

SYSTEMATIC REVIEW

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Enhanced recovery after gastrectomy: updated Meta-analysis of 27 randomized trials (2018–2025)

Wei Liu^{1†}, Lihuang He^{2†}, Chaoli Yin³ and Guojin Gong^{3*}

Abstract

Background Enhanced recovery after surgery (ERAS) programs are increasingly applied in upper-GI surgery, yet evidence in gastrectomy remains evolving with minimally invasive and robotic techniques. We updated the randomized evidence base to re-estimate effects on recovery, complications, and costs.

Methods We systematically searched PubMed, Embase, Web of Science, and Cochrane CENTRAL (2018–2025) for parallel-group randomized controlled trials comparing full-pathway ERAS programs versus conventional care in adult patients undergoing gastrectomy for gastric cancer, in accordance with PRISMA for Abstracts guidance. Length of stay was the primary endpoint; secondary outcomes included time to gastrointestinal recovery, postoperative complications, readmission, mortality, and hospital costs. Random-effects meta-analysis was performed, and certainty of evidence was evaluated using GRADE.

Results Twenty-seven trials ($n=3,274$ patients) met eligibility criteria. ERAS significantly shortened length of stay and accelerated gastrointestinal recovery. Overall postoperative complications were numerically lower under ERAS and became statistically significant in prespecified sensitivity analyses excluding high-risk-of-bias or overlapping trials (risk ratio [RR] 0.73, 95% CI 0.56–0.96). Individual complications (pneumonia, surgical-site infection, anastomotic leak) and 30-day readmission did not show clear evidence of a difference. Mortality was rare in both groups. Certainty of evidence was generally low to moderate.

Conclusions ERAS in gastrectomy for gastric cancer may accelerate postoperative recovery and reduce costs without increasing complications or readmission. Standardized protocols and reporting are needed to enhance reliability and facilitate wider adoption.

Keywords Gastric cancer, Gastrectomy, ERAS, Postoperative recovery, Meta-analysis

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Introduction

Gastric cancer remains a leading global cause of cancer mortality, with the highest burden in East Asia despite gradual incidence declines in many regions [1–3]. Against this epidemiologic backdrop, perioperative strategies that attenuate the surgical stress response and accelerate convalescence have become central to modern surgical oncology. Enhanced Recovery After Surgery (ERAS)—originally proposed as a multimodal, pathway-based framework—has transformed perioperative care across specialties by standardizing evidence-based practices spanning preoperative counseling and nutrition, opioid-sparing multimodal analgesia, goal-directed fluid therapy, normothermia, early mobilization, and early oral intake [4–9]. Procedure-specific adaptation is essential in upper gastrointestinal surgery because gastrectomy poses unique physiologic challenges—loss of reservoir function, altered gastric emptying, risk of anastomotic failure, and pulmonary vulnerability—that can influence pathway design and outcomes [10–12].

For gastrectomy, the ERAS[®] Society issued a dedicated consensus guideline that graded recommendations on nasogastric tubes, prophylactic drains, antiemetic and analgesic strategies, early feeding, mobilization, and discharge criteria [12]. Since then, randomized trials and systematic reviews in gastric cancer have generally demonstrated shorter length of stay (LOS), faster gastrointestinal recovery, and cost reductions with ERAS versus conventional care, without compromising safety [13–17]. Many earlier randomized trials described their pathways as ‘fast-track’ or ‘enhanced recovery’ rather than ERAS[®]; in this review we therefore use the term ‘ERAS/fast-track’ for the intervention concept, while retaining ‘ERAS’ in the title to align with contemporary guideline terminology. Early oral feeding (EOF)—a cornerstone ERAS component—appears feasible after gastrectomy and is associated with earlier return of bowel function and reduced LOS in randomized evidence and meta-analyses [18, 19]. In contrast, “traditional” elements such as routine nasogastric decompression and prophylactic abdominal drainage have been increasingly questioned: meta-analyses in abdominal surgery show little benefit or potential harm from routine nasogastric tubes [20, 21], and recent high-level evidence in gastrectomy (including a multicenter randomized trial) has reignited nuanced debate over selective versus routine drainage [22–24].

Concurrently, operative techniques have shifted toward minimally invasive and robotic gastrectomy with oncologic equipoise to open surgery and superior short-term recovery profiles, potentially interacting with ERAS effects and heterogeneity [25–27]. Our previous RCT-only meta-analysis of ERAS/fast-track pathways for gastrectomy, together with other syntheses, supported benefits on postoperative recovery but highlighted

variability in pathway fidelity, discharge thresholds, and outpatient support, with occasional signals around readmission [13, 14, 16, 17, 28]. In the present work, we update that review with an extended search window (to 2025), re-extract all RCTs, and apply contemporary methods (RoB 2, GRADE) to provide decision-relevant estimates for clinically meaningful outcomes (time to flatus/defecation/oral intake/ambulation, LOS, hospital cost) and key safety endpoints (overall complications, pneumonia, surgical-site infection, anastomotic leak, and readmission). Our study prespecifies PRISMA-concordant methods, RoB 2 risk-of-bias assessment, and GRADE certainty appraisal to deliver decision-relevant estimates for contemporary gastrectomy care [29–31].

Methods

Search strategy

An a priori protocol specifying eligibility criteria, outcomes, and analysis plans was finalised before data extraction; key elements are summarised in the Methods and the full protocol is provided in the Online Materials. The protocol was not prospectively registered (e.g., in PROSPERO), which we recognise as a limitation; however, all primary analyses were prespecified. We used a controlled-vocabulary plus free-text strategy. MeSH headings included “Fast-Track Surgery”[MeSH], “Gastrectomy”[MeSH], “Stomach Neoplasms”[MeSH], “Randomized Controlled Trial”[Publication Type], and “Random Allocation”[MeSH]; Emtree terms included ‘fast track surgery’/exp, ‘gastrectomy’/exp, ‘stomach cancer’/exp, and ‘randomized controlled trial’/exp. Free-text covered “enhanced recovery after surgery” (ERAS), fast-track, gastrectom*, gastric cancer*/stomach neoplasm*, and random*. The time window was Dec 1, 2018–Aug 4, 2025. We also manually searched Chinese databases (CNKI, VIP, Wanfang), and hand-searched reference lists and relevant guidelines; no language limits; conference abstracts without extractable outcomes were excluded. Full strategies and yields are provided in the Online Materials. Trials meeting eligibility but with non-extractable outcomes (e.g., graphical-only reporting or lacking dispersion for conversion) or potential population overlap were synthesized narratively only and excluded from all quantitative pooling. This did not affect the prespecified primary/secondary meta-analyses. Details are provided in the Online Materials.

We conducted a randomized controlled trials (RCTs) – only meta-analysis. We defined ERAS broadly to include both multi-component ERAS pathways and protocolized single-component ERAS interventions (“component ERAS”). Comparators were conventional care or pre-ERAS routines. Primary and secondary outcomes were prespecified. Risk of bias was assessed using RoB 2, and certainty of evidence was rated with GRADE. We

pre-specified subgroup analyses for the primary endpoint (length of stay) and key secondary outcomes. Subgroups included: (1) ERAS pathway type (multimodal/full ERAS pathway vs. partial/single-component fast-track elements), (2) surgical approach (open vs. laparoscopic/robotic), (3) extent of gastrectomy (distal vs. total or proximal), and (4) geographic region (East Asia vs. other regions). For each subgroup, we estimated pooled effects and heterogeneity using the same random-effects framework as in the primary analysis. Leave-one-out sensitivity analyses were conducted for outcomes with substantial heterogeneity ($I^2 \geq 75\%$), and additional sensitivity analyses excluded high-risk-of-bias or potentially overlapping trials. The review followed PRISMA 2020 (checklist/flow diagram) and methodological standards in the Cochrane Handbook; trial-level bias was assessed with RoB 2, and certainty of evidence with GRADE [29–31].

Eligibility criteria

Parallel-group randomized controlled trials; adults (≥ 18 y) with gastric neoplasms undergoing distal or total gastrectomy; ERAS/fast-track pathway versus conventional perioperative care; at least one prespecified endpoint (LOS, time to first flatus/defecation/oral intake/ambulation, total hospital cost, overall complications, pneumonia, surgical-site infection, anastomotic leak, readmission). Exclusions: non-randomized/quasi-randomized designs, non-gastric surgery, palliative bypass only, abstract-only without extractable data, and overlapping populations.

Information sources and search strategy

We searched PubMed, Embase, Web of Science, and Cochrane CENTRAL, and manually searched Chinese databases including CNKI, VIP, and Wanfang; full search details are provided in the Online Materials.

Study selection and data extraction

ERAS components and reported adherence were extracted. Where available, we recorded the proportion of patients in whom $\geq 70\%$ of planned ERAS items were achieved. Trials were categorised as high versus lower compliance, and exploratory subgroup analyses by compliance level were performed for LOS and overall complications. For trials reporting medians and interquartile ranges, we converted to means and standard deviations using published methods (Wan et al. and Luo et al.), as detailed in Table S5 (Online Materials). Sensitivity analyses restricted to trials with directly reported mean $\pm$ SD were prespecified for LOS and key gastrointestinal recovery outcomes (first flatus and first defecation) [32, 33]. Where reported, direct hospital costs were converted to 2020 US dollars using purchasing power parity-adjusted indices and country-specific inflation rates. We

distinguished studies reporting true costs from those reporting charges or tariffs, and conducted a sensitivity analysis restricted to true-cost studies. Given sparse and heterogeneous reporting, we summarised absolute mean differences in costs as an exploratory outcome. We cross-checked trial centers and enrollment windows; when overlap was suspected, we retained the most comprehensive dataset and tested robustness by excluding the potentially overlapping trial(s).

Risk of bias and certainty assessment

We applied the RoB 2 tool at the outcome level, evaluating randomization, deviations from intended interventions, missing outcome data, outcome measurement, and selection of the reported result. Domain-level judgments with concise justifications are provided for each trial and outcome in Table S3 (Online Materials), and traffic-light plots are shown in Figure S1. GRADE downgrades for risk of bias are explicitly tied to these assessments in the Summary-of-Findings table (Table S1) [29].

Effect measures and synthesis

We used inverse-variance random-effects models for all meta-analyses. Between-study variance (τ^2) was estimated using the DerSimonian–Laird method, and 95% confidence intervals were derived with Hartung–Knapp–Sidik–Jonkman (HKSJ) adjustment as our primary approach. Heterogeneity was summarised using τ^2 and I^2 , and for key outcomes (length of stay, time to first oral intake, time to first flatus, time to first defecation, and overall complications) we additionally report 95% prediction intervals [34, 35].

Results

We identified 417 records; after removing 28 duplicates, 389 titles/abstracts were screened. 175 full-texts were assessed and 163 were excluded (reasons detailed in Fig. 1. PRISMA diagram). We finally included 27 RCTs (12 new + 15 retained [17]) totaling 3,315 participants, and the selection process is shown in Fig. 1 and study characteristics in Table 1. Study characteristics. One new trial (Tian, 2025) [41] had non-extractable outcomes/potential overlap and was synthesized narratively without quantitative pooling (see Online Materials). These were conducted across East Asia, Europe, and North America, including both open and laparoscopic gastrectomy.

Continuous outcomes. ERAS significantly shortened length of hospital (MD -1.82 days, 95% CI -2.33 to -1.30 ; $I^2 = 84\%$; Fig. 3A) [40, 42–47] and significantly accelerated recovery: time to first ambulation (MD -1.23 days, 95% CI -1.70 to -0.77 ; $I^2 = 88\%$), time to first defecation (MD -1.19 days, 95% CI -1.67 to -0.71 ; $I^2 = 75\%$) [42, 44], and time to first oral intake (MD -1.79 days, 95% CI -2.66 to -0.93 ; $I^2 = 95\%$; Fig. 3B–D) [42,

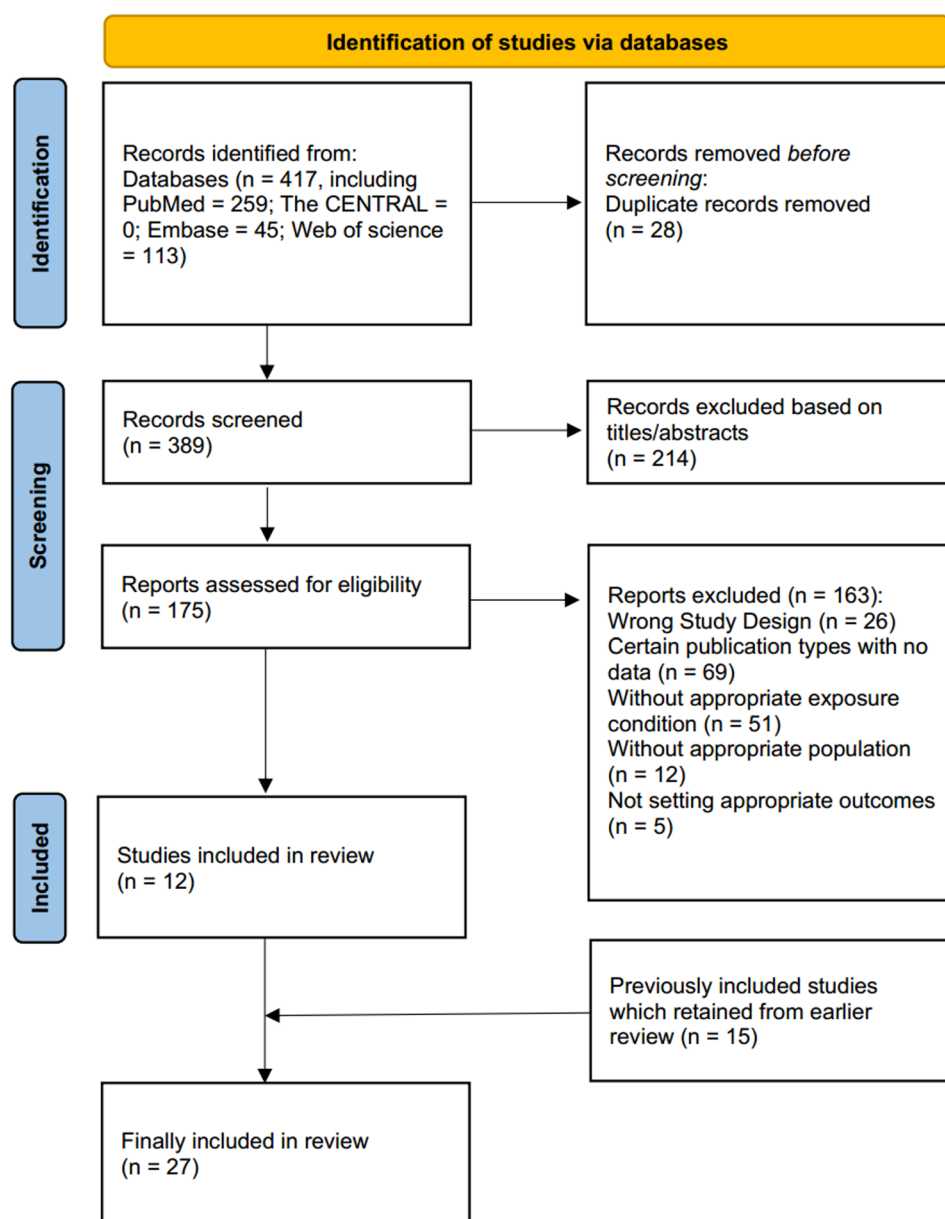


Fig. 1 PRISMA 2020 flow diagram. Flow of records, reports, and trials through the review, including reasons for full-text exclusion (non-randomized design, wrong population or procedure, insufficient extractable data, abstract-only, and overlapping datasets). Details on overlapping populations and sensitivity analyses are provided in Table S2 (Online Materials)

44]. In addition, time to first flatus was significantly earlier (MD - 0.65 days, 95% CI - 1.07 to - 0.22; $I^2 = 97\%$; Fig. 4A). Total hospital cost was significantly reduced (MD - 1347 USD, 95% CI - 2014 to - 680; $I^2 = 90\%$; Fig. 4B) [40, 42–45, 47].

Dichotomous outcomes. ERAS significantly reduced overall postoperative complications (RR 0.73, 95% CI 0.56–0.96; $I^2 = 0\%$; Fig. 2D) [40, 42–47]. Readmissions were reported in three RCTs. Pooled absolute risk differences showed no clear evidence of a difference between ERAS and conventional care, and confidence intervals were wide. Given the small number of studies, we

did not apply Egger's test or other formal small-study assessments. Discharge criteria and follow-up protocols differed between trials (Table S6), further limiting comparability.

Table 2 summarises the ERAS components included in the randomized trials and the pooled effects (with heterogeneity and statistical models) across primary and secondary outcomes, aligned with Figs. 2, 3 and 4 Table 3 presents the GRADE certainty-of-evidence assessments and RoB 2 risk-of-bias judgments by domain and overall for each outcome.

Table 1 Study characteristics

Study	Country	Arm	N	Age (years)	Female (%)	Open/Lap	Gastrectomy Type	Reconstruction	Stage (I/II/III/IV)
Tanaka, 2017 [14]	China	FTS + LADG	19	59 (49–71)	47.40%	Lap	Distal	B1: 13, B2: 6	I:1, II:10, III:8, IV:0
		LADG	22	62.5 (45–72)	54.50%	Lap	Distal	B1: 14, B2: 8	I:1, II:10, III:10, IV:1
		FTS + ODG	21	64 (40–71)	57.10%	Open	Distal	B1: 16, B2: 5	I:1, II:8, III:11, IV:1
		ODG	20	64.5 (49–75)	40.00%	Open	Distal	B1: 14, B2: 6	I:1, II:6, III:11, IV:2
Aoyama, 2019 [16]	Korea	ERAS	46	56.3 ± 10.4	28.30%	Lap (TLDG)	Distal	B1: 20, RNY: 26	Not reported
Wang, 2019 [18]	China	Conventional	51	54.5 ± 12.6	25.50%	Lap (TLDG)	Distal	B1: 21, RNY: 30	Not reported
		ERAS	30	63 ± 12	30.00%	Lap (LAG)	Distal	B1: 7, B2: 14, RNY: 9	II:13, III:17
		Conventional	31	62 ± 11	35.50%	Lap (LAG)	Distal:21, Total:9	B1: 8, B2: 10, RNY: 13	II:13, III:18
		FTS-1	64	62.4 ± 7.8	51.60%	Open	Distal:23, Total:8, Proximal	B1: 19, B2: 28, RNY: 17	I:9, II:34, III:21
Sauro, 2024 [36]	China	CC-1	64	63.0 ± 7.4	45.30%	Open	Distal:38, Proximal:11, Total:15	B1: 16, B2: 23, RNY: 25	I:13, II:32, III:19
		FTS-2	64	80.1 ± 4.0	42.20%	Open	Distal:33, Proximal:9, Total:22	B1: 15, B2: 29, RNY: 20	I:8, II:30, III:26
		CC-2	64	79.6 ± 3.5	37.50%	Open	Distal:35, Proximal:7, Total:22	B1: 11, B2: 29, RNY: 24	I:9, II:27, III:28
		FTS	41	59	46.30%	Open	Distal:37, Proximal:10, Total:17	Not specified	IB:5, II:21, III:15
He, 2010	China	Control	41	61	58.50%	Open	Not specified	Not specified	IB:6, II:23, III:12
Lee, 2020 [17]	Japan	ERAS	73	68 (29–85)	33%	Lap:63	Distal:54, Total:6, Prox:5, PP:7	B1: 32, RNY: 28, GJ: 8	I:55, II:8, III:10, IV:0
		Control	69	67 (44–85)	29%	Lap:60	Distal:49, Total:6, Prox:4, PP:8	B1: 25, RNY: 30, GJ: 9	I:47, II:7, III:15, IV:0
		FTS	21	> 65	Not specified	Open	Not specified	Not specified	IB–IIIB
		Control	21	> 65	Not specified	Open	Not specified	Not specified	IB–IIIB
Liu, 2014 [37]	China	FTS	46	42–76	34%	Open	Not specified	Not specified	Not specified
		Control	46	42–76	34%	Open	Not specified	Not specified	Not specified
		FTS	22	52.6 ± 11.6	41%	Lap	Distal only	B1: 18, B2: 1, RNY: 3	IA:19, IB:1, IIA:1, IIB:0, IIIB:1
		Control	22	57.5 ± 14.5	32%	Lap	Distal only	B1: 17, B2: 2, RNY: 3	IA:17, IB:3, IIA:1, IIB:1, IIIB:0
Kim, 2012	Korea	FTS	21	69.2 ± 5.1	52%	Lap	Distal:12, Prox:4, Total:5	B1: 6, B2: 9, RNY: 6	I:2, II:10, III:9
		Control	21	67.8 ± 3.9	57%	Open	Distal:10, Prox:5, Total:6	B1: 5, B2: 10, RNY: 4	I:3, II:9, III:9
		FTS + Lap	21	70.3 ± 5.8	43%	Lap	Distal:9, Prox:6, Total:6	B1: 6, B2: 8, RNY: 7	I:1, II:9, III:11
		Control + Lap	21	68.6 ± 4.9	48%	Open	Distal:10, Prox:6, Total:5	B1: 7, B2: 9, RNY: 3	I:3, II:10, III:8
Wan, 2014 [32]	China	FTS	45	58.8	29%	Open	Distal: 32, Proximal: 6, Total: 7	Not specified	Not specified
		Control	47	56.9	38%	Open	Distal: 36, Proximal: 6, Total: 5	Not specified	Not specified
		ERAS	73	61	34%	Lap	Distal: 56, Total: 17	B2: 56, RNY: 17	IB: 1, IIA: 9, IIB: 11, IIA: 20, IIB: 25, IIIC: 7
		Control	76	63	34%	Lap	Distal: 55, Total: 21	B2: 55, RNY: 21	IB: 2, IIA: 12, IIB: 21, IIIA: 14, IIB: 19, IIIC: 8
Xing, 2017	China	ERAS	30	60.20 ± 8.10	60%	Not specified	Not specified	B1: 19, B2: 11	I:1, II:15, III:13, IV:1
		Control	30	60.12 ± 8.14	47%	Not specified	Not specified	B1: 18, B2: 12	I:2, II:12, III:13, IV:3
		FTS	35	43.0	46%	Lap	Not specified	Not specified	IIa: 17, IIb: 18
		Control	35	43.9	43%	Lap	Not specified	Not specified	IIa: 19, IIb: 16
Zhang, 2018	China	ERAS	54	60.8	30%	Lap/Rob	Distal: 24, Total: 30	B2: 24, RNY: 30	T2-4N0-2M0 (locally advanced)
		Control	52	59.8	29%	Lap/Rob	Distal: 21, Total: 31	B2: 21, RNY: 31	T2-4, N0-2, M0 (locally advanced)

Table 1 (continued)

Study	Country	Arm	N	Age (years)	Female (%)	Open/Lap	Gastrectomy Type	Reconstruction	Stage (I/II/III/IV)
WHO Guidelines Approved by the Guidelines Review Committee, 2016 [38]	China	ERAS	54	60.8±9.4	29.6%	Rob (da Vinci)	Distal: 24, Total: 30	B2: 24, RNY: 30	T2, T3, T4
		Standard Care	52	59.8±7.9	28.8%	Rob (da Vinci)	Distal: 21, Total: 31	B2: 21, RNY: 31	T2, T3, T4
Cao, 2021	China	ERAS	85	70.8±3.4	35.3% (30/85)	Lap	Total	Esophagojeunal	23.5/51.8/24.7/0
Abdikarim, 2015 [15]	Korea	Conventional	86	71.4±3.7	37.2% (32/86)	Lap	Total	Esophagojeunal	20.9/57.0/22.1/0
		ERAS	71	61.7±10.9	35.2% (25/71)	56.3% Lap, 43.7% Open	Distal	B1/RNY/B2	74.6/9.9/15.5/0
		Conventional	76	61.7±11.0	28.9% (22/76)	52.6% Lap, 47.4% Open	Distal	B1/RNY/B2	76.3/15.8/7.9/0
Lu, 2020 [19]	Japan	LADG	81	63 (33–79)	37.0% (30/81)	Lap	Distal	B1/RNY (76.5/23.5)	69.1/30.9/0/0*
		ODG	82	67 (36–80)	36.6% (30/82)	Open	Distal	B1/RNY (85.4/14.6)	73.1/26.9/0/0*
Egger, 1997 [39]	China	ERAS	40	59±7	37.5% (15/40)	Lap/Open	Radical (Distal/Total/Proximal)	Not specified	17.5/32.5/50.0/0
		Conventional	40	60±6	35.0% (14/40)	Lap/Open	Radical (Distal/Total/Proximal)	Not specified	20.0/32.5/47.5/0
Egger, 1997 [39]	China	ERAS	186	58.3±10.5	30.6% (57/186)	Lap	Distal (94.6%)	RNY/B1/B2	22.0/41.4/36.6/0
		Conventional	184	58.6±10.9	32.6% (60/184)	Lap	Distal (96.2%)	RNY/B1/B2	18.5/40.2/41.3/0
Lee, 2025	Korea	ERAS	45	60.2±10.8	51.1% (23/45)	Lap/Rob (62.2/37.8)	Distal/Pylorus-preserving	Not specified	91.1/6.7/2.2/0*
		Conventional	47	59.3±10.2	44.7% (21/47)	Lap/Rob (63.8/36.2)	Distal/Pylorus-preserving	Not specified	80.9/12.8/6.4/0*
Swaminathan, 2020	India	ERAS	29	56.03±14.95	37.9% (11/29)	Open	Subtotal/Distal/Total	Not specified	0/0/100/0*
		Conventional	29	56.82±11.27	31.0% (9/29)	Open	Subtotal/Distal/Total	Not specified	0/0/100/0*
Weindel-mayer, 2025 [23]	China	ERAS	30	58.22±4.31	16.7% (5/30)	Lap/Open (63.3/36.7)	Proximal/Distal/Total	Not specified	23.3/35.0/36.7/0*
		Conventional	30	59.26±5.35	23.3% (7/30)	Lap/Open (56.7/43.3)	Proximal/Distal/Total	Not specified	16.7/30.0/53.3/0*
Weindel-mayer, 2025 [23]	China	EOF	51	53.41±9.77	27.5% (14/51)	Lap	Total	G/EJ	0/0/100/0*
		DOF	49	55.10±8.89	30.6% (15/49)	Lap	Total	G/EJ	0/0/100/0*
Zhou, 2021	China	TEAS	41	58.71±9.27	34.1% (14/41)	Lap/Rob (65.9/34.1)	Distal/Total (73.2/26.8)	RNY/B2	43.9/17.1/39.0/0
		Control	40	60.83±9.14	30.0% (12/40)	Lap/Rob (57.5/42.5)	Distal/Total (87.5/12.5)	RNY/B2	40.0/20.0/40.0/0

Table 1 (continued)

Study	Country	Arm	N	Age (years)	Female (%)	Open/Lap	Gastrectomy Type	Reconstruction	Stage (I/II/III/IV)
Zhao [†] , 2018 [40]	China	ERAS	186	58.3 ± 10.5	30.6%	Lap	Distal	B1: 7, B2: 54, RNY: 125	I: 22.0%, II: 41.4%, III: 36.6%
		Conventional	184	58.6 ± 10.9	32.6%	Lap	Distal	B1: 11, B2: 49, RNY: 124	I: 18.5%, II: 40.2%, III: 41.3%
Kate, 2020	India	ERAS	29	Not specified	Not specified	Open	Not specified	Not specified	Not specified
		Conventional	29	Not specified	Not specified	Open	Not specified	Not specified	Not specified

Values marked with an asterisk (*) were derived from secondary analysis or calculation. † Included in the review but excluded from quantitative pooling due to non-extractable data/potential overlap

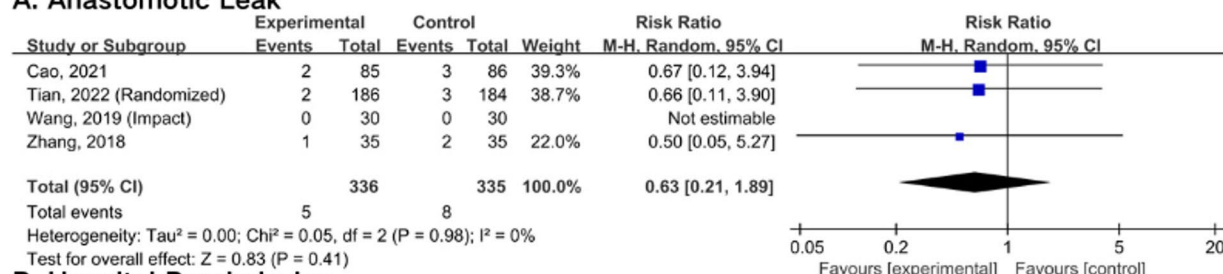
Abbreviation: Lap Laparoscopic, Open Open surgery, Rob Robotic/Robot, FTS Fast-Track Surgery, ERAS Enhanced Recovery After Surgery, LADG Laparoscopy-Assisted Distal Gastrectomy, ODG Open Distal Gastrectomy, TLDG Totally Laparoscopic Distal Gastrectomy, LAG Laparoscopy-Assisted Gastrectomy, FTS + LADG Fast-Track Surgery plus Laparoscopy-Assisted Distal Gastrectomy, FTS + ODG Fast-Track Surgery plus Open Distal Gastrectomy, FTS + Lap Fast-Track Surgery with Laparoscopic approach, FTS + Open Fast-Track Surgery with Open approach, Control + Lap Control (Conventional care) with Laparoscopic approach, Control + Open Control (Conventional care) with Open approach, Conventional Conventional care, Control Control (Conventional care), Standard Care Conventional care, FTS-1 Fast-Track Surgery group 1, FTS-2 Fast-Track Surgery group 2, CC-1 Conventional Care group 1, CC-2 Conventional Care group 2, EOF Early Oral Feeding, DOF Delayed Oral Feeding, TEAS Transcutaneous Electrical Acupoint Stimulation, B1 = B1 B2 = B2, RNY Roux-en-Y, G/Gastrojejunostomy, E/Esophageojunostomy

Publication bias and small-study effects were evaluated using funnel plots (Online Materials, Figures S5–S6), Egger’s test (Table 4), and trim-and-fill analyses for outcomes with ≥ 10 trials. For LOS, funnel plot asymmetry and borderline Egger’s test ($P \approx 0.06$) suggested possible small-study effects; trim-and-fill slightly attenuated the estimated benefit, and we downgraded certainty by one level. For overall complications, no major asymmetry was observed and Egger’s test was non-significant [39].

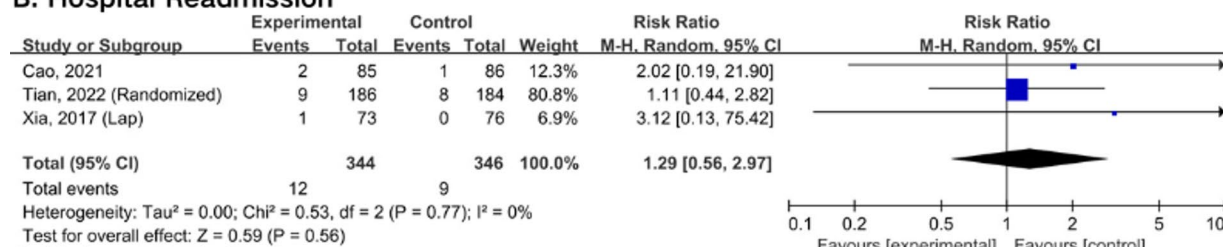
Discussion

In this RCT-only meta-analysis of gastrectomy, ERAS pathways—implemented within a contemporary surgical landscape increasingly dominated by laparoscopic and robotic approaches—were associated with materially faster postoperative recovery and meaningful reductions in resource use, without evidence of harm across major surgical safety endpoints. Specifically, ERAS shortened length of stay (LOS; Fig. 2) and accelerated the return of gastrointestinal function (time to first flatus, defecation, oral intake, and ambulation; Fig. 3A - D). Total hospital cost was reduced in trials that reported direct financial outcomes (Fig. 3E). Overall postoperative complications were reduced under ERAS in our primary analysis, whereas for specific safety endpoints (pneumonia, surgical-site infection, anastomotic leak, and readmission) there was no clear evidence of a difference between groups. Postoperative pneumonia, surgical-site infection, anastomotic leak, and readmission did not show clear evidence of a difference between ERAS and conventional care; confidence intervals were wide and compatible with modest relative benefit or harm. These findings, together with low event rates and limited power, suggest that ERAS is unlikely to confer large safety disadvantages, but important uncertainties remain. Three characteristics of the evidence base support the credibility and transportability of these findings. First, the directionality of effects was stable across endpoints: every functional recovery outcome favored ERAS, and no major safety signal emerged against ERAS. Second, although small-study effects were evident for some continuous outcomes, leave-one-out and risk-of-bias–restricted analyses did not meaningfully alter the conclusions, and the qualitative message remained coherent [29, 30]. Third, economic endpoints—variably reported and affected by cross-study differences in currency conversion and costing methods—also showed genuine heterogeneity driven by variation in ERAS bundles (e.g., early feeding, tube/drain policies, multimodal analgesia, ambulation targets, and protocol adherence), surgical approaches (open vs. laparoscopic/robotic, extent of lymphadenectomy, reconstruction routes), and discharge policies (readiness criteria, social-support checks, and weekend-discharge practices). Despite these differences, costs generally

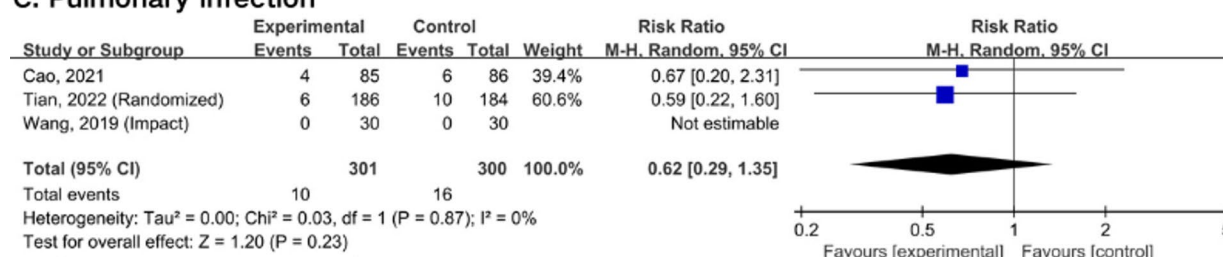
A. Anastomotic Leak



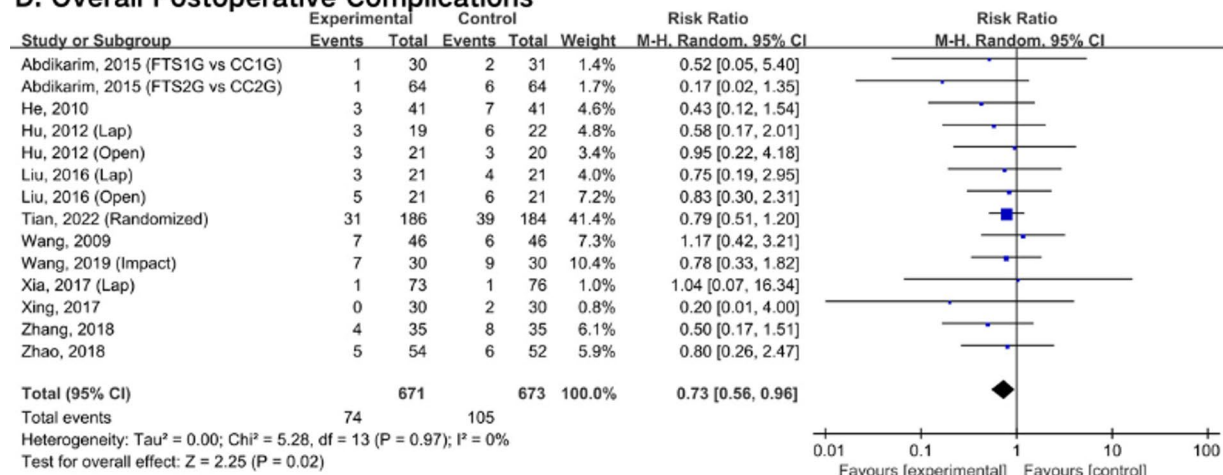
B. Hospital Readmission



C. Pulmonary Infection



D. Overall Postoperative Complications



E. Surgical Site Infection

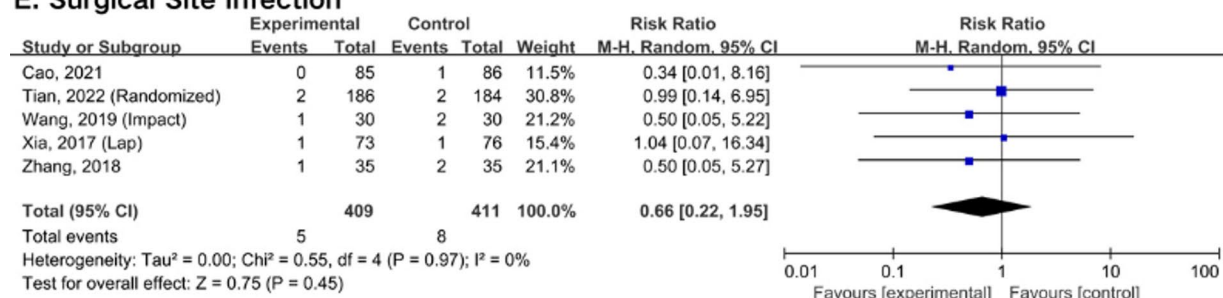
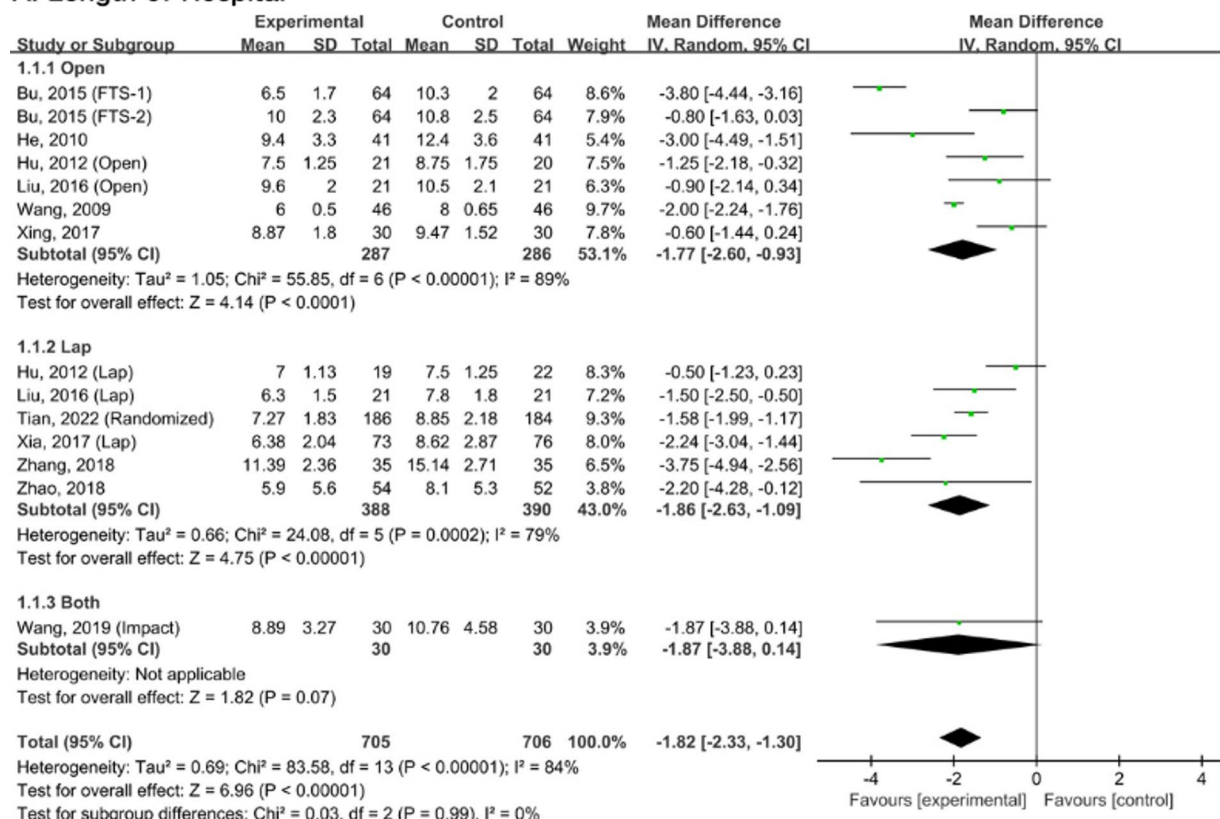


Fig. 2 Forest plot. Notes: Panels: (A) Anastomotic leak; (B) Hospital readmission; (C) Pulmonary infection (pneumonia); (D) Overall postoperative complications; (E) Surgical-site infection. Squares = study-specific effects (size proportional to inverse-variance weight); horizontal lines = 95% CI; center vertical line = null ($\text{RR} = 1$). Diamond = pooled effect (center = summary RR ; width = 95% CI). Model: Mantel-Haenszel random-effects. I^2 quantifies heterogeneity; τ^2 is between-study variance. Axes are on a log scale. 'Favours experimental/control' indicates direction ($\text{RR} < 1$ favours ERAS)

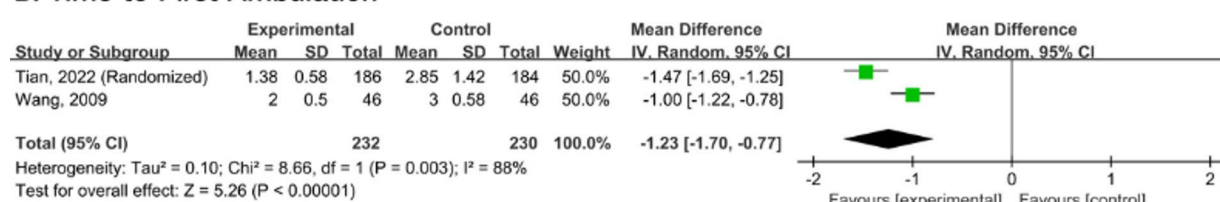
Table 2 Summary of enhanced recovery after surgery (ERAS) elements included in the randomized controlled trials

Studies	Preoperative				Perioperative					Postoperative			
	Preoperative Information/ Counseling	Reduce Fasting Times	Carbohydrate Loading	No Bowel Preparation	Optimize Anesthesia Protocols	Multimodal Anesthesia	Avoidance of NG Tubes/ Intra-abdominal Drains	Active prevention of hypothermia	Antimicrobial Prophylaxis	Narrow Incision Size	Urinary Catheter Removal	Early Progression to Food	Early Mobilization
Wang, 2019 [18]	✓	✓	✓	✓	✓	✓	✓	-	-	-	✓	✓	✓
Sauro, 2024 [36]	✓	✓	✓	✓	✓	✓	✓	✓	-	✓	✓	✓	✓
He, 2010	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Hu, 2012	✓	✓	✓	✓	✓	✓	✓	-	✓	✓	✓	✓	✓
Aoyama, 2019 [16]	✓	✓	✓	✓	✓	✓	✓	-	✓	✓	✓	✓	✓
Kim, 2012	✓	✓	✓	✓	✓	✓	✓	-	✓	✓	✓	✓	✓
Liu, 2016	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Lee, 2020 [17]	✓	✓	✓	✓	✓	✓	✓	-	✓	-	✓	✓	✓
Tang, 2010	✓	✓	✓	✓	✓	✓	✓	✓	-	✓	✓	✓	✓
Liu, 2014 [37]	✓	✓	-	✓	✓	✓	✓	✓	-	✓	✓	✓	✓
Wan, 2014 [32]	✓	✓	-	✓	✓	✓	✓	✓	-	✓	✓	✓	✓
Xia, 2017	✓	✓	✓	✓	✓	✓	✓	✓	-	✓	✓	✓	✓
Xing, 2017	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Zhang, 2018	✓	✓	-	✓	✓	✓	-	✓	-	✓	✓	✓	✓
WHO Guidelines Approved by the Guidelines Review Commit- tee, 2016 [38]	✓	✓	✓	✓	✓	✓	✓	✓	-	✓	✓	✓	✓
Swaminathan, 2020	✓	✓	✓	✓	✓	✓	✓	✓	✓	-	✓	✓	✓
Tian, 2022 (Pro)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Tian, 2022 (Ran)	✓	✓	✓	✓	✓	✓	-	✓	✓	✓	✓	✓	✓
Tian, 2025	✓	✓	✓	✓	✓	✓	-	✓	✓	✓	✓	✓	✓
Weindelmayr, 2025 [23]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Gan, 2020 [48]	✓	-	-	✓	-	-	-	-	✓	✓	-	✓	✓
Zhou, 2021	✓	✓	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Kate, 2020	✓	✓	✓	✓	✓	✓	✓	✓	✓	-	✓	✓	✓
Lu, 2020 [19]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Cao, 2021	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Lee, 2025	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Abdikarim, 2015 [15]	✓	✓	-	✓	✓	✓	-	✓	✓	✓	✓	✓	✓

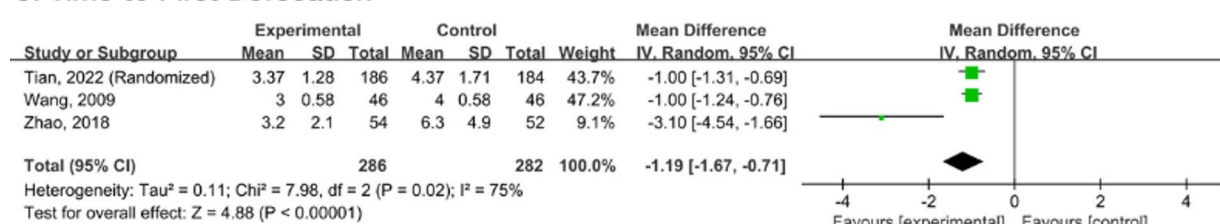
A. Length of Hospital



B. Time to First Ambulation



C. Time to First Defecation



D. Time to First Oral Intake

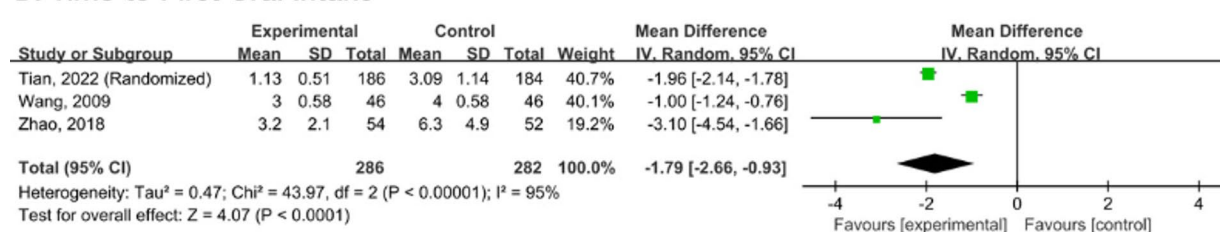
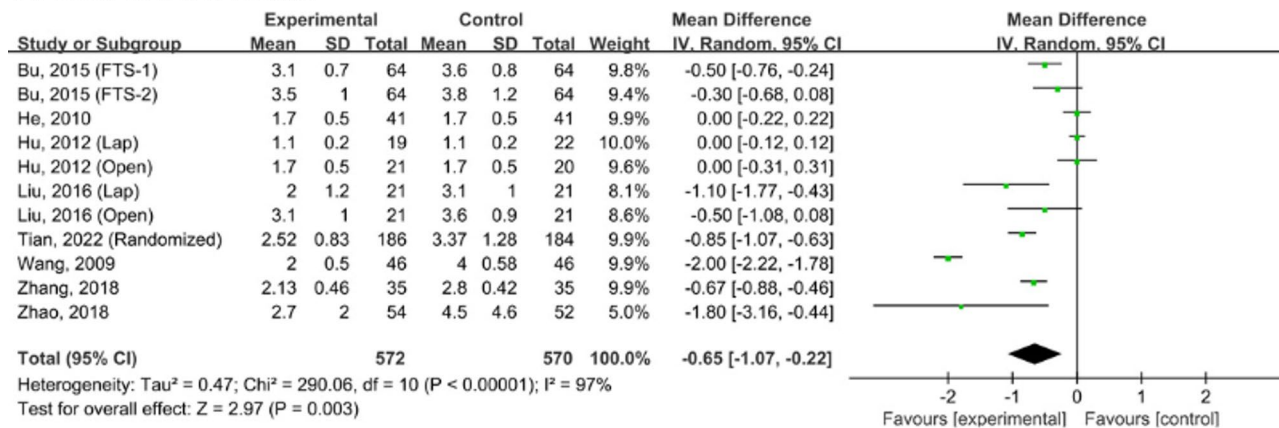


Fig. 3 Forest plot. Notes: Panels: **(A)** Length of hospital stay (with subgroups by surgical approach: open, laparoscopic, mixed); **(B)** Time to first ambulation; **(C)** Time to first defecation; **(D)** Time to first oral intake. Mean Difference (MD) with inverse-variance random-effects (IV, Random). Null line at MD=0. Negative MD indicates shorter time/LOS in ERAS (i.e., benefit). If subgroups are shown, diamonds per subgroup plus an overall diamond; 'Test for subgroup differences' reports the χ^2 and P-value

A. Time to First Flatus



B. Total Hospital Cost

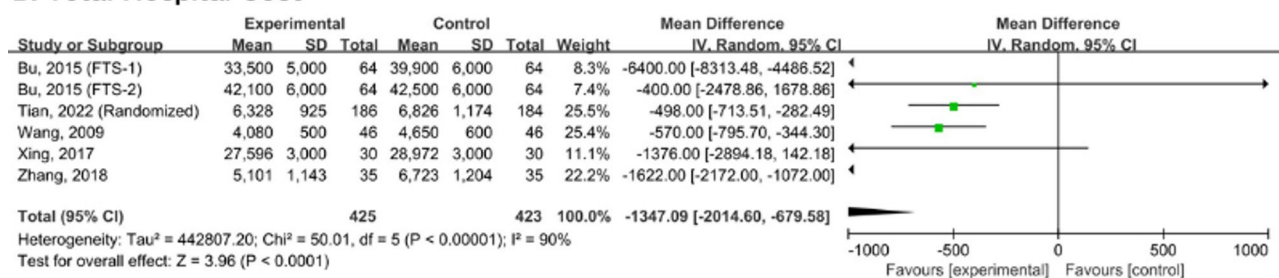


Fig. 4 Forest plot. Notes: Panels: (A) Time to first flatus (MD, IV Random); (B) Total hospital cost (MD, IV Random). Units — time in days; cost in USD unless otherwise stated. Clarify price year and exchange/PPP method in Methods. High heterogeneity (I²≥75%) should be addressed via subgroup/sensitivity analyses

decreased in parallel with shorter LOS and faster mobilization, underscoring the pragmatic value of ERAS for high-volume oncologic units [36].

Our results reinforce the directionality of pre-2020 RCT-only and mixed-design meta-analyses, which reported shorter LOS, earlier bowel recovery, and similar complication rates under ERAS [13, 17]. Compared with those earlier syntheses, the present work incorporates newer trials in which pathway components are more consistently standardized and audited. Early oral feeding (EOF) has transitioned from a cautious concept to a codified element; opioid-sparing multimodal analgesia, structured postoperative nausea and vomiting (PONV) prophylaxis, goal-directed fluid therapy (GDFT), and tube/drain minimization are now embedded rather than optional [12, 17–24, 37, 38, 48–50]. These process upgrades plausibly explain the stability of effect estimates for return-of-function endpoints despite heterogeneity in surgical approach and institutional discharge norms (Fig. 3A - D). Equally germane is the maturation of minimally invasive and robotic gastrectomy. Randomized trials and high-quality syntheses have shown oncologic equipoise between minimally invasive and open approaches, with improved short-term recovery for the former [25–27]. In such a milieu, one might anticipate diminishing marginal returns from ERAS. Yet our results indicate sustained

benefit, implying that ERAS and minimally invasive surgery are complementary: ERAS optimizes the physiologic milieu (analgesia, fluids, glycemic control, mobilization, feeding), while minimally invasive surgery reduces tissue trauma and inflammatory burden—together producing additive recovery gains. This complementarity is congruent with broader surgery-wide evidence linking higher ERAS compliance to shorter LOS without a readmission penalty [51].

In exploratory subgroup analyses, the direction of ERAS benefit on length of stay and overall complications was broadly consistent across distal versus total gastrectomy and across open versus minimally invasive approaches, although these analyses were underpowered and should be interpreted cautiously.

A recurring concern is whether earlier discharge under ERAS trades inpatient days for unplanned returns. Earlier mixed-design reviews offered inconsistent signals, often confounded by selection and institutional policies [36]. In our RCT-only update, readmissions did not increase (Fig. 3J). Plausible reasons include standardized, objective discharge criteria (pain controlled on oral agents, afebrile, predetermined ambulation targets, tolerance of oral intake, evidence of bowel function) and structured post-discharge contact (phone calls within 48–72 h, early clinic review), which mitigate avoidable returns.

Table 3 GRADE certainty of evidence summary table for meta-analysis (ERAS vs. Conventional care)

Nº of study	Risk of bias	Inconsistency	Indirectness	Imprecision	Publication bias	Nº of patients ERAS	Nº of patients Standard	Effect (95% CI)	Overall certainty of evidence
Length of Hospital Stay									
14	not serious	serious ^a	not serious	not serious	suspected ^b	705	706	MD −1.82 (−2.33 to −1.30)	⊕⊕○○ LOW
Hospital Costs									
6	not serious	serious ^a	serious ^b	not serious	not detected	425	423	MD −1347 (−2015 to −680)	⊕⊕○○ LOW
Time to First Flatus									
11	not serious	serious ^a	not serious	not serious	not detected	572	570	MD −0.65 (−1.07 to −0.22)	⊕⊕⊕○ MODERATE
Time to First Defecation									
3	not serious	serious ^a	not serious	not serious	not detected	286	282	MD −1.19 (−1.67 to −0.71)	⊕⊕⊕○ MODERATE
Time to First Oral Intake									
2	not serious	serious ^a	not serious	serious ^a	not detected	232	230	MD −1.79 (−2.66 to −0.93)	⊕⊕○○ LOW
Rate of Complication									
14	not serious	not serious	not serious	serious ^a	not detected	671	673	RR 0.73 (0.59 to 0.96)	⊕⊕⊕○ MODERATE
Pulmonary Infection									
2	not serious	not serious	not serious	serious ^a	not detected	331	330	RR 0.62 (0.29 to 1.35)	⊕⊕○○ LOW
Surgical Site Infection									
5	not serious	not serious	not serious	serious ^a	not detected	409	411	RR 0.66 (0.22 to 1.95)	⊕⊕○○ LOW
Anastomotic Leak									
4	not serious	not serious	not serious	serious ^a	not detected	336	335	RR 0.63 (0.21 to 1.89)	⊕⊕○○ LOW
Hospital Readmission									
3	not serious	not serious	not serious	serious ^a	not detected	344	346	RR 1.29 (0.56 to 2.97)	⊕⊕○○ LOW
Time to First Ambulation									
2	not serious	serious ^a	not serious	serious ^a	not detected	232	230	MD −1.23 (−1.70 to −0.77)	⊕⊕○○ LOW

1. ^a Inconsistency: high heterogeneity ($I^2 \geq 75\%$) and clinical diversity (open vs. laparoscopic, ERAS pathway composition, procedures/reconstructions)

2. ^b Indirectness: costs reported in different currencies/years; some studies converted median (IQR) to mean $\pm$ SD

3. ^c Imprecision: small number of studies for some outcomes

4. ^d Publication bias: suspected for LOS based on small-study effects in prior literature; downgraded one level

Lower surgical stress under minimally invasive platforms likely reduces post-acute symptom burden and health-care utilization [25–27]. Where single-center studies or mixed-design meta-analyses report higher readmission, the confidence intervals typically cross unity and the signal attenuates when pathway adherence and outpatient infrastructure are accounted for [36, 51]. Therefore, the core implication is not that ERAS inherently alters readmission risk, but that how ERAS is implemented, especially discharge thresholds and follow-up logistics, modulates this outcome.

Absolute event counts for anastomotic leak, surgical-site infection, and pneumonia are reported in Table 3. Fragility indices for anastomotic leak and pneumonia

were small but indicated that several events would need to change status to overturn statistical neutrality. These findings, together with wide confidence intervals, highlight limited power for rare safety outcomes.

Routine nasogastric decompression and prophylactic drainage after gastrectomy illustrate the ERAS principle of selective rather than routine use. Meta-analyses across abdominal procedures and procedure-specific randomized evidence undermine the rationale for default nasogastric tubes and routine drains, whereas risk-stratified policies (e.g., based on intraoperative complexity, reconstruction type, or anastomotic quality) strike a balance between surveillance and harm minimization [20–24]. As robotics enables more complex reconstructions with

Table 4 Egger's test

Outcome	Type	k	Egger intercept (β_0)	SE(β_0)	t-stat	df	P-value	k ≥ 10?	Interpretation
Length of hospital stay (days)	Continuous	14	0.918	1.337	0.687	12	0.505	Yes	No small-study effects ($P \geq 0.05$)
Time to first flatus (days)	Continuous	11	-2.799	3.500	-0.800	9	0.444	Yes	No small-study effects ($P \geq 0.05$)
Overall postoperative complications	Dichotomous	14	-0.270	0.461	-0.586	12	0.568	Yes	No small-study effects ($P \geq 0.05$)
Total hospital cost	Continuous	6	-2.952	1.472	-2.005	4	0.115	No	Underpowered ($k < 10$); interpret cautiously
Surgical site infection	Dichotomous	5	-0.712	0.610	-1.167	3	0.327	No	Underpowered ($k < 10$); interpret cautiously
Anastomotic leak	Dichotomous	3	-0.421	0.024	-17.203	1	0.037	No	Underpowered ($k < 10$); interpret cautiously; $P < 0.05$
Hospital readmission	Dichotomous	3	0.374	0.021	17.718	1	0.036	No	Underpowered ($k < 10$); interpret cautiously; $P < 0.05$
Time to first defecation (days)	Continuous	3	0.658	1.147	0.574	1	0.668	No	Underpowered ($k < 10$); interpret cautiously
Time to first oral intake (days)	Continuous	3	0.233	2.992	0.078	1	0.951	No	Underpowered ($k < 10$); interpret cautiously
Time to first ambulation (days)	Continuous	2	NA	NA	NA	NA	NA	No	Not computed ($k < 3$)
Pulmonary infection	Dichotomous	2	NA	NA	NA	NA	NA	No	Not computed ($k < 3$)

Egger regression assesses small-study effects. It requires at least three studies ($df = k - 2$); when $k < 3$, the test is not computable (NA). For $3 \leq k < 10$, the test is underpowered and results should be interpreted cautiously

stable anastomotic quality, such protocols can be refined prospectively, ideally with reporting of indications, duration, and criteria for early removal.

We pre-specified subgroup analyses for the primary endpoint (length of stay) and key secondary outcomes. Subgroups included: (1) ERAS pathway type (multimodal/full ERAS pathway vs. partial/single-component fast-track elements), (2) surgical approach (open vs. laparoscopic/robotic), (3) extent of gastrectomy (distal vs. total or proximal), and (4) geographic region (East Asia vs. other regions). For each subgroup, we estimated pooled effects and I^2 using the same DerSimonian–Laird random-effects model with HKSJ adjustment. Leave-one-out sensitivity analyses were conducted for outcomes with substantial heterogeneity ($I^2 \geq 75\%$) [34, 35].

For centers performing gastrectomy, the practical message is to continue implementing ERAS as routine perioperative care with vigilant attention to compliance. Operationally, we recommend: (1) prioritizing early oral feeding, early mobilization, and opioid-sparing multimodal analgesia as non-negotiable drivers of recovery (Fig. 3A and D) [12, 17–19, 37, 48, 52]; (2) embedding structured PONV prophylaxis and goal-directed fluid therapy to facilitate milestones without safety trade-offs [48, 53, 54]; (3) using tubes and drains selectively with explicit criteria for early removal, avoiding routine nasogastric decompression and prophylactic drainage in uncomplicated cases [20–24]; (4) defining quantifiable discharge thresholds and coupling them with 48–72-hour phone calls and early clinic review to stabilize

readmissions while enabling earlier discharge, and our neutral readmission signal (RR 1.29, 95% CI 0.56–2.97) is consistent with findings from recent large-scale audits/registries of high-volume ERAS programs, which likewise report no excess readmissions when standardized discharge criteria and early post-discharge contact are implemented [17, 51]; and (5) auditing pathway adherence alongside outcomes, given the consistent association between compliance and shorter LOS across surgical domains [36, 51].

Beyond intra-hospital care, structured prehabilitation and nutritional optimisation are increasingly recognised as integral components of perioperative management for gastrointestinal cancer surgery. Recent narrative data suggest that multimodal programmes combining exercise training, nutritional support, and psychological preparation can improve functional capacity and may reduce postoperative complications and length of stay in selected populations [55]. However, only a minority of gastrectomy ERAS/fast-track RCTs in our meta-analysis reported implementing such formal prehabilitation programmes, and perioperative nutritional assessment was inconsistently described. Large survey studies in surgical oncology highlight substantial variation and underuse of nutritional assessment and structured nutritional care across centres and countries [56, 57]. Together, these gaps likely attenuate the observed treatment effect of ERAS and contribute to between-trial heterogeneity, and they represent important targets for standardisation in future trials.

Strengths of this work include the exclusive focus on randomized trials, a time window extended to 2025, comprehensive coverage of recovery, safety, and cost, and rigorous adherence to PRISMA, RoB 2, and GRADE methods with explicit cross-referencing to your forest and funnel plots. Aligning the prose with your figures and supplementary tables minimizes transcription errors and improves transparency. Limitations arise from heterogeneity in ERAS content and discharge policies; the impracticability of blinding; low event rates for some safety endpoints (limiting precision for differences in SSI or leak); regional clustering; and non-standardized cost reporting that mixes charges, costs, and reimbursements, complicating cross-system comparison even when directionality is consistent. We therefore caution that, although the direction of effect is consistent, the magnitude of benefit may vary across settings. Although small-study assessment identified asymmetry for some continuous outcomes, the direction of effect was robust and sensitivity analyses supported the credibility of the main findings.

Future randomized trials should adopt core outcome sets that include patient-reported recovery (e.g., QoR-15) and days at home; prespecify discharge criteria and post-discharge contact schedules to clarify readmission dynamics; stratify by operative platform (including robotics) and reconstruction; prospectively measure ERAS adherence to enable dose–response analyses; and use standardized economic frameworks for resource use and cost [25, 48–51, 58–60]. These steps will better distinguish pathway effects from context effects and guide scalable implementation across diverse systems.

Conclusion

Contemporary randomized evidence in gastrectomy shows that ERAS consistently shortens LOS, accelerates functional recovery, and lowers costs, without evidence of increased major surgical complications. Readmission risk merits continued surveillance but is generally manageable particularly where discharge criteria and post-discharge pathways are explicit. Where resources allowed, ERAS should be adopted as routine perioperative care for gastrectomy, with ongoing audit of protocol adherence, safety indicators (including readmission), and patient-reported recovery. As minimally invasive and robotic techniques continue to diffuse, sustained ERAS deployment should prioritize fidelity to key elements, structured outpatient support, and standardized QoR-15–anchored outcomes. Future trials ought to report compliance, discharge and follow-up protocols, and test scalable, implementation-focused strategies that enable wider uptake in the robotic era [12, 17–26, 30, 36, 37, 52]. ERAS should be routinely implemented where resources allow, with ongoing auditing of safety and adherence.

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s12893-025-03399-2>.

Supplementary Material 1.

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Not applicable.

Authors' contributions

Conceptualization: W.L., L.H., G.G.; Data Curation: W.L., C.Y., G.G.; Formal Analysis: L.H., C.Y., G.G.; Funding Acquisition: G.G.; Investigation: W.L., G.G.; Methodology: L.H., G.G.; Project Administration: G.G.; Resources: W.L., G.G.; Software: L.H., G.G.; Supervision: W.L., L.H., G.G.; Validation: W.L., C.Y., G.G.; Visualization: L.H., C.Y., G.G.; Writing - Original Draft: W.L., L.H.; Writing - Review & Editing: C.Y., G.G.

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Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

All data were obtained from publicly available databases, and no additional ethics approval was required.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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