INTERNATIONAL JOURNAL OF SURGERY

OPEN

Efficacy and safety of robotic vs. laparoscopic gastrectomy for patients with gastric cancer: systematic review and meta-analysis

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Background: The emergence of robotic surgical systems compensated for the technological shortcomings of laparoscopic approaches. However, whether robotic gastrectomy (RG) has better perioperative outcomes and survival than laparoscopic gastrectomy (LG) for gastric cancer (GC) is still unclear but increasingly drawing attention.

Materials and methods: In this systematic review and meta-analysis, we searched PubMed, EMBASE, Web of Science, and Cochrane Library as of 20 January 2024, and referenced a list of eligible articles for all published studies comparing RG and LG for patients with GC. Data on study characteristics, individual characteristics, and outcome parameters were extracted. The quality of studies was assessed using the Revised Cochrane risk-of-bias 2 tool and the risk of bias in nonrandomized studies of interventions tool. The main outcome measures were overall survival (OS) and disease-free survival (DFS).

Results: The authors identified 3641 articles, of which 72 studies (30 081 patients) were included in the meta-analysis. Compared with LG, RG was associated with higher OS [hazard ratio (HR) = 0.89, 95% CI = 0.83–0.96], lower rate of overall postoperative complications [odds ratio (OR) = 0.77, 95% CI = 0.71–0.84], longer operating time [mean difference (MD) = 35.53, 95% CI = 29.23–41.83], less estimated blood loss (MD = − 37.45, 95% CI = − 46.24 to − 28.67), a higher number of retrieved lymph nodes (MD = 1.88, 95% CI = 0.77–3.00), faster postoperative recovery, and lower rate of conversion (OR = 0.44, 95% CI = 0.36–0.55). Mortality and DFS were not significantly different between the two groups. The subgroup of meta-analysis results also showed the advantages of robotic surgery over laparoscopic surgery in intracorporeal reconstruction, total gastrectomy, I/II stage, and BMI ≥ 25, especially for patients with stage I/II, there are better OS and DFS.

Conclusion: Our findings point to robotic surgery having great benefits compared with laparoscopic surgery in GC. Our study may help inform decision-making in applying robotic surgical systems to clinical treatment.

Keywords: gastric cancer, laparoscopic surgery, postoperative complications, robotic surgical system, survival

Introduction

Gastric cancer (GC) is the fifth most common cancer worldwide and the third leading cause of cancer-related mortality[1]. Although the treatment of GC uses multimodal therapeutic strategies, including surgery, chemotherapeutic agents[2], radiotherapies[3], and immunomodulatory drugs[4], surgery is still the main treatment option for resectable GC. According to Chinese, Japanese, Korean, the European Society for Medical Oncology (ESMO), and the National Comprehensive Cancer Network guidelines[5–9], standard gastrectomy with D2 lymphadenectomy is the recommended surgical procedure for resectable GC patients. Several studies have provided evidence that laparoscopic gastrectomy (LG) for GC is comparable to

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Sponsorships or competing interests that may be relevant to content are disclosed at the end of this article.

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International Journal of Surgery (2024) 110:8045–8056

Received 2 April 2024; Accepted 4 June 2024

Supplemental Digital Content is available for this article. Direct URL citations are provided in the HTML and PDF versions of this article on the journal's website, www.lww.com/international-journal-of-surgery.

Published online 14 June 2024

http://dx.doi.org/10.1097/JS9.0000000000001826

conventional open gastrectomy in terms of oncologic efficacy and that it yields better short-term outcomes[10–15]. However, laparoscopic surgery has some technical limitations. The emergence of robotic systems compensated for the shortcomings of laparoscopic technology, such as the lack of physiological tremor, high mobility of the simulated manipulator, high-definition 3D surgical vision, and comfortable remote console.

Previous studies revealed lower blood loss, easier and more retrieved lymph nodes (LNs), and faster postoperative recovery, with or without lower complications in robotic surgery[16–22]. Meanwhile, there are many meta-analysis studies that revealed great differences. The majority of meta-analysis showed lower blood loss, more retrieved LNs, shorter hospital stay in the robotic approach when compared with the laparoscopic one, and no difference in complications between the two approaches[23–28]. Several meta-analysis studies in recent years showed that robotic surgery was superior to laparoscopic surgery in terms of complications[29–31]. However, the above meta-analysis included some overlapping populations, and no further analysis was conducted to find the beneficiary population. Moreover, as many studies on robotic approach for GC have been reported, the results of meta-analysis need to be updated. To clarify the potential benefits and harms of two minimally invasive surgeries in GC, we conduct a meta-analysis to provide evidence support.

HIGHLIGHTS

- This comprehensive meta-analysis updates the emerging researches, which have a larger sample size and more information on long-term survival.
- Robotic surgery can improve the long-term survival and reduce postoperative complications, especially for patients with stage I/II, there is better overall survival and disease-free survival.
- The meta-analysis found the beneficiary population of robotic surgery (patients with stage I/II GC, or BMI ≥ 25 Kg/m^2, or who underwent total gastrectomy) to helps inform evidence-based strategies for robotic surgical system using in gastric cancer.

Materials and methods

The meta-analysis is guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA, Supplemental Digital Content 1, http://links.lww.com/JS9/C775, Supplemental Digital Content 2, http://links.lww.com/JS9/C776) and A Measurement Tool to Assess systematic Reviews 2 (AMSTAR2, Supplemental Digital Content 3, http://links.lww.com/JS9/C777)[32–34]. This study has been prospectively registered at PROSPERO (CRD42024506554).

Search strategy

We systematically searched PubMed, EMBASE, Web of Science, and Cochrane Library as of 20 January 2024. Medical subject headings terms (MeSH) and keywords were performed in our search course. In addition, all references of eligible articles were browsed to enlarge the search range. Full details of each search strategy are available in the Supplementary Appendix 1 (Supplemental Digital Content 4, http://links.lww.com/JS9/C778).

Eligibility criteria

All published randomized controlled trials (RCTs) and non-randomized controlled studies (NRSs), including prospective/retrospective cohort and observational studies comparing the outcomes of robotic and LG for GC were included in the meta-analysis. The inclusion criteria for studies were (1) contained the required outcome (see outcome section for details); (2) patients aged 18 years or older undergoing surgery for GC; and (3) studies have full-text manuscripts available. The exclusion criteria were (1) single-arm studies, reviews, comments, letters, and other types of studies; (2) studies not published in the English language. Note that when overlapping trial data were reported from two different sources, the source with the longest patient follow-up or largest sample size was included. Two authors (Z.L. and Y.M.) then collaborated to identify eligible studies, any disagreement was resolved by discussion or the third reviewer (Y.H.).

Outcomes and data extraction

The primary outcome of interest will be overall survival (OS) and disease-free survival (DFS), the key secondary outcomes are as follows: postoperative complications (overall complications, Clavien–Dindo Classification $\geq$ III, anastomosis leakage, intra-abdominal bleeding, intra-abdominal abscess/fluid collection, pulmonary infection, and pancreatic fistula), surgical outcomes (operation time, blood loss, number of retrieved LNs and conversion); postoperative outcomes (postoperative hospital stay, time to flatus, time to oral intake), and total cost.

For quality assurance purposes, two authors (Z.L. and W.Y.) extracted the following study data independently in duplicate into a data-extraction table, third reviewer (Y.H.) will resolve discrepancies between the two authors: study characteristics (author, year of publication, country, research span, trial design, classification, and patients per group), patient characteristics [age, sex, BMI, ASA score, and tumor stage (TNM classification)], and outcome parameters (as previously mentioned). Some trials reported the study using the median, range/interquartile range, to combine results, one may have to estimate the sample mean and SD for such trials[35]. Data extraction and estimation were carried out by Engauge Digitizer v.4.1 software according to a study by Tierney *et al*.[36] for trials that did not provide hazard ratios (HR) and 95% CI but provided survival information.

Quality assessment

The risk of bias will be assessed using the Revised Cochrane risk-of-bias tool (RoB.2)[37] and the risk of bias in nonrandomized studies of interventions tool[38], and the quality of evidence was assessed by the GRADE tool[39], by two authors (L.D. and L.N.), any disagreement was resolved by discussion or the third reviewer (Y.H.).

Statistical analysis

StataMP 15 software was applied to analyze the data. The odds ratio (OR) was used to assess dichotomous variables, the mean difference (MD) was calculated for continuous variables, and the survival data was assessed using HR and a 95% CI. Statistical heterogeneity was assessed using the values of I^2 and the results of χ^2 tests. I^2 <25% was considered low heterogeneity, 25–50% was considered moderate heterogeneity, and > 50% was considered high heterogeneity. Random-effects models were used for high heterogeneity (I^2 > 50%), whereas fixed-effects models were used for low-to-moderate heterogeneity. We built a funnel plot and conducted Egger's test for the primary outcome and overall postoperative complications to estimate publication bias. A sensitivity analysis was performed to verify the outcome's stability. Subgroup analysis was used to identify and explain the source of the difference. P-values were 2-sided, and $P<0.05$ was considered significant.

Results

Study selection, characteristics, and quality assessment

A total of 72 articles were included in our study, the selection process flow chart is presented in Figure 1, and the main baseline characteristics and general information of the included studies are presented in Supplementary Table S1 (Supplemental Digital Content 4, http://links.lww.com/JS9/C778).

According to the results obtained using the RoB.2 and risk of bias in nonrandomized studies of interventions tool, the risk of bias in each study ranged from moderate to serious. The results of the quality assessment of the included studies are presented in Supplementary Table S2 (Supplemental Digital Content 4, http://links.lww.com/JS9/C778) and Supplementary Table S3 (Supplemental Digital Content 4, http://links.lww.com/JS9/C778), respectively.

Meta-analysis

The primary outcome

The meta-analysis, recorded in 17 studies, indicated that a benefit of robotic gastrectomy (RG) on OS (HR = 0.89, 95% CI = 0.82–0.96, $P=0.002$), and a fixed-effect model was used because of a lack of heterogeneity ($I^2=12.4\%$) (Fig. 2A). The DFS outcomes were reported in 14 studies, the results suggested that no significant difference between the two techniques (HR = 0.95, 95% CI: 0.87–1.05, $P=0.312$). The analysis had no heterogeneity ($I^2=0\%$) using a fixed-effect model (Fig. 2B).

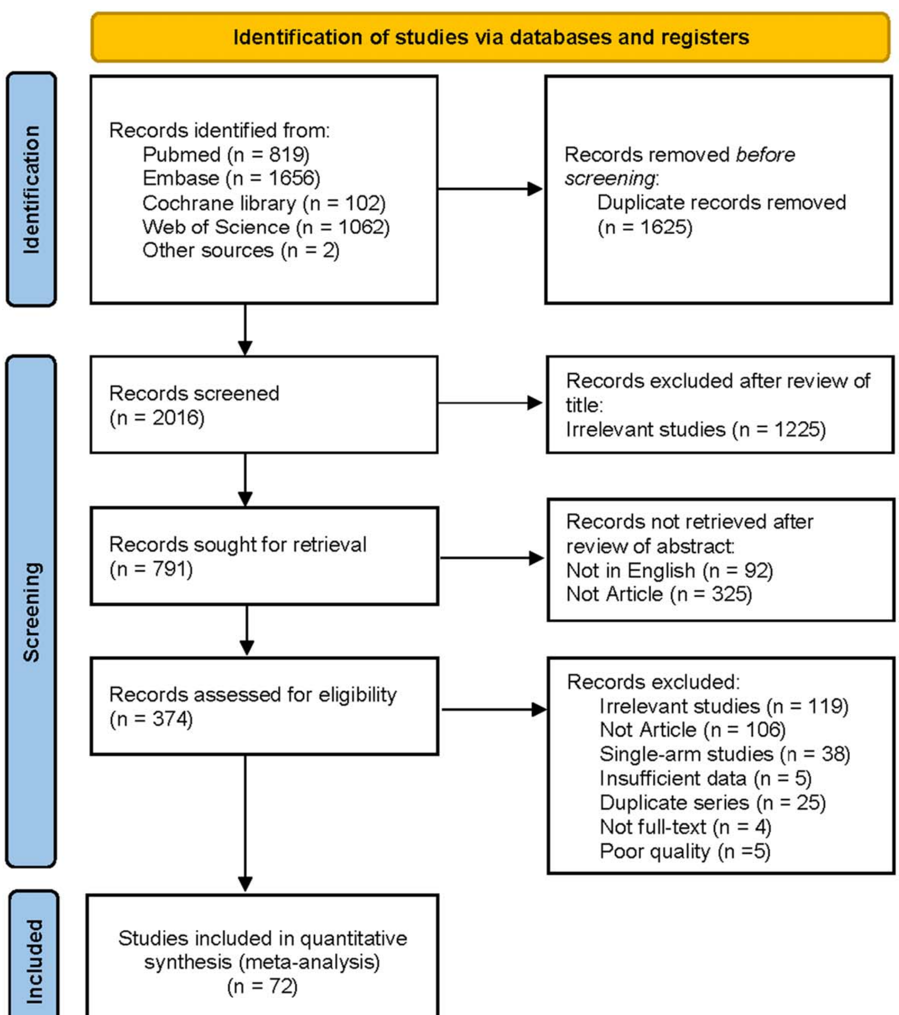

Figure 1. Flowchart of the study screening and evaluation process.

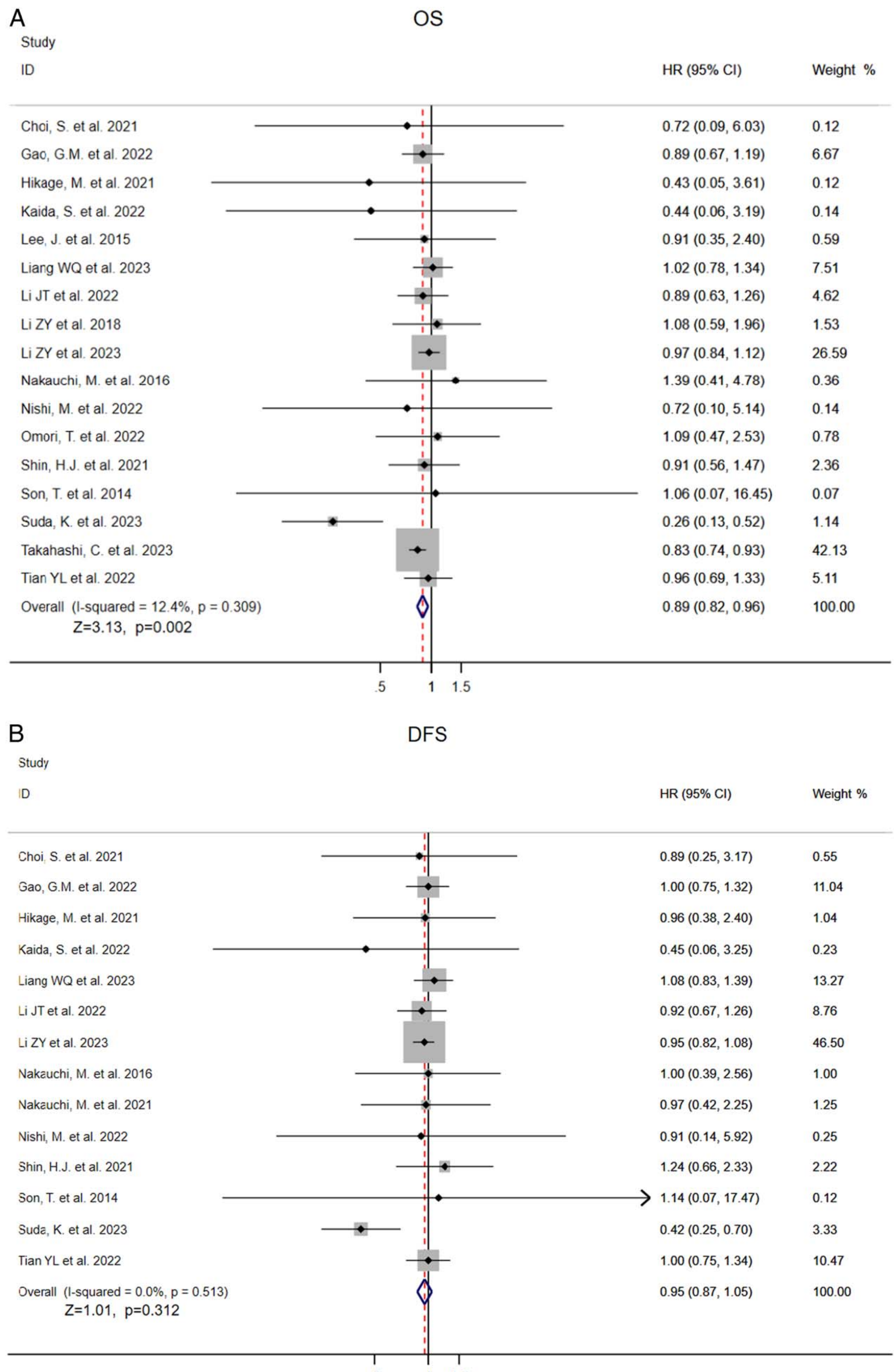

Figure 2. Forest plot of the meta-analysis for overall survival and disease-free survival. (A), overall survival, (B), disease-free survival.

The key secondary outcomes

Complications

Regarding overall complications, 51 studies reported data. The rate of overall postoperative complications in the RG group was significantly lower than that of LG group [OR = 0.77, 95% CI = 0.71–0.84, I^2 = 35.7%; 13.05% (1043/7990) and 15.26% (1845/12 088), respectively]. (Fig. 3A). Thirty-eight studies reported the rate of Clavien–Dindo Classification ≥ III postoperative complications, meta-analysis showed RG group was significantly lower than that of LG group (OR = 0.62, 95% CI = 0.53–0.73, I^2 = 24.2%) (Fig. 3B). Additionally, the rates of anastomosis leakage

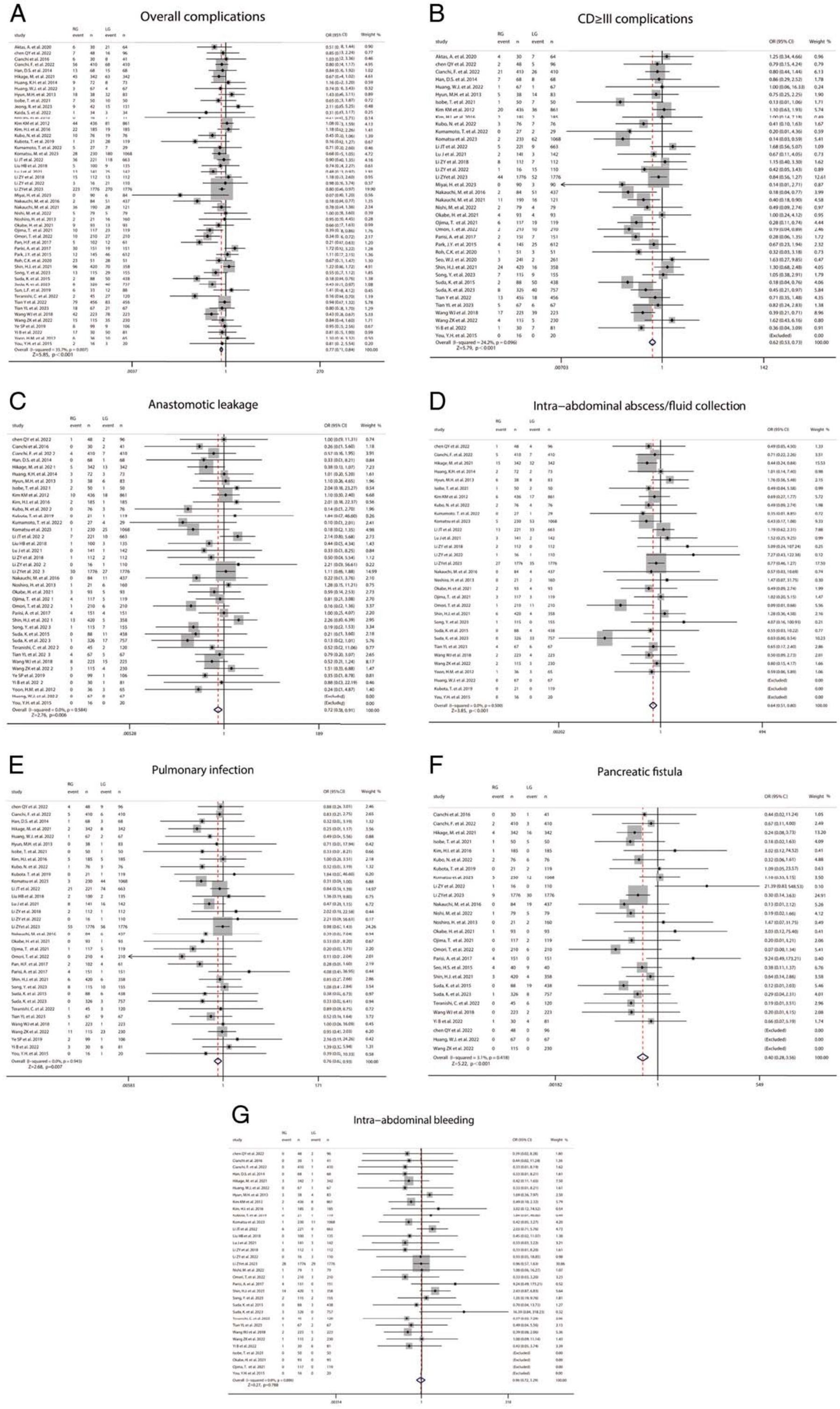

Figure 3. Forest plot of the meta-analysis for complications. (A) overall. complications, (B), CD ≥ III complications, (C), anastomosis leakage, (D), intra-abdominal abscess/fluid collection; (E), pulmonary infection; (F), pancreatic fistula; (G), intra-abdominal bleeding.

(OR = 0.72, 95% CI = 0.58–0.91, $I^2 = 0\%$) (Fig. 3C), intra-abdominal abscess/fluid collection (OR = 0.64, 95% CI = 0.51–0.80, $I^2 = 0\%$) (Fig. 3D), pulmonary infection (OR = 0.76, 95% CI = 0.62–0.93, $I^2 = 0\%$) (Fig. 3E), and pancreatic fistula (OR = 0.40, 95% CI = 0.28–0.56, $I^2 = 3.1\%$) (Fig. 3F) in the RG group were significantly lower. Regarding intra-abdominal bleeding, the result of the meta-analysis did not show a significant difference between the two groups (OR = 0.96, 95% CI = 0.72–1.29, $I^2 = 0\%$) (Fig. 3G). There was no heterogeneity (all $I^2 < 50\%$) in the above results, and a fixed effects model was used.

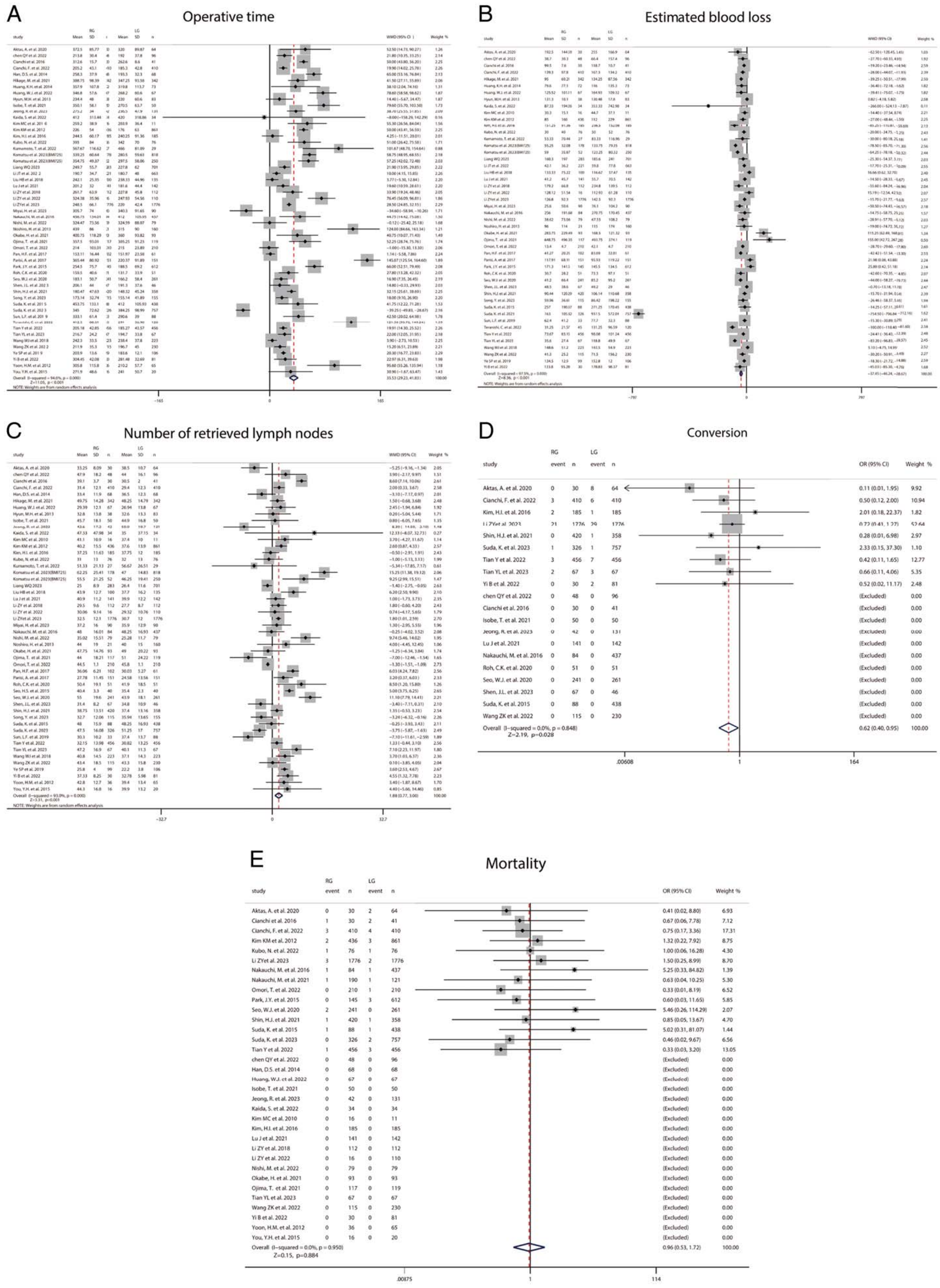

Figure 4. Forest plot of the meta-analysis for surgical outcomes. (A), operating time, (B), estimated blood loss, (C), number of retrieved lymph nodes, (D), conversion; (E) mortality.

Surgical outcomes

Fifty-two studies reported the operating time, operating time was significantly shorter in the LG group and meta-analysis showed a statistically significant difference (MD = 35.53, 95% CI = 29.23–41.83, I^2 = 94.6%) (Fig. 4A). Forty-seven studies reported estimated blood loss, estimated blood loss was significantly lower in the RG group (MD = −37.45, 95% CI = −46.24 to −28.67, I^2 = 97.5%) (Fig. 4B). The meta-analysis revealed a significantly increased number of retrieved LNs in the

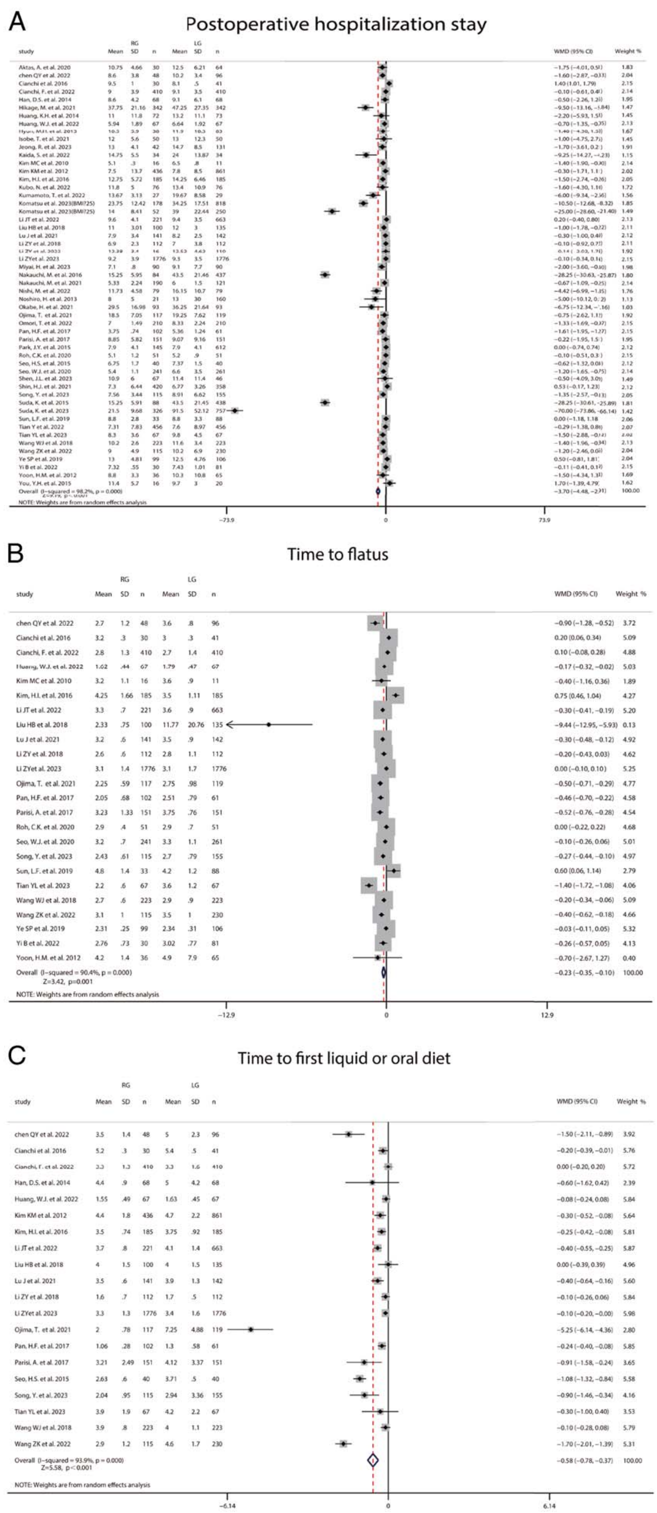

Figure 5. Forest plot of the meta-analysis for postoperative outcomes. (A), postoperative hospitalization stay, (B), time to first flatus, (C), time to first liquid or oral diet.

RG group (MD = 1.88, 95% CI = 0.77–3.00, $I^2 = 93\%$) (Fig. 4C). The conversion rate to open surgery was 2.09% (124/5935) in the RG group and 3.64% (268/7355) in the LG group. Meta-analysis of the 21 trials showed the rate of conversion to open surgery in RG was statistically significantly lower (OR = 0.62, 95% CI = 0.40–0.95, $I^2 = 0\%$) (Fig. 4D). Thirty-five studies reported the mortality rate. The mortality rate was 0.65% (49/7528) and 0.53% (53/9916) in the RG and LG group, respectively. Meta-analysis was not found that significant differences between the two groups (OR = 0.96, 95% CI = 0.53–1.72, $I^2 = 0\%$) (Fig. 4E).

Postoperative outcomes

The time of postoperative hospital stay, time to first flatus, and time to first liquid or oral intake were evaluated to assess postoperative recovery. In RG groups, the time of postoperative hospitalization stay (MD = − 3.70, 95% CI = − 4.48 to − 2.91, $I^2 = 98.2\%$), time to first flatus (MD = − 0.23, 95% CI = − 0.35 to − 0.10, $I^2 = 90.4\%$), and time to first liquid or oral diet (MD = − 0.58, 95% CI = − 0.78 to − 0.37, $I^2 = 93.9\%$) were significantly shorter than that of LG group (Fig. 5A, B, and C).

Total cost

Eleven studies reported the total cost of surgical procedures. The result of the meta-analysis showed that robotic surgery was considerably higher than laparoscopic surgery (MD = 2695.31, 95% CI = 2140.48–3250.14, $I^2 = 96.4\%$) (Fig. 6).

Subgroup analysis

Subgroup analyses were performed based on reconstruction methods (intracorporeal), resection extent (total gastrectomy), tumor stage (I/II stage), and BMI (BMI ≥25).

The intracorporeal anastomosis subgroup showed similar results to the full meta-analysis. There were significant differences between the two approaches in terms of postoperative complication, however, the pooled analysis of OS and DFS did not find significant differences between the two groups. In the total gastrectomy subgroup, the RTG group still showed significant advantages in terms of anastomosis leakage and intra-abdominal abscess/fluid collection (Table 1).

Tumor stage (I/II stage) subgroup analysis was conducted, the results showed a large benefit of RG on OS and DFS, and postoperative complications were similar to results of the full meta-analysis except for pulmonary infection. For BMI ≥25 patients, RG can reduce the incidence of severe complications and pancreatic fistula (Table 2).

Sensitivity analysis

We conducted a sensitivity analysis by sequentially excluding each study to observe the impact of individual studies on the results of the meta-analysis. When the studies of Aktas *et al.* 2020 and Tian *et al.* 2022 excluded, the results showed that the rate of conversion to open surgery in the RG group was not significantly different from that in the LG group (Supplementary sFig 1A and 1B, Supplemental Digital Content 4, http://links.lww.com/JS9/C778). The study of Takahashi *et al.* 2023 excluded, no significant difference between the two techniques in OS (Supplementary Fig S2A and 2B, Supplemental Digital Content 4, http://links.lww.com/JS9/C778). We also performed a sensitivity analysis by excluding studies with a high risk of bias from the result analysis, all results were consistent with the primary results obtained.

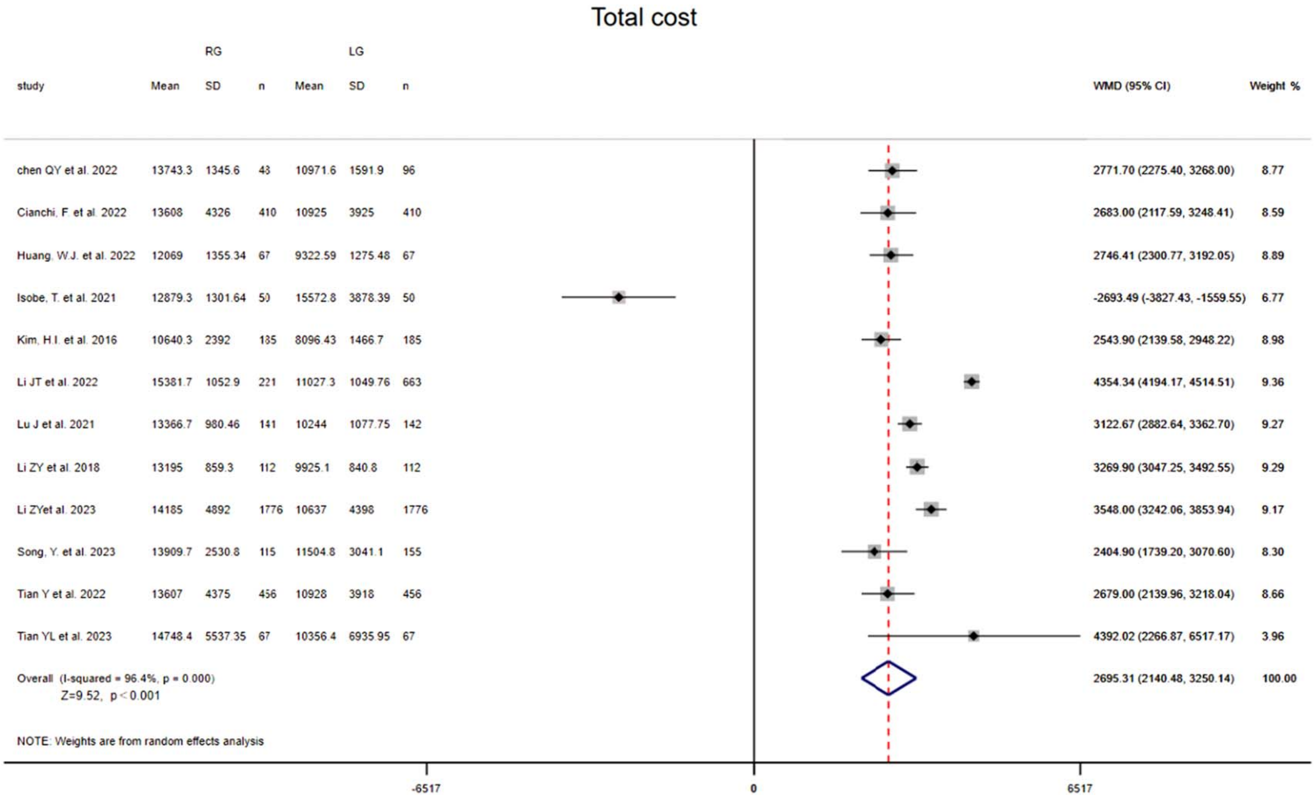

Figure 6. Forest plot of the meta-analysis for total cost.

Publication of bias and level of evidence

Publication bias in this meta-analysis was assessed using a funnel plot and Egger's test of OS, DFS, and overall complications. Visual inspection of the funnel plot revealed symmetry indicated a lack of publication bias, however, Egger's test of overall complications was statistically significant (Supplementary Fig S3A, 3B, Supplemental Digital Content 4, http://links.lww.com/JS9/C778, and Supplementary Fig S3C), therefore, we conducted trim-and-fill method to imputed seven studies for overall postoperative complications, the results were not different from those before (Supplementary Fig S4A and 4B, Supplemental Digital Content 4, http://links.lww.com/JS9/C778). According to the GRADE criteria, the overall certainty of evidence among OS, DFS, and overall complications ranged from high to moderate (Supplementary Table S4, Supplemental Digital Content 4, http://links.lww.com/JS9/C778).

Discussion

Nowadays, robotic surgical systems are widely utilized worldwide, becoming a focal point of research, particularly in the

Table 1

Subgroup of meta-analysis of intracorporeal reconstruction and total gastrectomy.

	Intracorporeal reconstruction						Total gastrectomy					
Variable	No. of studies	RG	LG	*P*	OR/HR(95%CI)	I2	No. of studies	RG	LG	*P*	OR/HR(95%CI)	I2
Postoperative complications												
Overall	18	1905	4239	< 0.001	0.72 (0.61 to 0.87)	40%	15	890	1404	0.15	0.85 (0.68 to 1.06)	0%
CD≥III	11	1578	3290	0.04	0.58 (0.34 to 0.98)	56%	8	578	888	0.23	0.76 (0.49 to 1.19)	0%
Anastomosis leakage	14	1783	3999	0.02	0.59 (0.39 to 0.91)	16%	11	743	1192	0.05	0.56 (0.31 to 1.00)	0%
Intra-abdominal bleeding	11	1602	3326	0.26	1.43 (0.77 to 2.66)	1%	7	551	856	0.24	0.63 (0.29 to 1.36)	0%
Intra-abdominal abscess/fluid collection	12	1653	3823	< 0.001	0.45 (0.28 to 0.70)	0%	9	614	950	0.02	0.47 (0.25 to 0.88)	0%
Pulmonary infection	12	1732	3798	0.008	0.56 (0.37 to 0.86)	0%	7	599	904	0.23	0.75 (0.48 to 1.20)	0%
Pancreatic fistula	12	1640	3817	0.003	0.42 (0.24 to 0.74)	0%	6	404	808	0.12	0.42 (0.14 to 1.24)	0%
Survival												
OS	4			0.26	0.62 (0.27 to 1.42)	71%	4			0.38	0.83 (0.56 to 1.25)	0%
DFS	4			0.36	0.73 (0.38 to 1.42)	61%	4			0.35	0.86 (0.63 to 1.18)	0%

CD, Clavien–Dindo classification; DFS, disease-free survival; HR, hazard ratio; LG, laparoscopic gastrectomy; OR, odds ratio; OS, overall survival; RG, roboticgastrectomy.

Table 2

Subgroup of meta-analysis of I/II stage and BMI ≥ 25.

	I/II stage						BMI≥25					
Variable	No. of studies	RG	LG	P	OR/HR(95%CI)	I2	No. of studies	RG	LG	P	OR/HR(95%CI)	I2
Postoperative complications												
Overall	16	1844	2918	0.004	0.76 (0.63 to 0.92)	0%	7	483	1054	0.13	0.76 (0.54 to 1.08)	24%
CD≥III	9	1347	1895	0.01	0.65 (0.46 to 0.92)	15%	4	321	886	0.002	0.25 (0.10 to 0.59)	0%
Anastomosis leakage	11	1450	2409	0.02	0.56 (0.34 to 0.93)	0%	3	185	391	0.23	0.42 (0.10 to 1.76)	13%
Intra-abdominal bleeding	8	1266	2195	0.86	0.94 (0.47 to 1.89)	2%	3	185	391	0.11	0.24 (0.04 to 1.36)	0%
Intra-abdominal abscess/fluid collection	9	1197	2156	< 0.001	0.42 (0.27 to 0.65)	33%	2	131	329	0.25	0.45 (0.12 to 1.73)	0%
Pulmonary infection	9	1342	2271	0.34	0.73 (0.38 to 1.40)	0%	3	185	391	0.2	0.52 (0.19 to 1.42)	38%
Pancreatic fistula	8	1276	2160	< 0.001	0.35 (0.19 to 0.64)	0%	2	131	104	0.009	0.09 (0.02 to 0.56)	0%
Survival												
OS	7			0.02	0.78 (0.64 to 0.96)	38%	3			0.79	0.93 (0.52 to 1.66)	0%
DFS	6			0.05	0.82 (0.67 to 1.00)	26%	2			0.91	0.96 (0.49 to 1.87)	0%

CD, Clavien–Dindo classification; DFS, disease-free survival; HR, hazard ratio; LG, laparoscopic gastrectomy; OR, odds ratio; OS, overall survival; RG, roboticgastrectomy.

context of GC, where studies have significantly increased. Previous meta-analyses are somewhat outdated, lacking the latest research and subject to some limitations. Therefore, we conducted this systematic review and updated meta-analysis to incorporate the most recent studies, providing a comprehensive analysis and attempting to identify the indications for robotic surgery in GC. Our meta-analysis indicates that RG is both feasible and safe. Despite longer operative times and higher total costs, patients in the RG group demonstrate significantly higher OS compared to those in the LG group. Additionally, RG exhibits significantly better outcomes in terms of postoperative complications, estimated blood loss, number of retrieved LNs, and postoperative recovery.

Long-term survival is one of the key indicators for assessing tumor treatment. Previous large-scale studies indicated no significant difference in long-term efficacy between RG and LG[40–45]. However, Suda *et al.*[22] research on patients with stage I/II GC suggested the advantageous 3-year outcomes of RG over LG. Takahashi *et al.*[46] study, including each consisting of 1278 patients, showed that the OS of RG was better than LG. Although both studies concluded that large-scale multicenter RCTs are needed to validate these findings, they were the supporting evidence that RG surgery may improve long-term survival outcomes. The meta-analysis results indicate a significantly higher OS with RG compared to LG, while the DFS shows no significant difference, which is in contrast to previous meta-analysis findings[24,26,29,30]. We speculate that the increased OS with RG may be attributed to radical lymphadenectomy, lower incidence of severe complications, and faster postoperative recovery. Lymphadenectomy is associated with the accurate evaluation of disease staging patient prognosis and follow-up treatment[47,48], making it a vital step in radical gastrectomy and providing survival benefits for GC patients[49,50]. The meta-analysis results demonstrate that RG achieves a significantly higher number of retrieved LNs, indicating its ability to perform more radical lymphadenectomy, which correlates with improved survival rates. Previous studies reported that severe postoperative complications were associated with long-term survival[51]. The incidence of severe complications with RG is significantly lower than with LG, which may also be a potential reason for the improved long-term efficacy. Rapid postoperative recovery enables patients to be in better physical condition, less affected by other diseases, and able to start chemotherapy sooner. Subgroup analysis of this study reveals that for stage I/II patients, RG significantly improved OS and DFS, while also having significantly lower postoperative complications. These results support the application of robotic surgical systems for stage I/II GC patients, providing benefits of survival and complications, but warrant further large-scale multicenter RCTs for validation.

Complications pose a significant concern in surgical procedures, as they can prolong hospital stays, increase total costs, and even impact patient long-term outcomes[52]. Therefore, complications are the most scrutinized and debated issue in current research on robotic surgery. Study by Ojima *et al.*[21] indicated the overall incidence of postoperative complications of grade II or higher was significantly higher in the LG group than in the RG group. Similarly, Lu *et al.*[18] RCT demonstrated the overall postoperative morbidity rate was significantly lower in the robotic distal gastrectomy than in the laparoscopic distal gastrectomy. Li *et al.*[19] research found no significant difference in overall postoperative complications, but robotic total gastrectomy was associated with a lower incidence of pulmonary infections. Conversely, studies by Kim *et al.*[17] and Chen *et al.*[16] suggested that overall complications and major complications were similar between RG and LG. The results of this meta-analysis indicate that RG is associated with significantly lower rates of postoperative complications compared to LG. Similar findings of overall complications were reported in meta-analyses by Feng *et al.*[29] and Jin *et al.*[30], while Jin *et al.*[30] and Gong *et al.*[31] meta-analyses suggested an association between RG and lower pancreatic fistula. Previous other meta-analyses showed no significant differences in postoperative complications between the two approaches[23–28]. The advantages of robotic surgical systems, such as high mobility of the simulated manipulator and high-definition 3D surgical vision, aid surgeons in performing radical gastrectomy and gastrointestinal reconstruction more effectively. Subgroup analysis in this study also indicates that RG significantly reduces the incidence of complications during intracorporeal reconstruction. Additionally, for challenging total gastrectomy, RG can lower the incidence of anastomotic leakage and intra-abdominal infections. Leakage is considered a major cause of morbidity and death[53]. Particularly in intracorporeal anastomosis, such as esophagojejunal anastomosis during total gastrectomy, where the higher anastomotic location and narrow space increase the difficulty. The flexibility and stability of robotic systems allow for better adjustment of the anastomotic angle and more accurate reinforcement of the anastomosis. This results in a more secure anastomosis with shorter operative times and fewer gastrointestinal contents entering the abdominal cavity, thus lowering the risk of anastomotic leakage and intra-abdominal infections. Moreover, the advantages of robotic surgery are manifested in extensive lymphadenectomy, particularly in the suprapancreatic areas, where it can effectively reduce pancreatic complications while maintaining stable and continuous pancreatic pressure. BMI ≥ 25 is a risk factor for pancreatic fistula[54]. In Europe and the Americas, there is a higher proportion of overweight patients, making this issue worthy of attention. Subgroup analysis results of this study show that RG reduces the incidence of severe complications and pancreatic fistula in GC patients with a BMI ≥ 25. Clearly, for patients with higher body weight, RG enables better surgical manipulation and reduces surgical trauma, these results support the application of robotic surgical systems for patients with BMI ≥ 25.

Furthermore, RG is associated with lower estimated blood loss and faster postoperative recovery, consistent with previous research[55]. The advantages of robotic surgical systems, such as 3D visualization, tremor filtering, and highly articulated EndoWrist instruments, help surgeons avoid vascular injury, reduce intraoperative blood loss and trauma, and accelerate the recovery of digestive function. This aligns with the principles of enhanced recovery after surgery[56,57], offering less trauma and lower pain perception, facilitating patient mobilization, and promoting recovery. Compared to LG, RG has longer operative times and higher total costs. Longer operative time is attributed to the setup and calibration time of the robotic system, which can take up to half an hour[58]. However, longer operative time is not absolute, studies by Li *et al.*[19], Hyun *et al.*[59], and Liu *et al.*[60] suggested no significant difference in operative times between RG and LG. With increased proficiency and collaboration among surgical teams, total operative times for robotic surgery can even be shorter than those for laparoscopic surgery[61]. The significant cost of RG, stemming from expensive equipment procurement, usage, and maintenance, inevitably results in higher costs compared to LG. Interestingly, Lu *et al.*[18] analysis of costs found that the overall increase in costs was primarily due to indirect costs (the amortization of capital equipment, supplies, and maintenance of services), while the direct costs of robotic surgery (medication and nursing expenses) were lower than those for laparoscopic surgery.

Nevertheless, this study has several limitations. Firstly, most included studies were retrospective, thus confounding bias is difficult to eliminate. Secondly, most included studies were conducted in East Asian countries, so the results may not be generalizable to other populations. Furthermore, only a few studies directly described HR and 95% CI. For others, we extracted OS and DFS data from survival curves using Engauge Digitizer v.4.1 software and converted continuous variable data from median (range/interquartile range) to mean and SD, which may introduce potential errors.

Conclusion

This meta-analysis points to RG having great benefits compared with LG in GC, especially in patients with stage I/II GC, or BMI ≥ 25, or who underwent total gastrectomy, we recommend robotic systems for surgery. However, further large-scale multicenter RCTs are needed for validation. Similar to the initial use of laparoscopic surgery for GC, RG faces numerous challenges and scrutiny. In the future, with the optimization of operative times and costs, a robotic surgical system is expected to become the preferred option for GC. Our study may help inform decision-making in applying robotic surgical systems to clinical treatment.

Ethical approval

As this study is based on aggregate data and does not involve humans, ethical approval is not required.

Source of funding

None.

Author contribution

Z.L., Y.H., and L.H.: conceived and designed this study; Z.L., H.B., C.W., and X.C.: searched literature bases; Z.L. and Y.M.: collaborated to identify eligible studies; Z.L. and W.Y.: extracted data from eligible studies; Z.L., W.Z., Y.Z., and J.C.: performed the statistical data analysis; L.N. and L.D.: assessed the quality of evidence; Z.L., W.Z., A.F., Q.X., and S.W.: accessed and verified all the data included in this study; Z.L., W.Z., and L.H.: wrote the original draft of the manuscript; Z.L., Y.H., and L.H.: contributed to project administration; Y.H. and L.H.: supervised the study.

Conflicts of interest disclosure

The authors declare no conflicts of interest.

Research registration unique identifying number (UIN)

1. Name of the registry: PROSPERO.
2. Unique identifying number or registration ID: CRD42024506554.
3. Hyperlink to your specific registration (must be publicly accessible and will be checked): crd.york.ac.uk/prospero/display_record.php?RecordID=506554.

Guarantor

Liu Hong and Zhenshun Li.

Data availability statement

Data is available upon request.

References

[1] Sung H, Ferlay J, Siegel RL, *et al*. Global cancer statistics 2020: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. CA Cancer J Clin 2021;71:209–49.
[2] Bang YJ, Kim YW, Yang HK, *et al*. Adjuvant capecitabine and oxaliplatin for gastric cancer after D2 gastrectomy (CLASSIC): a phase 3 open-label, randomised controlled trial. Lancet 2012;379:315–21.

[3] Cats A, Jansen EPM, van Grieken NCT, *et al.* Chemotherapy versus chemoradiotherapy after surgery and preoperative chemotherapy for resectable gastric cancer (CRITICS): an international, open-label, randomised phase 3 trial. Lancet Oncol 2018;19:616–28.
[4] Wang F, Wei XL, Wang FH, *et al.* Safety, efficacy and tumor mutational burden as a biomarker of overall survival benefit in chemo-refractory gastric cancer treated with toripalimab, a PD-1 antibody in phase Ib/II clinical trial NCT02915432. Ann Oncol 2019;30:1479–86.
[5] Japanese Gastric Cancer Association. Japanese Gastric Cancer Treatment Guidelines 2021 (6th edition). Gastric Cancer 2023;26:1–25.
[6] Muro K, Van Cutsem E, Narita Y, *et al.* Pan-Asian adapted ESMO Clinical Practice Guidelines for the management of patients with metastatic gastric cancer: a JSMO-ESMO initiative endorsed by CSCO, KSMO, MOS, SSO and TOS. Ann Oncol 2019;30:19–33.
[7] Lordick F, Carneiro F, Cascinu S, *et al.* Gastric cancer: ESMO Clinical Practice Guideline for diagnosis, treatment and follow-up. Ann Oncol 2022;33:1005–20.
[8] Wang FH, Zhang XT, Tang L, *et al.* The Chinese Society of Clinical Oncology (CSCO): clinical guidelines for the diagnosis and treatment of gastric cancer, 2023. Cancer Commun 2024;44:127–72.
[9] Ajani JA, D'Amico TA, Bentrem DJ, *et al.* Gastric Cancer, Version 2.2022, NCCN clinical practice guidelines in oncology. J Natl Compr Canc Netw 2022;20:167–92.
[10] Katai H, Mizusawa J, Katayama H, *et al.* Survival outcomes after laparoscopy-assisted distal gastrectomy versus open distal gastrectomy with nodal dissection for clinical stage IA or IB gastric cancer (JCOG0912): a multicentre, non-inferiority, phase 3 randomised controlled trial. Lancet Gastroenterol Hepatol 2020;5:142–51.
[11] Katai H, Mizusawa J, Katayama H, *et al.* Short-term surgical outcomes from a phase III study of laparoscopy-assisted versus open distal gastrectomy with nodal dissection for clinical stage IA/IB gastric cancer: Japan Clinical Oncology Group Study JCOG0912. Gastric Cancer 2017;20:699–708.
[12] Hu Y, Huang C, Sun Y, *et al.* Morbidity and mortality of laparoscopic versus open D2 distal gastrectomy for advanced gastric cancer: a randomized controlled trial. J Clin Oncol 2016;34:1350–7.
[13] Yu J, Huang C, Sun Y, *et al.* Effect of laparoscopic vs open distal gastrectomy on 3-year disease-free survival in patients with locally advanced gastric cancer: the class-01 randomized clinical trial. JAMA 2019;321:1983–92.
[14] Lee HJ, Hyung WJ, Yang HK, *et al.* Short-term outcomes of a multicenter randomized controlled trial comparing laparoscopic distal gastrectomy with D2 lymphadenectomy to open distal gastrectomy for locally advanced gastric cancer (KLASS-02-RCT). Ann Surg 2019;270:983–91.
[15] Hyung WJ, Yang HK, Park YK, *et al.* Long-term outcomes of laparoscopic distal gastrectomy for locally advanced gastric cancer: the KLASS-02-RCT randomized clinical trial. J Clin Oncol 2020;38:3304–13.
[16] Chen QY, Zhong Q, Liu ZY, *et al.* Surgical outcomes, technical performance, and surgery burden of robotic total gastrectomy for locally advanced gastric cancer: a prospective study. Ann Surg 2022;276:e434–43.
[17] Kim HI, Han SU, Yang HK, *et al.* Multicenter prospective comparative study of robotic versus laparoscopic gastrectomy for gastric adenocarcinoma. Ann Surg 2016;263:103–9.
[18] Lu J, Zheng CH, Xu BB, *et al.* Assessment of robotic versus laparoscopic distal gastrectomy for gastric cancer: a randomized controlled trial. Ann Surg 2021;273:858–67.
[19] Li Z, Qian F, Zhao Y, *et al.* A comparative study on perioperative outcomes between robotic versus laparoscopic D2 total gastrectomy. Int J Surg 2022;102:106636.
[20] Noshiro H, Ikeda O, Urata M. Robotically-enhanced surgical anatomy enables surgeons to perform distal gastrectomy for gastric cancer using electric cautery devices alone. Surg Endosc 2014;28:1180–7.
[21] Ojima T, Nakamura M, Hayata K, *et al.* Short-term outcomes of robotic gastrectomy vs laparoscopic gastrectomy for patients with gastric cancer: a randomized clinical trial. JAMA Surg 2021;156:954–63.
[22] Suda K, Sakai M, Obama K, *et al.* Three-year outcomes of robotic gastrectomy versus laparoscopic gastrectomy for the treatment of clinical stage I/II gastric cancer: a multi-institutional retrospective comparative study. Surg Endosc 2023;37:2858–72.
[23] Hyun MH, Lee CH, Kim HJ, *et al.* Systematic review and meta-analysis of robotic surgery compared with conventional laparoscopic and open resections for gastric carcinoma. Br J Surg 2013;100:1566–78.
[24] Liao G, Zhao Z, Khan M, *et al.* Comparative analysis of robotic gastrectomy and laparoscopic gastrectomy for gastric cancer in terms of their long-term oncological outcomes: a meta-analysis of 3410 gastric cancer patients. World J Surg Oncol 2019;17:86.
[25] Bobo Z, Xin W, Jiang L, *et al.* Robotic gastrectomy versus laparoscopic gastrectomy for gastric cancer: meta-analysis and trial sequential analysis of prospective observational studies. Surg Endosc 2019;33:1033–48.
[26] Ma J, Li X, Zhao S, *et al.* Robotic versus laparoscopic gastrectomy for gastric cancer: a systematic review and meta-analysis. World J Surg Oncol 2020;18:306.
[27] Guerrini GP, Esposito G, Magistri P, *et al.* Robotic versus laparoscopic gastrectomy for gastric cancer: the largest meta-analysis. Int J Surg 2020;82:210–28.
[28] Solaini L, Avanzolini A, Pacilio CA, *et al.* Robotic surgery for gastric cancer in the west: a systematic review and meta-analyses of short-and long-term outcomes. Int J Surg 2020;83:170–5.
[29] Feng Q, Ma H, Qiu J, *et al.* Comparison of long-term and perioperative outcomes of robotic versus conventional laparoscopic gastrectomy for gastric cancer: a systematic review and meta-analysis of PSM and RCT studies. Front Oncol 2021;11:759509.
[30] Jin T, Liu HD, Yang K, *et al.* Effectiveness and safety of robotic gastrectomy versus laparoscopic gastrectomy for gastric cancer: a meta-analysis of 12,401 gastric cancer patients. Updates Surg 2022;74:267–81.
[31] Gong S, Li X, Tian H, *et al.* Clinical efficacy and safety of robotic distal gastrectomy for gastric cancer: a systematic review and meta-analysis. Surg Endosc 2022;36:2734–48.
[32] Page MJ, McKenzie JE, Bossuyt PM, *et al.* The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71.
[33] Page MJ, McKenzie JE, Bossuyt PM, *et al.* The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. Int J Surg 2021;88:105906.
[34] Shea BJ, Reeves BC, Wells G, *et al.* AMSTAR 2: a critical appraisal tool for systematic reviews that include randomised or non-randomised studies of healthcare interventions, or both. BMJ 2017;358:j4008.
[35] Wan X, Wang W, Liu J, *et al.* Estimating the sample mean and standard deviation from the sample size, median, range and/or interquartile range. BMC Med Res Methodol 2014;14:135.
[36] Tierney JF, Stewart LA, Ghersi D, *et al.* Practical methods for incorporating summary time-to-event data into meta-analysis. Trials 2007;8:16.
[37] Sterne JAC, Savović J, Page MJ, *et al.* RoB 2: a revised tool for assessing risk of bias in randomised trials. BMJ 2019;366:l4898.
[38] Sterne JA, Hernán MA, Reeves BC, *et al.* ROBINS-I: a tool for assessing risk of bias in non-randomised studies of interventions. BMJ 2016;355:i4919.
[39] Guyatt GH, Oxman AD, Vist GE, *et al.* GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. BMJ 2008;336:924–6.
[40] Gao G, Liao H, Jiang Q, *et al.* Surgical and oncological outcomes of robotic- versus laparoscopic-assisted distal gastrectomy with D2 lymphadenectomy for advanced gastric cancer: a propensity score-matched analysis of 1164 patients. World J Surg Oncol 2022;20:315.
[41] Hikage M, Fujiya K, Kamiya S, *et al.* Robotic gastrectomy compared with laparoscopic gastrectomy for clinical stage I/II gastric cancer patients: a propensity score-matched analysis. World J Surg 2021;45:1483–94.
[42] Li JT, Lin JX, Wang FH, *et al.* Comparison of long-term outcomes after robotic versus laparoscopic radical gastrectomy: a propensity score-matching study. Surg Endosc 2022;36:8047–59.
[43] Li ZY, Zhou YB, Li TY, *et al.* Robotic gastrectomy versus laparoscopic gastrectomy for gastric cancer: a multicenter cohort study of 5402 patients in China. Ann Surg 2023;277:e87–95.
[44] Omori T, Yamamoto K, Hara H, *et al.* Comparison of robotic gastrectomy and laparoscopic gastrectomy for gastric cancer: a propensity score-matched analysis. Surg Endosc 2022;36:6223–34.
[45] Shin HJ, Son SY, Wang B, *et al.* Long-term comparison of robotic and laparoscopic gastrectomy for gastric cancer: a propensity score-weighted analysis of 2084 consecutive patients. Ann Surg 2021;274:128–37.
[46] Takahashi C, Glasser J, Schuster C, *et al.* Comparative outcomes of laparoscopic and robotic approaches to gastrectomy: a National Cancer Database study. Surg Endosc 2023;37:7530–7.
[47] Smith DD, Schwarz RR, Schwarz RE. Impact of total lymph node count on staging and survival after gastrectomy for gastric cancer: data from a large US-population database. J Clin Oncol 2005;23:7114–24.

[48] Jiao XG, Deng JY, Zhang RP, *et al*. Prognostic value of number of examined lymph nodes in patients with node-negative gastric cancer. World J Gastroenterol 2014;20:3640–8.
[49] Wu CW, Hsiung CA, Lo SS, *et al*. Nodal dissection for patients with gastric cancer: a randomised controlled trial. Lancet Oncol 2006;7: 309–15.
[50] Degiuli M, Sasako M, Ponti A, *et al*. Randomized clinical trial comparing survival after D1 or D2 gastrectomy for gastric cancer. Br J Surg 2014; 101:23–31.
[51] Li Z, Bai B, Zhao Y, *et al*. Severity of complications and long-term survival after laparoscopic total gastrectomy with D2 lymph node dissection for advanced gastric cancer: a propensity score-matched, case-control study. Int J Surg 2018;54(Pt A):62–9.
[52] Shimada H, Fukagawa T, Haga Y, *et al*. Does postoperative morbidity worsen the oncological outcome after radical surgery for gastrointestinal cancers? A systematic review of the literature. Ann Gastroenterol Surg 2017;1:11–23.
[53] Kim KM, An JY, Kim HI, *et al*. Major early complications following open, laparoscopic and robotic gastrectomy. Br J Surg 2012;99:1681–7.
[54] Zhou M, Zhong G, Sun H, *et al*. Risk factors for postoperative pancreatic fistula (POPF) in gastric cancer patients: a systematic review and meta-analysis. Eur J Surg Oncol 2023;49:107092.
[55] Calomino N, Malerba M, Tanzini G. Gastrectomia totale e qualità della vita Total gastrectomy and quality of life. Minerva Chir 1998;53: 135–40.
[56] Lee Y, Yu J, Doumouras AG, *et al*. Enhanced recovery after surgery (ERAS) versus standard recovery for elective gastric cancer surgery: a meta-analysis of randomized controlled trials. Surg Oncol 2020;32:75–87.
[57] Desiderio J, Trastulli S, D'Andrea V, *et al*. Enhanced recovery after surgery for gastric cancer (ERAS-GC): optimizing patient outcome. Transl Gastroenterol Hepatol 2020;5:11.
[58] Kandil EH, Noureldine SI, Yao L, *et al*. Robotic transaxillary thyroidectomy: an examination of the first one hundred cases. J Am Coll Surg 2012;214:558–66.
[59] Hyun MH, Lee CH, Kwon YJ, *et al*. Robot versus laparoscopic gastrectomy for cancer by an experienced surgeon: comparisons of surgery, complications, and surgical stress. Ann Surg Oncol 2013;20: 1258–65.
[60] Liu HB, Wang WJ, Li HT, *et al*. Robotic versus conventional laparoscopic gastrectomy for gastric cancer: a retrospective cohort study. Int J Surg 2018;55:15–23.
[61] Liu H, Kinoshita T, Tonouchi A, *et al*. What are the reasons for a longer operation time in robotic gastrectomy than in laparoscopic gastrectomy for stomach cancer? Surg Endosc 2019;33:192–8.