

Systematic Review

Dose-response relationship between exercise interventions and quality of life in older adults with cancer: A systematic review and meta-analysis

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ABSTRACT

Introduction: We aimed to systematically evaluate the effects of exercise interventions on quality of life in older adults with cancer and to explore the dose-response relationships associated with key exercise prescription parameters.

Materials and methods: We conducted searches of PubMed, Embase, Web of Science, Scopus, and the Cochrane Library; standardized mean differences (SMDs) with 95% confidence intervals (CIs) were calculated using a random-effects model. Subgroup analyses were performed to identify potential effect modifiers, and dose-response models were constructed to quantify the relationship between exercise dose and quality-of-life outcomes.

Results: A total of 32 studies involving 2557 older adults with cancer were included. Meta-analysis demonstrated that exercise interventions significantly improved quality of life (SMD = 0.27, 95% CI: 0.14–0.41). Subgroup analyses suggested that intervention characteristics were associated with differential effects, with relatively greater improvements observed in studies with intervention durations of 8–12 weeks (SMD = 0.37, 95% CI: 0.19–0.56, $p = 0.003$), a frequency of three sessions per week (SMD = 0.36, 95% CI: 0.18–0.54, $p < 0.001$), and session durations of less than 45 min (SMD = 0.39, 95% CI: 0.23–0.55, $p < 0.001$). Dose-response analysis indicated that the effect peaked at an overall weekly exercise volume of approximately 962.94 MET-min/week (Hedges' $g = 0.41$, 95% CI: 0.18–0.64).

Discussion: Exercise interventions significantly improve quality of life in older adults with cancer, with a weekly exercise volume of approximately 962.94 MET-min/week associated with greater improvements. Although exercise frequency and other parameters are related to quality of life, current evidence remains insufficient to support a standardized prescription, and individualized approaches should be considered.

1. Introduction

Cancer is a chronic disease characterized by uncontrolled proliferation and metastasis of abnormal cells and is associated with genetic and environmental factors [1]. Globally, cancer has emerged as one of the leading causes of disability and mortality among older adults [2]. According to the latest statistics from the World Health Organization (WHO, 2024), individuals aged 60 years and older account for approximately 60% of all newly diagnosed cancer cases and contribute to over 70% of cancer-related deaths. With the continued acceleration of global population aging, the number of older adults living with cancer is steadily increasing, rendering their health management and quality-of-life concerns a critical public health priority worldwide [3]. Older

adults with cancer face multiple challenges arising both from the disease itself and from its treatment. Although conventional therapies—such as surgery, chemotherapy, radiotherapy, and targeted interventions—can effectively slow disease progression, they are frequently accompanied by burdensome side effects, including fatigue, anxiety, depression, and declines in physical function [4]. These adverse effects not only compromise patients' physiological functioning but also exert detrimental impacts on psychological well-being and social participation, ultimately leading to a pronounced decline in overall quality of life. Consequently, enhancing quality of life has become a central objective within the rehabilitation and comprehensive care of older adults with cancer.

Exercise interventions, as safe and low-cost non-pharmacological

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rehabilitation strategies, have been increasingly investigated in older adults with cancer [5]. Evidence from randomized controlled trials indicates that regular exercise can improve physical function, alleviate psychological distress, and reduce cancer-related fatigue in this population [6].

Despite the broad recognition of exercise's beneficial effects, clear evidence regarding the optimal exercise prescription and appropriate dosage for older adults with cancer remains insufficient [7]. Substantial heterogeneity across existing studies—including variations in intervention protocols, participant characteristics, and selected outcome measures—further complicates efforts to standardize and quantify exercise prescriptions for this population [8]. This challenge is particularly pronounced in older populations, whose diminished physiological reserves and limited exercise tolerance necessitate carefully calibrated interventions. Determining how to maximize improvements in quality of life within a framework that remains safe and feasible for older adults with cancer represents a critical scientific question requiring urgent attention. Therefore, this study employed systematic review and meta-analytic methods to comprehensively evaluate the overall effects of exercise interventions on quality of life among older adults with cancer. Furthermore, metabolic equivalent minutes per week (METs·min/week) were used to construct a nonlinear dose–response model, enabling quantitative assessment of the relationship between exercise dosage and intervention efficacy. In addition, subgroup analyses were conducted to identify the moderating effects of key prescription parameters, thereby providing an evidence-based foundation for the development of scientifically grounded, feasible, and individualized exercise intervention programs for older adults with cancer.

2. Methods

This systematic review and meta-analysis were conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement [9]. The study protocol was prospectively registered in the PROSPERO database (Registration No. CRD420251148612).

2.1. Search strategy

This study systematically searched five electronic databases—PubMed, Embase, Scopus, Web of Science, and the Cochrane Library—from their inception to September 16, 2025. The search was restricted to English-language publications and randomized controlled trials (RCTs). A comprehensive strategy incorporating both Medical Subject Headings (MeSH) and free-text terms was employed. Core keywords included “older adults with cancer,” “exercise intervention,” and “quality of life,” which were combined using Boolean operators (AND, OR, NOT) to maximize search sensitivity and specificity. The detailed search strategies for each database are provided in Supplementary Material A. Literature retrieval and screening were conducted independently and in a double-blinded manner by two investigators. Any disagreements were resolved through consultation with a third researcher to ensure the scientific rigor and consistency of the search and selection process.

2.2. Inclusion criteria

We included studies in which: (1) participants were older adults with cancer aged ≥ 60 years; (2) articles were published in English; (3) the study design was an RCT; (4) the intervention consisted of regular, structured exercise programs, including aerobic training, resistance training, mind–body exercise, or multicomponent regimens; (5) control groups did not receive structured exercise interventions and were limited to usual lifestyle practices or standard care; and (6) the primary outcome was quality of life in patients with cancer. Commonly used quantitative assessment instruments included the Functional

Assessment of Cancer Therapy scales (FACT-G, FACT-P, FACT-B, FACT-H&N), the European Organisation for Research and Treatment of Cancer Quality of Life Questionnaire (EORTC QLQ-C30), the Short Form-36 Health Survey (SF-36), among others. For studies using the FACT series of instruments, priority was given to extracting the overall quality-of-life scores, rather than cancer-specific subscale outcomes.

2.3. Exclusion criteria

We excluded: (1) animal studies or non-human research; (2) duplicate publications, low-quality studies, or studies with a high risk of bias; (3) studies lacking full-text or containing incomplete outcome data; (4) studies that did not employ standardized quality-of-life assessment instruments as outcome measures; and (5) non-RCT study designs, including reviews, systematic reviews, meta-analyses, conference abstracts, commentaries, or studies using secondary-source data.

2.4. Study selection and data extraction

The processes of study selection and data extraction were conducted independently by two investigators, with any discrepancies resolved by a third reviewer. Initially, all records identified through database searches were imported into EndNote 21, where duplicates were removed using both automated and manual procedures before preliminary screening. According to the predefined inclusion and exclusion criteria, titles and abstracts were screened to identify potentially eligible studies, after which full texts were retrieved for secondary assessment to determine final eligibility. Data extraction was conducted using a standardized form and included the following elements: (1) study characteristics, including first author, year of publication, and country; (2) participant and intervention characteristics, including sample size in the intervention and control groups, mean age, duration of the exercise program, session length, and training frequency; and (3) outcome measures, primarily overall quality of life and its related domains in patients with cancer.

When essential data were missing, attempts were made to contact the study authors to obtain the necessary information.

2.5. Quality assessment

The methodological quality of the included studies was assessed using the Risk of Bias tool outlined in the *Cochrane Handbook for Systematic Reviews of Interventions*. The evaluation covered seven domains: random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, completeness of outcome data, selective reporting, and other potential sources of bias. The studies meeting the inclusion criteria were imported into Review Manager 5.3 to generate risk-of-bias summary plots, providing a visual representation of bias distribution across domains. These assessments served as a critical foundation for subsequent sensitivity analyses and the interpretation of potential sources of heterogeneity, thereby informing judgments regarding the robustness and reliability of the overall findings.

2.6. Statistical analysis

Statistical analyses were performed using Stata 18.0. Because the primary outcomes were continuous variables, weighted mean differences (WMDs) were applied when studies used identical measurement instruments, whereas standardized mean differences (SMDs) were used when different instruments were employed. All pooled results were reported with corresponding 95% confidence intervals (95% CIs). This method enables the standardization of effect sizes across different quality-of-life instruments, thereby improving the comparability of results across studies. Heterogeneity was assessed using the I^2 statistic and corresponding p -values. When $I^2 < 50\%$ and $p > 0.1$, heterogeneity was

considered low, and a fixed-effects model was applied; when $I^2 \geq 50\%$ and $p < 0.1$, substantial heterogeneity was assumed, and a random-effects model was used. Subgroup analyses were further conducted to identify potential factors modifying the effects of exercise interventions. All statistical tests were two-sided, with a significance level set at $p < 0.05$. Potential publication bias was preliminarily assessed using funnel plots, and sensitivity analyses were conducted via a leave-one-out approach to verify the stability and robustness of the pooled estimates. For studies employing multidimensional assessment instruments (e.g., the FACT series), priority was given to extracting total or composite quality-of-life scores to ensure comparability across studies.

To further examine the relationship between exercise dose and improvements in quality of life, this study standardized the prescribed exercise parameters—intensity, frequency, and duration—based on metabolic equivalents (METs) [10] and calculated the total weekly exercise volume (MET·min/week) for each intervention.

The exercise dose calculated in this study was primarily based on the prescribed exercise parameters reported in the original studies rather than the actual completed dose. This approach is consistent with common practice in exercise science research, where exercise exposure is defined using prescription components such as frequency, intensity, and session duration (i.e., the FITT principle) [11]. At the same time, previous meta-analyses have shown that exercise adherence is influenced by the manipulation of FITT parameters. In particular, increases in exercise intensity and longer session durations may reduce adherence, a phenomenon that is more pronounced in populations with chronic diseases [12]. Due to substantial variability in the reporting formats and definitions of adherence across the included studies, and the lack of a unified quantitative standard, adherence data were not incorporated into the adjustment of exercise dose calculations. Meanwhile, when available, effect sizes were preferentially calculated based on changes from baseline to post-intervention rather than solely on post-intervention endpoints, in order to minimize the influence of baseline differences and improve the accuracy of the estimates.

3. Results

3.1. Literature search results

A total of 3676 records were identified through searches of PubMed, Embase, Scopus, Web of Science, and the Cochrane Library. The flow diagram of the systematic search process is presented in Fig. 1. After removing duplicates, screening titles and abstracts, and excluding studies that did not meet the eligibility criteria, a total of 32 studies were ultimately included in the analysis [5,6,13–42].

3.2. Characteristics of included studies

The included studies comprised a total of 2557 older adults with cancer (1321 in the intervention groups and 1236 in the control groups), with a mean age of 68.88 ± 3.52 years. Across the included studies, intervention groups received various forms of exercise training—including resistance training, aerobic exercise, and mind–body practices—whereas control groups participated in usual care or routine lifestyle activities. Key exercise-prescription components evaluated in the interventions included training duration (weeks), session duration, and weekly frequency. Intervention durations ranged from 1 to 48 weeks, with individual sessions lasting 22 to 105 min, and training frequencies varying from 1 to 7 sessions per week. The primary outcome was quality of life among patients with cancer. Commonly used quantitative assessment instruments included the Functional Assessment of Cancer Therapy scales (FACT-G, FACT-P, FACT-B, FACT-H&N), the EORTC QLQ-C30, and the SF-36 (Table 1).

3.3. Quality assessment of included studies

All 32 included studies were appraised using the Cochrane Risk of Bias assessment tool (Fig. 2). The results indicated that most trials demonstrated a low risk of bias in domains such as random sequence

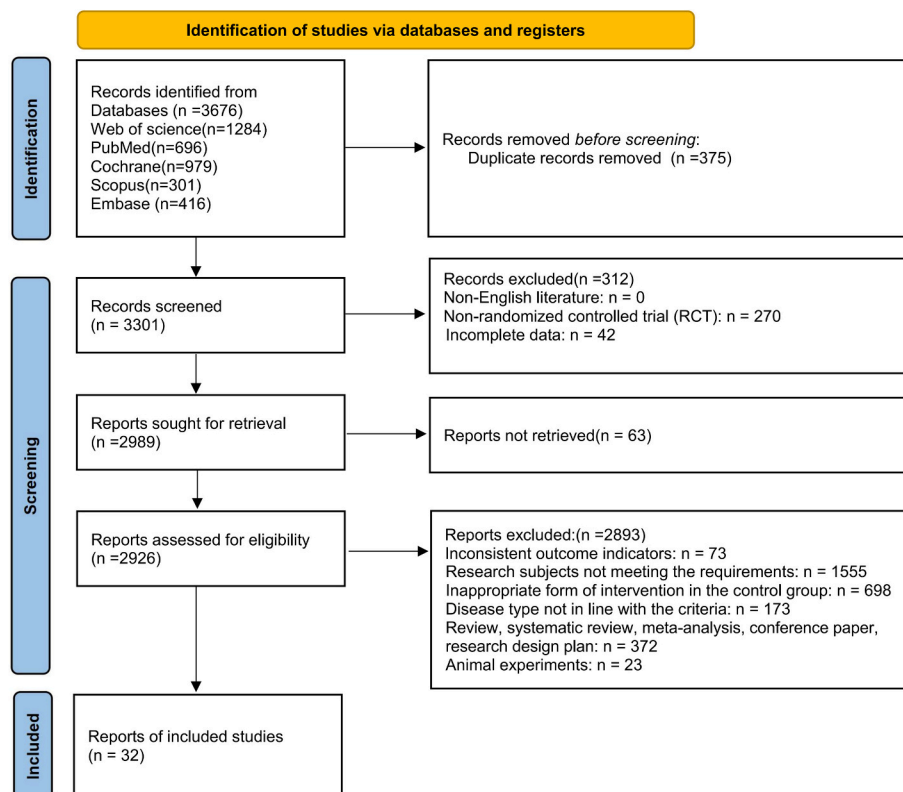


Fig. 1. PRISMA flow diagram of study selection.

Table 1
Characteristics of included studies.

First Author	Country	Experimental group	Control Group	Age (years)	Cancer Type	Experimental group	Intervention Duration (weeks)	Session Duration (min/session)	Frequency (sessions/week)	Exercise Intensity	Prescribed exercise volume (MET-min/week)	Quality of Life Scale
Segal (2003)	Canada	82	73	68.0 ± 7.7	Prostate cancer	Resistance training	12	60	3	4.3	774	FACT-P
McNeely (2004)	Canada	8	9	60.5 ± 7.9	Other cancers	Resistance training	12	45	3	3.8	513	FACT-G, FACT-H&N
Monga (2007)	United States	11	10	69.3 ± 4.8	Prostate cancer	Aerobic training	8	45	3	5.3	715.5	BDI, FACT-G, FACT-P
Segal (2009)	Canada	80	41	65.9 ± 7.6	Prostate cancer	Resistance training	24	40	3	4.3	516	FACT-G, FACT-P
Banasik (2010)	United States	9	9	62.9 ± 7.1	Breast cancer	Mind-body training	8	90	2	2.5	450	FACT-B, FACT-G
Galvão (2010)	Australia	29	28	69.8 ± 7.3	Prostate cancer	Resistance training	12	60	2	4.8	576	EORTC, QLQ-C30, SF-36
Bourke (2011)	United Kingdom	25	25	71.75 ± 7.08	Prostate cancer	Aerobic training	12	90	5	4.8	2160	FACT-G, FACT-P
Cormie (2013)	Australia	10	10	72.1 ± 5.14	Prostate cancer	Resistance training	12	60	2	5	600	FACT-BP, SF-36
Arbane (2014)	United Kingdom	64	67	67.5 ± 11	Other cancers	Aerobic training	4	30	7	4.8	1008	EORTC, QLQ-LC13, SF-36
Edvardsen (2014)	Norway	30	31	65.2 ± 8.9	Other cancers	Resistance training	20	60	3	6.5	1170	EORTC, QLQ-C30, SF-36
Galvão(2014)	Australia	50	50	71.7 ± 6.5	Prostate cancer	Aerobic training	48	60	2	4.8	576	SF-36
Miki (2014)	Japan	38	40	74.2 ± 5.7	Prostate cancer	Aerobic training	4	30	1	4.5	135	FACT-G
Cormie (2015)	Australia	32	31	68.4 ± 7.0	Prostate cancer	Resistance training	12	60	2	5.15	618	EORTC, QLQ-PR25, SF-36
Nilsen (2015)	Norway	28	30	66.0 ± 5.9	Prostate cancer	Resistance training	16	60	3	6	1080	EORTC, QLQC-30
Cramer (2016)	Germany	27	27	68.3 ± 9.7	Other cancers	Mind-body training	10	90	1	2.5	225	FACT-C, HADS
Winters-Stone (2016)	United States	32	32	71.8 ± 7.2	Prostate cancer	Resistance training	24	60	2	5	600	SF-36
Lai(2017)	China	30	30	72.1 ± 2.8	Other cancers	Aerobic training	1	100	7	3.5	2450	EORTC, QLQC-C30, QLQC-LC13
Loh(2019)	United States	130	122	66.6 ± 5.3	Breast cancer	Resistance training	6	22	7	4.8	739.2	FACT-G, POMS
Mardani (2021)	Iran	40	40	69.9 ± 5.6	Prostate cancer	Resistance training	12	105	4	4.2	1764	EORTC, QLQC-C30, QLQC-PR25
Mikkelsen (2022)	Denmark	41	43	71.8 ± 1.8	Other cancers	Resistance training	12	60	7	4.8	2016	EORTC, HADS, QLQC-30
Capela (2023)	Portugal	16	15	71.8 ± 5.9	Prostate cancer	Aerobic training	16	90	3	6	1620	EORTC, QLQ-C30, QLQ-PR25
Langlais (2023)	United States	15	10	71.8 ± 5.9	Prostate cancer	Aerobic training	12	60	3	6.5	1170	CES-D, EORTC, EQ-5D, QLQ-C30, VAS
Porserud (2024)	Sweden	45	41	71.5 ± 8.5	Other cancers	Resistance training	12	30	2	4.8	288	EORTC, HADS, QLQC-30
Paulo (2019)	Brazil	15	14	63.2 ± 7.1	Breast cancer	Resistance training	36	70	3	5.15	1081.5	EORTC, QLQ-BR23, QLQ-C30, SF-36
Sun (2023)	China	120	120	63.68 ± 7.01	Other cancers	Resistance training	12	40	5	4	800	SF-36
Stan (2016)	United States	14	9	61.4 ± 7.0	Breast cancer	Resistance training	12	90	5	3.4	1530	FACT-B

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Table 1 (continued)

First Author	Country	Experimental group	Control Group	Age (years)	Cancer Type	Experimental group	Intervention Duration (weeks)	Session Duration (min/session)	Frequency (sessions/week)	Exercise Intensity	Prescribed exercise volume (MET·min/week)	Quality of Life Scale
Villumsen (2017)	Denmark	21	20	67.6 ± 4.6	Prostate cancer	Mind-body training	12	60	3	5.5	990	EORTC, FACT-P, QLQ-C30
Cheung (2025)	China	105	103	71.0 ± 4.4	Prostate cancer	Mind-body training	16	60	5	3.8	1140	EORTC, QLQ-C30
Adeline (2021)	Canada	10	10	70.0 ± 4.0	Breast cancer	Resistance training	12	60	3	4.8	864	EORTC, FACT-G, QLQ-C30
Rosero (2020)	Spain	19	7	74.5 ± 3.6	Other cancers	Aerobic training	10	45	2	4.5	405	EORTC, QLQ-C30, QLQ-C-LC13, VAS
McIsaac (2022)	Canada	84	74	74.0 ± 6.0	Other cancers	Resistance training	5	60	3	3.5	630	EQ-5D
Yang (2025)	China	61	65	65.5 ± 4.2	Other cancers	Resistance training	12	25	7	3.5	612.5	GQOLI-74

Abbreviations: FACT-P, Functional Assessment of Cancer Therapy-Prostate; FACT-G, Functional Assessment of Cancer Therapy-General; FACT-H&N, Functional Assessment of Cancer Therapy-Head & Neck; FACT-B, Functional Assessment of Cancer Therapy-Breast;

EORTC, European Organisation for Research and Treatment of Cancer; QLQ-C30, EORTC Quality of Life Questionnaire-Core 30; SF-36, Short Form-36 Health Survey; FACT-BP, Functional Assessment of Cancer Therapy-Bone Pain; QLQ-LC13, EORTC Lung Cancer Module; QLQ-PR25, EORTC Prostate Cancer Module; FACT-C, Functional Assessment of Cancer Therapy-Colorectal; HADS, Hospital Anxiety and Depression Scale; POMS, Profile of Mood States; CES-D, Center for Epidemiologic Studies Depression Scale; EQ-5D, EuroQol Five-Dimension Scale; VAS, Visual Analogue Scale; QLQ-BR23, EORTC Breast Cancer Module; QLQ-LC13, EORTC Lung Cancer Module; GQOLI-74, Generic Quality of Life Inventory-74.

Note: MET, metabolic equivalent of task. Exercise intensity in this study was determined according to exercise type, session duration, and weekly frequency, with reference to ACSM's Guidelines for Exercise Testing and Prescription [55]. Prescribed exercise volume was calculated as MET value × session duration × weekly frequency and reported as MET·min/week.

generation, completeness of outcome data, and selective reporting, suggesting an overall high methodological quality across the evidence base. In the domains of allocation concealment and blinding of participants and personnel, several studies were rated as having an unclear risk of bias due to insufficient information regarding the implementation or reporting of blinding procedures. Only a small number of studies exhibited a high risk of bias in outcome-assessment blinding or other potential sources of bias. Overall, the included studies demonstrated good methodological quality, and the overall risk of bias was deemed acceptable. Consequently, the synthesized findings can be regarded as highly credible and methodologically robust.

3.4. Meta-analysis results

3.4.1. Effects of exercise interventions on quality of life

A total of 32 studies were included to evaluate the effects of exercise interventions on quality of life in older adults with cancer (Fig. 3). Given the presence of moderate heterogeneity across studies ($I^2 = 60.2\%$, $p < 0.001$), a random-effects model was applied. The pooled analysis demonstrated that exercise interventions significantly improved quality of life compared with control conditions, with an overall effect size of $SMD = 0.27$ (95% CI: 0.14–0.41), indicating a statistically significant difference.

3.4.2. Publication bias

Publication bias was preliminarily assessed using a funnel plot (Fig. 4). Most studies were distributed symmetrically on both sides of the overall effect estimate, forming an approximately inverted funnel shape with gradual convergence, and the majority of data points fell within the pseudo 95% CIs. Overall, the funnel plot exhibited good symmetry, suggesting a low risk of publication bias in the present meta-analysis.

3.4.3. Dose-response relationship analysis

Fig. 5 illustrates the nonlinear dose-response relationship between weekly exercise volume and the effect size of quality-of-life outcomes in older adults with cancer. To improve the robustness of model estimation under small-sample conditions, Hedges' g was used as the effect size metric for modeling. The results indicated that the effect peaked at an overall weekly exercise volume of approximately 962.94 MET·min/week (Hedges' $g \approx 0.41$, 95% CI ≈ 0.18 –0.64). Within the lower-dose range (approximately 200–500 MET·min/week), the effect size increased markedly with increasing exercise dose. As the dose approached approximately 600–1000 MET·min/week, the rate of increase slowed and gradually entered a plateau phase. When the exercise volume exceeded 1500 MET·min/week, the effect size showed a slight decline, with the curve demonstrating a mild downward trend. Overall, the nonlinear model exhibited an inverted U-shaped pattern characterized by an initial rapid increase, a mid-range plateau, and a slight decline at higher doses, suggesting that moderate levels of total weekly exercise volume are associated with greater improvements in quality of life, whereas excessive doses may yield diminishing returns.

3.4.4. Subgroup analyses

3.4.4.1. Effects of different exercise types on quality-of-life outcomes. Subgroup analysis was conducted according to exercise type, including aerobic exercise, mind-body exercise, and resistance training (Fig. 6). All three types of interventions were associated with improvements in quality of life among patients with cancer compared with usual care, with corresponding effect sizes of $SMD = 0.24$, 0.19, and 0.29, respectively. Although all subgroups showed positive effects, resistance training demonstrated a relatively larger effect size and reached statistical significance ($p < 0.001$), accompanied by substantial heterogeneity ($I^2 = 73.1\%$). However, no statistically significant differences were observed between subgroups ($p = 0.80$).

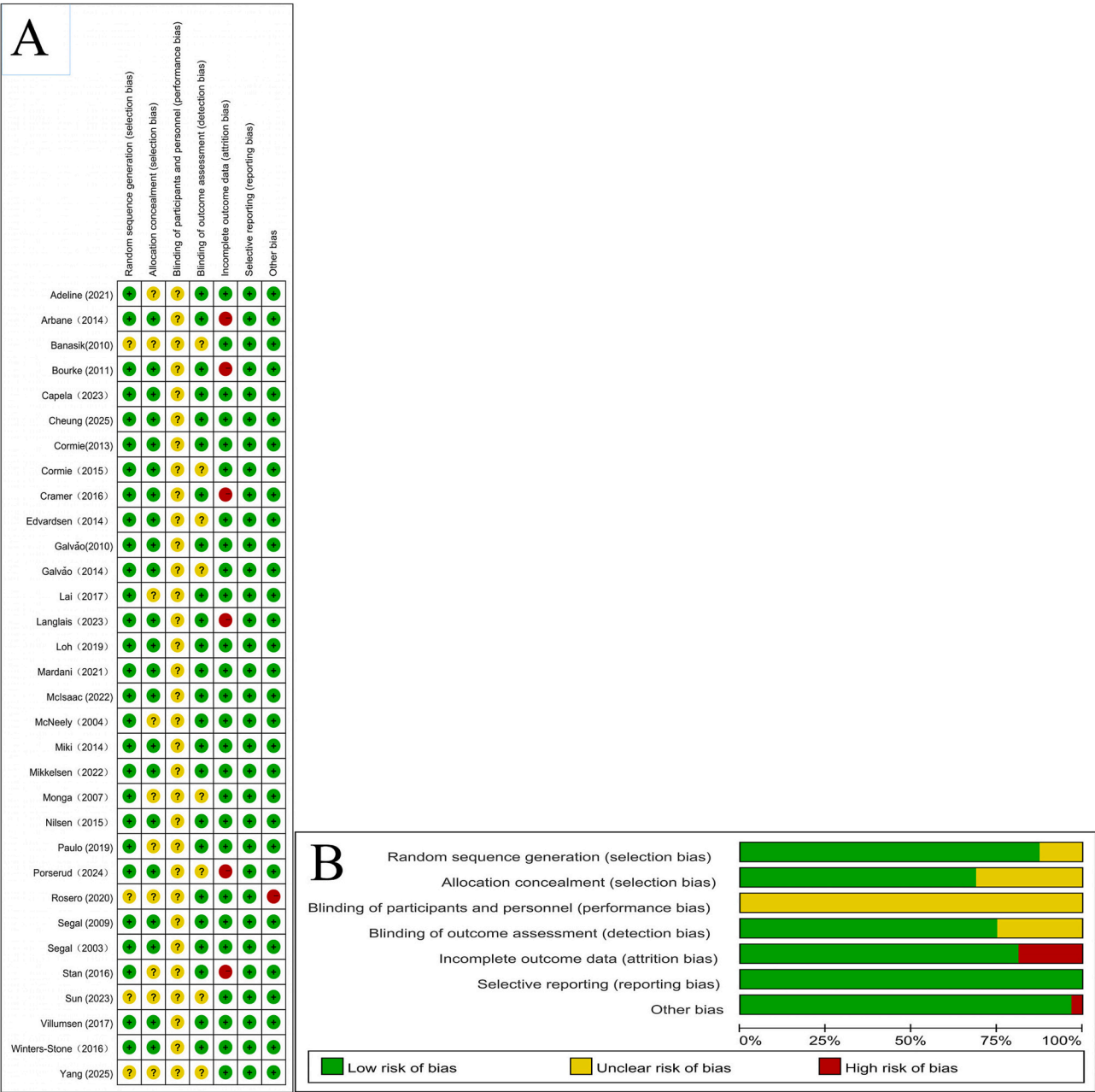


Fig. 2. (A) Distribution of methodological quality; (B) Risk-of-bias graph and summary.

3.4.4.2. Effects of intervention duration on quality-of-life outcomes. Subgroup analysis was performed according to intervention duration (<8 weeks, 8–12 weeks, and > 12 weeks; Fig. 7). The pooled effect sizes for the three subgroups were SMD = 0.05 (95% CI: –0.13 to 0.23), 0.37 (95% CI: 0.19–0.56), and 0.25 (95% CI: –0.03 to 0.52), respectively. The 8–12-week subgroup demonstrated the largest effect size and achieved statistical significance, while exhibiting substantial heterogeneity ($I^2 = 53.7\%$). Moreover, the between-subgroup difference was statistically significant ($p < 0.05$).

3.4.4.3. Effects of session duration on quality-of-life outcomes. Subgroup analysis was conducted according to session duration (<45 min, 45–60 min, and > 60 min; Fig. 8). All three duration categories were associated with improvements in quality of life among patients with cancer, with corresponding effect sizes of SMD = 0.39, 0.27, and 0.17, respectively, all reaching statistical significance ($p < 0.05$). Among these, the <45-min subgroup showed a relatively larger effect size, while the >60-min

subgroup exhibited the lowest heterogeneity ($I^2 = 0.0\%$, $p = 0.58$). However, no statistically significant differences were observed between subgroups ($p = 0.42$).

3.4.4.4. Effects of exercise frequency on quality-of-life outcomes. Subgroup analysis was conducted according to exercise frequency (<3 sessions/week, 3 sessions/week, and > 3 sessions/week; Fig. 9). All three frequency categories were associated with improvements in quality of life among patients with cancer, with corresponding effect sizes of SMD = 0.10, 0.36, and 0.34, respectively, with the latter two reaching statistical significance ($p < 0.05$). Among these, the 3 sessions/week subgroup demonstrated a relatively larger effect size, followed by the >3 sessions/week subgroup. The heterogeneity across the three subgroups was moderate, with I^2 values of 43.2%, 62.9%, and 68.1%, respectively. However, no statistically significant differences were observed between subgroups ($p = 0.23$).

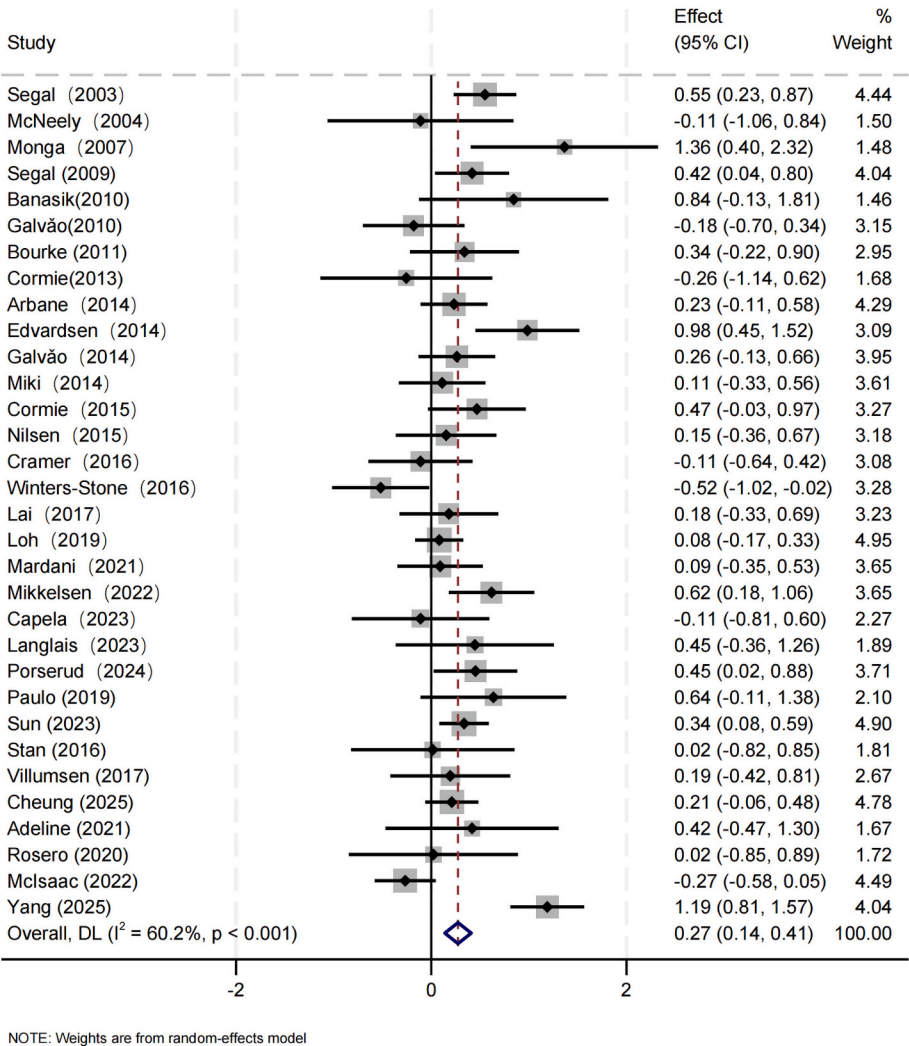


Fig. 3. Forest plot of the pooled effects of exercise interventions on quality of life in older adults with cancer.

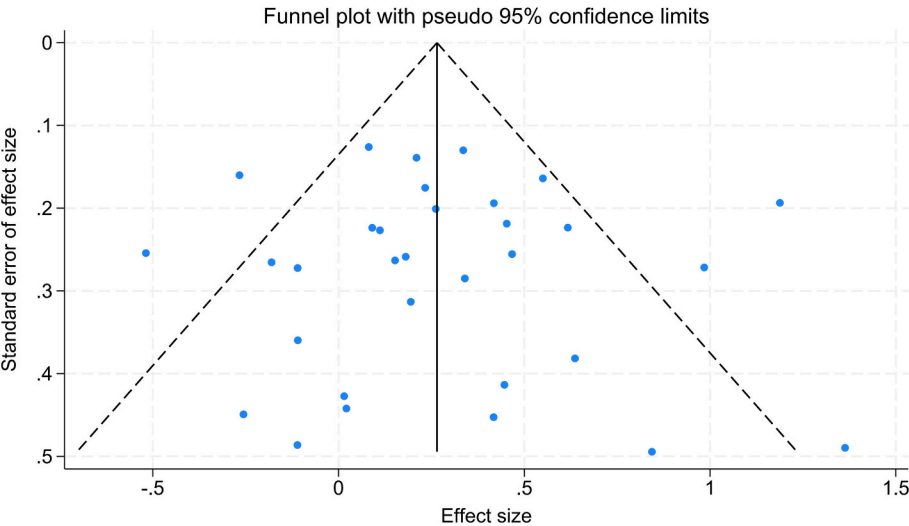


Fig. 4. Funnel plot assessing publication bias in the effects of exercise interventions on quality of life.

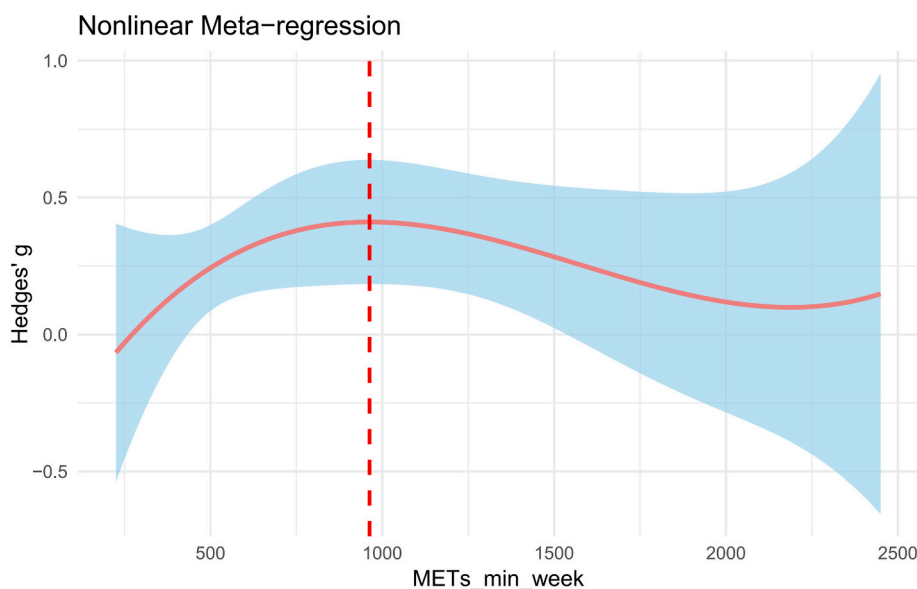


Fig. 5. Nonlinear dose–response relationship between weekly exercise volume (MET·min/week) and improvements in quality of life among older adults with cancer.

4. Discussion

4.1. Evidence synthesis

This study systematically evaluated the overall effects of exercise interventions on quality of life in older adults with cancer and, for the first time, employed METs·min/week as a unified dosage metric to construct a nonlinear dose–response model. This approach quantitatively identified the optimal balance between exercise volume and therapeutic benefit. The findings provide a scientific basis for developing evidence-based, individualized exercise prescriptions tailored to the needs of older adults living with cancer.

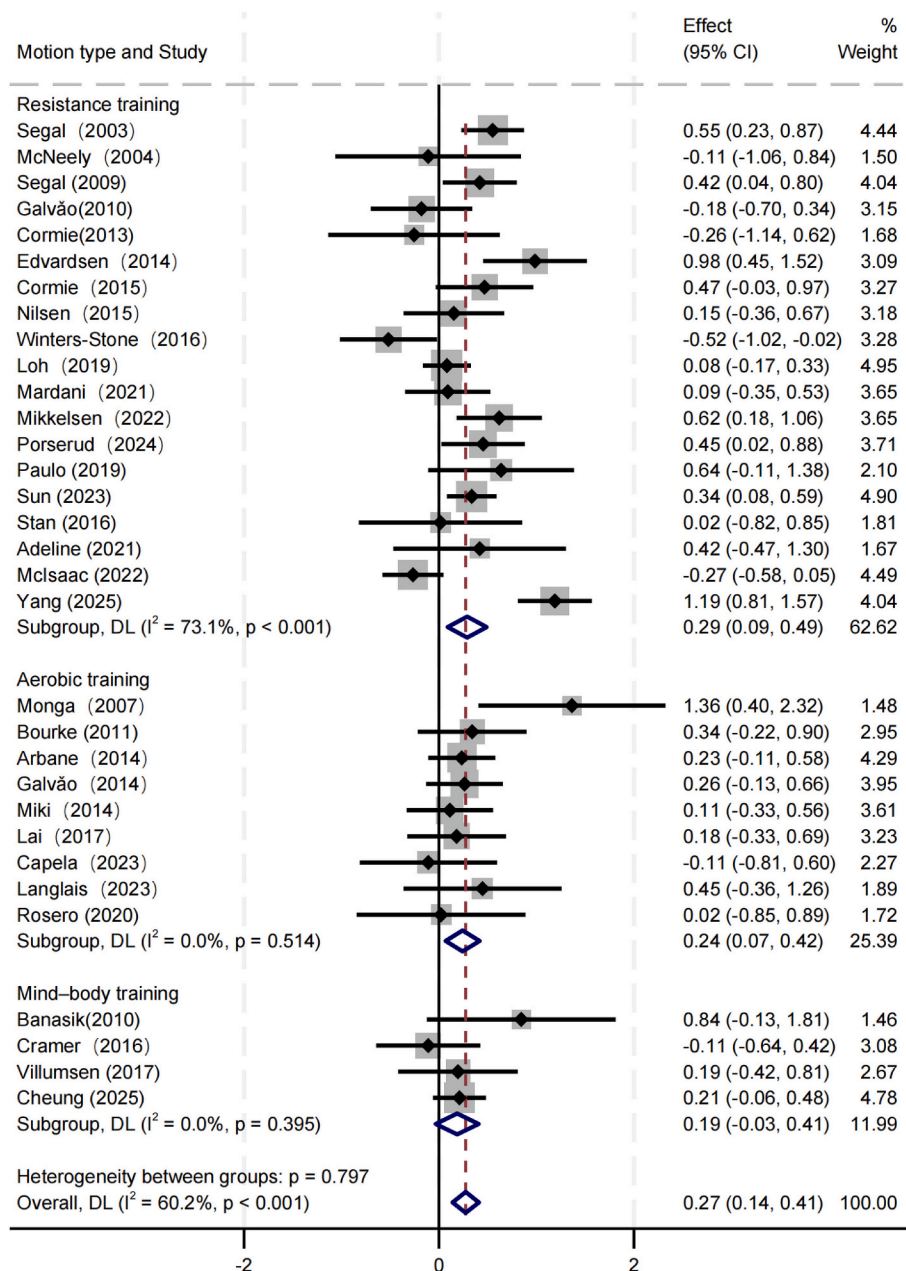
Meta-analysis demonstrated that exercise interventions significantly improved quality of life in older adults with cancer (SMD = 0.27, 95% CI: 0.14–0.41, $p < 0.001$), indicating that regular physical activity confers meaningful benefits during cancer treatment and rehabilitation. Dose–response modeling further revealed an inverted U-shaped relationship between exercise volume and effect size: when the exercise dose reached approximately 962.94 METs·min/week, improvements in quality of life approached a relatively high level. Beyond this point, further increases in dose were associated with a plateau or slight decline in effect, suggesting that higher exercise volumes may not yield additional benefits and could potentially offset intervention effects due to fatigue or reduced adherence. It is important to note that this dose–response relationship reflects an association estimated from prescribed exercise parameters rather than the actual dose completed by individuals. Therefore, the identified dose should be interpreted as a reference range associated with more favorable quality-of-life outcomes, rather than a definitive optimal dose. Beyond this point, the effect size exhibited a slight decline, suggesting that higher exercise volume may not yield additional benefits and may instead offset part of the therapeutic gains, potentially due to increased fatigue or reduced adherence [43]. This finding aligns with previous research conducted in populations with breast, prostate, and lung cancer, collectively underscoring the pivotal role of moderate exercise in cancer rehabilitation [44].

Notably, the WHO (2020) recommends that older adults engage in 150–300 min of moderate-intensity or 75–150 min of vigorous-intensity aerobic activity per week, corresponding to approximately 500–1000 METs·min/week. The reference dose identified in this study (approximately 962.94 MET·min/week) is broadly consistent with the aforementioned recommended range, supporting the potential suitability of

moderate exercise volumes in older adults with cancer. These findings suggest that, in this population, a moderate level of exercise may achieve a favorable balance between safety and improvements in quality of life. In contrast, insufficient exercise doses may fail to adequately stimulate the desired metabolic and psychological responses, whereas excessively high doses may increase cardiovascular strain or exacerbate cancer-related fatigue [45]. Therefore, an exercise regimen characterized by moderate dosage and high adherence may represent the optimal strategy for balancing meaningful improvements in quality of life with safety and feasibility.

Subgroup analyses further confirmed the robustness of the findings. All types of exercise interventions showed positive effects, among which resistance training demonstrated the largest effect size (SMD = 0.29), indicating that resistance exercise may contribute more to improvements in quality of life through maintaining muscle mass and physical function. Aerobic exercise and mind–body exercise also showed significant effects, suggesting the multidimensional value of comprehensive exercise prescriptions. Further analysis revealed that, in terms of intervention duration, the 8–12-week group showed the largest effect size, outperforming the <8-week and >12-week groups. In terms of frequency, interventions performed approximately three times per week showed the best effects, outperforming both <3 sessions/week and >3 sessions/week. Regarding session duration, the <45-min group showed the largest effect size, followed by the 45–60-min group (SMD = 0.27), and the >60-min group (SMD = 0.17). Overall, combinations characterized by shorter intervention duration, moderate frequency, and moderate session length were more favorable for achieving optimal outcomes. These findings are consistent with the conclusions reported by [46,47].

Taken together, the available evidence suggests that exercise frequency, intervention duration, and session length reported across studies are associated with improvements in quality of life within certain ranges. Overall, a moderate level of total weekly exercise volume—approximately 900–1000 MET·min/week—appears to be associated with more favorable intervention effects and may offer advantages in terms of safety and feasibility. However, these findings are derived from independently designed exercise prescriptions across different studies. Given that comparable total exercise volumes can be achieved through varying combinations of intensity, type, and duration, the present MET·min/week–based analysis cannot disentangle the independent contributions of individual FITT components. Therefore, current evidence is insufficient to support direct translation of this dose



NOTE: Weights and between-subgroup heterogeneity test are from random-effects model

Fig. 6. Subgroup analysis of the effects of different exercise types on quality of life in older adults with cancer.

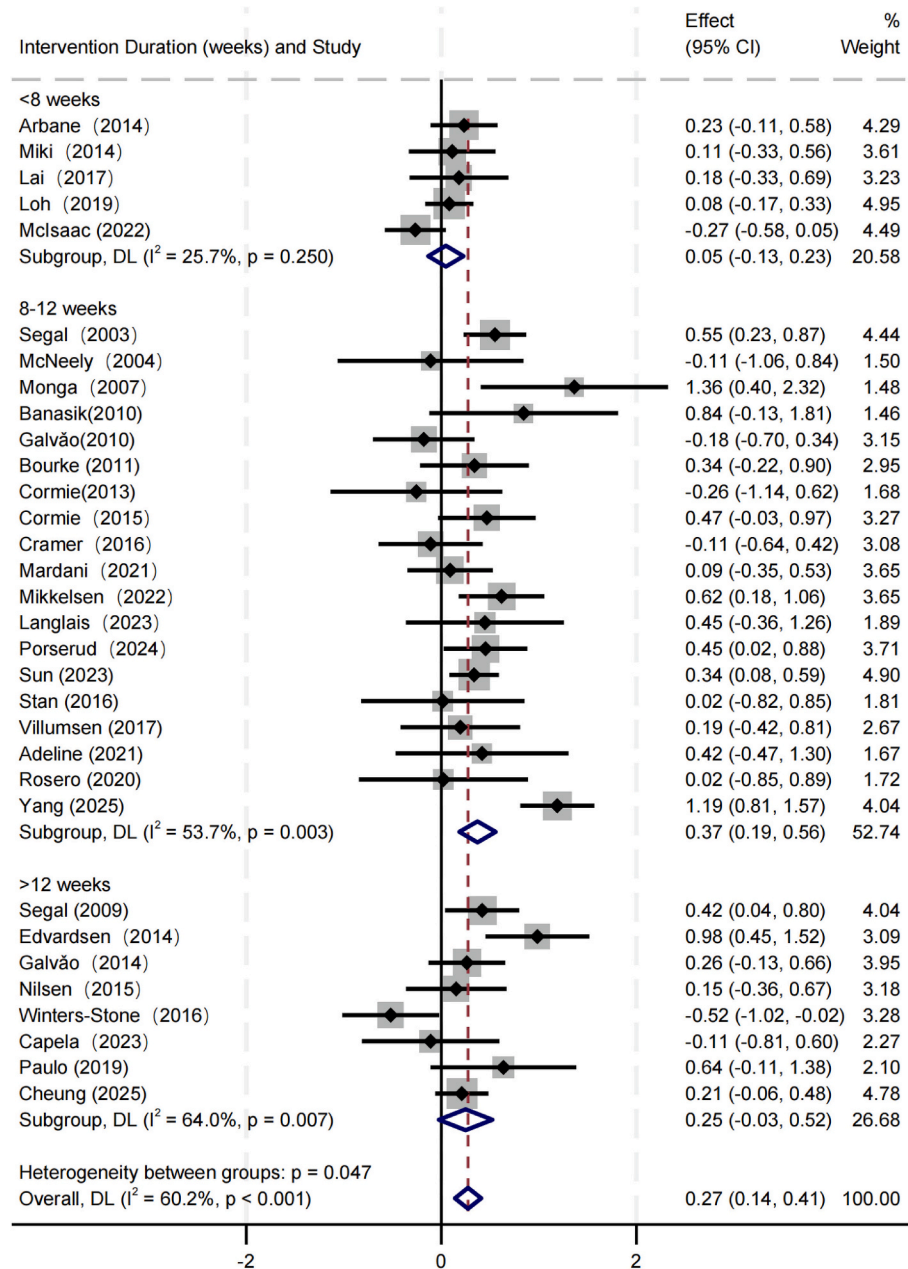
range into a standardized exercise prescription, and the findings should be interpreted as a reference range for exercise volume.

4.2. Clinical implications of the dose-response analysis

The findings of this study underscore the pivotal role of exercise interventions in enhancing the quality of life among older adults with cancer, demonstrating that total weekly exercise volume and regular physical activity can substantially improve both physiological functioning and psychological well-being in this population. For older adults living with cancer, the combined impact of disease burden, treatment-related adverse effects, and age-associated physiological decline significantly constrains their exercise tolerance and capacity for sustained participation. In this context, designing exercise programs that are both appropriate and feasible becomes particularly crucial. The optimal

dosage range identified in this study (approximately 900–1000 METs-min/week) suggests that moderate volumes of exercise are sufficient to elicit meaningful improvements in quality of life without imposing an excessive physiological burden. This dose range was estimated based on prescribed exercise parameters and should be interpreted as a reference range rather than an actual effective dose at the individual level.

Compared with younger individuals with cancer or healthy older adults, older adults with cancer are more susceptible to fatigue, declines in cardiopulmonary function, and loss of muscle mass. Excessive exercise volumes may therefore delay physiological recovery, reduce adherence, or even precipitate adverse events. Therefore, moderate ranges of total weekly exercise volume interventions offer advantages not only in terms of safety but also in sustaining long-term participation. Exercise of moderate intensity can enhance cardiorespiratory fitness and



NOTE: Weights and between-subgroup heterogeneity test are from random-effects model

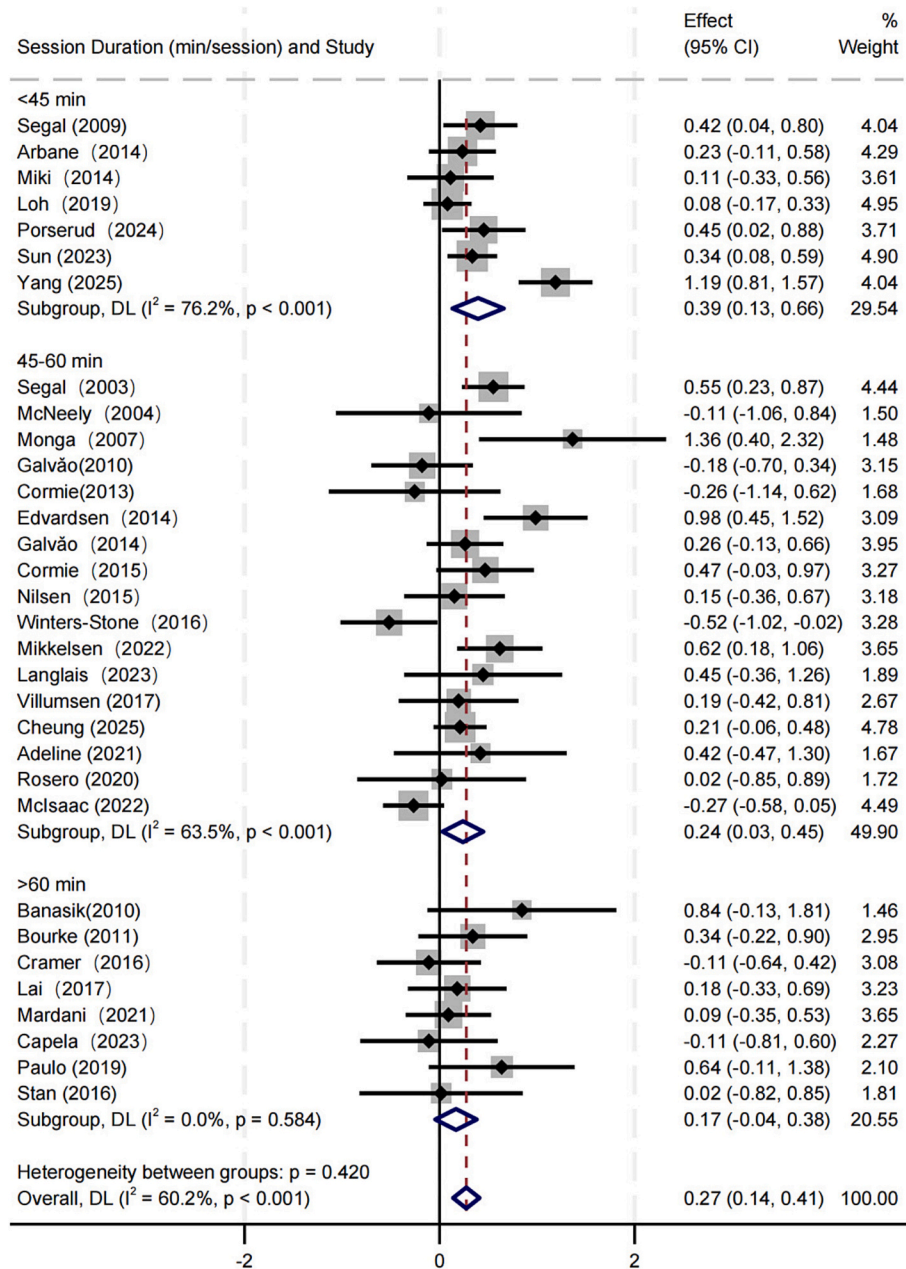
Fig. 7. Subgroup analysis of the effects of different intervention durations on quality of life in older adults with cancer.

muscle strength while simultaneously activating endogenous anti-inflammatory pathways and neuroendocrine regulatory mechanisms, thereby contributing to improvements in emotional well-being and cognitive function [48,49]. The interplay between these physiological and psychological mechanisms may represent the key pathway through which moderate ranges of total weekly exercise volume produce substantial improvements in quality of life.

Moreover, the findings support the implementation of individualized, progressive exercise prescriptions in the rehabilitation of older adults with cancer. Given the substantial variability in cancer type, treatment stage, and functional reserve across patients, clinical interventions should incorporate dynamic adjustments in exercise intensity, frequency, and modality to accommodate each patient's evolving physiological capacity and therapeutic needs. For example, during the early stages of rehabilitation, low-to-moderate-intensity

aerobic or mind-body exercises may be prioritized, with resistance-training components introduced progressively as physiological tolerance improves. This gradual progression can promote restoration of muscle function and enhance patients' sense of self-efficacy [50,51]. Such a gradual, tiered intervention model not only aligns with established safety principles in oncology rehabilitation but also corresponds well with the psychological and behavioral characteristics of older adults [52].

These clinical implications are further supported by the consensus-based exercise recommendations for older adults living with and beyond cancer [53]. The expert panel emphasized that exercise prescriptions for older cancer survivors should be individualized according to health status, functional capacity, comorbidities, treatment-related symptoms, and exercise tolerance. They also recommended that professionals who prescribe and deliver exercise should be able to modify



NOTE: Weights and between-subgroup heterogeneity test are from random-effects model

Fig. 8. Subgroup analysis of the effects of different session durations on quality of life in older adults with cancer.

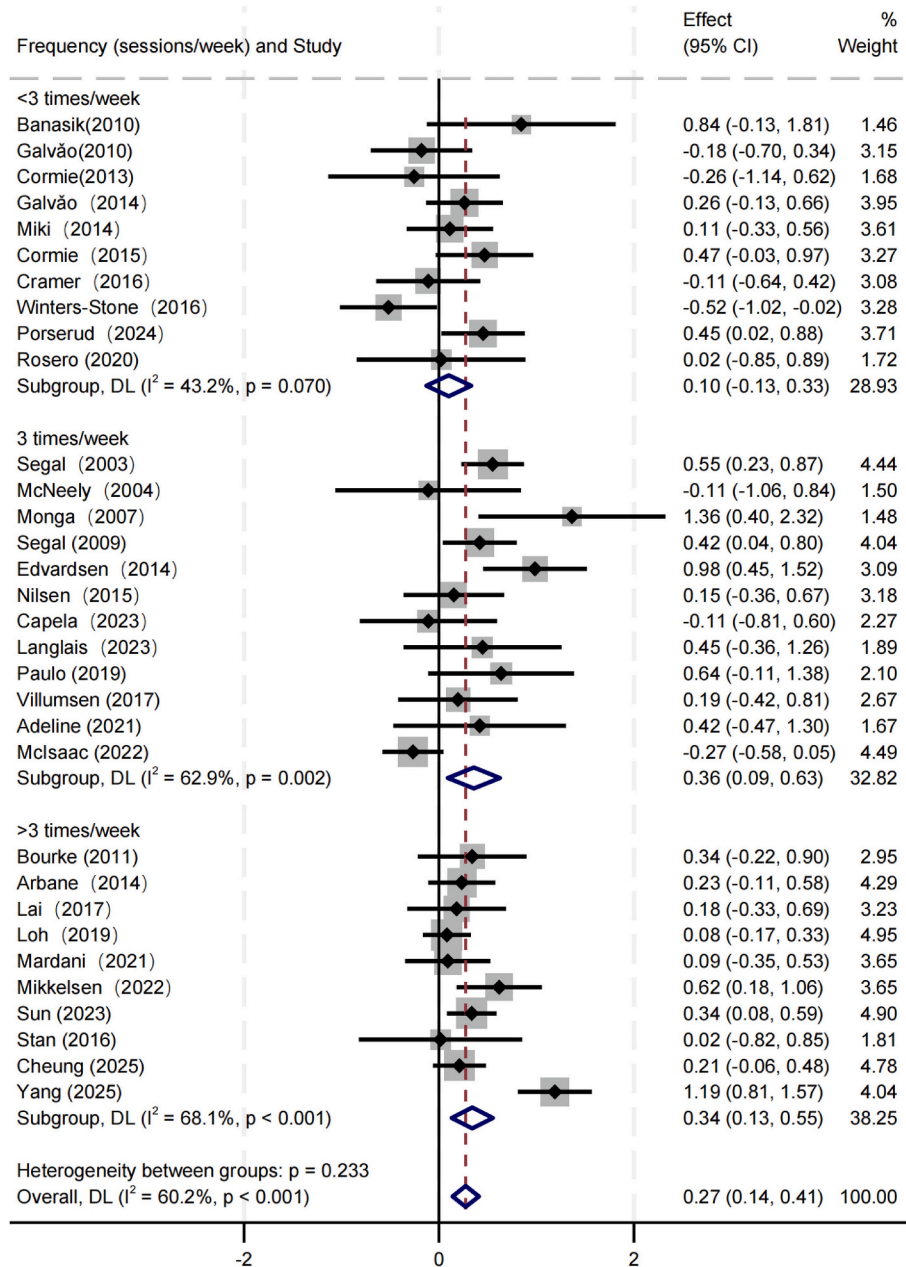
and tailor programs appropriately, and should be encouraged to gain relevant experience, education, and/or advanced certification in exercise for older adults and/or cancer survivors. Moreover, for older cancer survivors with significant deficits in strength, mobility, and/or balance, exercise programming should first focus on improving muscle strength, flexibility, and balance before progressing toward aerobic capacity. Therefore, although the present dose-response analysis provides a quantitative reference for total weekly exercise volume, practical exercise prescriptions should be individualized, professionally guided, and function-oriented rather than based solely on a fixed exercise dose.

More importantly, the dose-response curve constructed in this study provides a quantitative reference for understanding the relationship between exercise dose and improvements in quality of life. Compared with traditional guidelines that typically describe recommended activity levels based on fixed duration or frequency, this study quantified the

association between total weekly exercise volume and intervention effects, thereby identifying a dose range associated with more favorable improvements in quality of life. This finding enables clinicians and rehabilitation specialists to optimize exercise prescriptions based on each patient's specific condition, thereby advancing the precision application of prescribed exercise in real-world practice [54].

Although this study substantiates the clinical value of a moderate range of total weekly exercise volume exercise, further research is needed to clarify how dose-response relationships may vary across different cancer types, treatment modalities, and comorbidity profiles. Future studies should integrate biomarkers, multidimensional quality-of-life instruments, and long-term follow-up data to deepen the understanding of exercise-related mechanisms and dose-response patterns.

Overall, this study provides important evidence to inform rehabilitation management in older adults with cancer, highlighting that within



NOTE: Weights and between-subgroup heterogeneity test are from random-effects model

Fig. 9. Subgroup analysis of the effects of different exercise frequencies on quality of life in older adults with cancer.

a safe and controlled range, total weekly exercise volume and structured exercise interventions can substantially enhance overall quality of life and confer meaningful health benefits.

It should be noted that the estimated exercise volume was derived from prescribed parameters rather than the actual amount performed, and therefore should be interpreted as a reference range for exercise prescription.

Reporting of baseline physical activity levels and prior exercise behavior was inconsistent across the included studies, and some studies did not provide such information. This lack of reporting limited our ability to further stratify or adjust for this potential confounding factor. In exercise oncology research, baseline activity levels may influence individuals' responsiveness to exercise interventions, thereby affecting improvements in quality of life. Therefore, this potential source of bias should be taken into account when interpreting the dose-response

findings of the present study.

4.3. Strengths and limitations

This study represents the first dose-response meta-analysis to systematically evaluate the effects of exercise interventions on quality-of-life improvements in older adults with cancer. It innovatively applied METs-min/week to quantify exercise dosage and employed a nonlinear dose-response model to identify, from a quantitative perspective, the optimal range of exercise-prescription parameters associated with improvements in quality of life. The study adhered to PRISMA guidelines, conducted a systematic search across five major databases, and employed dual-review screening and subgroup analyses to ensure the scientific rigor and robustness of the findings. Collectively, the results provide a quantitative foundation for the precise formulation of exercise

prescriptions for older adults with cancer. However, only studies published in English were included in this analysis, which may have introduced language bias and led to the omission of relevant studies published in other languages, particularly those from non-English-speaking countries. In addition, the included studies were predominantly conducted in North America, Europe, and other developed regions, with relatively limited representation from developing countries or settings with different healthcare systems, potentially resulting in regional bias. This imbalance in geographic distribution may affect the generalizability of the findings, as variations in healthcare resources, rehabilitation models, cultural contexts, and the implementation of exercise interventions across countries may influence both the effectiveness of interventions and adherence.

In this study, exercise dose was defined based on prescribed intervention parameters rather than actual completed dose. In prior research, exercise dose has typically been operationalized using the prescribed frequency, intensity, and duration specified in the intervention protocol, rather than the amount actually performed by individuals [11]. However, in real-world intervention settings, discrepancies often arise between prescribed and actual exercise due to factors such as adherence, individual tolerance, and treatment-related side effects. Previous meta-analyses have shown that exercise adherence is influenced by FITT parameters, with higher prescribed intensity particularly associated with reduced adherence; in populations with chronic conditions, longer session durations may further compromise adherence [12]. This suggests that the actual dose achieved under different prescribed parameters may not correspond to the intended dose, potentially leading to misclassification of exercise exposure and consequently affecting the estimation of the dose–response relationship. Therefore, the approximately 962.94 MET-min/week identified in this study should be interpreted as a reference prescription range associated with improvements in quality of life, rather than an actual effective dose. Furthermore, because similar total weekly exercise volumes can be achieved through different combinations of exercise type, intensity, frequency, and duration, the use of a total dose metric limits the ability to disentangle the independent effects of different FITT components, thereby constraining the translation of these findings into exercise prescriptions.

Future studies should standardize the reporting of intervention parameters, enhance sample size and geographic representativeness, and conduct long-term randomized controlled trials to verify the sustainability and generalizability of the observed intervention effects.

5. Conclusion

This systematic review and meta-analysis demonstrated that exercise interventions can significantly improve quality of life in older adults with cancer. Dose–response analysis indicated an inverted U-shaped relationship between exercise volume (MET-min/week) and improvements in quality of life, with approximately 962.94 MET-min/week corresponding to relatively favorable effects. It should be noted that this estimate was derived from prescribed intervention parameters and did not fully account for potential factors such as adherence and baseline physical activity; therefore, the dose–response relationship should be interpreted with caution. Subgroup analyses suggested that exercise type and intervention characteristics may influence outcomes; however, current evidence is insufficient to support their direct translation into a fixed, standardized exercise prescription. Future studies should incorporate adherence-related information, expand sample sizes, and extend follow-up durations. High-quality, multicenter randomized controlled trials are warranted to further elucidate the long-term mechanisms and optimal dose range of exercise interventions, thereby supporting their evidence-based application in cancer rehabilitation.

Artificial intelligence–assisted writing statement

The authors used artificial intelligence–based language tools solely

for language editing purposes. All scientific content, data analysis, and conclusions were independently developed by the authors.

Author contribution

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 Quality control of data and algorithms: HM. Y; JH. W
 Data analysis and interpretation: Q. G; HM. Y
 Statistical analysis: ZQ. G
 Manuscript preparation: ZQ. G
 Manuscript editing: YX. W; C. L; JX. K
 Manuscript review: YX. W; C. L; JX. K

Declaration of competing interest

The authors declare no competing interests.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jgo.2026.103048>.

References

- [1] Rodin G, Feldman A, Trapani D, Skelton M, Unger-Saldana K, Essue B, et al. The human crisis in cancer: a lancet oncology commission. *Lancet Oncol* 2025;26(1): e628–70. [https://doi.org/10.1016/s1470-2045\(25\)00530-3](https://doi.org/10.1016/s1470-2045(25)00530-3).
- [2] DePinto RA. The age of cancer. *Nature* 2000;408(2):248–54. <https://doi.org/10.1038/35041694>.
- [3] Yang W, Zhang T, Song X, Dong G, Xu L, Jiang F. SNP-target genes interaction perturbing the cancer risk in the post-GWAS. *Cancers (Basel)* 2022;14(3). <https://doi.org/10.3390/cancers14225636>.
- [4] Bellizzi KM, Mustian KM, Bowen DJ, Resnick B, Miller SM. Aging in the context of cancer prevention and control : perspectives from behavioral medicine. *Cancer* 2008;113(4):3479–83. <https://doi.org/10.1002/cncr.23937>.
- [5] Mikkelsen MK, Lund CM, Vinther A, Tolver A, Johansen JS, Chen I, et al. Effects of a 12-week multimodal exercise intervention among older patients with advanced cancer: results from a randomized controlled trial. *Oncologist* 2022;27(5):67–78. <https://doi.org/10.1002/onco.13970>.
- [6] Loh KP, Kleckner IR, Lin PJ, Mohile SG, Canin BE, Flannery MA, et al. Effects of a home-based exercise program on anxiety and mood disturbances in older adults with cancer receiving chemotherapy. *J Am Geriatr Soc* 2019;67(6):1005–11. <https://doi.org/10.1111/jgs.15951>.
- [7] Forbes CC, Swan F, Greenley SL, Lind M, Johnson MJ. Physical activity and nutrition interventions for older adults with cancer: a systematic review. *J Cancer Surviv* 2020;14(7):689–711. <https://doi.org/10.1007/s11764-020-00883-x>.
- [8] Liu Y, Jiang M, Pan X, Geng J. Effects of exercise on mobility, balance and gait in patients with the chronic stroke: a systematic review and meta-analysis. *Sci Rep* 2025;15(8):24158. <https://doi.org/10.1038/s41598-025-09458-1>.
- [9] Chandler, J., Cumpston, M., Li, T., Page, M. J., & Welch, V. (2019). *Cochrane handbook for systematic reviews of interventions*. Hoboken: Wiley, 4(9), 14651858.
- [10] Ainsworth BE, Haskell WL, Whitt MC, Irwin ML, Swartz AM, Strath SJ, et al. Compendium of physical activities: an update of activity codes and MET intensities. *Med Sci Sports Exerc* 2000;32(10):S498–504.
- [11] Courneya KS, McKenzie DC, Mackey JR, Gelmon K, Friedenreich CM, Yasui Y, et al. Effects of exercise dose and type during breast Cancer chemotherapy: multicenter randomized trial. *JNCI J Natl Cancer Inst* 2013;105(11):1821–32. <https://doi.org/10.1093/jnci/djt297>.
- [12] Burnet K, Higgins S, Kelsch E, Moore JB, Stoner L. The effects of manipulation of frequency, intensity, time, and type (FITT) on exercise adherence: a meta-analysis. *Transl Sports Med* 2020;3(12):222–34. <https://doi.org/10.1002/tsm2.138>.
- [13] Adeline F, Hugo PR, René M, Tamas F, Eléonor R, Michel P. Effects of a mixed exercise program on cancer related-fatigue and health-related quality of life in oncogeriatric patients: a feasibility study. *J Geriatr Oncol* 2021;12(13):915–21. <https://doi.org/10.1016/j.jgo.2021.02.025>.
- [14] Arbane G, Douiri A, Hart N, Hopkinson NS, Singh S, Speed C, et al. Effect of postoperative physical training on activity after curative surgery for non-small cell lung cancer: a multicentre randomised controlled trial. *Physiotherapy* 2014;100(14):100–7. <https://doi.org/10.1016/j.physio.2013.12.002>.
- [15] Banasik J, Williams H, Haberman M, Blank SE, Bendel R. Effect of Iyengar yoga practice on fatigue and diurnal salivary cortisol concentration in breast cancer survivors. *J Am Acad Nurse Pract* 2011;23(15):135–42. <https://doi.org/10.1111/j.1745-7599.2010.00573.x>.
- [16] Bourke L, Doll H, Crank H, Daley A, Rosario D, Saxton JM. Lifestyle intervention in men with advanced prostate cancer receiving androgen suppression therapy: a

- feasibility study. *Cancer Epidemiol Biomarkers Prev* 2011;20(16):647–57. <https://doi.org/10.1158/1055-9965.Epi-10-1143>.
- [17] Capela A, Antunes P, Coelho CA, Garcia CL, Custódio S, Amorim R, et al. Effects of walking football on adherence, safety, quality of life and physical fitness in patients with prostate cancer: findings from the PROSTATA_MOVE randomized controlled trial. *Front Oncol* 2023;13(17):1129028. <https://doi.org/10.3389/fonc.2023.1129028>.
 - [18] Cheung DST, Chan WL, Chau PH, Soong IS, Yeung WF, Lee SF, et al. The effect of qigong on frailty in older cancer survivors: a randomised controlled trial. *Age Ageing* 2025;54(18):afaf184. <https://doi.org/10.1093/ageing/afaf184>.
 - [19] Cormie P, Galvao DA, Spry N, Joseph D, Chee R, Taaffe DR, et al. Can supervised exercise prevent treatment toxicity in patients with prostate cancer initiating androgen-deprivation therapy: a randomised controlled trial. *BJU Int* 2015;115(19):256–66. <https://doi.org/10.1111/bju.12646>.
 - [20] Cormie P, Newton RU, Spry N, Joseph D, Taaffe DR, Galvao DA. Safety and efficacy of resistance exercise in prostate cancer patients with bone metastases. *Prostate Cancer Prostatic Dis* 2013;16(20):328–35. <https://doi.org/10.1038/pcan.2013.22>.
 - [21] Cramer H, Pokhrel B, Fester C, Meier B, Gass F, Lauche R, et al. A randomized controlled bicenter trial of yoga for patients with colorectal cancer. *Psycho-Oncology* 2016;25(21):412–20. <https://doi.org/10.1002/pon.3927>.
 - [22] Edvardsen E, Skjongsberg OH, Holme I, Nordsletten L, Borchsenius F, Anderssen SA. High-intensity training following lung cancer surgery: a randomised controlled trial. *Thorax* 2015;70(22):244–50. <https://doi.org/10.1136/thoraxjnl-2014-205944>.
 - [23] Galvao DA, Spry N, Denham J, Taaffe DR, Cormie P, Joseph D, et al. A multicentre year-long randomised controlled trial of exercise training targeting physical functioning in men with prostate cancer previously treated with androgen suppression and radiation from TROG 03.04 RADAR. *Eur Urol* 2014;65(23):856–64. <https://doi.org/10.1016/j.eururo.2013.09.041>.
 - [24] Galvao DA, Taaffe DR, Spry N, Joseph D, Newton RU. Combined resistance and aerobic exercise program reverses muscle loss in men undergoing androgen suppression therapy for prostate Cancer without bone metastases: a randomized controlled trial. *J Clin Oncol* 2010;28(24):340–7. <https://doi.org/10.1200/jco.2009.23.2488>.
 - [25] 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(25):30–6.
 - [26] Langlais CS, Chen YH, Van Blarigan EL, Chan JM, Ryan CJ, Zhang L, et al. Quality of life for men with metastatic castrate-resistant prostate cancer participating in an aerobic and resistance exercise pilot intervention. *Urol Oncol Sem Orig Invest* 2023;41(26):e1–11. <https://doi.org/10.1016/j.urolonc.2022.11.016>.
 - [27] Mardani A, Razi SP, Mazaheri R, Haghani S, Vaismoradi M. Effect of the exercise programme on the quality of life of prostate cancer survivors: a randomized controlled trial. *Int J Nurs Pract* 2021;27(27):e12883. <https://doi.org/10.1111/ijn.12883>.
 - [28] McIsaac DI, Hladkovic 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(28):41–8. <https://doi.org/10.1016/j.bja.2022.04.006>.
 - [29] McNeely ML, Parliament M, Courneya KS, Seikaly H, Jha N, Scrimger R, et al. A pilot study of a randomized controlled trial to evaluate the effects of progressive resistance exercise training on shoulder dysfunction caused by spinal accessory neurectomy/neurectomy in head and neck cancer survivors. *Head Neck* 2004;26(29):518–30. <https://doi.org/10.1002/hed.20010>.
 - [30] Miki E, Kataoka T, Okamura H. Feasibility and efficacy of speed-feedback therapy with a bicycle ergometer on cognitive function in elderly cancer patients in Japan. *Psychoneurology* 2014;23(30):906–13. <https://doi.org/10.1002/pon.3501>.
 - [31] Monga U, Garber SL, Thornby J, Vallbona C, Kerrigan AJ, Monga TN, et al. Exercise prevents fatigue and improves quality of life in prostate cancer patients undergoing radiotherapy. *Arch Phys Med Rehabil* 2007;88(31):1416–22. <https://doi.org/10.1016/j.apmr.2007.08.110>.
 - [32] Nilsen TS, Raastad T, Skovlund E, Courneya KS, Langberg CW, Lilleby W, et al. Effects of strength training on body composition, physical functioning, and quality of life in prostate cancer patients during androgen deprivation therapy. *Acta Oncol* 2015;54(32):1805–13. <https://doi.org/10.3109/0284186x.2015.1037008>.
 - [33] Paulo TRS, Rossi FE, Vizeu J, Tosello GT, Seidinger SC, Simoes RR, et al. The impact of an exercise program on quality of life in older breast cancer survivors undergoing aromatase inhibitor therapy: a randomized controlled trial. *Health Qual Life Outcomes* 2019;17(33). <https://doi.org/10.1186/s12955-019-1090-4>. Article 17.
 - [34] Porsrud A, Karlsson P, Aly M, Rydwick E, Torikka S, Henningssohn L, et al. Effects of an exercise intervention in primary care after robot-assisted radical cystectomy for urinary bladder cancer: a randomised controlled trial. *BMC Cancer* 2024;24(34). <https://doi.org/10.1186/s12885-024-12647-2>. Article 891.
 - [35] Rosero ID, Ramírez-Vélez R, Martínez-Velilla N, Cedeño-Veloz BA, Morilla I, Izquierdo M. Effects of a multicomponent exercise program in older adults with non-small-cell lung cancer during adjuvant/palliative treatment: an intervention study. *J Clin Med* 2020;9(35). <https://doi.org/10.3390/jcm9030862>. Article 862.
 - [36] Segal RJ, Reid RD, Courneya KS, Malone SC, Parliament MB, Scott CG, et al. Resistance exercise in men receiving androgen deprivation therapy for prostate cancer. *J Clin Oncol* 2003;21(36):1653–9. <https://doi.org/10.1200/jco.2003.09.534>.
 - [37] Segal RJ, Reid RD, Courneya KS, Sigal RJ, Kenny GP, Prud'Homme DG, et al. Randomized controlled trial of resistance or aerobic exercise in men receiving radiation therapy for prostate cancer. *J Clin Oncol* 2009;27(37):344–51. <https://doi.org/10.1200/jco.2007.15.4963>.
 - [38] Stan DL, Croghan KA, Croghan IT, Jenkins SM, Sutherland SJ, Cheville AL, et al. Randomized pilot trial of yoga versus strengthening exercises in breast cancer survivors with cancer-related fatigue. *Support Care Cancer* 2016;24(38):4005–15. <https://doi.org/10.1007/s00520-016-3233-z>.
 - [39] Sun J, Ge L, Cao CJ, Yao W, Wang XL. Effects of resistance exercise in elderly cancer patients. *Afr Health Sci* 2023;23(39):298–304. <https://doi.org/10.4314/ahs.v23i2.34>.
 - [40] Villumsen BR, Jorgensen MG, Frystyk J, Hordam B, Borre M. Home-based 'exergaming' was safe and significantly improved 6-min walking distance in patients with prostate cancer: a single-blinded randomised controlled trial. *BJU Int* 2019;124(40):600–8. <https://doi.org/10.1111/bju.14782>.
 - [41] Winters-Stone KM, Lyons KS, Dobek J, Dieckmann NF, Bennett JA, Nail L, et al. Benefits of partnered strength training for prostate cancer survivors and spouses: results from a randomized controlled trial of the exercising together project. *J Cancer Surviv* 2016;10(41):633–44. <https://doi.org/10.1007/s11764-015-0509-0>.
 - [42] Yang CJ, Chen L, Zhou Q, Hou H, Xie FY. Effectiveness of home-based exercise combined with nutritional care intervention in elderly patients with gastric cancer and sarcopenia: a retrospective study. *Front Med* 2025;12(42):1544689. <https://doi.org/10.3389/fmed.2025.1544689>.
 - [43] Wasfy MM, Baggish AL. Exercise dose in clinical practice. *Circulation* 2016;133(43):2297–313. <https://doi.org/10.1161/circulationaha.116.018093>.
 - [44] Kang DW, Boulé NG, Field CJ, Fairley AS, Courneya KS. Effects of supervised high-intensity interval training on motivational outcomes in men with prostate cancer undergoing active surveillance: results from a randomized controlled trial. *Int J Behav Nutr Phys Act* 2022;19(44):126. <https://doi.org/10.1186/s12966-022-01365-2>.
 - [45] Campanini I, Ligabue MB, Bò MC, Bassi MC, Lusuardi M, Merlo A. Self-managed physical activity in cancer survivors for the management of cancer-related fatigue: a scoping review. *PLoS One* 2022;17(45):e0279375. <https://doi.org/10.1371/journal.pone.0279375>.
 - [46] Campbell LL, Winters-Stone KM, Wiskemann J, May AM, Schwartz AL, Courneya KS, et al. Exercise guidelines for cancer survivors: consensus statement from international multidisciplinary roundtable. *Med Sci Sports Exerc* 2019;51(46):2375–90. <https://doi.org/10.1249/mss.0000000000002116>.
 - [47] Sanders LMJ, Hortobágyi T, la Bastide-van Gemert S, van der Zee EA, van Heuvelen MJG. Dose-response relationship between exercise and cognitive function in older adults with and without cognitive impairment: a systematic review and meta-analysis. *PLoS One* 2019;14(47):e0210036. <https://doi.org/10.1371/journal.pone.0210036>.
 - [48] Cannioto RA, Moysich KB. Epithelial ovarian cancer and recreational physical activity: a review of the epidemiological literature and implications for exercise prescription. *Gynecol Oncol* 2015;137(48):559–73. <https://doi.org/10.1016/j.ygyno.2015.03.016>.
 - [49] Liu H, Sun Z, Zeng H, Han J, Hu M, Mao D, et al. Meta-analysis of the effects of multi-component exercise on cognitive function in older adults with cognitive impairment. *Front Aging Neurosci* 2025;17(49):1551877. <https://doi.org/10.3389/fnagi.2025.1551877>.
 - [50] Ren X, Wang X, Sun J, Hui Z, Lei S, Wang C, et al. Effects of physical exercise on cognitive function of breast cancer survivors receiving chemotherapy: a systematic review of randomized controlled trials. *Breast* 2022;63(50):113–22. <https://doi.org/10.1016/j.breast.2022.03.014>.
 - [51] Zhou HJ, Wang T, Xu YZ, Chen YN, Deng LJ, Wang C, et al. Effects of exercise interventions on cancer-related fatigue in breast cancer patients: an overview of systematic reviews. *Support Care Cancer* 2022;30(51):10421–40. <https://doi.org/10.1007/s00520-022-07389-5>.
 - [52] Foulkes SJ, Haykowsky MJ, Li T, Wang J, Kennedy M, Kirkham AA, et al. Determinants of impaired peak oxygen uptake in breast Cancer survivors: JACC: CardioOncology primer. *JACC CardioOncol* 2024;6(52):33–7. <https://doi.org/10.1016/j.jacc.2023.11.005>.
 - [53] Winters-Stone KM, Meyers G, Eckstrom E, Cheville A, Garcia JM, McNeely ML, et al. Exercise recommendations for older adults living with and beyond cancer: a consensus statement by the advancing capacity to integrate exercise into the care of older cancer survivors expert panel. *Cancer* 2026;132(53):e70252. <https://doi.org/10.1002/cncr.70252>.
 - [54] Yun D, Han SS, Lee J, Kim Y, Kim K, Jin K, et al. Study protocol for a consortium linking health medical records, biospecimens, and biosignals in Korean patients with acute kidney injury (LINKA cohort). *Kidney Res Clin Pract* 2024;54. <https://doi.org/10.23876/j.krcp.24.061>.
 - [55] Ozemek C, Bonikowske A, Christle J, Gallo P. ACSM'S guidelines for exercise testing and prescription. Lippincott Williams & Wilkins; 2025.