% CI
Hu SD 2017	98.33	26.42	39	123.15	61.41	39	8.6	−24.82 [−45.80, −3.84]
Lee J 2015	47	57.9	133	87.1	216.9	267	7.2	−40.10 [−67.92, −12.28]
Li SY 2018	50.8	12.1	50	88.3	14.6	56	11.4	−37.50 [−42.59, −32.41]
Liu ZL 2020	94	52	108	130	32	263	10.7	−36.00 [−46.54, −25.46]
Pugliese R 2010	90	48	18	148	53	52	7.5	−58.00 [−84.4, −31.56]
Shen XQ 2018	123	39	65	142	40	97	10.3	−19.00 [−31.38, −6.62]
Wang WJ 2019	148.6	51.2	223	143.5	54.9	223	10.8	5.10 [−4.75, 14.95]
Xue YG 2016	110.9	110.2	35	167.1	105.9	35	3.8	−56.20 [−106.83, −5.57]
Ye SP 2019	134.5	12.9	99	152.8	12	106	11.5	−18.30 [−21.72, −14.88]
Ye SP 2020	150	151	285	166	139	285	8.0	−16.00 [−39.83, 7.83]
Zhang XL 2012	80.8	53.1	97	153.7	26.4	70	10.4	−72.90 [−85.14, 60.66]
Total (95% CI)			**1152**			**1493**	**100.0**	**−31.93 [−44.03, −19.83]**

Heterogeneity: $\tau^2 = 328.67$; $\chi^2 = 146.78$, d$f = 10$ ($p < 0.00001$); $I^2 = 93\%$
Test for overall effect: $Z = 5.17$ ($p < 0.00001$)

Favours (RAG)   Favours (LAG)

C

Study or subgroup	RAG Mean	SD	Total	LAG Mean	SD	Total	Weight (%)	Mean difference IV, random, 95% CI
Cui H 2020	25.2	9	187	29.1	12.4	344	10.1	−3.90 [−5.74, −2.06]
Hu SD 2017	25.23	10.93	39	25.64	9.24	39	6.6	−0.41 [−4.90, 4.08]
Li SY 2018	26.5	7.2	50	25.2	7.5	56	8.9	1.30 [−1.50, 4.10]
Liu ZL 2020	45	11	108	41	10	263	9.4	4.00 [1.60, 6.40]
Pugliese R 2010	25	4.5	18	31	8	52	8.6	−6.00 [−9.01, −2.99]
Shen XQ 2018	36.77	13.42	65	35.54	11.83	97	7.2	1.23 [−2.79, 5.25]
Wang WJ 2019	40.8	14.5	223	37.1	14.3	223	9.1	3.70 [1.03, 6.37]
Xue VG 2016	29.8	5.7	35	22.7	10.2	35	7.4	7.10 [3.23, 10.97]
Ye SP 2019	25.8	4	99	22.2	3.8	106	10.9	3.80 [2.53, 4.67]
Ye SP 2020	26.4	3.7	285	22.6	3.8	285	11.2	3.80 [3.18, 4.42]
Zhang XL 2012	23.1	5.4	97	20	4.3	70	10.5	3.10 [1.63, 4.57]
Total (95% CI)			**1206**			**1570**	**100.0**	**1.65 [−0.14, 3.44]**

Heterogeneity: $\tau^2 = 7.38$; $\chi^2 = 105.73$, d$f = 10$ ($p < 0.00001$); $I^2 = 91\%$
Test for overall effect: $Z = 1.80$ ($p = 0.07$)
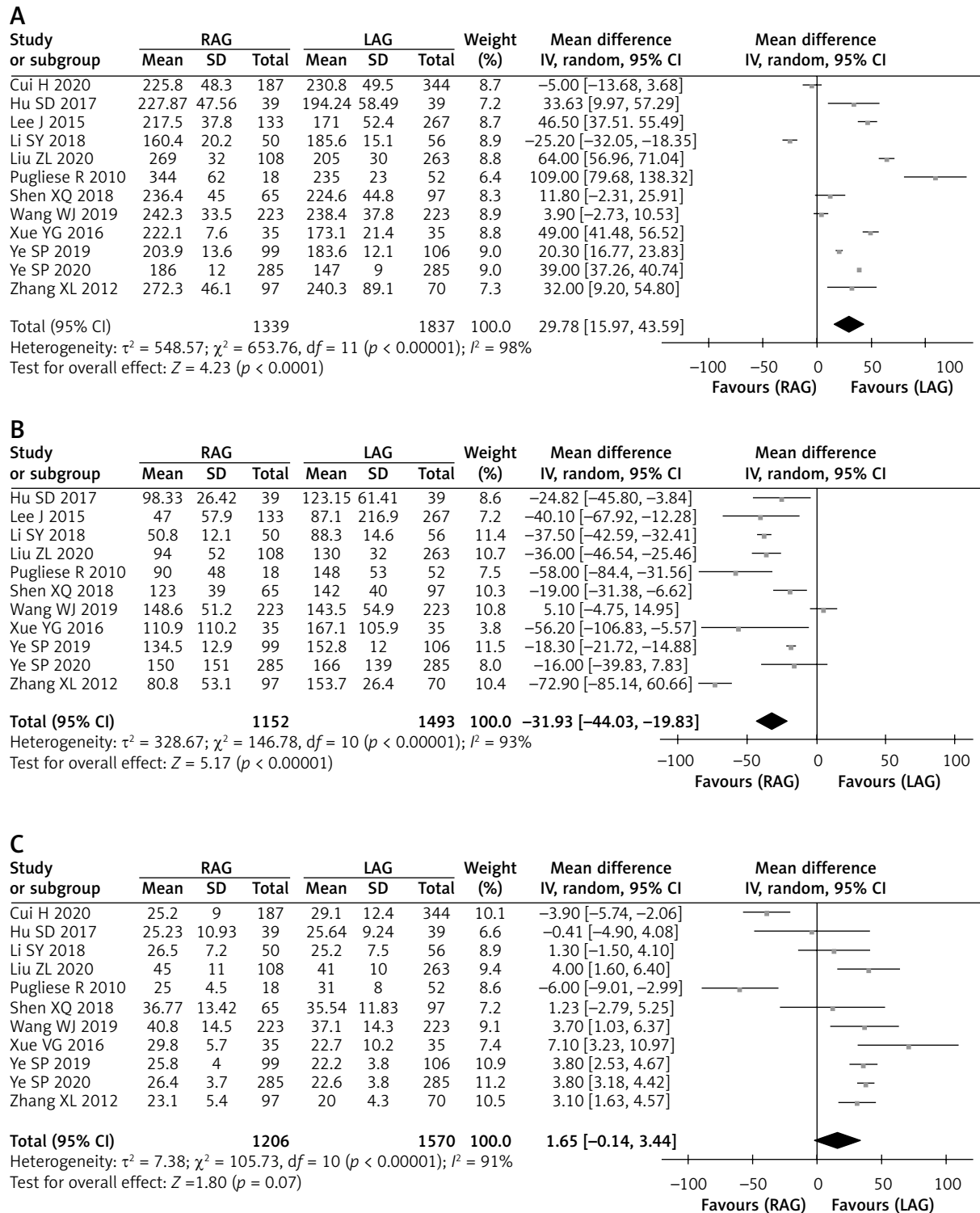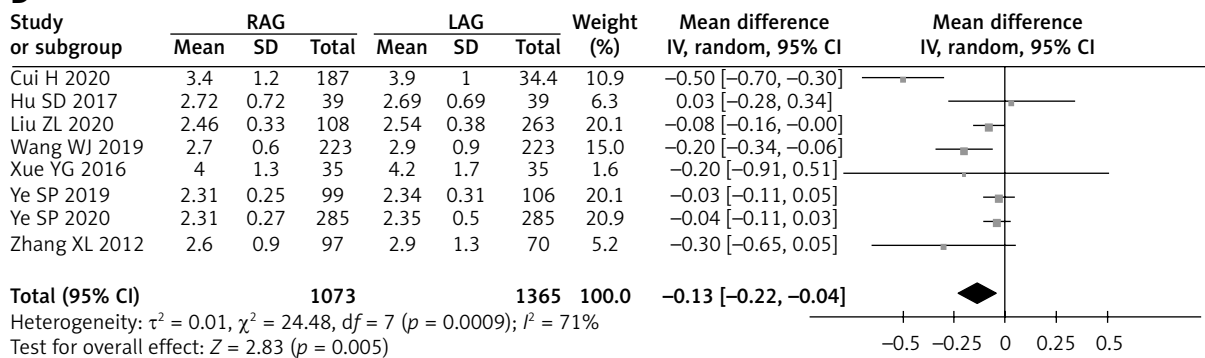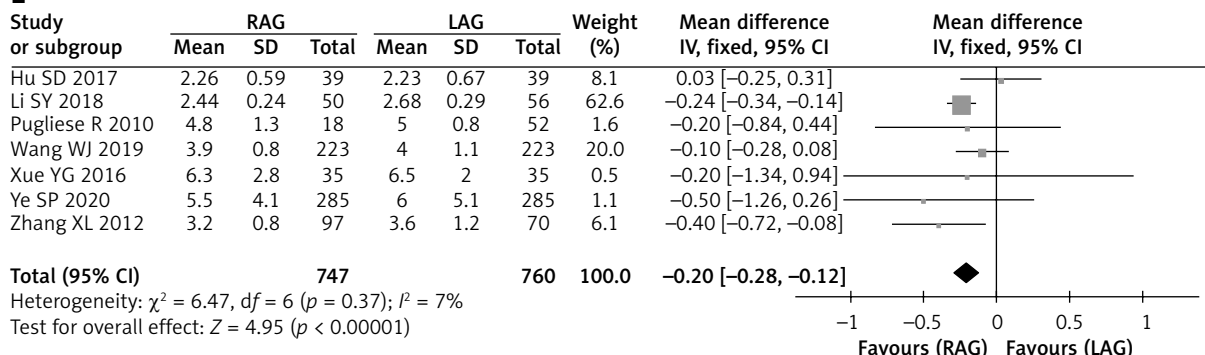
Favours (RAG)   Favours (LAG)

Figure 2. Forest plots for comparison of the clinical efficacy of RAGD2 and LAGD2. Operating time (**A**), operative blood loss (**B**), number of retrieved lymph nodes (**C**)
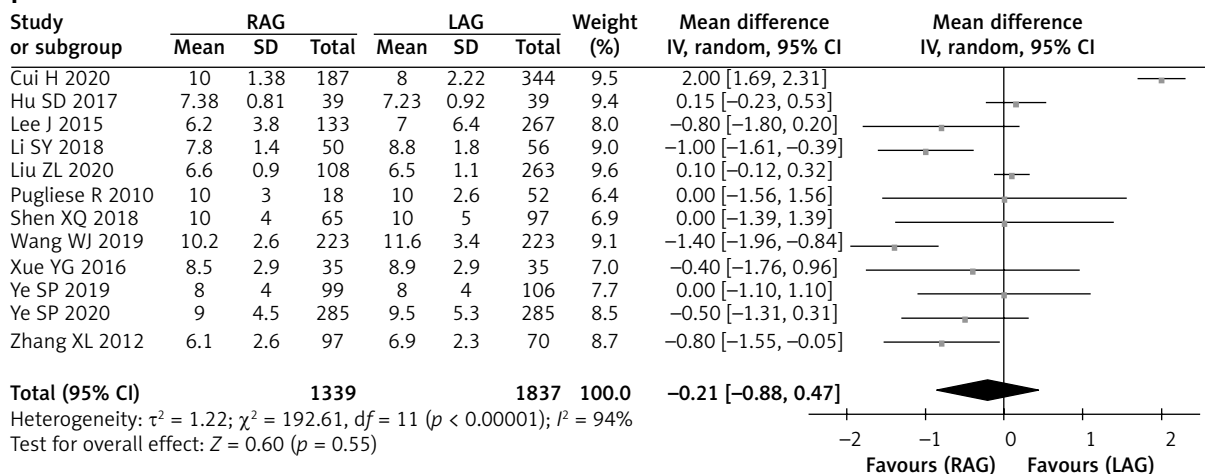
D

Study	RAG			LAG			Weight	Mean difference	Mean difference
or subgroup	Mean	SD	Total	Mean	SD	Total	(%)	IV, random, 95% CI	IV, random, 95% CI
Cui H 2020	3.4	1.2	187	3.9	1	34.4	10.9	−0.50 [−0.70, −0.30]	
Hu SD 2017	2.72	0.72	39	2.69	0.69	39	6.3	0.03 [−0.28, 0.34]	
Liu ZL 2020	2.46	0.33	108	2.54	0.38	263	20.1	−0.08 [−0.16, −0.00]	
Wang WJ 2019	2.7	0.6	223	2.9	0.9	223	15.0	−0.20 [−0.34, −0.06]	
Xue YG 2016	4	1.3	35	4.2	1.7	35	1.6	−0.20 [−0.91, 0.51]	
Ye SP 2019	2.31	0.25	99	2.34	0.31	106	20.1	−0.03 [−0.11, 0.05]	
Ye SP 2020	2.31	0.27	285	2.35	0.5	285	20.9	−0.04 [−0.11, 0.03]	
Zhang XL 2012	2.6	0.9	97	2.9	1.3	70	5.2	−0.30 [−0.65, 0.05]	
Total (95% CI)			1073			1365	100.0	−0.13 [−0.22, −0.04]	

Heterogeneity: $\tau^2 = 0.01$, $\chi^2 = 24.48$, df = 7 ($p = 0.0009$); $I^2 = 71\%$
Test for overall effect: $Z = 2.83$ ($p = 0.005$)

−0.5 −0.25 0 0.25 0.5
Favours (RAG)   Favours (LAG)

E

Study	RAG			LAG			Weight	Mean difference	Mean difference
or subgroup	Mean	SD	Total	Mean	SD	Total	(%)	IV, fixed, 95% CI	IV, fixed, 95% CI
Hu SD 2017	2.26	0.59	39	2.23	0.67	39	8.1	0.03 [−0.25, 0.31]	
Li SY 2018	2.44	0.24	50	2.68	0.29	56	62.6	−0.24 [−0.34, −0.14]	
Pugliese R 2010	4.8	1.3	18	5	0.8	52	1.6	−0.20 [−0.84, 0.44]	
Wang WJ 2019	3.9	0.8	223	4	1.1	223	20.0	−0.10 [−0.28, 0.08]	
Xue YG 2016	6.3	2.8	35	6.5	2	35	0.5	−0.20 [−1.34, 0.94]	
Ye SP 2020	5.5	4.1	285	6	5.1	285	1.1	−0.50 [−1.26, 0.26]	
Zhang XL 2012	3.2	0.8	97	3.6	1.2	70	6.1	−0.40 [−0.72, −0.08]	
Total (95% CI)			747			760	100.0	−0.20 [−0.28, −0.12]	

Heterogeneity: $\chi^2 = 6.47$, df = 6 ($p = 0.37$); $I^2 = 7\%$
Test for overall effect: $Z = 4.95$ ($p < 0.00001$)

−1 −0.5 0 0.5 1
Favours (RAG)   Favours (LAG)

F

Study	RAG			LAG			Weight	Mean difference	Mean difference
or subgroup	Mean	SD	Total	Mean	SD	Total	(%)	IV, random, 95% CI	IV, random, 95% CI
Cui H 2020	10	1.38	187	8	2.22	344	9.5	2.00 [1.69, 2.31]	
Hu SD 2017	7.38	0.81	39	7.23	0.92	39	9.4	0.15 [−0.23, 0.53]	
Lee J 2015	6.2	3.8	133	7	6.4	267	8.0	−0.80 [−1.80, 0.20]	
Li SY 2018	7.8	1.4	50	8.8	1.8	56	9.0	−1.00 [−1.61, −0.39]	
Liu ZL 2020	6.6	0.9	108	6.5	1.1	263	9.6	0.10 [−0.12, 0.32]	
Pugliese R 2010	10	3	18	10	2.6	52	6.4	0.00 [−1.56, 1.56]	
Shen XQ 2018	10	4	65	10	5	97	6.9	0.00 [−1.39, 1.39]	
Wang WJ 2019	10.2	2.6	223	11.6	3.4	223	9.1	−1.40 [−1.96, −0.84]	
Xue YG 2016	8.5	2.9	35	8.9	2.9	35	7.0	−0.40 [−1.76, 0.96]	
Ye SP 2019	8	4	99	8	4	106	7.7	0.00 [−1.10, 1.10]	
Ye SP 2020	9	4.5	285	9.5	5.3	285	8.5	−0.50 [−1.31, 0.31]	
Zhang XL 2012	6.1	2.6	97	6.9	2.3	70	8.7	−0.80 [−1.55, −0.05]	
Total (95% CI)			1339			1837	100.0	−0.21 [−0.88, 0.47]	

Heterogeneity: $\tau^2 = 1.22$; $\chi^2 = 192.61$, df = 11 ($p < 0.00001$); $I^2 = 94\%$
Test for overall effect: $Z = 0.60$ ($p = 0.55$)

−2 −1 0 1 2
Favours (RAG)   Favours (LAG)

Figure 2. Cont. Time to first flatus (**D**), time to liquid diet (**E**), and postoperative length of stay (**F**)

Postoperative complications

No significant heterogeneity in postoperative complications among the included studies was observed between the RAGD2 and LAGD2 groups ($p > 0.05$, $I^2 < 50\%$), and the fixed-effects model was used to pool effect values. The risks of wound infection (RR = 0.74, 95% CI: 0.42–1.30; $p = 0.29$, Figure 3 A), intra-abdominal infection (RR = 0.76, 95% CI: 0.29–2.02; $p = 0.58$, Figure 3 B), pneumonia (RR = 0.84, 95% CI: 0.41–1.74; $p = 0.65$, Figure 3 C), intestinal obstruction (RR = 0.70, 95% CI: 0.27–1.87;

$p = 0.48$, Figure 3 D), delayed gastric emptying (RR = 1.14, 95% CI: 0.47–2.75; $p = 0.78$, Figure 3 E), and anastomosis leakage (RR = 0.58, 95% CI: 0.30–1.10; $p = 0.10$, Figure 3 F) was slightly lower in the RAGD2 group than in the LAGD2 group, but the difference was not statistically significant.

Five studies [10, 16, 18, 21, 22] reported severe complications, and nine studies [10, 16–18, 20–24] reported overall complications. Notably, severe com-

plications, such as Clavien-Dindo classification ≥ III (RR = 0.62, 95% CI: 0.43–0.90; $p = 0.01$, Figure 3 G) and overall complications (RR = 0.75, 95% CI: 0.62–0.91; $p = 0.003$, Figure 3 H) were significantly lower in the RAGD2 group than in the LAGD2 group.

In addition, the death rate was reported in five studies [15–17, 21, 23]. There was no significant heterogeneity between the studies ($p = 0.79$, $I^2 = 0\%$). No significant difference in death rate was found
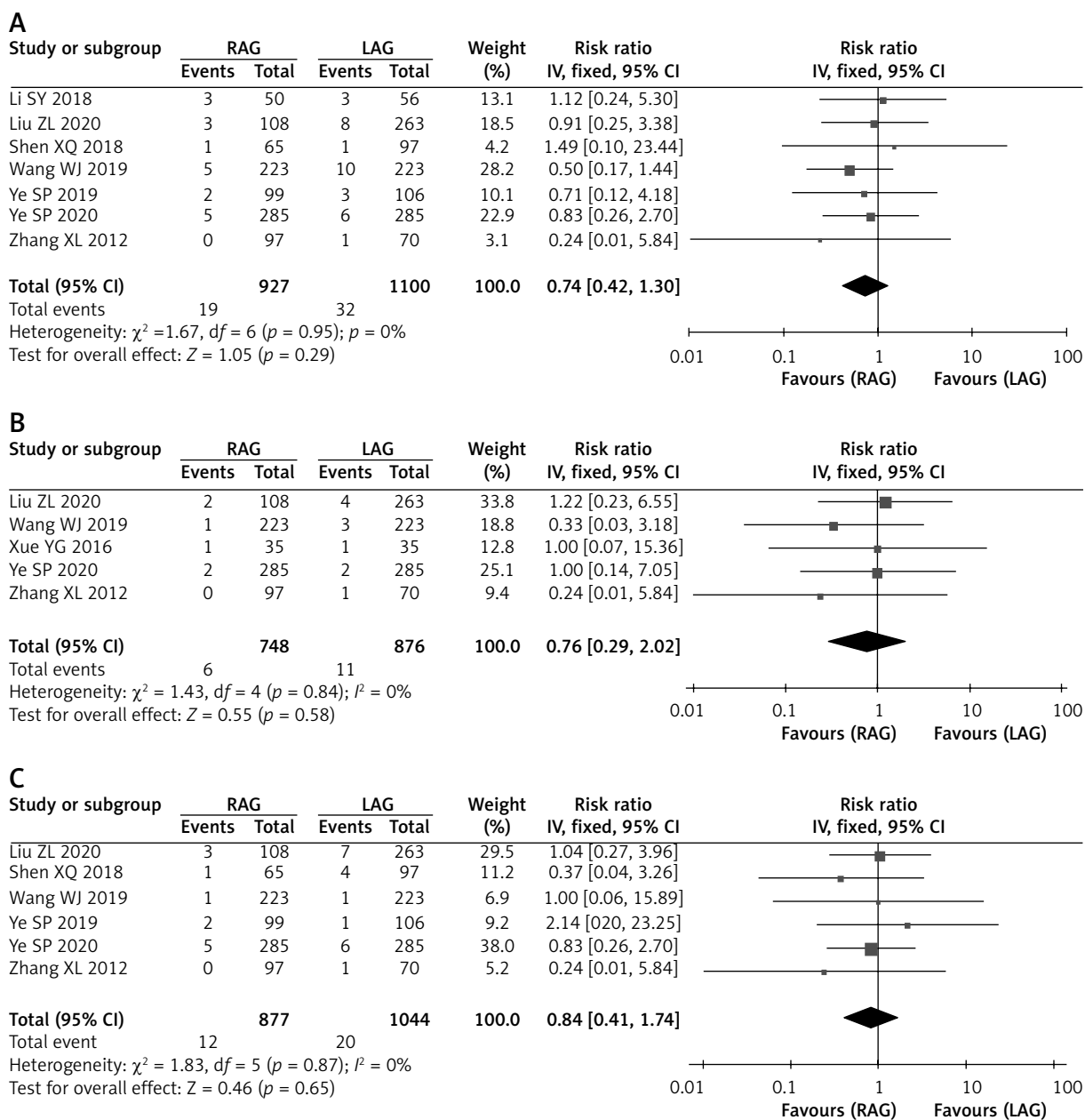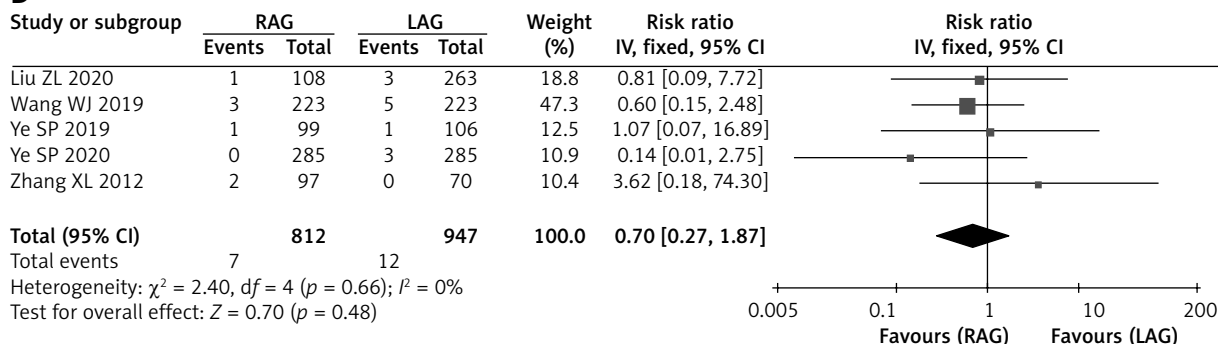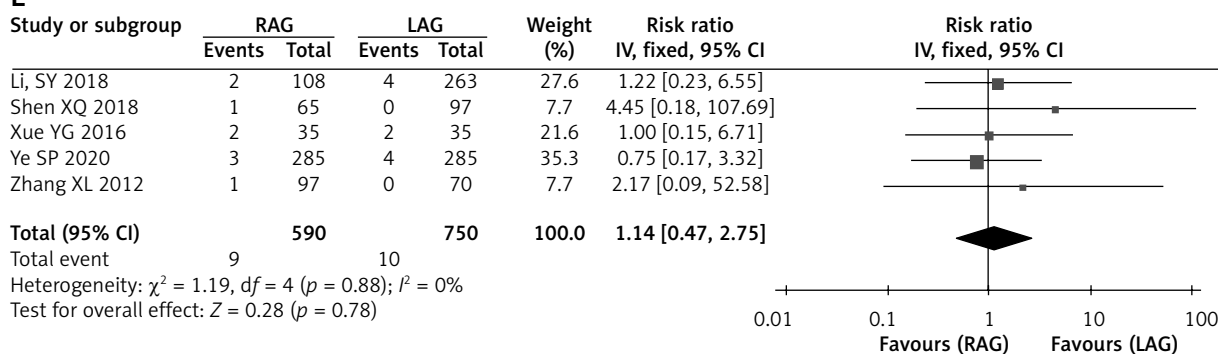
A

Study or subgroup	RAG Events	RAG Total	LAG Events	LAG Total	Weight (%)	Risk ratio IV, fixed, 95% CI
Li SY 2018	3	50	3	56	13.1	1.12 [0.24, 5.30]
Liu ZL 2020	3	108	8	263	18.5	0.91 [0.25, 3.38]
Shen XQ 2018	1	65	1	97	4.2	1.49 [0.10, 23.44]
Wang WJ 2019	5	223	10	223	28.2	0.50 [0.17, 1.44]
Ye SP 2019	2	99	3	106	10.1	0.71 [0.12, 4.18]
Ye SP 2020	5	285	6	285	22.9	0.83 [0.26, 2.70]
Zhang XL 2012	0	97	1	70	3.1	0.24 [0.01, 5.84]
Total (95% CI)		**927**		**1100**	**100.0**	**0.74 [0.42, 1.30]**
Total events	19		32			

Heterogeneity: $\chi^2 = 1.67$, df = 6 ($p = 0.95$); $I^2 = 0\%$
Test for overall effect: $Z = 1.05$ ($p = 0.29$)

B

Study or subgroup	RAG Events	RAG Total	LAG Events	LAG Total	Weight (%)	Risk ratio IV, fixed, 95% CI
Liu ZL 2020	2	108	4	263	33.8	1.22 [0.23, 6.55]
Wang WJ 2019	1	223	3	223	18.8	0.33 [0.03, 3.18]
Xue YG 2016	1	35	1	35	12.8	1.00 [0.07, 15.36]
Ye SP 2020	2	285	2	285	25.1	1.00 [0.14, 7.05]
Zhang XL 2012	0	97	1	70	9.4	0.24 [0.01, 5.84]
Total (95% CI)		**748**		**876**	**100.0**	**0.76 [0.29, 2.02]**
Total events	6		11			

Heterogeneity: $\chi^2 = 1.43$, df = 4 ($p = 0.84$); $I^2 = 0\%$
Test for overall effect: $Z = 0.55$ ($p = 0.58$)

C

Study or subgroup	RAG Events	RAG Total	LAG Events	LAG Total	Weight (%)	Risk ratio IV, fixed, 95% CI
Liu ZL 2020	3	108	7	263	29.5	1.04 [0.27, 3.96]
Shen XQ 2018	1	65	4	97	11.2	0.37 [0.04, 3.26]
Wang WJ 2019	1	223	1	223	6.9	1.00 [0.06, 15.89]
Ye SP 2019	2	99	1	106	9.2	2.14 [020, 23.25]
Ye SP 2020	5	285	6	285	38.0	0.83 [0.26, 2.70]
Zhang XL 2012	0	97	1	70	5.2	0.24 [0.01, 5.84]
Total (95% CI)		**877**		**1044**	**100.0**	**0.84 [0.41, 1.74]**
Total event	12		20			

Heterogeneity: $\chi^2 = 1.83$, df = 5 ($p = 0.87$); $I^2 = 0\%$
Test for overall effect: $Z = 0.46$ ($p = 0.65$)

Figure 3. Forest plots for comparison of the postoperative complications between RAGD2 and LAGD2. Wound infection (**A**), intra-abdominal infection (**B**), pneumonia (**C**)
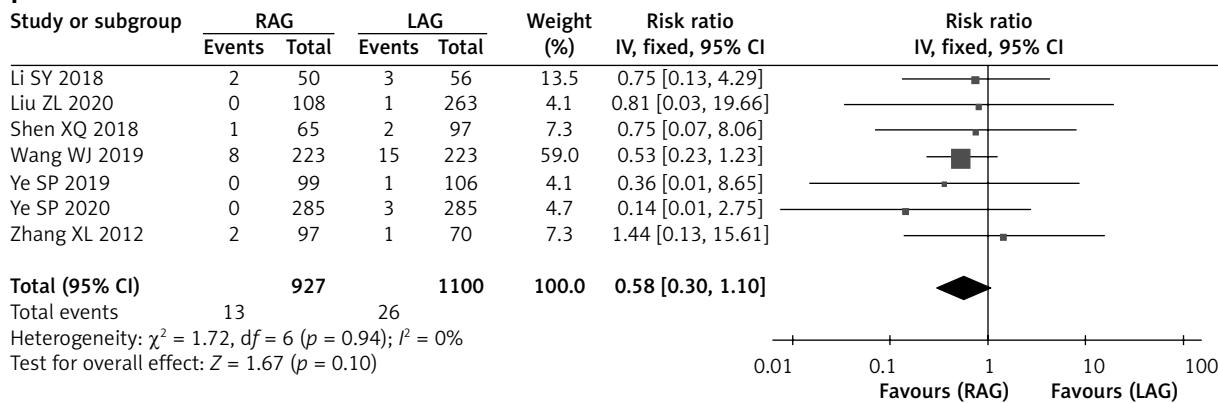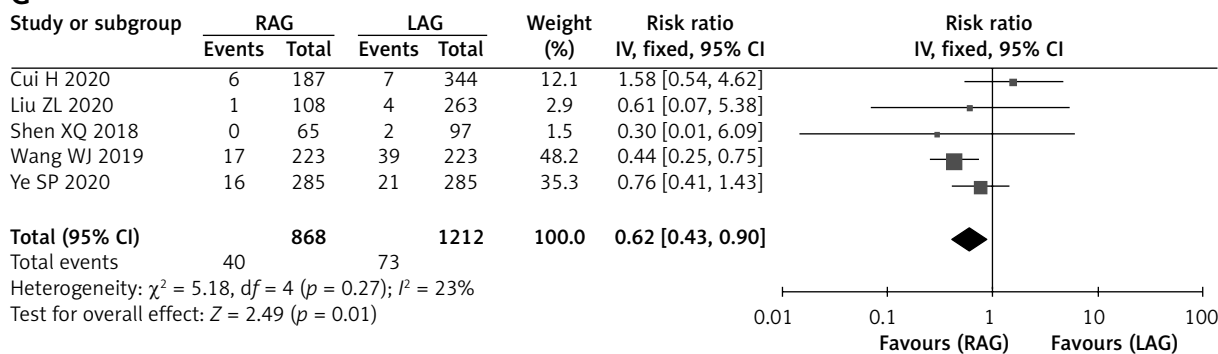
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D

Study or subgroup	RAG Events	RAG Total	LAG Events	LAG Total	Weight (%)	Risk ratio IV, fixed, 95% CI
Liu ZL 2020	1	108	3	263	18.8	0.81 [0.09, 7.72]
Wang WJ 2019	3	223	5	223	47.3	0.60 [0.15, 2.48]
Ye SP 2019	1	99	1	106	12.5	1.07 [0.07, 16.89]
Ye SP 2020	0	285	3	285	10.9	0.14 [0.01, 2.75]
Zhang XL 2012	2	97	0	70	10.4	3.62 [0.18, 74.30]
Total (95% CI)		812		947	100.0	0.70 [0.27, 1.87]
Total events	7		12			

Heterogeneity: $\chi^2 = 2.40$, d$f = 4$ ($p = 0.66$); $I^2 = 0\%$
Test for overall effect: $Z = 0.70$ ($p = 0.48$)

Favours (RAG)   Favours (LAG)

E

Study or subgroup	RAG Events	RAG Total	LAG Events	LAG Total	Weight (%)	Risk ratio IV, fixed, 95% CI
Li, SY 2018	2	108	4	263	27.6	1.22 [0.23, 6.55]
Shen XQ 2018	1	65	0	97	7.7	4.45 [0.18, 107.69]
Xue YG 2016	2	35	2	35	21.6	1.00 [0.15, 6.71]
Ye SP 2020	3	285	4	285	35.3	0.75 [0.17, 3.32]
Zhang XL 2012	1	97	0	70	7.7	2.17 [0.09, 52.58]
Total (95% CI)		590		750	100.0	1.14 [0.47, 2.75]
Total event	9		10			

Heterogeneity: $\chi^2 = 1.19$, d$f = 4$ ($p = 0.88$); $I^2 = 0\%$
Test for overall effect: $Z = 0.28$ ($p = 0.78$)

Favours (RAG)   Favours (LAG)

F

Study or subgroup	RAG Events	RAG Total	LAG Events	LAG Total	Weight (%)	Risk ratio IV, fixed, 95% CI
Li SY 2018	2	50	3	56	13.5	0.75 [0.13, 4.29]
Liu ZL 2020	0	108	1	263	4.1	0.81 [0.03, 19.66]
Shen XQ 2018	1	65	2	97	7.3	0.75 [0.07, 8.06]
Wang WJ 2019	8	223	15	223	59.0	0.53 [0.23, 1.23]
Ye SP 2019	0	99	1	106	4.1	0.36 [0.01, 8.65]
Ye SP 2020	0	285	3	285	4.7	0.14 [0.01, 2.75]
Zhang XL 2012	2	97	1	70	7.3	1.44 [0.13, 15.61]
Total (95% CI)		927		1100	100.0	0.58 [0.30, 1.10]
Total events	13		26			

Heterogeneity: $\chi^2 = 1.72$, d$f = 6$ ($p = 0.94$); $I^2 = 0\%$
Test for overall effect: $Z = 1.67$ ($p = 0.10$)

Favours (RAG)   Favours (LAG)

G

Study or subgroup	RAG Events	RAG Total	LAG Events	LAG Total	Weight (%)	Risk ratio IV, fixed, 95% CI
Cui H 2020	6	187	7	344	12.1	1.58 [0.54, 4.62]
Liu ZL 2020	1	108	4	263	2.9	0.61 [0.07, 5.38]
Shen XQ 2018	0	65	2	97	1.5	0.30 [0.01, 6.09]
Wang WJ 2019	17	223	39	223	48.2	0.44 [0.25, 0.75]
Ye SP 2020	16	285	21	285	35.3	0.76 [0.41, 1.43]
Total (95% CI)		868		1212	100.0	0.62 [0.43, 0.90]
Total events	40		73			

Heterogeneity: $\chi^2 = 5.18$, d$f = 4$ ($p = 0.27$); $I^2 = 23\%$
Test for overall effect: $Z = 2.49$ ($p = 0.01$)

Favours (RAG)   Favours (LAG)

Figure 3. Cont. Intestinal obstruction (**D**), delayed gastric emptying (**E**), anastomosis leakage (**F**), severe complications (**G**)

H

| Study or subgroup | RAG | | LAG | | Weight | Risk ratio | Risk ratio |
	Events	Total	Events	Total	(%)	IV, fixed, 95% CI	IV, fixed, 95% CI
Cui H 2020	24	187	37	344	15.6	1.19 [0.74, 1.93]	
Li SY 2018	5	50	6	56	2.9	0.93 [0.30, 2.87]	
Liu ZL 2020	15	108	40	263	12.0	0.91 [0.53, 1.58]	
Shen XQ 2018	4	65	7	97	2.6	0.85 [0.26, 2.80]	
Wang WJ 2019	42	223	78	223	34.2	0.54 [0.39, 0.75]	
Xue YG 2016	5	35	7	35	3.3	0.71 [0.25, 2.04]	
Ye SP 2019	8	99	9	106	4.4	0.95 [0.38, 2.37]	
Ye SP 2020	35	285	48	285	22.3	0.73 [0.49, 1.09]	
Zhang XL 2012	6	97	5	70	2.8	0.87 [0.28, 2.72]	
Total (95% CI)		1149		1479	100.0	0.75 [0.62, 0.91]	
Total events	144		237				

Heterogeneity: $\chi^2 = 8.57$, d$f = 8$ ($p = 0.38$); $I^2 = 7\%$
Test for overall effect: $Z = 2.97$ ($p = 0.003$)

0.5 0.7 1 1.5 2
Favours (RAG)   Favours (LAG)

I

| Study or subgroup | RAG | | LAG | | Weight | Risk ratio | Risk ratio |
	Events	Total	Events	Total	(%)	IV, fixed, 95% CI	IV, fixed, 95% CI
Liu ZL 2020	0	108	0	263		Not estimable	
Pugliese R 2010	1	18	1	52	12.1	2.89 [0.19, 43.83]	
Wang WJ 2019	2	223	1	223	15.6	2.00 [0.18, 21.90]	
Xue YG 2016	3	35	4	35	44.2	0.75 [0.18, 3.11]	
Ye SP 2020	3	285	2	285	28.1	1.50 [0.25, 8.91]	
Total (95% CI)		669		858	100.0	1.25 [0.49, 3.22]	
Total events	9		8				

Heterogeneity: $\chi^2 = 1.05$, d$f = 3$ ($p = 0.79$); $I^2 = 0\%$
Test for overall effect: $Z = 0.46$ ($p = 0.64$)

0.02 0.1 1 10 50
Favours (RAG)   Favours (LAG)

Figure 3. Cont. Overall complications (**H**), and death rate (**I**)

between the RAGD2 and LAGD2 groups (RR = 1.25, 95% CI: 0.49–3.22; $p = 0.64$, Figure 3 I).

Publication bias and sensitivity analysis

Table II shows that publication bias do not occur for all indicators ($p > 0.05$). Notably, after ignoring the studies of Cui et al. [10] or Pugliese et al. [15], the combined results of the number of retrieved lymph nodes became statistically significant ($p < 0.05$). Similarly, the combined results of postoperative length of stay also became statistically significant when we ignored the study of Cui et al. [10]. The difference between RAGD2 and LAGD2 with respect to severe complications and overall complications became non-significant when we omitted the study of Wang et al. [16].

Discussion

In recent years, minimally invasive surgery technology has developed rapidly in the field of gastroin-testinal surgery, and this technology has paved the way for improving the safety and accuracy of future operations [25]. Accordingly, the meta-analysis was designed to assess the efficacy of RAGD2 in comparison with LAGD2 in patients with gastric cancer. A total of 12 studies were included in the present meta-analysis. Compared with LAGD2, RAGD2 had a longer operating time, less operative blood loss, shorter time to first flatus and liquid diet, and fewer severe complications as well as overall complications. Similar efficacy was found in the two groups with respect to the number of retrieved lymph nodes, postoperative length of stay, and death rate. This meta-analysis demonstrated that RAGD2 might have good reproducibility and safety in gastric cancer patients, and this technology might be promoted in clinical practice.

Laparoscopic gastrectomy has been reported as an effective alternative to open surgery for the treatment of gastric cancer. Zheng et al. [26] confirmed

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Table II. Results of publication bias and sensitivity analysis

Outcomes	Egger's test, *P*-value	Sensitivity analyses, WMD/RR (95% CI)
Operative time	0.479	24.33 (10.28, 38.38) to 34.50 (22.83, 46.18) min
Operative blood loss	0.405	−31.93 (−44.03, −19.83) to −22.01 (−32.98, −11.04) ml
Numbers of retrieved lymph nodes	0.175	1.21 (−0.64, 3.07) to 2.38 (0.96, 3.80)#
Time to first flatus	0.162	−0.16 (−0.28, −0.05) to −0.07 (−0.11, −0.02) days
Time to liquid diet	0.985	−0.23 (−0.32, −0.14) to −0.14 (−0.27, −0.01) days
Postoperative length of stay	0.233	−0.45 (−0.85, −0.05) to −0.08 (−0.76, 0.59) days#
Wound infection	0.882	0.70 (0.38, 1.28) to 0.86 (0.44, 1.68)
Intra-abdominal infection	0.202	0.60 (0.18, 1.99) to 0.92 (0.31, 2.73)
Pneumonia	0.595	0.77 (0.33, 1.83) to 0.93 (0.43, 2.02)
Intestinal obstruction	0.758	0.58 (0.21, 1.63) to 0.86 (0.30, 2.41)
Delayed gastric emptying	0.053	1.01 (0.40, 2.55) to 1.43 (0.47, 4.28)
Anastomosis leakage	0.959	0.54 (0.28, 1.05) to 0.65 (0.24, 1.77)
Severe complications	0.74	0.55 (0.37, 0.82) to 0.87 (0.52, 1.46)#
Overall complications	0.229	0.69 (0.56, 0.85) to 0.89 (0.70, 1.12)#
Death	0.055	1.11 (0.41, 3.05) to 1.87 (0.53, 6.64)

#The sensitivity analysis result is unstable. The combined result of numbers of retrieved lymph nodes became statistically significant after ignoring the research by Cui (2020) or Pugliese (2010, p < 0.05). The combined result of postoperative length of stay became statistically significant after ignoring the research by Cui (2020, p < 0.05). The combined result of postoperative length of stay became statistically non-significant after ignoring the research by Wang (2019, p > 0.05).

that laparoscopic D2 plus complete mesogastrium excision had lower intraoperative blood loss and a higher number of lymph nodes than conventional D2 total gastrectomy. Nevertheless, traditional laparoscopy brings some challenges to surgeons, such as limited manipulation and ergonomic discomfort. Therefore, the emergence of robotic technology can overcome most of these challenges [27]. RAGD2 technology was developed and first reported in 2002 [28]. Based on 3D vision, high magnification, and increased degrees of freedom, RAGD2 may be superior to LAGD2 [29]. Furthermore, RAGD2 would be helpful for surgeons. A recent study showed that blood loss in RAGD2 was 23.7 ml less than that with laparoscopic or open surgery [30]. This meta-analysis showed that RAGD2 required a longer operating time, which has been reported in previous studies. RAGD2 required a longer total operative time than LAGD2 as a result of the longer docking time. However, the actual surgical time was similar between the two groups [30, 31]. Furthermore, a lower estimated blood loss in RAGD2 was previously demonstrated by Shen *et al.* [32]. Regarding the time to first flatus time, only two of the included studies reported a shorter time to first flatus time for RAGD2. Significant heterogeneity was also observed. Thus, performing further high-quality studies is recommend-

ed. It is well known that there are many perigastric lymph nodes and blood vessels around the stomach, and the number of lymph node dissections is related to accurate pathological staging and prognosis. The performance of laparoscopic procedures can be limited by excessive intra-abdominal fat. Robotic surgery is a better tool for treating patients with thicker abdominal walls [33, 34]. For patients undergoing D2 lymphadenectomy, pancreatic damage cannot be ignored. Previous reports have suggested that specialized equipment might reduce the risk of pancreatic fistula, and Guerra *et al.* further demonstrated a relatively rare pancreatic complication with RAGD2 [35]. In line with previous data, we found that RAGD2 required a longer operating time and benefited from less operating blood loss, shorter time to first flatus and time to liquid diet, and fewer severe and overall complications. Thus, RAGD2 might be helpful for patients with gastric cancer.

There are some advantages in this meta-analysis. This study investigated D2 (lymphatic dissection) gastrectomy and included patients with similar basic clinical data. Furthermore, quality assessment demonstrated the high methodological quality of the enrolled studies. All outcome indicators had no significant publication bias, and the combined results were highly reliable. However, this study has some

limitations. First, the included studies were retrospective studies, which had an inherent bias. For example, some baseline information was missing in some studies, such as tumor size, TNM stage, and ASA classification, which might affect the accuracy of the combined results. RCTs with larger sample sizes were recommended to verify the results of this meta-analysis. Second, there was a certain degree of heterogeneity among the included studies in terms of factors such as sex, age, BMI, tumor size, and TNM staging. However, these indicators lacked clear thresholds for grouping, and subgroup analysis and quantitative analysis methods were restricted to explore the potential influence on the results. Third, sensitivity analysis showed that the pooled results of the number of retrieved lymph nodes, postoperative length of stay, severe complications, and overall complications were unstable. Therefore, this conclusion should be confirmed by further studies with larger sample sizes.

Conclusions

Compared with LAGD2, RAGD2 might be a better choice for treating gastric cancers based on the lower operative blood loss, shorter time to first flatus and time to liquid diet, and fewer severe and overall complications. However, our findings need to be confirmed by more high-quality RCTs to address the obvious heterogeneity among the included studies.

Acknowledgments

Conflict of interest

The authors declare no conflict of interest.

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