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RESEARCH

Systematic review and meta-analysis of short-term outcomes: robot-assisted versus laparoscopic surgery for gastric cancer patients with visceral obesity

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Abstract
The objective of this meta-analysis was to assess the comparative efficacy of robot-assisted and laparoscopic surgery in treating gastric cancer among patients characterized by a high visceral fat area (VFA). In April 2024, we conducted a comprehensive literature review using major international databases, such as PubMed, Embase, and Google Scholar. We restricted our selection to articles written in English, excluding reviews, protocols without published data, conference abstracts, and irrelevant content. Our analysis focused on continuous data using 95% confidence intervals (CIs) and standard mean differences (SMDs), while dichotomous data were assessed with odds ratios (ORs) and 95% CIs. We set the threshold for statistical significance at $P<0.05$. Data extraction included baseline characteristics, primary outcomes (such as operative time, major complications, lymph node yield, and anastomotic leakage), and secondary outcomes. The meta-analysis included three cohort studies totaling 970 patients. The robotic-assisted group demonstrated a significantly longer operative time compared to the laparoscopic group, with a weighted mean difference (WMD) of − 55.76 min (95% CI − 74.03 to − 37.50; $P<0.00001$). This group also showed a reduction in major complications, with an odds ratio (OR) of 2.48 (95% CI 1.09–5.66; $P=0.03$) and fewer occurrences of abdominal infections (OR 3.17, 95% CI 1.41–7.14; $P=0.005$), abdominal abscesses (OR 3.83, 95% CI 1.53–9.57; $P=0.004$), anastomotic leaks (OR 4.09, 95% CI 1.73–9.65; $P=0.001$), and pancreatic leaks (OR 8.93, 95% CI 2.33–34.13; $P=0.001$). However, no significant differences were observed between the groups regarding length of hospital stay, overall complications, estimated blood loss, or lymph node yield. Based on our findings, robot-assisted gastric cancer surgery in obese patients with visceral fat appears to be correlated with fewer major complications compared to laparoscopic surgery, while maintaining similar outcomes in other surgical aspects. However, it is important to note that robot-assisted procedures do tend to have longer operative times.

Keywords Robot-assisted · Laparoscopic · Visceral obesity · Gastric cancer · Meta-analysis

Abbreviations

NOS	Newcastle ottawa scale
CIs	Confidence intervals
ORs	Odds ratios
WMD	Weighted mean difference
VFA	Visceral fat area
SDs	Standard deviation
BMI	Body mass index
RG	Robot-assisted gastrectomy
LG	Laparoscopic gastrectomy
GC	Gastric cancer
MeSH	Medical subject headings
PICOS	Population intervention comparison outcomes study type
RCTs	Randomized controlled trials

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Introduction

Gastric cancer (GC) remains a significant global health issue, with over one million new cases diagnosed annually. Ranking as the fifth most common cancer and the third

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leading cause of cancer-related deaths globally, the standard treatments for GC include radical gastrectomy and D2 lymphadenectomy [1, 2]. Since the first successful laparoscopic gastrectomy (LG) was performed by Kitano [3] et al. in 1994, LG has become a common surgical method worldwide. The benefits of LG over traditional open gastrectomy include less-invasive techniques that offer enhanced visualization of anatomical structures, reduced surgical trauma and pain, decreased intraoperative blood loss, and quicker postoperative recovery [4, 5]. Nevertheless, limitations of LG include reliance on two-dimensional imaging, diminished tactile feedback, amplified physiological tremors, and restricted device flexibility and motion range [6]. These constraints are particularly challenging in patients with visceral obesity, where excessive visceral fat can constrict the surgical field, complicating the dissection process and potentially leading to suboptimal lymph node removal [7].

Since Hashizume [8] et al. introduced robotic gastrectomy (RG) in 2002, the use of robotic systems in surgery has expanded, providing articulated instruments, three-dimensional magnified views, and tremor filtration. These features facilitate the precise dissection of gastric cancer without increasing the surgical workload [9]. Robotic systems stabilize the surgical field via fixed traction on adipose-rich lymphoid tissue, enhancing the delineation of surgical planes and reducing the risks associated with visceral fat traction, such as bleeding and decreased surgical precision [10].

The emergence of robot-assisted surgery has shown promising results in various specialties, notably urology, gynecology, and bariatric surgery, especially in patients with high body mass index (BMI) [11–13]. Advantages of robotic surgery include reduced estimated blood loss, shorter hospital stays, and fewer complications. A study by Yu et al. [14] compared the outcomes of robotic and laparoscopic surgeries in obese GC patients, suggesting that RG offers a safer, more effective alternative with less trauma and faster recovery than LG. However, BMI may not accurately represent visceral adiposity, as it does not differentiate between muscle and fat distribution across the body. The visceral fat area (VFA) provides a more precise measure of abdominal adipose tissue. This distinction is particularly relevant for women, who may have a high BMI but normal VFA due to fat distribution patterns [15].

Given the rising global obesity rates and the increasing application of robotic systems in GC treatment, there is a growing expectation that more patients with visceral obesity will undergo robot-assisted surgeries. Despite this trend, comparative studies on the outcomes of robot-assisted versus laparoscopic surgeries in this patient group remain limited. This article aims to conduct the first systematic review and meta-analysis of the short-term outcomes between robot-assisted and laparoscopic surgeries for GC patients with visceral obesity, addressing this critical gap in the literature.

Literature search

This study was conducted in strict adherence to the PRISMA [16] (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines and registered with the PROSPERO database (CRD14325435643). Two trained researchers independently screened papers and meticulously extracted data based on predefined inclusion and exclusion criteria to determine their suitability for this systematic review. We collected relevant literature data up until 01 April 2024. Our extensive literature search included prominent databases, such as PubMed, Embase, and Google Scholar, and was limited to English language articles. We used Medical Subject Headings (MeSH) terms and keywords like "gastric cancer", "surgery", "robot-assisted", and "laparoscopy" in our search strategy. Additionally, a manual search was performed, and further relevant references were scrutinized to reduce the possibility of missing significant studies.

Inclusion and exclusion criteria

This study is structured around the PICOS (Population, Intervention, Comparison, Outcomes, Study Type) framework, which guides the formulation and examination of clinical questions systematically. The population (P) targeted comprises patients diagnosed with gastric cancer and visceral obesity requiring surgical intervention. The intervention (I) studied is robot-assisted surgery, while the comparison (C) involves laparoscopic surgery. Primary outcomes (O) include operative time, major complications, lymph node yield, and anastomotic leakage. Secondary outcomes encompass estimated blood loss, length of hospital stay, overall complications, abdominal infection, abdominal abscess, and pancreatic leakage. The types of studies included (S) are cohort studies, case–control studies, and randomized controlled trials (RCTs). Exclusion criteria eliminate non-English language publications, non-comparative studies, conference abstracts, case studies, studies involving non-adult populations, letters, and other unpublished manuscripts.

Study screening and selection

Two independent authors (YLW and BXY) manually screened all retrieved records. In instances where these authors could not reach a consensus, a third author (JGM) was consulted to resolve any disagreements. Papers deemed relevant to the objectives of this study were selected for further analysis by reading the full text.

Data items

Two assessors independently extracted data, encompassing general information, such as first author, publication year, and country, as well as demographic characteristics like age, male, and visceral fat area (VFA). Additionally, outcome measures, such as operative time, major complications, lymph node yield, estimated blood loss, length of hospital stay, and overall complications, were meticulously collected.

Statistical analysis

In this study, statistical analyses were performed using Review Manager V5.4.1 software, provided by the Cochrane Collaboration, Oxford, UK. Results were expressed using 95% confidence intervals (CIs) and odds ratios (ORs) for dichotomous variables, and weighted mean differences (WMDs) for continuous variables. For studies presenting data in medians, quartiles, or extremes, Luo's transformation method was utilized to convert these figures into means and standard deviations (SDs) [17]. The analysis of dichotomous variables was conducted using the Cochran–Mantel–Haenszel method, while the inverse variance method was applied for continuous variables. Due to the expected substantial heterogeneity across trials, a random-effects model was employed in all analyses. Heterogeneity was evaluated using the I^2 statistic, where 0–40% suggests low heterogeneity, 40–60% moderate heterogeneity, 60–90% significant heterogeneity, and 90–100% high heterogeneity [18]. A threshold of $P<0.05$ was set for statistical significance in this study.

Bias risk assessment

In this research, given that all included studies were cohort studies, the Newcastle–Ottawa Scale (NOS) was employed to assess the risk of bias in non-randomized controlled trials. The quality of the literature was evaluated using a semi-quantitative star system, with a maximum of nine stars. To ensure the robustness of the results and identify potential sources of heterogeneity, a 'leave-one-out' approach was used, where one study was excluded at a time to examine the impact on the overall estimates.

When the number of included studies was ≤ 10, the statistical power of the test was deemed insufficient; thus, no further publication bias analysis was conducted [19, 20].

Results

Baseline characteristics

Based on the search strategy and literature inclusion and exclusion criteria, three studies were identified that met our standards and were subsequently included in the meta-analysis [21–23]. Table 1 in our report provides a comprehensive summary of the characteristics and perioperative outcomes of these studies. Collectively, the studies encompassed 970 patients, with 265 receiving robotic-assisted surgery and 705 undergoing laparoscopic surgery. Figure 1 in our report features a PRISMA flowchart that outlines this selection process. Table 2 details the comparison of key characteristics and variables across these studies. Our analysis showed no statistically significant differences in age ($P=0.31$), visceral fat area (VFA) ($P=0.06$), and the proportion of male participants ($P=0.58$), demonstrating comparability among the included studies.

Assessment of quality

In this study, literature with a Newcastle–Ottawa Scale (NOS) score of ≥ 7 stars was designated as high quality. All three cohort studies included in our analysis achieved a score of ≥ 7 stars. Table 3 provides a comprehensive overview of the quality assessment of these cohort studies.

Primary outcome measures

A summary of the three studies revealed that the robot-assisted group had a longer operative time (WMD − 55.76 min, 95% CI − 74.03 to − 37.50; $P<0.00001$) (Fig. 2A), fewer major complications (OR 2.48, 95% CI 1.09–5.66; $P=0.03$) (Fig. 2B), and fewer anastomotic leaks (OR 4.09, 95% CI 1.73–9.65; $P=0.001$) (Fig. 2C). Additionally, there were no significant differences in lymph node yield (WMD − 0.28, 95% CI − 2.27–1.72; $P=0.79$) compared with the laparoscopic group (Fig. 2D).

Secondary outcome measures

Following data collection from the three included articles, a meta-analysis was conducted. The analysis revealed that the robotic group had fewer abdominal infections (OR 3.17, 95% CI 1.41–7.14; $P=0.005$) (Fig. 3A), fewer abdominal abscesses (OR 3.83, 95% CI 1.53–9.57; $P=0.004$) (Fig. 3B), and fewer pancreatic leaks (OR 8.93, 95% CI 2.33–34.13; $P=0.001$) (Fig. 3C) compared with the laparoscopic group. However, no significant difference was found between the two groups in terms of estimated blood loss (WMD − 7.47 mL, 95% CI − 25.20–10.25; $P=0.41$) (Fig. 3D) and length of hospital stay (WMD 0.13 days, 95% CI − 0.53–0.78; $P=0.70$) (Fig. 4A). Furthermore, there was no significant difference in overall complications between the two groups (OR 1.61, 95% CI 0.78–3.32; $P=0.20$) (Fig. 4B).

Table 1 Characteristics studied and perioperative outcomes

References	Hikage2022		Kubo2024		Park2015	
Type	LG	RG	LG	RG	LG	RG
Country	Japan		Japan		Korea	
Define	VFA ≥ 113.6		VFA ≥ 106		VFA ≥ 100	
Patient, *n*	366	151	71	71	268	43
Male, *n*	316	125	56	55	188	32
Age, years	70.65 (9.39)	70.36 (8.51)	64.50 (31.78)	65.94 (42.37	62.3 (10.2)	57.7 (11.0)
ASA ≥ 3	38	11	5	10	NA	NA
VFA (cm^2)	163.24 (39.31)	155.68 (38.20)	185.27 (136.96)	171.28 (102.91))	NA	NA
Operative time, minutes	303.61 (95.12)	353.04 (102.60)	377.76 (87.02)	416.29 (99.88)	193.5(64.3)	263.3 (39.8)
Length of hospital stay, days	10.32 (10.92)	13.05 (23.28)	12.0 (3.02)	11.70 (1.51)	7.7 (4.2)	7.6 (2.5)
Estimated blood loss, ml	31.83 (81.11)	45.39 (100.33)	60.58 (52.97)	55.29 (41.61)	160.4 (141.1)	190.7 (127.0)
Retrieved lymph nodes, number	38.34 (19.29)	37.48(14.57)	26.94 (11.35)	27.29 (12.10)	31.2 (11.2)	33.0 (11.2)
Overall complications	NA	NA	17	12	22	2
Major complications	30	4	12	3	28	4
Anastomotic leakage	16	2	18	5	NA	NA
Pancreatic fistula	12	0	14	2	NA	NA
Intra-abdominal abscess	16	2	14	4	NA	NA
Intra-abdominal infectious	24	3	13	5	NA	NA

RG Robot-assisted gastrectomy, *LG* laparoscopic gastrectomy, *ASA*, American society of anesthesiologists score, *VFA* visceral fat area, *NA* not available, *SD* standard deviation function; M(SD)

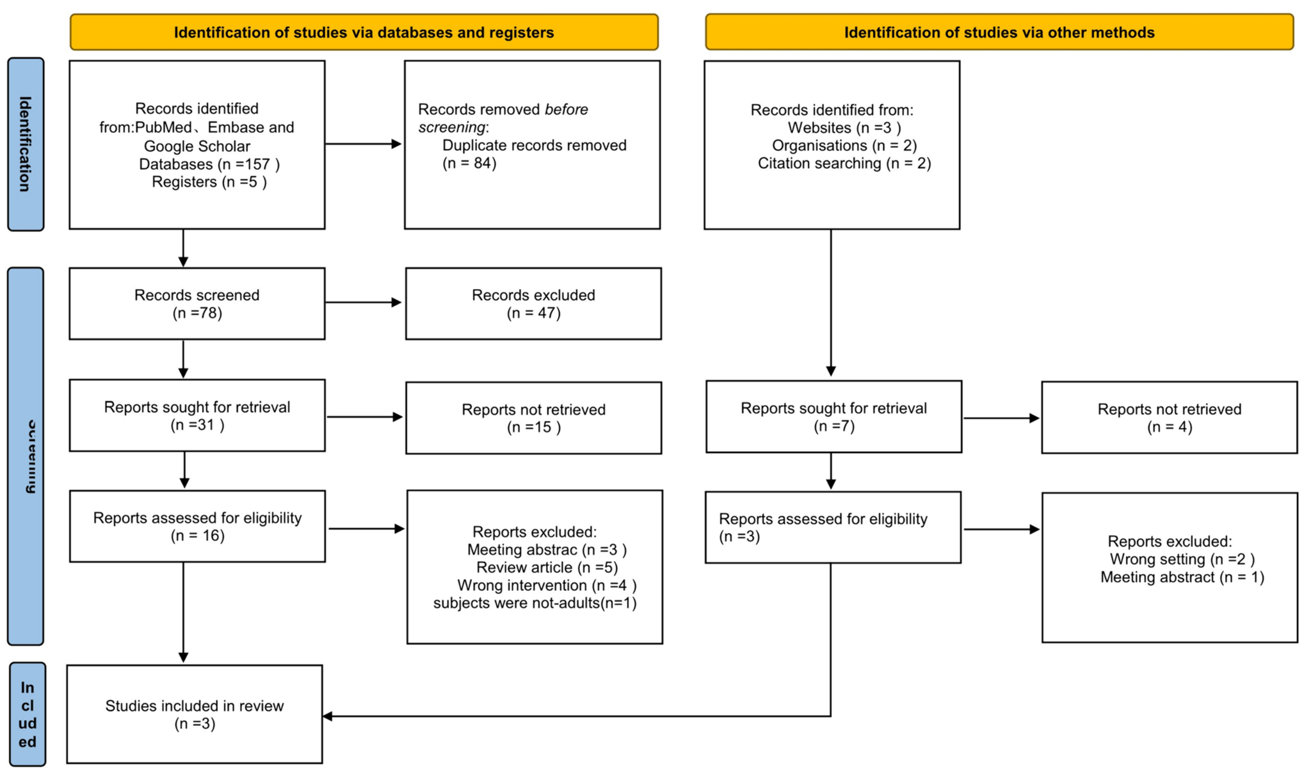

Fig. 1 The PRISMA Flowchart

Table 2 The demographics of the studies

Variable	Number of studies with available data	WMD/OR	95% CI	*P*-value
Age (years)	3	1.82	(− 1.71, 5.35)	0.31
VFA	2	7.77	(0.59, 10.95)	0.06
Male(*n*)	3	1.11	(0.76, 1.61)	0.58

WMD Weighted mean difference, *OR* odds ratio, *CI* confidence interval, *VFA* visceral fat area

Sensibility analysis

In our meta-analysis, we noted moderate heterogeneity in certain outcomes, with I^2 values of 59% for the duration of surgery and 49% for estimated blood loss. To address these differences and ensure reliable conclusions, we conducted sensitivity analyses using the “leave-one-out method” to identify potential sources of heterogeneity. Our findings revealed that excluding Park's study resulted in a decrease in heterogeneity of results for operative time from $I^2 = 59\%$ to $I^2 = 0\%$. Despite this decrease, the outcomes still demonstrated that operative time remained longer in the robotic group compared to the laparoscopic group (WMD − 46.42, 95% CI − 62.62 to − 30.22; $P < 0.00001$) (Fig. 4C). Further analysis revealed that the definition of surgery time differed in Park’s study compared to the other studies. In Park’s study, surgery time was defined as the time from skin incision to closure, while in the other two articles, it may have started timing from anesthesia or even earlier. This difference likely contributed to the increased heterogeneity observed. Similarly, excluding Kubo’s study led to a reduction in heterogeneity of results for estimated blood loss from $I^2 = 49\%$ to $I^2 = 0\%$. Subsequently, the outcomes showed no significant difference in estimated blood loss between the robotic-assisted and laparoscopic groups (WMD − 16.21, 95% CI − 32.75–0.33; $P = 0.05$) (Fig. 4D). Sensitivity analyses did not reveal any apparent heterogeneity changes in the results for length of stay as well as other outcome measures without significant heterogeneity. This consistency underscores the robustness of our results in these.

Discussion

In gastric cancer patients with visceral obesity, robotic-assisted surgeries typically require longer durations compared to laparoscopic surgeries, corroborated by findings such as those from Yu et al. [14] who reported a mean difference of 28.20 min (95% CI 2.76–53.65; $P < 0.00001$) in patients with higher BMI. This increased duration can be attributed to the additional setup and complex docking procedures necessary for the robotic arms, with preparatory activities for robotic surgery takes about 30 min on average [24]. Studies like Song et al. [25] observed that the time needed for docking the robotic arms stabilized at approximately 15 min after the initial 25 cases. Woo et al. [26] also reported a reduction in average operative time from 233 to 219 min following the first 100 robotic gastrectomies, highlighting that gaining experience can significantly reduce docking time. Additionally, the learning curve for robotic gastrectomy (RG) initially extends operative times. However, technological advancements, such as those seen with the Vinci Xi systems featuring arm-based structures and laser aiming, have made docking quicker, thereby reducing the overall time required for robot-assisted surgeries despite the initial learning challenges.

Our pooled analysis of the included studies shows that robotic-assisted gastric cancer surgery results in fewer major complications like abdominal infections, abscesses, anastomotic leaks, and pancreatic leaks compared to traditional laparoscopic approaches. Yet, the overall complication rates between the two methods do not differ significantly. Complications, such as pancreatic fistula and anastomotic leakage, prevalent in gastrectomy for obese gastric cancer patients, critically impact survival outcomes through associated intra-abdominal infections [27, 28]. Thus, reducing these infections is essential. Innovations in robotic surgery, such as wrist-mounted surgical instruments and the shock absorption capabilities of robotic systems, allow for more precise anatomical dissection near the pancreas. This precision helps ensure accurate

Table 3 Study quality of case–control studies based on the Newcastle–Ottawa scale

NOS			Selection				Comparability	Outcome			Overall score
ID	Year	Study design	1	2	3	4	5	6	7	8	
Hikage	2022	Cohort study		★	★	★	★	★	★	★	7
Kubo	2024	Cohort study	★		★	★	★	★	★	★	7
Park	2015	Cohort study	★		★	★	★	★	★	★	8

1: Representativeness of the exposed cohort, 2: Selection of the non-exposed cohort, 3: Assessment of exposure, 4: Demonstration that outcome of interest was not present at the start of the study, 5: Comparability of cohorts based on the design or analysis, 6: Ascertainment of outcome, 7: Long enough follow-up for outcomes to occur, 8: Adequacy of follow-up of cohorts

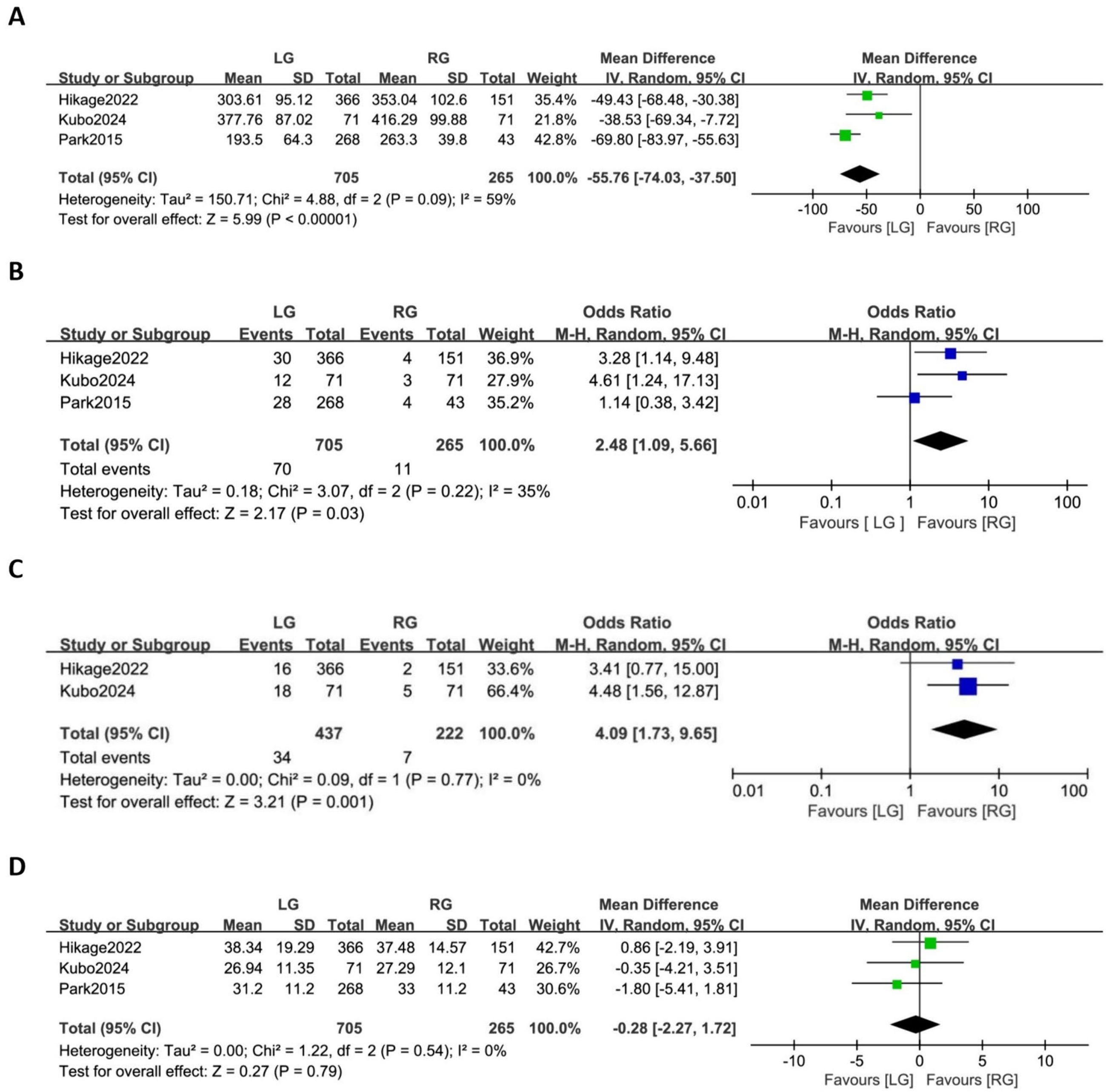

Fig. 2 **A** Forest plots of operation time; **B** Forest plots of major complications; **C** Forest Plots of anastomotic leaks; **D** Forest plots of lymph node yield

in vivo anastomoses, reducing the likelihood of postoperative anastomotic and pancreatic leaks. The use of articulated robotic forceps also aids in minimizing pancreatic compression during the dissection of supra-pancreatic lymph nodes, further mitigating the risk of postoperative intra-abdominal complications [29]. Data from our literature review indicate that the incidence of intra-abdominal infection complications in robotic gastrectomy is 2.1%, compared to 4.7% in laparoscopic gastrectomy [30]. Given these findings, along with the minimal surgical trauma offered by RG, this approach is deemed safe and effective for managing gastric cancer in obese patients, thereby enhancing short-term surgical outcomes. These results support the viability and potential superiority of robotic-assisted surgery for this specific patient group.

A meta-analysis incorporating three studies revealed no significant differences in estimated blood loss between robotic gastrectomy and laparoscopic gastrectomy. In contrast, other studies, such as one by Woo et al., [26] reported that RG resulted in reduced estimated blood loss compared

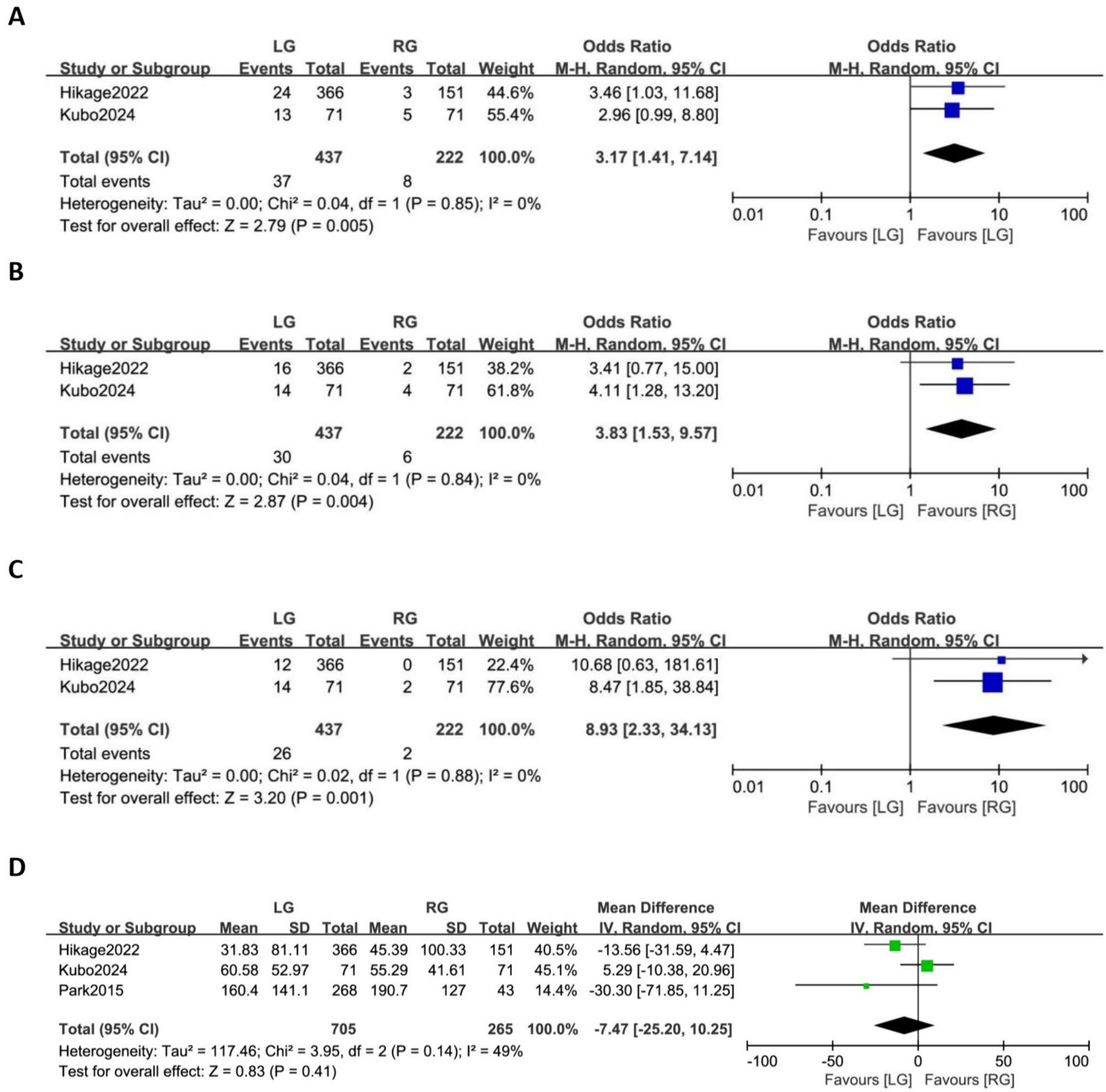

Fig. 3 **A** Forest plots of abdominal infections; **B** Forest plots of abdominal abscesses; **C** Forest plots of pancreatic leaks; **D** Forest plots of estimated blood loss

to LG, despite longer operative times. A broader meta-analysis conducted by Ma et al. [14], which included 19 studies, also found that RG led to significantly less estimated blood loss, with a weighted mean difference (WMD) of 28.66 ml (95% CI 18.59–38.73, $P<0.001$), presenting a discrepancy with our initial results. The main sources of blood loss during minimally invasive gastrectomy typically arise during lymph node dissection due to vascular injury. RG offers the advantage of a three-dimensional surgical view providing 10–15-fold magnification, which significantly enhances the surgeon's ability to observe the relationship between vessels and surrounding tissues. This superior visualization facilitates the precise identification of different tissue structures [31]. Moreover, the robotic manipulator arm, which eliminates hand tremors, adds to the surgical stability and precision, aiding in avoiding excessive tissue traction and inadvertent vascular damage, and allowing surgeons to more effectively manage and minimize bleeding from small vessels [32]. These findings underline the need for additional high-quality randomized controlled trials to further evaluate

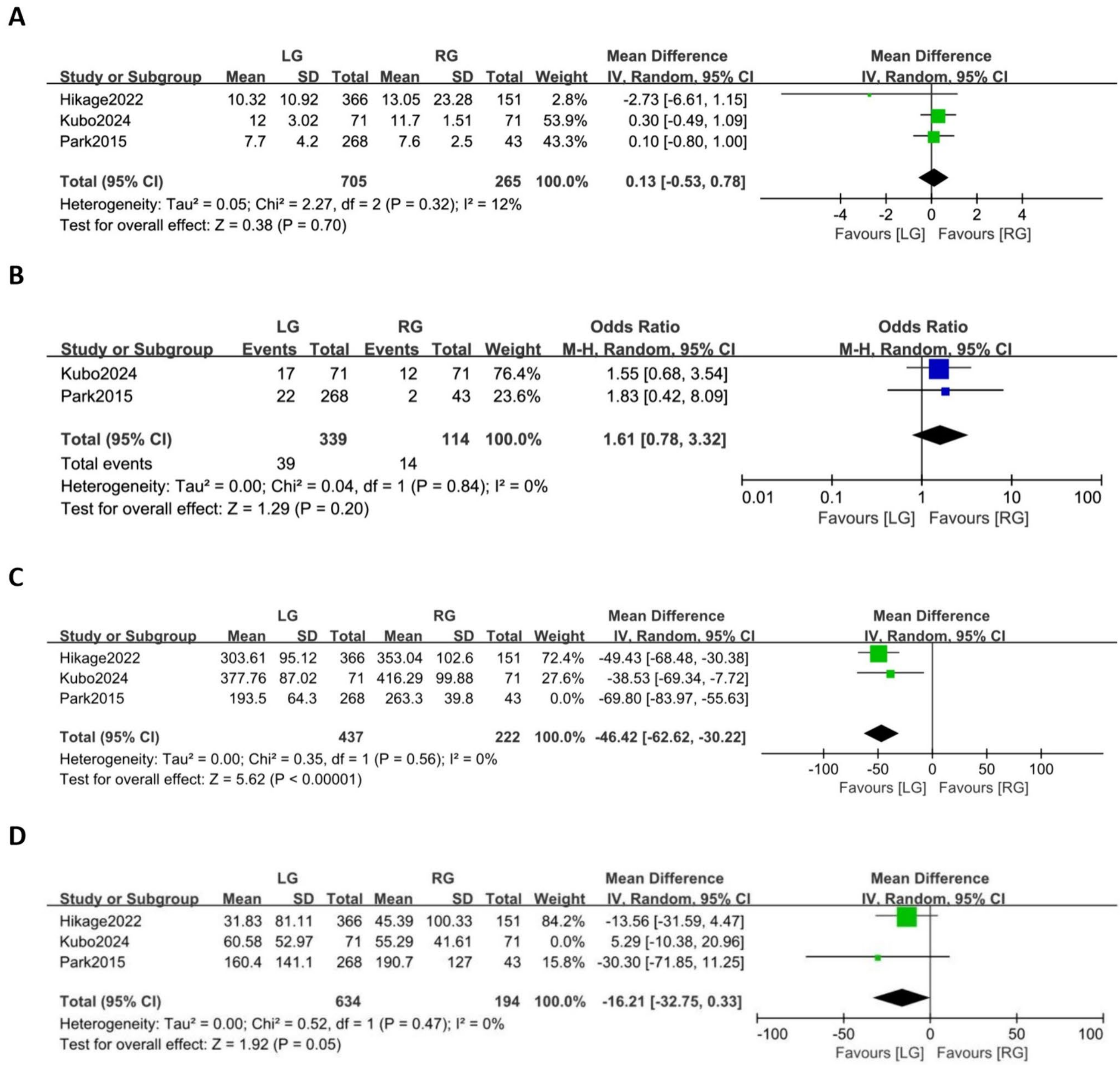

Fig. 4 **A** Forest plots of hospital stay; **B** Forest plots of overall complications; **C** Forest plots of operative time after leave-one-out; **D** Forest plots of estimated blood loss after leave-one-out

and clarify the comparative efficacy and outcomes of RG versus LG, especially in terms of blood loss and other vital surgical metrics.

Additionally, a meta-analysis of three studies found no significant differences in the number of lymph nodes removed between RG and LG. However, larger studies like those conducted by Guerrini et al. [33] and research by Zhang et al. [31] suggest a significant difference in lymph node harvest between the two surgical techniques. Furthermore, Hyun et al. [34] found that RG yielded fewer lymph nodes than LG in patients with higher BMI, indicating inconsistency in research outcomes. Extensive lymph node dissection is critical in radical surgery for gastric cancer to accurately determine the stage and prognosis of the disease, and to reduce the risk of metastasis and recurrence [35]. Studies by Smith et al. and [36] Schwartz et al. [37] have demonstrated that a higher number of examined lymph nodes correlates with improved survival rates post-surgery for patients with both early and more advanced stages of gastric cancer. These inconsistencies point to the need for large-scale, multicenter randomized controlled trials to further investigate lymph node collection outcomes in obese patients using both surgical methods, providing more reliable evidence for future clinical decisions.

Lastly, the same meta-analysis of three studies also indicated no significant differences in the length of hospital stay between RG and LG. Hospitalization duration can be affected by various factors, including the discretion of the attending physician, local healthcare practices, and the patient's postoperative recovery. Given these variables and the current lack of conclusive findings, there is a distinct need for additional high-quality, controlled trials to further explore these outcomes.

Limitations

Our study faces several significant limitations that merit attention. First, the inclusion of only three retrospective studies, with the absence of any randomized controlled trials, limits the robustness of our meta-analysis and may introduce publication bias. Second, the scarcity of available data prevented us from analyzing critical metrics, such as surgical costs, overall survival rates, and recurrence rates. This limitation may affect the comprehensiveness and depth of our findings. Last, our analysis exclusively relied on studies conducted in Asia, which imposes geographical limitations on the applicability of our results.

Conclusions

In summary, our meta-analysis offers evidence supporting the specific advantages of robot-assisted gastrectomy (RG) over laparoscopic gastrectomy (LG) for treating obese patients with gastric cancer (GC). Notably, RG is associated with a reduction in surgical complications, positioning it as an effective and safe surgical approach for patients with visceral GC, despite the longer duration of surgery.

Author contributions Every author contributed to the conceptualization and design of the study. YLW and BXY were tasked with data collection and analysis. YLW authored the initial draft of the manuscript, while JGM performed critical revisions, significantly enriching the intellectual content. All authors reviewed preliminary versions, provided feedback, and approved the final manuscript, ensuring a collaborative and thorough development process.

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Data availability The original contributions detailed in the study are encompassed within the article material. For additional inquiries, please contact the corresponding author/s directly.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval and consent to participate Not applicable.

Consent for publication Not applicable.

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