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Original Article

Exercise-based prehabilitation programs reduce hospital stay and postoperative complications in surgical patients with cancer: a systematic review and meta-analysis

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ABSTRACT

Objectives: To evaluate the effectiveness of exercise-based prehabilitation program on hospital length of stay and postoperative complications in patients with cancer undergoing surgery, and to identify which intervention characteristics are associated with greater reductions in postoperative morbidity.
Data source: A systematic search was conducted in PubMed and Web of Science from inception to June 2026.
Study selection: After eligibility assessment, 152 articles were reviewed in full, and 55 randomized controlled trials were included in the meta-analyses.
Outcomes measures: Hospital length of stay (HLOS) and postoperative complications including overall (i.e., any deviation from the normal postoperative course), major and minor complications, comprehensive complication index, pulmonary complications, pneumonias and readmissions.
Results: Exercise-based prehabilitation programs significantly reduced HLOS in the overall analysis (d = -0.21, approximately -0.79 days), although heterogeneity was substantial (I^2=85%). In stratified analyses, HLOS was significantly reduced in gastrointestinal cancers, whereas non-significant reductions were noted in thoracic and genitourinary cancers. Overall postoperative complications were reduced in the overall analysis (RR = 0.82, I^2=46%), with significant reductions observed in gastrointestinal and thoracic cancers. Postoperative pulmonary complications and pneumonias were also decreased (RR = 0.69 and 0.59; respectively). Moderator analyses indicated that larger effects were observed in studies including a higher proportion of women and older patients, and in supervised multidisciplinary aerobic or concurrent training programs.
Conclusion: Exercise-based prehabilitation programs are effective in reducing HLOS and postoperative complications in patients undergoing cancer surgery, with larger effects observed in women and older patients. Implementing supervised, multidisciplinary aerobic or concurrent training prehabilitation may serve as promising strategies to maximize postoperative recovery.

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1. Introduction

Cancer prevalence and mortality rates are rapidly increasing worldwide, making it a leading cause of morbidity and death [1]. Although surgery is considered the primary treatment for most cancers [2], it is not exempt from complications [3]. >40% of patients with cancer undergoing surgery experience postoperative complications [4,5], which are strongly associated with impaired long-term health--related quality of life [6] and survival [4,5]. In addition, many patients face prolonged hospital length of stay (HLOS), which contributes to functional decline [7] and imposes substantial costs on health systems [8].

Unhealthy lifestyles and their related comorbidities increase the risk of postoperative morbidity in patients with cancer [9–12]. In this context, prehabilitation interventions delivered before surgery to improve patients' physiological reserve, have emerged as a promising strategy to mitigate these risks [13]. Recent findings suggest that exercise-based prehabilitation (i.e., only exercise, or exercise in combination with nutritional and/or psychological interventions) programs may reduce HLOS and postoperative complications in surgical populations [14]. However, the evidence in patients with cancer remains fragmented [15,16], and the optimal components of these interventions – whether unimodal or multidisciplinary – as well as the most effective exercise characteristics according to the FITT principles (i.e., frequency, intensity, type, and time) and program duration, are still uncertain [15].

We therefore conducted a systematic review and meta-analysis to determine whether exercise-based prehabilitation programs improve postoperative outcomes in patients with cancer undergoing surgery. Moreover, we aimed to identify which aspects of the FITT criteria are associated with the greatest benefits.

2. Methods

2.1. Identification and selection of studies

All procedures followed in this study adhered to the Cochrane Collaboration Handbook for conducting systematic reviews and meta-analyses [17] and the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines (**Table S1**) [18]. The protocol of the systematic review was prospectively registered in the International Prospective Register for Systematic Reviews (PROSPERO; CRD42024525874).

A systematic review was performed in MEDLINE (via PubMed) and Web of Science databases from inception to June 2026. This systematic review included randomized controlled trials (RCTs) investigating the effects of exercise-based prehabilitation programs on postoperative outcomes. Reference lists of prior reviews were screened, and corresponding authors were contacted when data were missing. The complete search strategy is presented in **Table S2**.

2.2. Eligibility criteria

Study inclusion criteria followed PICOs strategy [17]: (1) Participants: adult patients with cancer undergoing surgery; (2) Intervention: exercise-based prehabilitation programs, either unimodal (exercise only) or multidisciplinary (exercise plus nutrition and/or psychology); (3) Control: usual care without the proposed intervention; (4) Outcomes: postoperative outcomes within the first 30 days after surgery, including HLOS, overall complications, defined as the proportion of patients experiencing at least one postoperative complication as reported by each individual study, major complications (i.e., Grade III or more, as categorized by Clavien-Dindo classification [19]; which categorizes the complications into five severity grades based on the treatment required), minor complications (i.e., Grade I-II), Comprehensive Complications Index (CCI) [20], postoperative pulmonary complications, pneumonias, and hospital readmission; (5) Study design: RCTs.

Exclusion criteria were: (1) participants younger than 18 years old; (2) non-eligible publication types (e.g., review articles, comments, observational studies or before-and-after designs); (3) absence of an exercise intervention; (4) control groups receiving any additional preoperative or postoperative intervention except for the enhanced recovery after surgery (ERAS) protocol or general recommendations. ERAS refers to evidence-based, procedure-specific, and periodically updated multidisciplinary perioperative care pathways aimed at reducing surgical stress, optimizing recovery, and improving postoperative outcomes [21]. Two independent researchers (MFE and CGS) screened all studies for eligibility, with discrepancies resolved by the senior author (FAG). During Title/Abstract screening, records were not excluded solely because postoperative outcomes were not mentioned, and full-text were retrieved whenever the population and intervention suggested potential eligibility. Language was restricted to English or Spanish.

2.3. Data extraction and risk of bias assessment

Data were extracted from the studies in a standardized form by MFE, AMM, and AOJ. For the calculation of the effect size (ES) and risk ratio (RR), we obtained from the original manuscripts: (i) mean and standard deviation (SD) of HLOS and CCI, (ii) number of patients experiencing the postoperative outcomes detailed above, and (iii) sample sizes. The collection of postoperative outcomes was based on the complications reported in each study; therefore, complications definition and reporting criteria depended on each trial criteria. We extracted overall complications, postoperative pulmonary complications (a subset of overall complications) and pneumonia (a subset of postoperative pulmonary complications) when reported, and analyzed these outcomes independently. Corresponding authors were contacted when necessary. When mean or SD were not reported, validated methods were applied to estimate them [22–24].

Additional information retrieved included: (1) author and year of publication; (2) country of data collection; (3) sample characteristics (i.e., age, sex, body mass index (BMI), cancer type, and receipt of neoadjuvant treatment). Cancer types were grouped into clinically meaningful categories – gastrointestinal, thoracic, genitourinary, and breast or mixed – which were used as a proxy for the surgical macroregions. Neoadjuvant treatment was categorized as absent, received by only a proportion of participants before the intervention, or administered concurrently with prehabilitation; 4) intervention characteristics: (i) modality (i.e., only exercise or exercise plus nutrition and/or psychology), (ii) timeline (i.e., prehabilitation or prehabilitation plus rehabilitation), (iii) exercise type (i.e., aerobic, resistance, or concurrent), (iv) frequency, (v) intensity, (vi) volume (minutes/week), (vii) supervision (supervised, home-based or mixed-settings), and (viii) duration (weeks); (5) methodological aspects: (i) whether the control group followed ERAS guidelines, and (ii) whether the Clavien-Dindo classification was used to record postoperative complications.

Methodological quality was independently assessed by two reviewers (MFE and CGS) using the Physiotherapy Evidence Database (PEDro) scale [25]. The original PEDro scale comprises 11 items addressing key methodological aspects. Nonetheless, because blinding of participants and therapists is generally not feasible in non-pharmacological trials, and these criteria are rarely fulfilled in such trials [26], these two items were excluded from the final score. Therefore, the methodological quality was assessed using a 9-item PEDro scale, as presented in **Supplementary Table S3**.

2.4. Statistical analysis

A random-effects model, specifically the inverse variance method [27,28] was applied to assess the postoperative outcomes in patients receiving exercise-based prehabilitation compared with usual care. This method was used to calculate pooled ES estimates with 95% confidence intervals (95% CIs), accounting for heterogeneity and variations in study

characteristics (i.e., country, setting, population type, and distribution). RR with 95% CIs were calculated for dichotomous data, while mean difference (MD) with 95% CIs were analyzed for continuous outcomes.

Cochran's Q test and I^2 index were used to assess statistical heterogeneity. I^2 was classified as: 0–40%, might not be important; 30–60%, may represent moderate heterogeneity; 50–90%, substantial; 75–100%, considerable [29]. Given the aims of this study and the clinical heterogeneity detected in the analyses, analyses for HLOS and overall complications were conducted stratified by clinically meaningful cancer site categories, including gastrointestinal, thoracic, and genitourinary. For postoperative pulmonary complications and pneumonias, additional analyses were conducted according to thoracic versus non-thoracic cancer context. Where sufficient data were avilable, potential moderators of ESs were additionally examined for both the overall and the cancer-stratified analyses using meta-regression (continuous variables) and analyses of variance (categorical variables). Each moderator was analyzed separately, due to the limited number of studies for some outcomes.

Sensitivity analyses were performed to assess the influence of each individual study on pooled ES and RR. Publication bias was evaluated using Egger's test [30] and Rosenthal's fail-safe N method [31], which estimates the number null results studies required to be reduce significance to an alpha level of 0.05. Risk of bias/methodological was also examined as a moderator variable (total PEDro score) using meta-regression to assess its influence on postoperative outcomes. All statistical analyses were performed using the metaphor package [32] in R.

3. Results

3.1. Search results

The systematic search retrieved 16,056 records. After removal of duplicates and screening by title and abstract, 152 articles were assessed in full-text review. The study selection process is detailed in Fig. 1. A total of 55 RCTs were included [33–87]. In one study, only the control group and the exercise-based intervention group were considered, as the additional arm involving inspiratory training alone was not classified as an exercise intervention [42]. One RCT was divided into two independent samples because there were two intervention groups [81].

3.2. Participants and studies characteristics

Descriptive characteristics of participants and interventions are presented in Table 1 **and Supplementary Table S4**. The total sample comprised 5378 participants (n = 2670 intervention and n = 2708 control), of whom 39.8% were women. At baseline, the mean age of the total sample was 65.2 years (SD = 9.0), and mean BMI was 25.2 kg/m^2 (SD = 4.3).

Most studies were conducted in patients with gastrointestinal cancer (n = 31) [33–35,38–40,45,51,54,56–60,64,66,72,74–87], followed by thoracic cancers (n = 15) [36,41,42,44,46–50,53,61–63,68,71] and genitourinary cancers (n = 7) [37,43,55,65,67,69,70]. One study included multiple cancer sites [52] and one study was conducted in patients with breast cancer [73]. Regarding the type of intervention, 32 interventions applied only-exercise intervention [36–41,43–48,50,51,53,57,59–65,68–71,74–76,78,81], 14 combined exercise with dietary and psychological support [34,35,49,55,56,58,66,67,72,77,79,82,83,86], 8 combined exercise with nutrition [33,52,54,80,81,84,85,87], and 2 combined exercise with psychological support [42,73]. The duration of the preoperative programs ranged from 1 to 16 weeks, with a mean duration of 4.12 weeks. Most interventions were conducted exclusively during the preoperative period, except for 7 studies that extended the programs into the postoperative phase [43,51,60,61,66,77,78]. Regarding exercise programs, most studies combined aerobic and resistance training (n = 38) [33–36,38,40,43,45,48,49,51–56,58,59,62–67,72–83,85,87], whereas 16 studies implemented aerobic training alone [37,39,41,42,44,46,47,50,57,60,61,68–71,86]. Only one of the included studies prescribed resistance training alone [84]. High intensity interval training (HIIT) was reported in 10 studies [33,37,39,40,47,50,56,63,68,69], of which 4 combined HIIT with resistance training

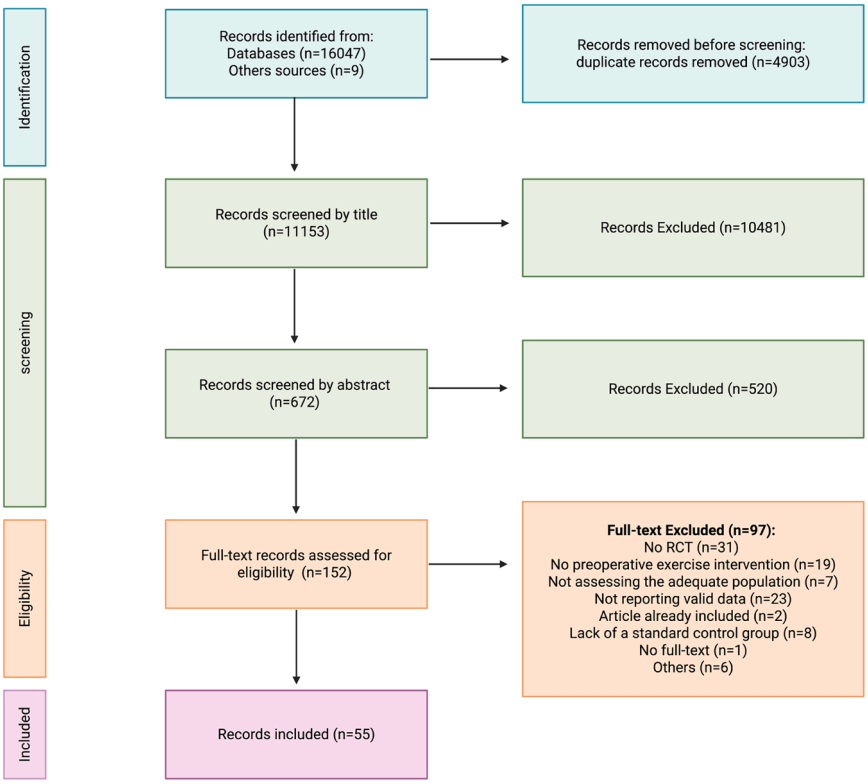


Fig. 1. Flowchart of the search and selected studies.

Table 1
General characteristics of the included studies.

Source	Country	Study design	Participants analyzed, N		Sex (women %)	Age (SD)	BMI (SD)	Type of cancer	Neoadjuvant treatment	Measured outcomes
Allen et al. (2022) [35]	United Kingdom	RCT	22	23	15.0	64.0 (8.0)	27.9 (4.9)	Esophagogastric	All radio- and/or chemotherapy	HLOS; PPC30D; READ30D
Ausania et al. (2019) [33]	Spain	RCT	18	22	45.0	65.9 (10.8)	25.8 (3.8)	Pancreatic	None	HLOS; PC30D; PCMJ30D; PCMN30D; READ30D
Banerjee et al. (2018) [37]	United Kingdom	RCT	27	28	11.7	72.1 (7.6)	27.0 (4.3)	Bladder	Some participants with neoadjuvant treatment (other no)	HLOS; PC30D; PCMJ30D; PCMN30D; PPN30D
Bausys et al. (2023) [34]	Lithuania	RCT	61	61	36.9	62.5 (10.6)	26.3 (5.2)	Gastric	Some participants with neoadjuvant treatment (other no)	HLOS
Benzo et al. (2011) [36]	United States	RCT	10	9	52.6	71.1 (7.6)	NR	Lung	NR	HLOS; PPC30D; PPN30D
Berardi et al. (2025) [87]	Italy	RCT	30	30	47.0	67.9 (11.1)	24.3 (2.0)	Liver	None	HLOS; READ30D
Berkel et al. (2022) [40]	Netherlands	RCT	28	29	47.4	73.5 (6.5)	30.2 (4.5)	Colorectal	Some participants with neoadjuvant treatment (other no)	HLOS; PC30D; PCMJ30D; PCMN30D; CCI30D; READ30D
Blackwell et al. (2020) [69]	United Kingdom	RCT	18	16	2.5	71.5 (3.1)	NR	Urological	None	PC30D; PCMJ30D; PCMN30D
Casanovas-Álvarez (2024) [73]	Spain	RCT	32	32	100.0	52.0 (11.8)	25.2 (5.0)	Breast	All radio- and/or chemotherapy	HLOS
Chen et al. (2024) [72]	China	RCT	58	57	47.0	NR	NR	Gastric	None	HLOS; PC30D; CCI30D; PPC30D; READ30D
Danielsson et al. (2025) [76]	Sweden	RCT	27	24	55.0	77.0 (6.0)	NR	Colorectal	Some participants with neoadjuvant treatment (other no)	HLOS; PC30D; PPC30D; CCI30D
Dronkers et al. (2010) [38]	Netherlands	RCT	22	20	26.2	70.0 (6.4)	26.2 (3.4)	Colon	None	HLOS; PC30D; PPC30D; PPN30D
Dunne et al. (2016) [39]	United Kingdom	RCT	19	16	29.7	61.6 (11.1)	29.5 (4.1)	Liver	Some participants with neoadjuvant treatment (other no)	HLOS; PC30D; PCMJ30D; READ30D
Fagevik-Olsén et al. (2026) [78]	Sweden	RCT	38	32	20.0	67.3 (7.6)	25.3 (3.7)	Oesophageal	Some participants with neoadjuvant treatment (other no)	PC30D; PPC30D; PPN30D
Fujimoto et al. (2025) [84]	Japan	RCT	18	27	62.2	80.4 (4.7)	21.8 (4.2)	Gastrointestinal	None	PC30D
Guang-Chuan et al. (2026) [79]	China	RCT	66	65	34.3	56.9 (9.9)	NR	Gastric	None	HLOS; PC30D; READ30D
Hamad et al. (2025) [74]	United States	RCT	28	36	36.0	66.2 (9.6)	NR	Gastrointestinal	Some participants with neoadjuvant treatment (other no)	HLOS; PC30D; CCI30D; READ30D
Han et al. (2024) [41]	China	RCT	94	100	0	63.2 (8.9)	24.1 (2.5)	Lung	None	HLOS; PPC30D; PPN30D; READ30D
Huang et al. (2017) [42]	China	RCT	30	30	31.7	63.3 (7.6)	NR	Lung	NR	HLOS; PPC30D; PPN30D
Jensen et al. (2014) [43]	Denmark	RCT	50	57	26.2	70.1 (6.5)	26.0 (2.3)	Bladder	NR	HLOS; READ30D
Karenovics et al. (2017) [68]	Switzerland	RCT	74	77	60.3	64.0 (11.5)	24.7 (4.3)	Lung	Some participants with neoadjuvant treatment (other no)	PPC30D
Karlsson et al. (2019) [45]	Sweden	RCT	10	11	62.0	77.8 (8.2)	NR	Colorectal	Some participants with neoadjuvant treatment (other no)	HLOS; PC30D
Kawata et al. (2026) [80]	Japan	RCT	25	24	16.0	65.3 (8.6)	22.1 (3.2)	Esophageal	NR	HLOS; PC30D; PPN30D
Lai et al. (2017) [46]	China	RCT	51	50	44.6	64.2 (7.4)	NR	Lung	NR	HLOS; PPC30D; PPN30D
Lai et al. (2017) [44]	China	RCT	30	30	43.3	72.1 (2.8)	NR	Lung	NR	HLOS; PPC30D; PPN30D
Lai et al. (2019) [47]	China	RCT	34	34	48.5	63.8 (7.5)	NR	Lung	NR	HLOS; PPN30D
Liang et al. (2025) [75]	China	RCT	104	101	19.0	55.5 (10.8)	23.5 (3.5)	Liver	None	HLOS; PC30D; PPC30D; READ30D
Licker et al. (2017) [50]	Switzerland	RCT	74	77	39.7	64.0 (11.5)	24.7 (4.8)	Lung	Some participants with neoadjuvant treatment (other no)	HLOS; PC30D; PPC30D; PPN30D
Liu et al. (2020) [49]	China	RCT	37	36	68.5	56.2 (9.5)	23.5 (3.2)	Lung	None	HLOS; PCMJ30D; PPN30D
Liu et al. (2026) [83]	China	RCT	43	42	17.7	65.3 (7.5)	22.8 (3.0)	Gastric	All radio- and/or chemotherapy	HLOS; PC30D; PPN30D

(*continued on next page*)

Table 1 (*continued*)

Source	Country	Study design	Participants analyzed, N		Sex (women %)	Age (SD)	BMI (SD)	Type of cancer	Neoadjuvant treatment	Measured outcomes
Loughney et al. (2024) [51]	Ireland	RCT	36	35	27.0	62.2 (9.0)	27.8 (5.0)	Esophagogastric	All radio- and/or chemotherapy	HLOS; PC30D; PCMJ30D; PCMN30D; CCI30D; READ30D
Machado et al. (2024) [48]	Portugal	RCT	20	21	31.7	68.1 (9.3)	26.5 (3.7)	Lung	None	HLOS
McIsaac et al. (2022) [52]	Canada	RCT	94	88	56.6	74.0 (6.5)	NR	Intra-abdominal and thoracic	Some participants with neoadjuvant treatment (other no)	HLOS; PC30D; PPC30D; READ30D
Minella et al. (2021) [55]	Canada	RCT	35	35	30.0	67.9 (10.3)	27.4 (4.8)	Bladder	Some participants with neoadjuvant treatment (other no)	HLOS; PC30D; PCMJ30D; PCMN30D; READ30D
Minella et al. (2018) [54]	Canada	RCT	26	25	25.5	67.6 (9.6)	25.9 (4.7)	Esophagogastric	Some participants with neoadjuvant treatment (other no)	HLOS; PC30D; PCMJ30D; PCMN30D; CCI30D; READ30D
Molenaar et al. (2023) [56]	Multicenter	RCT	123	128	45.0	68.3 (11.9)	27.5 (4.9)	Colorectal	None	HLOS; PC30D; CCI30D; READ30D
Morano et al. (2013) [53]	Brazil	RCT	12	12	62.5	66.8 (7.8)	NR	Lung	NR	HLOS; PPC30D; PPN30D
Moug et al. (2019) [57]	Scotland	RCT	18	22	35.4	65.9 (10.5)	27.3 (3.3)	Rectal	All radio- and/or chemotherapy	HLOS; PC30D
Northgraves et al. (2020) [59]	United Kingdom	RCT	10	11	47.6	63.8 (11.3)	29.0 (5.1)	Colorectal	Some participants with neoadjuvant treatment (other no)	HLOS; PC30D
Orerup et al. (2022) [60]	Sweden	RCT	317	351	40.0	68.0 (11.0)	26.0 (4.5)	Colorectal	Some participants with neoadjuvant treatment (other no)	HLOS; CCI30D
Pehlivan et al. (2011) [61]	Turkey	RCT	30	30	NR	54.4 (8.4)	23.6 (3.2)	Lung	NR	HLOS; PC30D; PPN30D
Pesce et al. (2024) [58]	Italy	RCT	35	36	40.9	69.0 (9.2)	27.9 (5.1)	Colorectal	None	HLOS; PC30D; PCMJ30D; PCMN30D; READ30D
Santa Mina et al. (2018) [65]	Canada	RCT	44	42	0.0	61.7 (7.5)	27.1 (4.3)	Prostate	NR	HLOS; PC30D; PCMJ30D; PCMN30D;
Sebio-García et al. (2016) [63]	Spain	RCT	10	12	9.0	70.1 (7.9)	27.4 (3.9)	Lung	None	HLOS; PC30D
Steffens et al. (2021) [64]	Australia	RCT	11	11	45.5	60.1 (17.0)	NR	Colorectal	Some participants with neoadjuvant treatment (other no)	HLOS; PC30D; PCMJ30D; PCMN30D
Sugimura et al. (2025) (1) [81]	Japan	RCT	26	31	19.4	69.5 (4.5)	20.9 (3.1)	Esophageal	All radio- and/or chemotherapy	PC30D; PPN30D
Sugimura et al. (2025) (2) [81]	Japan	RCT	31	31	22.7	68.1 (5.0)	21.4 (3.6)	Esophageal	All radio- and/or chemotherapy	PC30D; PPN30D
Sun et al. (2026) [82]	China	RCT	169	178	27.4	70.4 (3.7)	23.4 (3.5)	Gastric	Some participants with neoadjuvant treatment (other no)	HLOS; READ30D
Tai et al. (2026) [86]	China	RCT	100	100	53.0	65.6 (7.2)	24.0 (8.8)	Colorectal	None	HLOS
Tenconi et al. (2021) [62]	Italy	RCT	68	69	38.6	66.9 (10.7)	NR	Lung	None	HLOS; PC30D
Triguero-Cánovas et al. (2023) [66]	Spain	RCT	23	21	34.1	67.7 (8.0)	28.1 (8.3)	Colorectal	None	HLOS; PC30D
Xia et al. (2022) [70]	China	RCT	78	78	100.0	39.3 (8.9)	NR	Gynecological	NR	PC30D
Yamamoto et al. (2026) [85]	Japan	RCT	41	44	37.0	73.1 (5.9)	NR	Gastric	None	HLOS; PC30D; PCMJ30D; PPN30D
Yan et al. (2026) [77]	China	RCT	48	48	NR	71.6 (5.2)	22.6 (3.0)	Gantrointestinal	None	PC30D
Zebalski et al. (2024) [66]	Poland	RCT	36	34	100.0	56.3 (13.0)	26.9 (4.0)	Ovarian	All radio- and/or chemotherapy	HLOS; PC30D; READ30D
Zhou et al. (2024) [70]	China	RCT	51	50	60.4	55.8 (9.1)	23.4 (3.3)	Lung	NR	HLOS; PC30D; PPC30D; READ30D

Abbreviations: BMI: Body mass index; CCI30D: Comprehensive Complication Index in the first 30 days post-surgery; HLOS: Hospital Length of Stay; NR: Not reported; Participants analyzed, N: Patients analyzed for the interest outcomes in the systematic review; PC30D: Postoperative complication in the first 30 days post-surgery; PCMJ30D: Major postoperative complication in the first 30 days post-surgery; PCMN30D: Minor postoperative complication in the first 30 days post-surgery; PPC30D: Postoperative pulmonary complication in the first 30 days post-surgery; PPN30D: Postoperative pneumonia in the first 30 days post-surgery; READ30D: Readmission in the first 30 days post-surgery; RCT: Randomized controlled trial.

and 6 employed aerobic HIIT exclusively.

3.3. Effects of exercise-based prehabilitation programs on HLOS

The effects of exercise-based prehabilitation programs on HLOS are shown in Fig. 2. The overall ES was −0.21 (95% CI, −0.32 to −0.09),

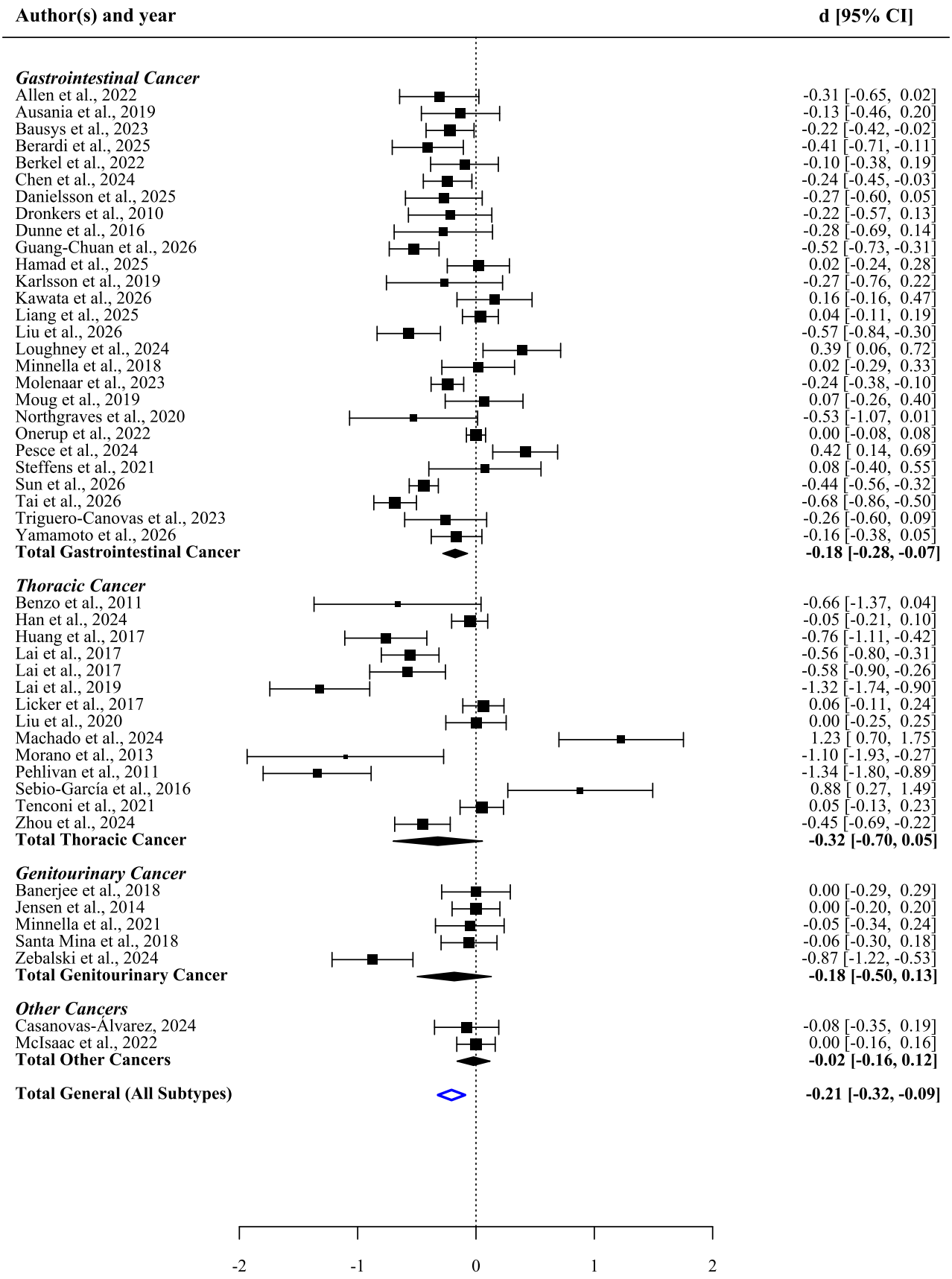


Fig. 2. Forest plot of the standardized mean differences (d) for hospital length of stay, stratified by cancer types. A positive value means an increase of the outcome in the intervention group. CI = confidence interval.

indicating a significant raw reduction of nearly one day (−0.79 days; $P < 0.01$). Substantial heterogeneity was observed across studies ($Q_{(47)} = 314.78$, $P < 0.01$; $I_2 = 90.71\%$). When stratified by cancer subtypes, exercise-based prehabilitation programs significantly reduced HLOS in gastrointestinal cancers (ES: −0.18; −0.74 days), with substantial heterogeneity detected between included studies ($Q_{(26)} = 140.30$, $P < 0.01$; $I_2 = 81.56\%$). Although not statistically significant, reductions in HLOS were also observed in thoracic (ES: −0.32; −1.17 days) and genitourinary cancers (ES: −0.18; −0.55 days). Substantial heterogeneity was noted for thoracic ($Q_{(13)} = 147.48$, $P < 0.01$; $I_2 = 95.94\%$) and genitourinary cancers ($Q_{(4)} = 21.20$, $P < 0.01$; $I_2 = 85.70\%$). Raw data are presented in **Supplementary Table S5**.

3.4. Effects of exercise-based prehabilitation programs on postoperative complications

The effects of exercise-based prehabilitation programs on the number of patients experiencing postoperative complications within 30 days after surgery are presented in Fig. 3. These programs significantly reduced the risk of postoperative complications (RR, 0.82; 95% CI, 0.73 to 0.92; $P < 0.01$). Moderate heterogeneity was detected ($I_2 = 45.8\%$; $P < 0.01$). These interventions also demonstrated significant reductions in postoperative complications in patients with gastrointestinal (RR, 0.88; 95% CI, 0.78 to 0.99) and thoracic cancers (RR, 0.76; 95% CI, 0.58 to 0.99). No heterogeneity was detected across studies in any case ($P > 0.05$). A non-significant trend toward complications reduction was observed in genitourinary cancers, with substantial heterogeneity between studies ($I_2 = 71.1\%$; $P < 0.01$).

Results for major and minor complications are shown in **Supplementary Figures S1 and S2**. Exercise-based prehabilitation programs did not significantly reduce either outcome ($P > 0.05$), and no heterogeneity between studies was observed ($I_2 = 0.00\%$, $P > 0.05$; $I_2 = 15.80\%$; $P > 0.05$; respectively). Raw data are provided in **Supplementary Table S6**.

The effects on CCI at 30 days after surgery are presented in **Supplementary Figure S3**. The overall ES was −0.18 (95% CI, −0.38 to 0.03), indicating no effect ($P > 0.05$). Substantial heterogeneity was detected ($I_2 = 85.36\%$; $P < 0.001$). Raw data of CCI are shown in **Supplementary Table S5**.

3.5. Effects of exercise-based prehabilitation programs on postoperative pulmonary outcomes and readmissions

Results for postoperative pulmonary complications and pneumonias within 30 days after the surgical procedure are presented in **Supplementary Figures S4 and S5**. Both outcomes were significantly reduced: pulmonary complications (RR, 0.69; 95% CI, 0.61 to 0.78; $P < 0.001$) and pneumonias (RR, 0.59; 95% CI, 0.42 to 0.83; $P < 0.01$). No heterogeneity was detected ($I_2 = 20.10\%$, $P > 0.05$; $I_2 = 00.0\%$, $P > 0.05$). Raw data are provided in **Supplementary Table S7**.

Readmissions rates within the first 30 days are shown in **Supplementary Figure S6**. Exercise-based prehabilitation programs did not affect readmissions (RR, 0.93; 95% CI, 0.72 to 1.22), with no heterogeneity observed ($I_2 = 0.00\%$; $P > 0.05$). Raw data are presented in **Supplementary Table S7**.

3.6. Analyses of potential moderator variables

To address heterogeneity, participants and intervention characteristics were examined as potential moderators of the effects of exercise-based prehabilitation programs on postoperative outcomes. Study-level participants moderators included sex, age, BMI, cancer type, and receipt of neoadjuvant treatment. Intervention-level moderators included type (unimodal vs. multidisciplinary) and timeline of the program, exercise type, frequency, intensity, volume, supervision, and duration. Moreover, inclusion of the ERAS protocol in the control group and the use of the Clavien-Dindo classification to record postoperative complications were analyzed as methodological moderators. Complete results are provided in **Supplementary Tables S8-S11.**

For HLOS, analyses in all cancers showed that women and patients with thoracic cancer may benefit the most. A lower BMI was related to greater effects in thoracic cancers, whereas greater benefits were observed in younger patients and women in genitourinary cancers. Concerning intervention characteristics, preoperative supervised (d=−0.40; $P < 0.0001$) multidisciplinary aerobic programs at high intensity were associated with greater HLOS reductions in all cancers. By cancer subtype, preoperative supervised multidisciplinary concurrent programs at moderate intensity seemed more effective in gastrointestinal cancers, while shorter perioperative supervised aerobic programs with high weekly frequency seemed more effective in thoracic cancers. No intervention characteristics emerged in genitourinary cancers. Absence of neoadjuvant treatment was associated with greater effects across all cancers, particularly in gastrointestinal cancers. Absence of ERAS was associated with greater reductions in HLOS in all and thoracic cancers, while in gastrointestinal cancers reductions were slightly higher when ERAS was present.

For postoperative complications, analyses across all cancers showed greater benefit in studies with higher proportion of women and in patients with genitourinary cancers. By cancer type, older patients benefited more in gastrointestinal cancers, while younger patients benefited more in thoracic and genitourinary cancers. Lower BMI in thoracic and higher rates of women in genitourinary cancers were associated with greater reductions. Regarding intervention characteristics, supervised (RR = 0.72) and mixed settings multidisciplinary aerobic (RR = 0.64) or concurrent (RR = 0.84) high-intensity programs showed the greatest reductions in all cancers. In gastrointestinal cancers, supervised multidisciplinary programs were associated with greater reductions, while aerobic programs in thoracic and shorter light-intensity programs in genitourinary cancers emerged as significant moderators. Absence of neoadjuvant treatment and presence of ERAS was associated with greater effectiveness across all cancers, with ERAS presence also detected in gastrointestinal cancers. Clavien-Dindo use was associated with greater effects across all and gastrointestinal cancers, but lower effects in genitourinary. No moderators were detected for major complications, whereas shorter programs in older patients were associated with greater reductions in minor complications.

For postoperative pulmonary complications, patients with thoracic cancer appeared to benefit the most. Supervised programs, including unimodal aerobic exercise conducted at high-intensity were associated with lower complication rates across all cancers, particularly in the absence of neoadjuvant therapy and ERAS. For postoperative pneumonias, greater effects were observed in patients with non-thoracic cancers. Unimodal concurrent programs delivered at moderate-intensity in mixed settings emerged as the most effective strategy for reducing pneumonia rate, particularly in the absence of ERAS. The use of Clavien-Dindo for registering complications was associated with greater intervention effects. No significant moderators were detected for readmissions.

3.7. Sensitivity analyses and assessment of risk of bias

Sensitivity analyses were conducted only for outcomes including >10 studies. In all cancer analyses, two studies influenced the effects of exercise-based prehabilitation programs on overall postoperative complications, one influenced the effects on minor complications, four influenced the effect on pulmonary complications, two influenced the effect on pneumonia, and two influenced readmission rate. However, exclusion of these studies did not significantly alter the pooled estimates, and they were therefore retained in the final analyses. No influential studies were identified for HLOS in the overall, gastrointestinal, or thoracic cancer analyses.

Publication bias was assessed using Egger's test and Rosenthal's fail-

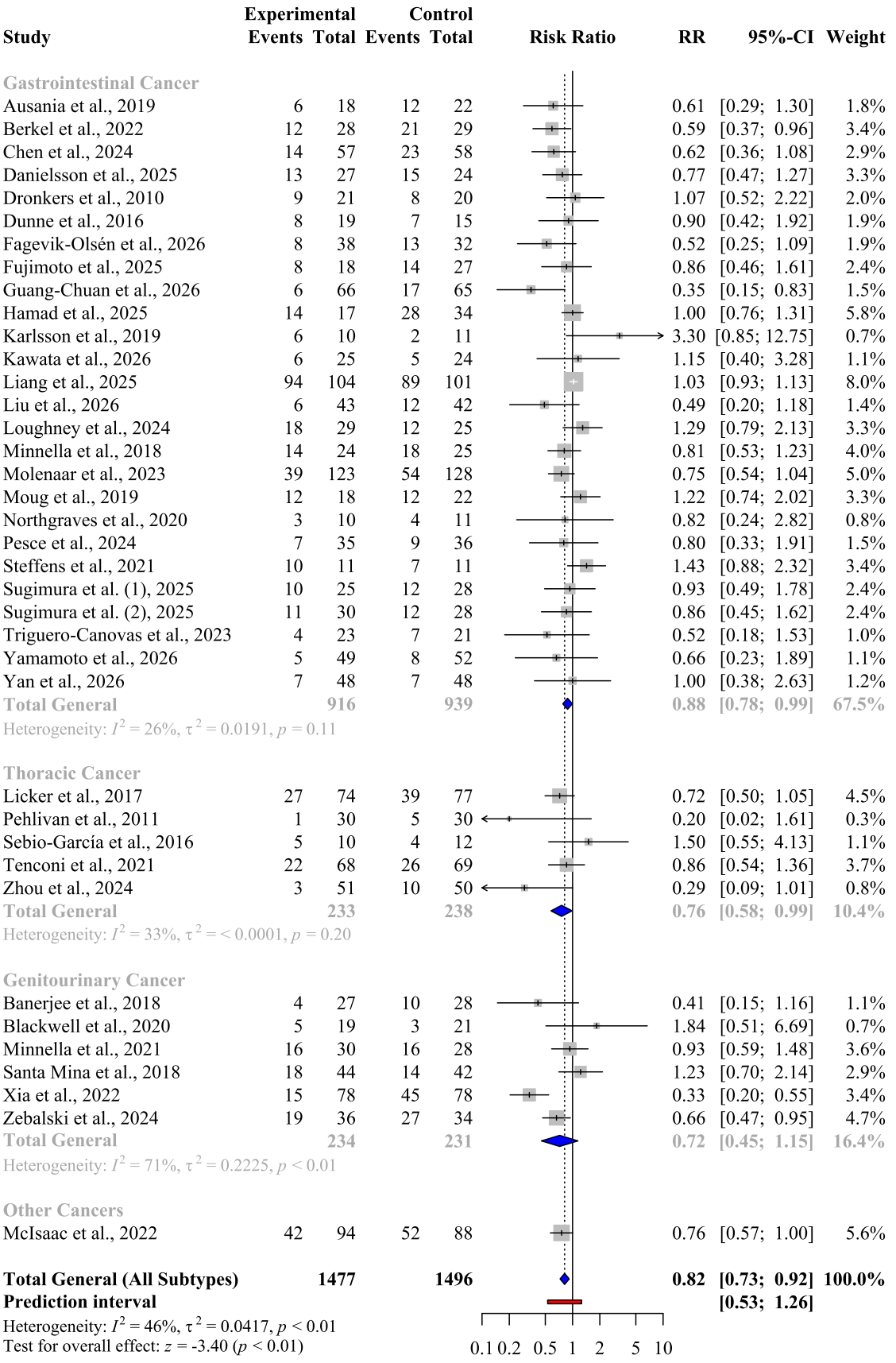


Fig. 3. Forest plot of the relative risk (RR) for overall postoperative complications, stratified by cancer types. An RR < 1 indicates a reduced risk after intervention. CI = confidence interval.

safe N method. According to Egger's test, none of the outcomes demonstrated significant bias after sensitivity analyses ($P > 0.05$). Rosenthal' *fail safe* N values for the HLOS analyses ranged from 8 to 1794, indicating robust findings for the overall, gastrointestinal, and thoracic cancer analyses. Accordingly, no evidence of publication bias was detected for the postoperative outcomes.

Methodological quality of the included studies is reported in **Supplementary Table S3**. Analyses of methodological quality as a potential moderator revealed no significant associations ($P > 0.05$), indicating that study quality did not influence the results.

4. Discussion

In this systematic review and meta-analysis, we evaluated the impact of exercise-based prehabilitation programs on postoperative outcomes in patients undergoing cancer surgery. Our findings indicate that exercise-based prehabilitation reduced HLOS, overall postoperative complications, and pulmonary complications. Notably, larger effects were observed in studies including a higher proportion of women and older patients. Regarding exercise prescription, the results suggest that incorporating supervised, multidisciplinary aerobic or concurrent exercise could represent the most effective approach. Despite the limited number and heterogeneity available, these features may help inform future trials aimed at optimizing prehabilitation protocols. Overall, the evidence reinforces that prescribing exercise prior to surgery is a key determinant of postoperative recovery in patients with cancer.

4.1. Effects of exercise-based prehabilitation programs on HLOS

Exercise-based prehabilitation significantly reduced HLOS, a clinically relevant finding given its association with improved prognosis [7]. This result is consistent with previous evidence showing that exercise interventions shorten HLOS in patients with cancer undergoing chemotherapy, radiotherapy, or stem cell/bone marrow transplantation [88]. The smaller effect size and substantial heterogeneity observed here likely reflect differences in treatment context, timing, and population characteristics. Indeed, based on our findings, patients with thoracic cancer appeared to derive larger benefits, consistent with prior evidence [16].

Studies including a higher proportion of men showed smaller effects, which may be partially explained by sex-related differences in physiological responsiveness to exercise stimuli [89]. This pattern was observed in all and genitourinary cancers, suggesting that the influence of sex may have different weight in different surgical contexts. Higher BMI was associated with reduced benefits in patients with thoracic cancer, possibly because obesity amplifies the biological response to surgery through heightened cytokine signaling, impaired immune regulation, and reduced metabolic flexibility, thereby increasing postoperative risk [10,90]. Future studies should address this high-risk population. In genitourinary cancers, younger patients appeared to benefit more, which may be partly explained by study characteristics, as the two studies conducted in genitourinary patients in whom the mean age exceeded 70 years reported null effects [37,43]. The prescribed exercise interventions may have failed to meet the minimal dose required to elicit physiological adaptations. Adherence to evidence-based and individualized prescriptions appears crucial, particularly in older and more comorbid populations [91].

Regarding intervention characteristics, aerobic exercise appeared superior when considering all cancer types and thoracic cancers specifically. This may be explained by its capacity to enhance cardiorespiratory fitness, a major determinant of patients' prognosis [92]. Even modest improvements in cardiorespiratory fitness can enhance physiological reserve and reduce surgical stress responses [93], supporting the incorporation of aerobic training into perioperative oncology care. Concurrent training, combining aerobic and resistance exercise, also emerged as an effective strategy for reducing HLOS in gastrointestinal cancers. Resistance training may be particularly valuable in contexts of prolonged recovery or risk of muscle wasting [94]; yet none of the included studies for HLOS investigated resistance training in isolation, and in those combining it with aerobic exercise, the resistance component was often poorly described. Well-designed trials are needed to clarify its role in prehabilitation. Supervision was detected as a critical factor for reducing HLOS, as guided sessions ensure adherence, appropriate load progression, and optimal physiological response [95]. This is consistent with previous evidence demonstrating that supervised exercise is more effective than home-based programs [96], and with a previous randomized controlled trials reporting no effects of home-based exercise prehabilitation on postoperative outcomes in frail patients [97]. Future trials should test whether the inclusion of technology-supported home-based programs can reproduce these benefits while improving scalability and reducing implementation burden [98].

Multidisciplinary programs were associated with greater reductions in HLOS, particularly in gastrointestinal cancers, in agreement with previous evidence [99]. This may reflect the synergistic effect of combining exercise with nutritional and psychological support, as optimizing nutritional status may potentiate the adaptive response to training, while psychological support could enhance adherence and mitigate preoperative anxiety, both of which influence recovery trajectories [99]. Although exercise intensity was not influencing results in thoracic and genitourinary cancers, high-intensity programs were associated with the largest reductions when all cancers were considered. These findings suggest that both training volume and intensity may be relevant, although further research is needed to determine optimal exercise prescription. In thoracic cancers, shorter programs with higher frequency were related to greater effects, highlighting the relevance of training consistency over program duration, particularly when the time between diagnosis and surgery is limited. Additionally, interventions delivered across the perioperative continuum (prehabilitation + postoperative rehabilitation) seemed more effective in thoracic surgery, while preoperative-only appeared more effective in gastrointestinal cancer. Future trials should further analyze the role of exercise-based intervention across the perioperative continuum, specifically in gastrointestinal context.

Our findings also suggest that the effects of exercise-based interventions in HLOS may be attenuated in patients receiving neoadjuvant treatment. Neoadjuvant therapy may blunt prehabilitation benefits due to treatment-related fatigue and deconditioning [100]. Finally, trials in which the control group did not report to follow ERAS protocol showed larger effects, suggesting that the relative benefit of exercise-based prehabilitation may be greater in non-ERAS settings due to greater room for improvement and the effectiveness of ERAS itself [101]. However, in gastrointestinal cancers, reductions in HLOS were slightly more pronounced when ERAS was present, which may reflect the larger number of available studies. Future studies should test whether well-structured multidisciplinary prehabilitation programs can provide additional benefits within contemporary ERAS frameworks, particularly in thoracic cancer patients.

4.2. Effects of exercise-based prehabilitation programs on postoperative complications

Exercise-based prehabilitation reduced the RR of postoperative complications by 18%, a clinically meaningful effect given its strong association with long-term outcomes [4,6]. This finding is consistent with previous reviews in abdominal cancer [99], but only partially aligns Steffens et al [16], who suggested that benefits may be limited to lung cancer. Although the magnitude of the effects is slightly lower than that previously reported for ERAS pathways [102], which reduced complications by 29% in surgical patients, it remains clinically relevant, particularly because exercise-based prehabilitation may provide additional benefits when integrated into optimized perioperative care.

In our analyses, cancer type moderated the effects on postoperative

complications, with smaller effects detected in gastrointestinal cancer surgery, highlighting the need for additional trials in this setting. Consistent with the previous outcome, studies including a higher proportion of women showed greater reductions, which may reflect sex-related differences in exercise responsiveness, surgical risk, and biological response to surgical stress [103], involving an increased systemic inflammation, endothelial activation, and metabolic stress in female sex [104]. Older patients appeared to benefit more overall, supporting the concept that higher-risk patients may derive greater benefit from prehabilitation and may therefore represent a priority group. However, in genitourinary and thoracic cancers, younger patients benefited more, possibly reflecting differences in study characteristics and the difficulty of providing an adequate training stimulus to the older population. The lower effectiveness observed in patients with higher BMI undergoing thoracic cancer surgery further highlights the need for tailored interventions in this metabolically vulnerable population.

Supervised multidisciplinary aerobic exercise, particularly when delivered at high intensity, appeared to offer the greatest benefits. This reinforces the importance of structured and closely monitored programs aimed at improving aerobic capacity and cardiorespiratory fitness [105]. The apparent superiority of multidisciplinary approaches is also consistent with previous evidence [99], and it may reflect the relevance of nutritional and psychological factors in surgical oncology. Concurrent programs were also beneficial, especially in gastrointestinal cancers, although their effects were smaller than those observed with aerobic-only interventions. Resistance training is often underreported, lacked clear intensity prescription, and was commonly delivered at volumes below evidence-based threshold [106] (**Supplementary Table S4**). Moreover, only one study examined resistance training in isolation for postoperative complications [84], using a poorly described and probably suboptimal program. Therefore, the specific contribution of well-prescribed resistance training to perioperative oncology care remains an important question for future trials.

The lower effects observed in studies including neoadjuvant therapy support the idea that treatment-related fatigue, deconditioning, and reduced tolerance to exercise may attenuate the benefits of prehabilitation. Nevertheless, a recent trial reported significant reductions in postoperative complications in a subgroup of patients receiving neoadjuvant chemotherapy [82], suggesting that this subgroup should not be excluded from future research, but rather targeted with better-adapted programs. The greater effectiveness observed in gastrointestinal cancer studies conducted within ERAS pathways may reflect the larger number of studies in this context but also suggest that exercise-based prehabilitation could provide additional benefits when integrated into optimized perioperative care. No significant effects were observed on major/minor complications, on the CCI, or on readmission rate; and no clear moderators were detected across outcomes. These results may reflect the limited number of studies reporting these outcomes, underscoring the need for future research with standardized reporting of these postoperative outcomes.

4.3. Effects of exercise-based prehabilitation programs on postoperative pulmonary complications

Our findings demonstrate that exercise-based prehabilitation programs significantly reduced the risk of postoperative pulmonary complications and pneumonias, with particularly pronounced benefits in patients with thoracic cancer for pulmonary complications, which concur with previous evidence [107]. As with HLOS, the presence of neoadjuvant treatment attenuated the benefits of prehabilitation on postoperative pulmonary complications, indicating that this group warrants target investigation. Moreover, future studies in thoracic cancer should provide additional information of patients' respiratory status, including the need for long-term oxygen therapy, and explore whether these patients may benefit from exercise-based prehabilitation.

High-intensity supervised aerobic exercise emerged as the most effective strategy for reducing pulmonary complications, consistent with the pattern observed in other outcomes. The potential added value of high-intensity interval training on clinical prognosis may relate to its greater capacity to elicit physiological adaptations [14], although evidence remains limited. For postoperative pneumonia, greater effects were observed in non-thoracic cancers, and concurrent programs conducted at moderate intensity in mixed settings were associated with larger benefits. This partly concurs with the HLOS findings in gastrointestinal cancers and may suggest a key role of combining aerobic and resistance training in the preoperative setting. Further studies should address whether incorporating resistance training into prehabilitation programs can reduce postoperative pulmonary complications. Greater benefits were also noted in studies where the control group did not implement ERAS protocol, underscoring the importance of evaluating prehabilitation in contemporary care pathways. Finally, larger effects were observed in studies using Clavien-Dindo.

Taken together, the overall reduction in postoperative morbidity observed across all cancer types supports the potential effectiveness of exercise-based prehabilitation programs. Moreover, these programs may also be effective for improving some psychological aspects, such as perioperative sleep and health-related quality of life, yet more evidence is needed [108,109]. Although specific cost-effectiveness studies are needed, these findings support the integration of exercise programs across the perioperative continuum. The cost of one hospital day varies widely across healthcare systems and surgical contexts but has been estimated at approximately €500–1500 [110,111]. Therefore, even a reduction of one hospital day may have relevant economic implications, especially in thoracic cancers, where reductions greater than one day were observed. Moreover, postoperative complications may further increase the cost of each hospital day [111], reinforcing the economic relevance of the observed benefits. Accordingly, exercise-based prehabilitation may be cost-effective, as previously suggested in studies evaluating direct hospital costs [112]. In addition, postoperative complications have been associated with delayed return to work [113], which may increase indirect costs, and further supports the implementation of these programs.

To conclude, although additional research is needed to establish optimal exercise prescriptions, the available evidence may inform some practical recommendations. First, preoperative exercise-based programs are effective to produce meaningful improvements in postoperative recovery and should begin as soon as surgery is scheduled, since the influence of intervention duration on postoperative outcomes remains uncertain. Second, exercise prescriptions may prioritize supervised aerobic or concurrent training to induce the necessary physiological and metabolic adaptations that enhance surgical resilience. Third, programs should be supervised by specialized trainers, ensuring appropriate load progression, and optimizing physiological response to training. Finally, multidisciplinary programs combining exercise with nutritional and psychological interventions appear to exert synergistic effects and may be considered whenever feasible, as they address complementary determinants of recovery such as nutritional status, stress regulation, and adherence. Future studies should also determine whether prehabilitation may expand surgical eligibility among frail, high-risk patients who might otherwise be considered unsuitable candidates for surgery.

To note, postoperative complications were collected as reported in each individual study, therefore, definitions criteria depended on the original trial. As we recently discussed [114], the registration of postoperative complications suffers an important methodological weakness, the lack of standardization, which limits comparability across studies and reproducibility. In this line, we explored whether the use or not of Clavien-Dindo classification moderated the effects. Particularly, we have observed that this was influencing the results on overall postoperative complications, pulmonary complications, and pneumonias. In general, higher effects were observed when studies used Clavien-Dindo to report postoperative complications, highlighting the need to adopt

standardized and transparent methods to generate more replicable and high-quality evidence.

4.4. Limitations

This study has several limitations. Although a substantial number of trials were included, evidence remains limited for certain types of cancer, particularly genitourinary ones. In addition, the literature search was restricted to PubMed and Web of Science, and therefore, potentially eligible studies indexed exclusively in other databases may have been missed. The small number of studies available for some moderators and subgroups may have influenced the findings. Substantial heterogeneity was observed across some postoperative outcomes, such as HLOS, and pooled estimates should therefore be interpreted cautiously. Moreover, differences in healthcare systems, hospital discharge policies, resource availability, and perioperative care organization across countries may have influenced the results. Data reporting inconsistencies further restricted our ability to conduct detailed analyses for some outcomes. Similarly, baseline clinical and perioperative factors were not consistently reported across studies, limiting us from specifically examining whether these factors modified the effects of exercise-based prehabilitation. In addition, the number of studies assessing major and minor complications, and CCI was insufficient to draw firm conclusions, although these represent novel endpoints in the meta-analysis literature. Moreover, the lack of standardized methods for reporting postoperative complications may have influenced the results. Nonetheless, to our knowledge, this is the first study to systematically examine which intervention components and characteristics are the most effective in optimizing postoperative recovery in patients with cancer.

5. Conclusions

Exercise-based prehabilitation programs effectively reduce HLOS and postoperative complications in patients with cancer undergoing surgery, with larger benefits observed in thoracic cancer surgery. Exploratory moderators suggested that supervised multidisciplinary aerobic or concurrent training programs may be associated with greater benefits. Further trials should evaluate their impact on the CCI and major complications and specifically address patients receiving neoadjuvant treatment and those with higher BMI.

Additional information

Author contributions: MFE: Conceptualization, methodology, investigation, data curation, Writing – Original Draft. **SCC**: Conceptualization, methodology, investigation, and Writing – Original Draft. **CGS:** Conceptualization, data curation and Writing – Original Draft. **AOP**: Data curation, Writing – Review and Editing. **AMM**: Data curation and Writing – Review and Editing. **ACB**: Formal analyses, visualization and Writing – Review and Editing. **JRR:** Supervision and Writing – Review and editing. **FAG**: Conceptualization, Writing- Review and Editing, supervision, project administration and funding acquisition.

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Declaration of competing interest

The authors declare no conflict of interest.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ejim.2026.107104.

Data availability

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

References

[1] Sung H, Ferlay J, Siegel RL, Laversanne M, Soerjomataram I, Jemal A, 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. https://doi.org/10.3322/caac.21660.

[2] Sullivan R, Alatise OI, Anderson BO, Audisio R, Autier P, Aggarwal A, et al. Global cancer surgery: delivering safe, affordable, and timely cancer surgery. Lancet Oncol 2015;16:1193–224. https://doi.org/10.1016/S1470-2045(15)00223-5.

[3] Finnerty CC, Mabvuure NT, Kozar RA, Herndon DN. The surgically induced stress response. J Parenter Enter Nutr 2013;37:21S–9S. https://doi.org/10.1177/0148607113496117.

[4] Breugom AJ, van Dongen DT, Bastiaannet E, Dekker FW, van der Geest LGM, Liefers GJ, et al. Association between the most frequent complications after surgery for stage I–III colon cancer and short-term survival, long-term survival, and recurrences. Ann Surg Oncol 2016;23:2858–65. https://doi.org/10.1245/s10434-016-5226-z.

[5] Andalib A, Ramana-Kumar AV, Bartlett G, Franco EL, Ferri LE. Influence of postoperative infectious complications on long-term survival of lung cancer patients: a population-based cohort study. J Thorac Oncol 2013;8:554–61.

[6] Kauppila JH, Johar A, Lagergren P. Medical and surgical complications and health-related quality of life after esophageal cancer surgery. Ann Surg 2020;271:502–8. https://doi.org/10.1097/SLA.0000000000003097.

[7] Sultan A, Pati AK, Choudhary V, Parganiha A. Hospitalization-induced exacerbation of the ill effects of chemotherapy on rest-activity rhythm and quality of life of breast cancer patients: a prospective and comparative cross-sectional follow-up study. Chronobiol Int 2018;35:1513–32. https://doi.org/10.1080/07420528.2018.1493596.

[8] Roemer, M. Cancer-related hospitalizations for adults, 2017. HCUP Statistical Brief #270, Agency for Healthcare Research and Quality; 2021.

[9] Shariq OA, Hanson KT, McKenna NP, Kelley SR, Dozois EJ, Lightner AL, et al. Does metabolic syndrome increase the risk of postoperative complications in patients undergoing colorectal cancer surgery? Dis Colon Rectum 2019;62:849–58. https://doi.org/10.1097/DCR.0000000000001334.

[10] Fleming CA, O'Connell EP, Kavanagh RG, O'Leary DP, Twomey M, Corrigan MA, et al. Body composition, inflammation, and 5-year outcomes in colon cancer. JAMA Netw Open 2021;4:e2115274. https://doi.org/10.1001/jamanetworkopen.2021.15274.

[11] Cheng E, Ou F-S, Ma C, Spiegelman D, Zhang S, Zhou X, et al. Diet-and lifestyle-based prediction models to estimate cancer recurrence and death in patients with stage III colon cancer (CALGB 89803/Alliance). J Clin Oncol 2022;40:740–51. https://doi.org/10.1200/JCO.21.

[12] Onerup A, Angenete E, Bonfre P, Börjesson M, Haglind E, Wessman C, et al. Self-assessed preoperative level of habitual physical activity predicted postoperative complications after colorectal cancer surgery: a prospective observational cohort study. Eur J Surg Oncol 2019;45:2045–51. https://doi.org/10.1016/j.ejso.2019.06.019.

[13] Carli F, Zavorsky GS. Optimizing functional exercise capacity in the elderly surgical population. Curr Opin Clin Nutr Metab Care 2005:23–32.

[14] Clifford K, Woodfield JC, Tait W, Campbell HA, Baldi JC. Association of preoperative high-intensity interval training with cardiorespiratory fitness and postoperative outcomes among adults undergoing major surgery: a systematic review and meta-analysis. JAMA Netw Open 2023;6:e2320527. https://doi.org/10.1001/jamanetworkopen.2023.20527.

[15] Del Bianco N, Borsati A, Toniolo L, Ciurnielli C, Belluomini L, Insolda J, et al. What is the role of physical exercise in the era of cancer prehabilitation? A systematic review. Crit Rev Oncol Hematol 2024;198:104350. https://doi.org/10.1016/j.critrevonc.2024.104350.
[16] Steffens D, Hancock M, Jiang W, Solomon M, Koh C, Hirst N, et al. An updated systematic review and meta-analysis of unimodal prehabilitation with exercise intervention to enhance postoperative outcomes in cancer surgery. Anesth Analg 2025;140:811–20. https://doi.org/10.1213/ANE.0000000000007226.
[17] Higgins, J., Thomas, J., Chandler, J., Cumpston, M., Li, T., Page, M., et al., editors. Cochrane handbook for systematic reviews of interventions version 6.4 (updated 2023). Cochrane, 2023. Available from www.training.cochrane.org/handbook. n.d.
[18] Ardern CL, Büttner F, Andrade R, Weir A, Ashe MC, Holden S, et al. Implementing the 27 PRISMA 2020 Statement items for systematic reviews in the sport and exercise medicine, musculoskeletal rehabilitation and sports science fields: the PERSiST (implementing Prisma in Exercise, Rehabilitation, Sport medicine and SporTs science) guidance. Br J Sports Med 2022;56:175–95. https://doi.org/10.1136/bjsports-2021-103987.
[19] Clavien PA, Barkun J, de Oliveira ML, Vauthey JN, Dindo D, Schulick RD, et al. The Clavien-Dindo classification of surgical complications: five-year experience. Ann Surg 2009;250:187–96. https://doi.org/10.1097/SLA.0b013e3181b13ca2.
[20] Slankamenac K, Graf R, Barkun J, Puhan MA, Clavien PA. The comprehensive complication index: a novel continuous scale to measure surgical morbidity. Ann Surg 2013;258:1–7. https://doi.org/10.1097/SLA.0b013e318296c732.
[21] Gustafsson UO, Rockall TA, Wexner S, How KY, Emile S, Marchuk A, et al. Guidelines for perioperative care in elective colorectal surgery: enhanced recovery after surgery (ERAS) society recommendations 2025. Surgery 2025;184:109397. https://doi.org/10.1016/j.surg.2025.109397.
[22] Shi J, Luo D, Weng H, Zeng XT, Lin L, Chu H, et al. Optimally estimating the sample standard deviation from the five-number summary. Res Synth Methods 2020;11:641–54. https://doi.org/10.1002/jrsm.1429.
[23] Luo D, Wan X, Liu J, Tong T. Optimally estimating the sample mean from the sample size, median, mid-range, and/or mid-quartile range. Stat Methods Med Res 2018;27:1785–805. https://doi.org/10.1177/0962280216669183.
[24] Wan, X., Wang, W., Liu, J., Tong, T. Estimating the sample mean and standard deviation from the sample size, median, range and/or interquartile range. vol. 14. 2014.
[25] Maher CG, Sherrington C, Herbert RD, Moseley AM, Elkins M. Reliability of the PEDro scale for rating quality of randomized controlled trials. Phys Ther 2003;83:713–21. https://doi.org/10.1093/ptj/83.8.713.
[26] Foley NC, Bhogal SK, Teasell RW, Bureau Y, Speechley MR. Estimates of quality and reliability with the physiotherapy evidence-based database scale to assess the methodology of randomized controlled trials of pharmacological and nonpharmacological interventions. Phys Ther 2006;86:817–24. https://doi.org/10.1093/ptj/86.6.817.
[27] Riley RD, Higgins JPT, Deeks JJ. Interpretation of random effects meta-analyses. BMJ 2011;342:d549. https://doi.org/10.1136/bmj.d549.
[28] Borenstein M, Hedges LV, Higgins JPT. A basic introduction to fixed-effect and random-effects models for meta-analysis. Res Synth Methods 2010;1:97–111. https://doi.org/10.1002/jrsm.12.
[29] Higgins JPT, Thompson SG. Quantifying heterogeneity in a meta-analysis. Stat Med 2002;21:1539–58. https://doi.org/10.1002/sim.1186.
[30] Egger M, Smith GD, Schneider M, Minder C. Papers bias in meta-analysis detected by a simple, graphical test. BMJ 1997;315:629–34. https://doi.org/10.1136/bmj.315.7109.629.
[31] Rosenthal R. The file drawer problem and tolerance for null results. Psychol Bull 1979;86:638–41.
[32] Viechtbauer, W. Conducting meta-analyses in R with the metafor package. vol. 36. 2010.
[33] Ausania F, Senra P, Meléndez R, Caballeiro R, Ouviña R, Casal-Núñez E. Prehabilitation in patients undergoing pancreaticoduodenectomy: a randomized controlled trial. Rev Esp Enferm Dig 2019;111:603–8. https://doi.org/10.17235/REED.2019.6182/2019.
[34] Bausys A, Luksta M, Anglickiene G, Maneikiene VV, Kryzauskas M, Rybakovas A, et al. Effect of home-based prehabilitation on postoperative complications after surgery for gastric cancer: randomized clinical trial. Br J Surg 2023;110:1800–7. https://doi.org/10.1093/bjs/znad312.
[35] Allen SK, Brown V, White D, King D, Hunt J, Wainwright J, et al. Multimodal prehabilitation during neoadjuvant therapy prior to esophagogastric cancer resection: effect on cardiopulmonary exercise test performance, muscle mass and quality of life—A pilot randomized clinical trial. Ann Surg Oncol 2022;29:1839–50. https://doi.org/10.1245/s10434-021-11002-0.
[36] Benzo R, Wigle D, Novotny P, Wetzstein M, Nichols F, Shen RK, et al. Preoperative pulmonary rehabilitation before lung cancer resection: results from two randomized studies. Lung Cancer 2011;74:441–5. https://doi.org/10.1016/j.lungcan.2011.05.011.
[37] Banerjee S, Manley K, Shaw B, Lewis L, Cucato G, Mills R, et al. Vigorous intensity aerobic interval exercise in bladder cancer patients prior to radical cystectomy: a feasibility randomised controlled trial. Support Care Cancer 2018;26:1515–23. https://doi.org/10.1007/s00520-017-3991-2.
[38] Dronkers JJ, Lamberts H, Reutelingsperger I, Naber RH, Dronkers-Landman CM, Veldman A, et al. Preoperative therapeutic programme for elderly patients scheduled for elective abdominal oncological surgery: a randomized controlled pilot study. Clin Rehabil 2010;24:614–22. https://doi.org/10.1177/0269215509358941.
[39] Dunne DFJ, Jack S, Jones RP, Jones L, Lythgoe DT, Malik HZ, et al. Randomized clinical trial of prehabilitation before planned liver resection. Br J Surg 2016;103:504–12. https://doi.org/10.1002/bjs.10096.
[40] Berkel AEM, Bongers BC, Kotte H, Weltevreden P, De Jongh FHC, Eijsvogel MMM, et al. Effects of community-based exercise prehabilitation for patients scheduled for colorectal surgery with high risk for postoperative complications: results of a randomized clinical trial. Ann Surg 2022;275:e299–306. https://doi.org/10.1097/SLA.0000000000004702.
[41] Han D, Wang X, Sun X, Cao Y, Li C, Guo W, et al. Ultra-short-period perioperative pulmonary rehabilitation on short-term outcomes after surgery in smoking patients with lung cancer: a randomized clinical trial. Int J Surg 2025;111:581–8. https://doi.org/10.1097/JS9.0000000000001856.
[42] Huang J, Lai Y, Zhou X, Li S, Su J, Yang M, et al. Short-term high-intensity rehabilitation in radically treated lung cancer: a three-armed randomized controlled trial. J Thorac Dis 2017;9:1919–29. https://doi.org/10.21037/jtd.2017.06.15.
[43] Jensen BT, Petersen AK, Jensen JB, Laustsen S, Borre M. Efficacy of a multiprofessional rehabilitation programme in radical cystectomy pathways: a prospective randomized controlled trial. Scand J Urol 2015;49:133–41. https://doi.org/10.3109/21681805.2014.967810.
[44] Lai Y, Huang J, Yang M, Su J, Liu J, Che G. Seven-day intensive preoperative rehabilitation for elderly patients with lung cancer: a randomized controlled trial. J Surg Res 2017;209:30–6. https://doi.org/10.1016/j.jss.2016.09.033.
[45] Karlsson E, Farahnak P, Franzén E, Nygren-Bonnier M, Dronkers J, Van Meeteren N, et al. Feasibility of preoperative supervised home-based exercise in older adults undergoing colorectal cancer surgery – A randomized controlled design. PLoS One 2019;14:e0219158. https://doi.org/10.1371/journal.pone.0219158.
[46] Lai Y, Su J, Qiu P, Wang M, Zhou K, Tang Y, et al. Systematic short-term pulmonary rehabilitation before lung cancer lobectomy: a randomized trial. Interact Cardiovasc Thorac Surg 2017;25:476–83. https://doi.org/10.1093/icvts/ivx141.
[47] Lai Y, Wang X, Zhou K, Su J, Che G. Impact of one-week preoperative physical training on clinical outcomes of surgical lung cancer patients with limited lung function: a randomized trial. Ann Transl Med 2019;7:544. https://doi.org/10.21037/atm.2019.09.151.
[48] Machado P, Pimenta S, Garcia AL, Nogueira T, Silva S, dos Santos CL, et al. Effect of preoperative home-based exercise training on quality of life after lung cancer surgery: a multicenter randomized controlled trial. Ann Surg Oncol 2024;31:847–59. https://doi.org/10.1245/s10434-023-14503-2.
[49] Liu Z, Qiu T, Pei L, Zhang Y, Xu L, Cui Y, et al. Two-week multimodal prehabilitation program improves perioperative functional capability in patients undergoing thoracoscopic lobectomy for lung cancer: a randomized controlled trial. Anesth Analg 2020;131:840–9. https://doi.org/10.1213/ANE.0000000000004342.
[50] Licker M, Karenovics W, Diaper J, Frésard I, Triponez F, Ellenberger C, et al. Short-term preoperative high-intensity interval training in patients awaiting lung cancer surgery: a randomized controlled trial. J Thorac Oncol 2017;12:323–33. https://doi.org/10.1016/j.jtho.2016.09.125.
[51] Loughney L, Bolger J, Tully R, Sorensen J, Bambrick M, Carroll PA, et al. The effect of a pre-operative and post-operative exercise programme versus standard care on physical fitness of patients with oesophageal and gastric cancer undergoing neoadjuvant treatment prior to surgery (the PERIOP-OG trial): a randomized controlled trial. Int J Surg 2024;110:6632–46. https://doi.org/10.1097/JS9.0000000000001663.
[52] McIsaac DI, Hladkowicz E, Bryson GL, Forster AJ, Gagne S, Huang A, et al. Home-based prehabilitation with exercise to improve postoperative recovery for older adults with frailty having cancer surgery: the PREHAB randomised clinical trial. Br J Anaesth 2022;129:41–8. https://doi.org/10.1016/j.bja.2022.04.006.
[53] Morano MT, Araújo AS, Nascimento FB, Da Silva GF, Mesquita R, Pinto JS, et al. Preoperative pulmonary rehabilitation versus chest physical therapy in patients undergoing lung cancer resection: a pilot randomized controlled trial. Arch Phys Med Rehabil 2013;94:53–8. https://doi.org/10.1016/j.apmr.2012.08.206.
[54] Minnella EM, Awasthi R, Loiselle SE, Agnihotram RV, Ferri LE, Carli F. Effect of exercise and nutrition prehabilitation on functional capacity in esophagogastric cancer surgery: a randomized clinical trial. JAMA Surg 2018;153:1081. https://doi.org/10.1001/jamasurg.2018.1645.
[55] Minnella EM, Awasthi R, Bousquet-Dion G, Ferreira V, Austin B, Audi C, et al. Multimodal prehabilitation to enhance functional capacity following radical cystectomy: a randomized controlled trial. Eur Urol Focus 2021;7:132–8. https://doi.org/10.1016/j.euf.2019.05.016.
[56] Molenaar CJL, Minnella EM, Coca-Martinez M, Ten Cate DWG, Regis M, Awasthi R, et al. Effect of multimodal prehabilitation on reducing postoperative complications and enhancing functional capacity following colorectal cancer surgery: the PREHAB randomized clinical trial. JAMA Surg 2023;158:572. https://doi.org/10.1001/jamasurg.2023.0198.
[57] Moug SJ, Mutrie N, Barry SJE, Mackay G, Steele RJC, Boachie C, et al. Prehabilitation is feasible in patients with rectal cancer undergoing neoadjuvant chemoradiotherapy and may minimize physical deterioration: results from the REx trial. Colorectal Dis 2019;21:548–62. https://doi.org/10.1111/codi.14560.
[58] Pesce A, Fabbri N, Colombari S, Uccellatori L, Grazzi G, Lordi R, et al. A randomized controlled clinical trial on multimodal prehabilitation in colorectal cancer patients to improve functional capacity: preliminary results. Surg Endosc 2024;38:7440–50. https://doi.org/10.1007/s00464-024-11198-8.
[59] Northgraves MJ, Arunachalam L, Madden LA, Marshall P, Hartley JE, MacFie J, et al. Feasibility of a novel exercise prehabilitation programme in patients

scheduled for elective colorectal surgery: a feasibility randomised controlled trial. Support Care Cancer 2020;28:3197–206. https://doi.org/10.1007/s00520-019-05098-0.
[60] Onerup A, Andersson J, Angenete E, Bock D, Börjesson M, Ehrencrona C, et al. Effect of short-term homebased pre- and postoperative exercise on recovery after colorectal cancer surgery (PHYSSURG-C): a randomized clinical trial. Ann Surg 2022;275:448–55. https://doi.org/10.1097/SLA.0000000000004901.
[61] Pehlivan E, Turna A, Gurses A, Gurses HN. The effects of preoperative short-term intense physical therapy in lung cancer patients: a randomized controlled trial. Ann Thorac Cardiovasc Surg 2011;17:461–8. https://doi.org/10.5761/atcs.oa.11.01663.
[62] Tenconi S, Mainini C, Rapicetta C, Braglia L, Galeone C, Cavuto S, et al. Rehabilitation for lung cancer patients undergoing surgery: results of the PUREAIR randomized trial. Eur J Phys Rehabil Med 2021;57:1002–11. https://doi.org/10.23736/S1973-9087.21.06789-7.
[63] Sebio García R, Yáñez-Brage MI, Giménez Moolhuyzen E, Salorio Riobo M, Lista Paz A, Borro Mate JM. Preoperative exercise training prevents functional decline after lung resection surgery: a randomized, single-blind controlled trial. Clin Rehabil 2017;31:1057–67. https://doi.org/10.1177/0269215516684179.
[64] Steffens D, Young J, Beckenkamp PR, Ratcliffe J, Rubie F, Ansari N, et al. Feasibility and acceptability of a preoperative exercise program for patients undergoing major cancer surgery: results from a pilot randomized controlled trial. Pilot Feasibility Stud 2021;7. https://doi.org/10.1186/s40814-021-00765-8.
[65] Santa Mina D, Hilton WJ, Matthew AG, Awasthi R, Bousquet-Dion G, Alibhai SMH, et al. Prehabilitation for radical prostatectomy: a multicentre randomized controlled trial. Surg Oncol 2018;27:289–98. https://doi.org/10.1016/j.suronc.2018.05.010.
[66] Triguero-Cánovas D, López-Rodríguez-Arias F, Gómez-Martínez M, Sánchez-Guillén L, Peris-Castelló F, Alcaide-Quirós MJ, et al. Home-based prehabilitation improves physical conditions measured by ergospirometry and 6MWT in colorectal cancer patients: a randomized controlled pilot study. Support Care Cancer 2023;31. https://doi.org/10.1007/s00520-023-08140-4.
[67] Zębalski MA, Parysek K, Krzywon A, Nowosielski K. LUNA EMG as a marker of adherence to prehabilitation programs and its effect on postoperative outcomes among patients undergoing cytoreductive surgery for ovarian cancer and suspected ovarian tumors. Cancers 2024;16:2493. https://doi.org/10.3390/cancers16142493.
[68] Karenovics W, Licker M, Ellenberger C, Christodoulou M, Diaper J, Bhatia C, et al. Short-term preoperative exercise therapy does not improve long-term outcome after lung cancer surgery: a randomized controlled study. Eur J Cardio-Thorac Surg 2017;52:47–54. https://doi.org/10.1093/ejcts/ezx030.
[69] Blackwell JEM, Doleman B, Boereboom CL, Morton A, Williams S, Atherton P, et al. High-intensity interval training produces a significant improvement in fitness in <31 days before surgery for urological cancer: a randomised control trial. Prostate Cancer Prostatic Dis 2020;23:696–704. https://doi.org/10.1038/s41391-020-0219-1.
[70] Xia X, Ding G, Shi L, Wang M, Tian J. Effects of preoperative walking on bowel function recovery for patients undergoing gynecological malignancy laparoscopy. Precis Med Sci 2022;11:122–9. https://doi.org/10.1002/prm2.12071.
[71] Zhou N, Ripley-Gonzalez JW, Zhang W, Xie K, You B, Shen Y, et al. Preoperative exercise training decreases complications of minimally invasive lung cancer surgery: a randomized controlled trial. J Thorac Cardiovasc Surg 2025;169:516–528.e10. https://doi.org/10.1016/j.jtcvs.2024.04.009.
[72] Chen J, Hong C, Chen R, Zhou M, Lin S. Prognostic impact of a 3-week multimodal prehabilitation program on frail elderly patients undergoing elective gastric cancer surgery: a randomized trial. BMC Gastroenterol 2024;24. https://doi.org/10.1186/s12876-024-03490-7.
[73] Casanovas-Álvarez A, Estanyol B, Ciendones M, Padròs J, Cuartero J, Barnadas A, et al. Effectiveness of an exercise and educational-based prehabilitation program in patients with breast cancer receiving neoadjuvant chemotherapy (PREOptimize) on functional outcomes: a randomized controlled trial. Phys Ther 2024;104. https://doi.org/10.1093/ptj/pzae151.
[74] Hamad A, Zhang H, Zhang Y, Shen C, Fa P, Huang H, et al. Understanding the mechanism behind preoperative exercise therapy in patients with gastrointestinal cancers: a prospective randomized clinical trial. BMC Sports Sci Med Rehabil 2025;17. https://doi.org/10.1186/s13102-025-01094-6.
[75] Liang S, Yuan L, Wang A, Li S, Wei Y, Wen T, et al. Effect of short-term exercise-based prehabilitation program for patients undergoing liver cancer surgery: a randomized controlled trial. Surgery 2025;180:109115. https://doi.org/10.1016/j.surg.2024.109115.
[76] Danielsson J, Andersson M, Nygren-Bonnier M, Thorell A, Soop M, Sturesson C, et al. Effect of preoperative exercise on postoperative complications after colorectal cancer surgery in older people with low physical fitness: the CANOPTIPHYS randomised controlled trial. J Geriatr Oncol 2025;16:102280. https://doi.org/10.1016/j.jgo.2025.102280.
[77] Yan Y-L, Yao T-Q, Gu C-H, Wang X-L, Xin Y, Quan Y-J, et al. The effect of perioperative multimodal rehabilitation on the frailty state of older people patients with frailty gastrointestinal surgery: a randomized controlled trial. BMC Geriatr 2025;26. https://doi.org/10.1186/s12877-025-06672-4.
[78] Fagevik Olsén M, Löthgren S, Trölle U, Elf E, Toomväli-Petersson S, Hermansson M, et al. Positive effects of a perioperative training intervention in Ivor Lewis oesophageal surgery: a randomised, controlled multicentre trial. BMC Surg 2026;26. https://doi.org/10.1186/s12893-025-03416-4.
[79] Mu GC, Tu YH, Xie HL, Liu SY, Jia K, He MY, et al. Multimodal prehabilitation enhances perioperative outcomes in gastric cancer patients: a single-center randomized controlled trial. Front Nutr 2026;12. https://doi.org/10.3389/fnut.2025.1676180.
[80] Kawata S, Hiramatsu Y, Honke J, Takashima S, Shirai Y, Shibata Y, et al. Preoperative short-term nutrition and exercise trial program for patients with esophageal cancer: a randomized clinical trial: thoracic oncology. Ann Surg Oncol 2026;33:2094–102. https://doi.org/10.1245/s10434-025-18804-6.
[81] Sugimura K, Kanemura T, Takeoka T, Sugase T, Matsuura N, Yamamoto K, et al. Exercise and nutrition prehabilitation program during preoperative chemotherapy followed by esophagectomy in older patients with esophageal cancer: a randomized clinical trial. Ann Gastroenterol Surg 2026;10:470–82. https://doi.org/10.1002/ags3.70127.
[82] Sun Y, Tian Y, Cao S, Li L, Yu W, Ding Y, et al. Supervised multimodal prehabilitation and clinical outcomes in older patients with frailty and gastric cancer. JAMA Surg 2026;161:223. https://doi.org/10.1001/jamasurg.2025.6256.
[83] Liu Q, Meng C, Cao S, Liu X, Tian Y, Li Z, et al. The whole-course of supervised home-based multi-modal prehabilitation to improve clinical outcome in patients undergoing neoadjuvant chemotherapy prior to gastrectomy: a single-center randomized controlled trial. Gastric Cancer 2026;29:669–79. https://doi.org/10.1007/s10120-026-01735-w.
[84] Fujimoto T, Akasaka H, Yasunobe Y, Yoshida S, Onishi Y, Minami T, et al. Preoperative resistance training and amino acid supplementation in frail patients with gastrointestinal cancer: a randomized clinical trial. Geriatr Gerontol Int 2025;25:1765–73. https://doi.org/10.1111/ggi.70226.
[85] Yamamoto K, Shinno N, Omori T, Yanagimoto Y, Masuike Y, Ushimaru Y, et al. Exercise–nutrition prehabilitation attenuates lean body mass loss before gastrectomy: a randomized controlled trial. Gastric Cancer 2026;29:854–64. https://doi.org/10.1007/s10120-026-01747-6.
[86] Tai R, Yang F, Wang J, Wan S, Xiang Q, Cheng Y, et al. Evaluating the impact of a modified multi-modal prehabilitation program on perioperative outcomes in Chinese patients undergoing colorectal cancer surgery. Front Surg 2026;13. https://doi.org/10.3389/fsurg.2026.1703293.
[87] Berardi G, Cucchetti A, Colasanti M, Angrisani M, Moschetta G, Chiappori D, et al. Prehabilitation with exercise and nutrition to reduce morbidity of major hepatectomy in patients with sarcopenia: the PREHEP randomized clinical trial. JAMA Surg 2025;160:1068. https://doi.org/10.1001/jamasurg.2025.3102.
[88] Mizrahi D, Lai JKL, Wareing H, Ren Y, Li T, Swain CTV, et al. Effect of exercise interventions on hospital length of stay and admissions during cancer treatment: a systematic review and meta-analysis. Br J Sports Med 2024;58:97–109. https://doi.org/10.1136/bjsports-2023-107372.
[89] Chen J, Wang Y, Zhong Z, Chen X, Zhang L, Jie L, et al. Sex differences in the association of wearable accelerometer-derived physical activity with coronary heart disease incidence and mortality. Nat Cardiovasc Res 2025;4:1539–49. https://doi.org/10.1038/s44161-025-00732-z.
[90] Doyle SL, Lysaght J, Reynolds JV. Obesity and post-operative complications in patients undergoing non-bariatric surgery. Obes Rev 2010;11:875–86. https://doi.org/10.1111/j.1467-789X.2009.00700.x.
[91] Aquina CT, Mohile SG, Tejani MA, Becerra AZ, Xu Z, Hensley BJ, et al. The impact of age on complications, survival, and cause of death following colon cancer surgery. Br J Cancer 2017;116:389–97. https://doi.org/10.1038/bjc.2016.421.
[92] Kodama S. Cardiorespiratory fitness as a quantitative predictor of all-cause mortality and cardiovascular events in healthy men and women. JAMA 2009;301:2024. https://doi.org/10.1001/jama.2009.681.
[93] Voorn MJJ, Franssen RFW, Verlinden J, Bootsma GP, de Ruysscher DK, Bongers BC, et al. Associations between pretreatment physical performance tests and treatment complications in patients with non-small cell lung cancer: a systematic review. Crit Rev Oncol Hematol 2021;158:103207. https://doi.org/10.1016/j.critrevonc.2020.103207.
[94] Huang CY, Yang YC, Chen TC, Chen JR, Chen YJ, Wu MH, et al. Muscle loss during primary debulking surgery and chemotherapy predicts poor survival in advanced-stage ovarian cancer. J Cachexia Sarcopenia Muscle 2020;11:534–46. https://doi.org/10.1002/jcsm.12524.
[95] Machado P, Paixão A, Oliveiros B, Martins RA, Cruz J. Effect of home-based exercise prehabilitation on postoperative outcomes in colorectal cancer surgery: a systematic review and meta-analysis. Support Care Cancer 2025;33. https://doi.org/10.1007/s00520-024-09069-y.
[96] Gutiérrez-Espinoza H, Araya-Quintanilla F, Zavala-González J, Valenzuela-Fuenzalida J, Celi-Lalama D, Ramírez-Vélez R. Supervised versus home exercise program in subacromial impingement syndrome: a randomized controlled trial with 1-year of follow-up. Ann Phys Rehabil Med 2026;69:102106. https://doi.org/10.1016/j.rehab.2026.102106.
[97] McIsaac DI, Lee S, Fergusson D, Gillis C, Khadaroo RG, Meliambro A, et al. Home-based prehabilitation for older surgical patients with frailty. JAMA Surg 2026;161:113. https://doi.org/10.1001/jamasurg.2025.5288.
[98] Tay SS, Zhang F, Neo EJR. The use of technology in cancer prehabilitation: a systematic review. Front Oncol 2024;14. https://doi.org/10.3389/fonc.2024.1321493.
[99] Soh NH, Yau CRZ, Low XZ, Kadir HA, Fong WJ, Ramalingam MB, et al. Prehabilitation outcomes in surgical oncology patients undergoing major abdominal surgery: a meta-analysis of randomized control trials. Ann Surg Oncol 2025;32:1236–47. https://doi.org/10.1245/s10434-024-16527-8.
[100] Jones LW, Courneya KS, Mackey JR, Muss HB, Pituskin EN, Scott JM, et al. Cardiopulmonary function and age-related decline across the breast cancer: survivorship continuum. J Clin Oncol 2012;30:2530–7. https://doi.org/10.1200/JCO.2011.39.9014.

[101] Ljungqvist O, Scott M, Fearon KC. Enhanced recovery after surgery a review. JAMA Surg 2017;152:292. https://doi.org/10.1001/jamasurg.2016.4952.
[102] Sauro KM, Smith C, Ibadin S, Thomas A, Ganshorn H, Bakunda L, et al. Enhanced recovery after surgery guidelines and hospital length of stay, readmission, complications, and mortality: a meta-analysis of randomized clinical trials. JAMA Netw Open 2024;7:e2417310. https://doi.org/10.1001/jamanetworkopen.2024.17310.
[103] Liatsou E, Bellos I, Katsaros I, Michailidou S, Karela NR, Mantziari S, et al. Sex differences in survival following surgery for esophageal cancer: a systematic review and meta-analysis. Dis Esophagus 2024;37. https://doi.org/10.1093/dote/doae063.
[104] Squiccimarro E, Lorusso R, Margari V, Labriola C, Whitlock R, Paparella D. Sex-related differences in systemic inflammatory response and outcomes after cardiac surgery and cardiopulmonary bypass. Interdiscip Cardiovasc Thorac Surg 2025;40. https://doi.org/10.1093/icvts/ivaf066.
[105] Bettariga F, Newton RU, Bishop C, Maestroni L, Borsati A, Avancini A, et al. Periodizing exercise medicine prescription for patients with cancer: a narrative opinion. Sports Med 2025;55:2987–99. https://doi.org/10.1007/s40279-025-02311-5.
[106] Currier BS, D'Souza AC, Singh MAF, Lowisz CV, Rawson ES, Schoenfeld BJ, et al. American College of Sports Medicine position Stand. Resistance training prescription for muscle function, hypertrophy, and physical performance in healthy adults: an overview of reviews. Med Sci Sports Exerc 2026;58:851–72. https://doi.org/10.1249/MSS.0000000000003897.
[107] Boden I, Reeve J, Jernås A, Denehy L, Fagevik Olsén M. Preoperative physiotherapy prevents postoperative pulmonary complications after major abdominal surgery: a meta-analysis of individual patient data. J Physiother 2024;70:216–23. https://doi.org/10.1016/j.jphys.2024.02.012.
[108] Voorn MJJ, Driessen EJM, Reinders R, van Kampen-van den Boogaart VEM, Bongers BC, Janssen-Heijnen MLG. Effects of exercise prehabilitation and/or rehabilitation on health-related quality of life and fatigue in patients with non-small cell lung cancer undergoing surgery: a systematic review. Eur J Surg Oncol 2023;49:106909. https://doi.org/10.1016/j.ejso.2023.04.008.
[109] Fernandez-Escabias M, Miron B, Flor-Alemany M, Carrilho-Candeias S, Orellana-Jaen A, Fernandez-Escabias R, et al. Effects of exercise-based prehabilitation programs on sleep in patients with cancer undergoing surgery: a systematic review and meta-analysis. Eur J Surg Oncol 2026;52:111314. https://doi.org/10.1016/j.ejso.2025.111314.
[110] Aravani A, Samy EF, Thomas JD, Quirke P, Morris EJA, Finan PJ. A retrospective observational study of length of stay in hospital after colorectal cancer surgery in England (1998-2010). Medicine 2016;95:e5064. https://doi.org/10.1097/MD.0000000000005064.
[111] Hedou J, Mendes G, Bellan G, El Khoury D, Verdonk F. Impact of postoperative complications on cost and length of stay: multicentre prospective clinical study. Br J Surg 2025;113. https://doi.org/10.1093/bjs/znaf290.
[112] Sabajo CR, Michels CTJ, van der Hout A, van den Heuvel B, Dekker JW, Klaase JM, et al. The financial impact of implementation of a prehabilitation program for colorectal cancer patients in the Netherlands: a budget impact analysis. Eur J Surg Oncol 2025;51:110375. https://doi.org/10.1016/j.ejso.2025.110375.
[113] den Bakker CM, Anema JR, Huirne JAF, Twisk J, Bonjer HJ, Schaafsma FG. Predicting return to work among patients with colorectal cancer. Br J Surg 2020;107:140–8. https://doi.org/10.1002/bjs.11313.
[114] Fernandez-Escabias M, Mirón-Pozo B, Orellana-Jaen A, Amaro-Gahete FJ. Defining and capturing postoperative complications in cancer surgery: beyond definitions and time frames. Ann Surg Oncol 2026;33:2839–42. https://doi.org/10.1245/s10434-026-19085-3.