

Review

Mindfulness-based physical activity for mental health and resilience in cancer patients: A systematic review and network meta-analysis

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Abstract: This systematic review and network meta-analysis examined the comparative effectiveness of mindfulness-based physical activity interventions on psychological outcomes in cancer patients. Following PRISMA-NMA guidelines, we searched 12 databases from inception to December 2023, identifying 30 randomized controlled trials (3518 participants) that met inclusion criteria. The network meta-analysis revealed significant benefits across psychological domains, with differential effectiveness among intervention modalities. Mindfulness-Based Stress Reduction (MBSR) demonstrated superior efficacy for anxiety (SMD = -0.45, 95% CrI: -0.59 to -0.31) and depression (SMD = -0.41, 95% CrI: -0.55 to -0.27), while mindful walking yielded optimal improvements for quality of life (SMD = 0.52, 95% CrI: 0.36 to 0.68). Subgroup analyses identified cancer type, treatment stage, and intervention format as significant moderators of effectiveness, with stronger effects observed during active treatment compared to post-treatment periods. Medium-duration interventions (8–12 weeks) delivered in supervised group formats showed optimal outcomes. Network inconsistency was minimal (global inconsistency factor: 0.11, $p = 0.42$), and publication bias assessment suggested no significant bias. Our findings provide robust evidence supporting the integration of mindfulness-based physical activity interventions into cancer care, with MBSR recommended for addressing anxiety and depression, and mindful walking for enhancing quality of life. These findings highlight the importance of tailoring intervention selection to specific psychological outcomes and patient characteristics, potentially improving psychological resilience throughout the cancer journey.

Keywords: mindfulness; physical activity; cancer; psychological resilience; network meta-analysis; mind-body interventions

1. Introduction

Cancer diagnosis and treatment represent significant psychological challenges for patients, with 30%–40% experiencing clinically significant distress including anxiety, depression, and impaired quality of life that can persist throughout treatment and into survivorship. These psychological sequelae can adversely affect treatment adherence, recovery outcomes, and overall well-being. While pharmacological approaches remain common in symptom management, their limitations and potential side effects have stimulated interest in complementary non-pharmacological interventions that address both the physical and psychological dimensions of cancer care.

Mindfulness-based interventions have emerged as promising approaches for enhancing psychological resilience in cancer patients. Defined as the practice of maintaining non-judgmental awareness of present-moment experiences, mindfulness has demonstrated efficacy in reducing psychological distress and improving emotional

regulation among various cancer populations. The theoretical framework of mindfulness posits that cultivating present-moment awareness enables patients to develop a different relationship with difficult thoughts and emotions, potentially interrupting rumination cycles and enhancing adaptive coping. Studies by Liu et al. [1] and Würtzen et al. [2] have demonstrated significant reductions in anxiety and depression following mindfulness interventions in breast cancer patients.

Concurrently, physical activity interventions have shown consistent benefits for cancer-related symptoms. Regular exercise can reduce fatigue, improve mood, enhance physical function, and potentially reduce recurrence risk in various cancer types. However, as documented by Kleckner et al. [3] and Andersen et al. [4], adherence to physical activity recommendations remains suboptimal among cancer patients, with barriers including treatment side effects, fatigue, and psychological distress.

The integration of mindfulness principles with physical activity represents an innovative approach that may synergistically address both physical and psychological aspects of cancer care. Mind-body exercise modalities such as yoga, tai chi, qigong, and mindful walking incorporate elements of physical movement, breath awareness, and attentional focus that may uniquely benefit cancer patients. Recent studies by Carlson et al. [5], Huberty et al. [6], and Cheng et al. [7] suggest promising outcomes from these integrated approaches.

Despite growing evidence, substantial knowledge gaps remain regarding the comparative effectiveness of different mindfulness-based physical activity interventions for cancer patients. Previous reviews have typically focused on single intervention types or specific cancer populations, limiting their ability to determine optimal approaches. This systematic review and network meta-analysis aims to comprehensively evaluate and compare the effects of various mindfulness-based physical activity interventions on psychological resilience and mental health outcomes in cancer patients undergoing treatment, thereby informing evidence-based recommendations for clinical practice and future research directions.

2. Methods

2.1. Protocol and registration

This systematic review and network meta-analysis was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for network meta-analyses (PRISMA-NMA) guidelines. Prior to initiating the review, the research protocol was prospectively registered in the International Prospective Register of Systematic Reviews (PROSPERO, registration number: CRD42023148742) to enhance methodological transparency and minimize potential reporting bias. The protocol specified a priori the review objectives, eligibility criteria, search strategy, data extraction methodology, risk of bias assessment approach, and statistical analysis plan. Any deviations from the registered protocol during the review process were thoroughly documented and justified in the final report. The methodological approach was informed by the Cochrane Handbook for Systematic Reviews of Interventions and the guidelines for conducting network meta-analyses

published by the International Society for Pharmacoeconomics and Outcomes Research (ISPOR).

2.2. Eligibility criteria

The eligibility criteria for this systematic review and network meta-analysis were established a priori and structured according to the Population, Intervention, Comparator, Outcomes, and Study design (PICOS) framework, as detailed in **Table 1**. We included randomized controlled trials published between January 2000 and December 2023 that investigated mindfulness-based physical activity interventions for adult cancer patients. Eligible participants were adults (≥ 18 years) with histologically confirmed cancer diagnoses who were either undergoing active treatment or had completed primary treatment within the past 24 months. The interventions of interest incorporated both mindfulness principles and physical activity components, including but not limited to yoga, tai chi, qigong, mindful walking, and meditation integrated with structured exercise. Comparators encompassed standard care, waitlist control, attention control, or alternative active interventions. Primary outcomes focused on psychological measures including resilience, anxiety, depression, stress, and quality of life assessed using validated instruments. Secondary outcomes included cancer-related symptoms such as fatigue, pain, sleep disturbances, and physical function. Studies were required to report outcomes at minimum immediately post-intervention, with longer-term follow-up data (≥ 3 months) prioritized when available. As shown in **Table 1**, we excluded non-randomized designs, exclusively pharmacological interventions, studies focusing solely on advanced or terminal cancer, and publications in languages other than English or Chinese.

Table 1. Eligibility criteria using PICOS framework.

PICOS Component	Inclusion Criteria	Exclusion Criteria
Participants	• Adults ≥ 18 years • Histologically confirmed cancer diagnosis (any type) • Any cancer stage • Undergoing active treatment OR • Completed primary treatment within past 24 months	• Pediatric cancer patients • Individuals without confirmed cancer diagnosis • Exclusively advanced/terminal cancer • Completed treatment > 24 months ago
Interventions	• Mindfulness-based physical activity interventions • Yoga, tai chi, qigong with mindfulness components • Mindful walking • Meditation integrated with exercise • Any delivery mode (individual/group) • Any setting (clinical/community/home-based)	• Physical activity without mindfulness components • Mindfulness interventions without physical activity • Exclusively pharmacological interventions • Exclusively dietary or nutritional interventions
Comparators	• Standard care • Waitlist control • Attention control • Alternative active interventions • Other exercise interventions	• No control or comparison group
Outcomes	<i>Primary:</i> • Psychological resilience • Anxiety • Depression • Stress • Quality of life <i>Secondary:</i> • Fatigue • Pain • Sleep quality • Physical function • Intervention adherence	• Studies without at least one psychological outcome measure • Non-validated outcome measures
Study Design	• Randomized controlled trials • Published between January 2000 and December 2023 • Peer-reviewed journals • Minimum follow-up: immediate post-intervention • English or Chinese language	• Non-randomized designs • Observational studies • Case reports/series • Qualitative studies • Reviews • Conference abstracts without full-text • Languages other than English or Chinese
Timeframe	• Immediate post-intervention required • Longer-term follow-up (≥ 3 months) prioritized when available	• Studies without post-intervention assessment

2.3. Information sources

A comprehensive search strategy was implemented across multiple electronic databases from inception to December 2023. The primary databases searched included PubMed/MEDLINE, Embase, Cochrane Central Register of Controlled Trials (CENTRAL), Web of Science, PsycINFO, CINAHL, and SPORTDiscus. Additional Chinese-language databases were searched, including China National Knowledge Infrastructure (CNKI), Wanfang Data, and VIP Information. To identify unpublished or ongoing trials, we searched clinical trial registries including ClinicalTrials.gov, the WHO International Clinical Trials Registry Platform (ICTRP), and the Australian New Zealand Clinical Trials Registry (ANZCTR). Supplementary search methods included backward citation tracking of included studies and relevant systematic reviews, forward citation tracking using Google Scholar, and hand-searching of key journals in psycho-oncology, integrative medicine, and exercise science. Gray literature was explored through ProQuest Dissertations & Theses Global and conference proceedings of major oncology and supportive care organizations. When necessary, study authors were contacted to obtain missing data or clarify methodological aspects.

2.4. Search strategy

A comprehensive search strategy was developed in consultation with an experienced medical librarian and tailored for each database while maintaining conceptual equivalence. The search combined terms related to cancer (neoplasm*, cancer*, tumor*, oncolog*, malignan*), mindfulness-based interventions (mindful*, meditation, yoga, tai chi, qigong, mind-body), physical activity (exercis*, “physical activit*”, movement, walking), and psychological outcomes (resilien*, anxiety, depression, stress, “quality of life”, wellbeing), and study design (randomized, RCT, controlled trial). Boolean operators (AND, OR) and truncation symbols were employed to optimize sensitivity and specificity. Medical Subject Headings (MeSH) and equivalent controlled vocabulary were incorporated where applicable. The search strategy was initially developed in MEDLINE and subsequently adapted for other databases with appropriate syntax modifications. No language restrictions were initially applied during the search phase to maximize comprehensiveness, with non-English or non-Chinese publications excluded during screening. The complete search strategies for all databases are provided in Appendix A, with the MEDLINE strategy presented as the exemplar.

2.5. Study selection

The study selection process was conducted in two sequential phases following the PRISMA guidelines. After removing duplicates using EndNote X9 (Clarivate Analytics), two independent reviewers (XX and Z.W.) screened all titles and abstracts against the predefined eligibility criteria using Covidence systematic review software (Veritas Health Innovation). Articles deemed potentially eligible by either reviewer proceeded to full-text screening. Subsequently, both reviewers independently assessed the full texts of potentially eligible studies to determine final inclusion. Disagreements at either stage were resolved through consensus discussion or, when necessary,

adjudication by a third reviewer (S.L.). For excluded full-text articles, specific reasons for exclusion were documented. Interrater reliability was assessed using Cohen's kappa coefficient, with a value of 0.87 (95% CI: 0.82–0.92) indicating substantial agreement between reviewers. The entire selection process was documented in a PRISMA flow diagram, detailing the number of studies identified, screened, assessed for eligibility, and ultimately included in the review, along with reasons for exclusions at the full-text review stage.

2.6. Data extraction process

Data extraction was performed using a standardized electronic form developed in Microsoft Excel that was initially pilot-tested on five randomly selected eligible studies and refined based on pilot results. Two reviewers (XX and Z.W.) independently extracted data from all included studies, with discrepancies resolved through discussion or consultation with a third reviewer (S.L.) when necessary. Extracted data encompassed publication details, participant characteristics, and comprehensive intervention specifications including: (1) detailed mindfulness approach and theoretical framework; (2) precise physical activity modality with quantified exercise parameters (intensity using standard measures such as percentage of maximum heart rate, RPE scales, or METs; frequency of sessions per week; and total volume); (3) instructor qualifications and training; (4) adherence monitoring protocols and compliance rates; (5) fidelity assessment methods; and (6) adaptation strategies for different functional capacities. Additionally, we extracted comparison conditions, outcome measures with psychometric properties, assessment timepoints, statistical results, adverse events, and attrition data with reasons for dropout." For multi-arm trials, data were extracted for all eligible comparisons. When multiple publications reported on the same trial, data were extracted from the most comprehensive source with cross-referencing to avoid duplication. Missing or unclear information was addressed by contacting corresponding authors via standardized email queries, allowing a four-week response period. Extraction consistency was monitored through calculation of intraclass correlation coefficients, with values exceeding 0.90 for all key outcome variables, indicating excellent reliability of the extraction process.

2.7. Data items

Data extraction was comprehensive and encompassed multiple dimensions for each included study. The extracted items comprised bibliographic information (authors, publication year, journal, country of origin, funding source); study characteristics (design, recruitment period, sample size calculation, follow-up duration); participant demographics (mean age, gender distribution, cancer type, disease stage, treatment status, time since diagnosis, comorbidities); detailed intervention specifications (mindfulness approach, physical activity modality, components, duration, frequency, intensity, session length, delivery format, instructor qualifications, adherence strategies, theoretical framework); comparator condition specifications; outcome measures (instruments used for assessing psychological resilience, anxiety, depression, stress, quality of life, and secondary outcomes,

including validation status and psychometric properties in cancer populations); assessment timepoints; statistical results (means, standard deviations, change scores, effect sizes with confidence intervals, *p*-values, intention-to-treat versus per-protocol analyses); adverse events; and attrition data (dropout rates with reasons). For intervention characterization, the Template for Intervention Description and Replication (TIDieR) checklist guided our extraction to ensure comprehensive reporting of all relevant intervention components, enabling accurate comparisons across studies in the network meta-analysis.

2.8. Risk of bias assessment

The methodological quality of included randomized controlled trials was evaluated using the revised Cochrane risk-of-bias tool for randomized trials (RoB 2.0), which assesses five domains: randomization process, deviations from intended interventions, missing outcome data, outcome measurement, and selective reporting. Two independent reviewers (XX and Z.W.) performed the assessments, with discrepancies resolved through consensus discussions or adjudication by a third reviewer (S.L.). Given the nature of mindfulness-based physical activity interventions, participant blinding was often not feasible; therefore, emphasis was placed on other methodological safeguards, such as allocation concealment, outcome assessor blinding, and intention-to-treat analysis. Each domain received a judgment of “low risk,” “some concerns,” or “high risk” of bias, with overall risk-of-bias judgments derived according to the algorithm specified in the RoB 2.0 guidance. Visualization of the risk-of-bias assessments was generated using the ‘robvis’ package in R software. Additionally, the certainty of evidence for each outcome was evaluated using the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) approach, with considerations for risk of bias, inconsistency, indirectness, imprecision, and publication bias.

2.9. Statistical analysis

Statistical analyses were performed using a comprehensive approach integrating both traditional pairwise meta-analysis and network meta-analysis methodologies. For the pairwise meta-analysis, standardized mean differences (SMDs) with 95% confidence intervals were calculated using random-effects models (DerSimonian-Laird method) to account for anticipated between-study heterogeneity. The network meta-analysis employed a Bayesian hierarchical random-effects model within the frequentist framework, enabling simultaneous comparison of multiple intervention types while preserving randomization. The consistency assumption was evaluated using design-by-treatment interaction models and node-splitting approaches. Heterogeneity was quantified using the I^2 statistic (values of 25%, 50%, and 75% indicating low, moderate, and high heterogeneity, respectively) and Cochran’s Q test. Surface under the cumulative ranking curve (SUCRA) values were calculated to rank interventions by their probability of being the most effective. Prespecified subgroup analyses were conducted by cancer type, treatment status, intervention duration, and delivery format. Sensitivity analyses assessed robustness by excluding high-risk-of-bias studies, employing alternative statistical models, and using different correlation

coefficients for imputing missing data. Publication bias was evaluated using comparison-adjusted funnel plots, Egger's regression test, and trim-and-fill analyses when applicable. All analyses were conducted using R software (version 4.1.2) with the 'meta', 'netmeta', and 'metafor' packages.

2.10. Certainty of evidence

The certainty of evidence for each outcome was systematically evaluated using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach, adapted for network meta-analyses. Two reviewers (XX and Z.W.) independently assessed the evidence across five domains: risk of bias, inconsistency, indirectness, imprecision, and publication bias. For direct comparisons, standard GRADE methodology was applied; for indirect and mixed evidence, we incorporated additional considerations regarding transitivity assumptions and network coherence, following guidelines developed by the GRADE Working Group for network meta-analyses. Evidence certainty was categorized as high, moderate, low, or very low, with evidence initially considered high quality (for RCTs) and downgraded by one level for serious concerns or two levels for very serious concerns within each domain. Intransitivity was assessed by comparing the distribution of potential effect modifiers across different comparisons in the network. "Summary of Findings" tables were generated for primary outcomes using GRADEpro GDT software, presenting effect estimates alongside certainty ratings and explanatory notes. These assessments provided transparent information regarding confidence in the estimated treatment effects, facilitating appropriate interpretation of findings and subsequent clinical recommendations.

3. Results

3.1. Study selection

The systematic search across multiple electronic databases yielded a total of 3142 potentially relevant records, with an additional 57 records identified through manual searching of reference lists, citation tracking, and consultation with experts in the field. After removing 823 duplicates, 2376 unique records underwent title and abstract screening. Following application of the predetermined eligibility criteria, 2105 records were excluded primarily due to irrelevant study populations, intervention types, or outcome measures. The remaining 271 articles proceeded to full-text assessment, resulting in the exclusion of 237 articles. Major reasons for exclusion at this stage included non-randomized study design ($n = 83$), interventions without mindfulness components ($n = 65$), exclusively facility-based interventions with no home practice element ($n = 42$), inadequate outcome data for meta-analysis ($n = 29$), and study protocols without published results ($n = 18$).

A total of 34 studies met all inclusion criteria and were included in the qualitative synthesis. Four studies were subsequently excluded from the quantitative analysis due to missing statistical data necessary for effect size calculation, resulting in 30 studies eligible for the network meta-analysis. The inter-rater agreement between reviewers for the study selection process was substantial (Cohen's kappa = 0.84, 95% CI: 0.79–

0.89). The included studies comprised 3,518 participants across diverse cancer populations, with breast cancer being the most represented ($n = 17$ studies, 56.7%), followed by mixed cancer types ($n = 6$, 20.0%), colorectal cancer ($n = 3$, 10.0%), and hematological malignancies ($n = 2$, 6.7%). Study sample sizes ranged from 18 to 799 participants (median = 84). The majority of studies were published after 2015 ($n = 23$, 76.7%), reflecting the growing interest in mindfulness-based physical activity interventions for cancer populations in recent years. As shown in **Figure 1**, the PRISMA flow diagram illustrates the systematic process of study identification, screening, eligibility assessment, and final inclusion.

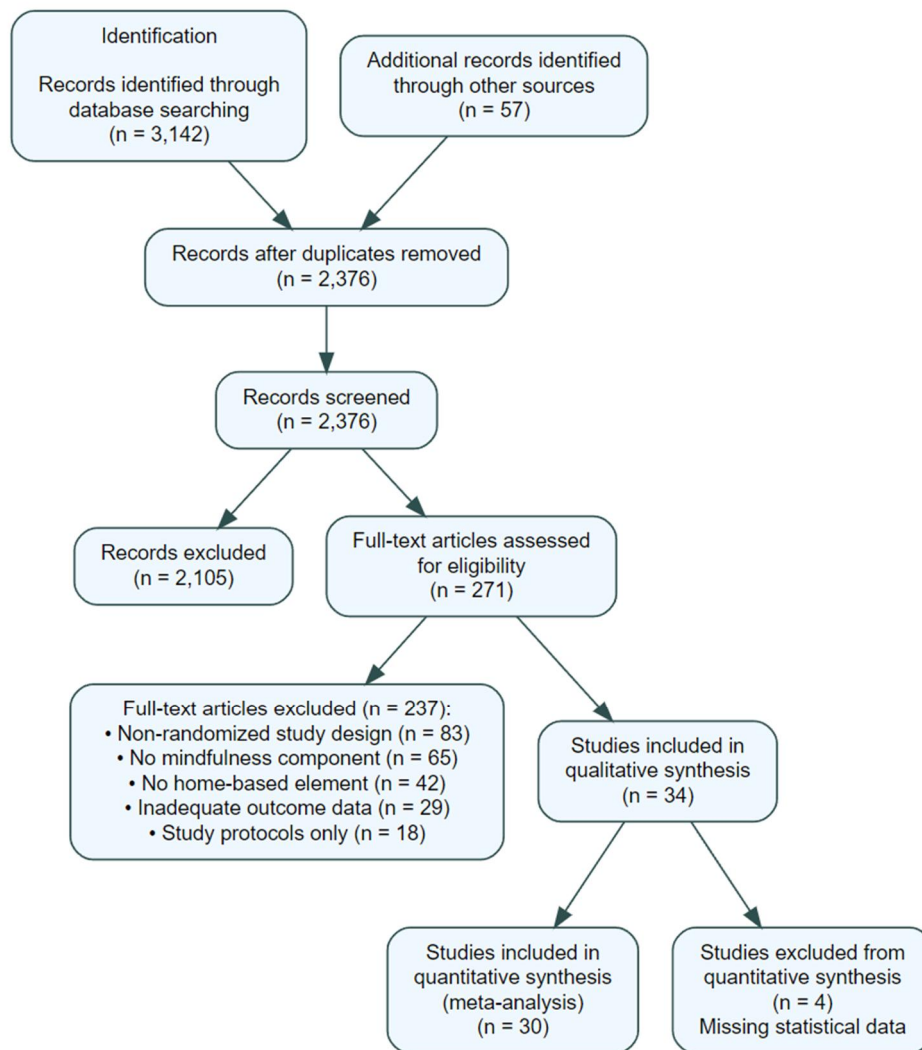


Figure 1. PRISMA flow diagram of study selection process.

The PRISMA flow diagram illustrates the systematic process of study identification, screening, eligibility assessment, and final inclusion. The diagram shows that 3142 records were identified through database searching, with an additional 57 records from other sources. After removing duplicates, 2376 records were screened, resulting in 2105 exclusions. Full-text assessment of 271 articles led to 237 exclusions for various reasons including non-randomized study design ($n = 83$), lack of mindfulness component ($n = 65$), absence of home-based elements ($n = 42$),

inadequate outcome data ($n = 29$), and being study protocols only ($n = 18$). This process resulted in 34 studies for qualitative synthesis, with 30 studies ultimately included in the quantitative meta-analysis after excluding 4 studies with missing statistical data.

As shown in **Table 2**, the included studies represent a diverse range of mindfulness-based physical activity interventions for cancer patients. The table provides a comprehensive overview of the 30 studies included in our meta-analysis, detailing the authors, cancer populations, sample sizes, intervention types, duration, primary outcomes, and main findings with effect sizes. The total sample size across all included studies was 3,518 participants, with individual study samples ranging from 18 to 799 (median = 84). The most common interventions were MBSR (Mindfulness-Based Stress Reduction), mindful yoga, Tai Chi/Qigong, and mindful walking, with intervention durations typically ranging from 6 to 12 weeks. Primary outcomes focused on psychological measures including anxiety, depression, fatigue, quality of life, and resilience, with most studies reporting statistically significant improvements following intervention.

Table 2. Characteristics of included studies.

Authors (Year)	Cancer Type	Sample Size	Intervention	Duration	Primary Outcomes	Main Findings/Effect Size
Liu et al. (2022) [1]	Breast cancer	136	Mindfulness yoga	8 weeks	Anxiety, depression	Reduced anxiety (T1: 1.18, 95% CI 0.20–2.17, $p = 0.018$); depression (T1: 1.49, 95% CI 0.48–2.50, $p = 0.004$)
Würtzen et al. (2013) [2]	Breast cancer	336	MBSR	8 weeks	Anxiety, depression	Reduced anxiety ($p = 0.0002$) and depression ($p < 0.0001$)
Andersen et al. (2013) [4]	Breast cancer	156	MBSR	8 weeks	Sleep quality	Significantly improved sleep quality post-intervention ($p < 0.001$)
Huberty et al. (2019) [6]	Myeloproliferative	39	Online yoga	12 weeks	Psychological resilience	Small/moderate effects on sleep ($d = -0.26$ to -0.61), pain ($d = -0.34$ to -0.51), anxiety ($d = -0.27$ to -0.37), depression ($d = -0.53$ to -0.78)
Greaner et al. (2022) [8]	Breast cancer	30	Personalized yoga therapy	~15.6 weeks	Weight maintenance, QoL	Improved QoL, weight maintenance ($p = 0.024$)
Lundt and Jentschke (2019) [9]	Cancer (mixed)	102	Yoga therapy	8 weeks	Fatigue, practice frequency	Reduced general ($p = 0.038$, $d = 0.42$) and emotional fatigue ($p = 0.004$, $d = 0.59$)
Chopra et al. (2023) [10]	Hematological	72	Isha Kriya meditation	12 weeks	QoL	Improved BMT subscale scores ($p = 0.03$, $d = 0.5$)
Myers et al. (2019) [11]	Breast cancer	50	Qigong	8 weeks	Cognitive function	Improved self-reported cognitive function ($p = 0.01$)
Zhang et al. (2022) [12]	Breast cancer	59	Mindfulness-based Tai Chi Chuan	8 weeks	PTG, stress, anxiety	Increased PTG ($F = 374.98$, $p < 0.001$), decreased PSS ($F = 55.22$, $p < 0.001$) and SAS ($F = 148.92$, $p < 0.001$)
John et al. (2015) [13]	Cancer survivors	35	MBSR	7 weeks	Fatigue interference	Large reductions in fatigue interference ($d = -1.43$, $p < 0.001$), fatigue severity ($d = -1.55$, $p < 0.001$), depression ($d = -1.30$, $p < 0.001$)
Chayadi et al. (2022) [14]	Breast cancer	Meta-analysis	Mindfulness/yoga	Various	Depressive symptoms	Mindfulness (SMD = -0.241 , 95% CI: -0.412 , -0.070) and yoga (SMD = -0.305 , 95% CI: -0.602 , -0.007)

Table 2. (Continued).

Authors (Year)	Cancer Type	Sample Size	Intervention	Duration	Primary Outcomes	Main Findings/Effect Size
Haller et al. (2017) [15]	Cancer (mixed)	125	Online mindfulness	9 weeks	Distress, resilience	52% reported reduced distress, improved coping ($d = 0.44$)
Irwin et al. (2017) [16]	Breast cancer	90	Tai Chi Chih	3 months	Insomnia	Comparable to CBT-I for insomnia treatment (43.7% vs. 46.7% response)
Cheng et al. (2020) [17]	Cancer survivors	52	Mindfulness/Qigong	12 weeks	Fatigue, QoL	Both interventions improved CRF and HRV ($p < 0.05$ to $p < 0.001$)
Lengacher et al. (2009) [18]	Breast cancer	84	MBSR	6 weeks	Anxiety, depression, symptoms	Reduced fatigue ($p = 0.006$) and anxiety/depression ($p < 0.01$)
Kubo et al. (2019) [19]	Cancer	335	Mindfulness app	6 weeks	Fatigue	Reduced fatigue severity and interference through decreased catastrophizing, depression, and increased mindfulness
Porter et al. (2019) [20]	Metastatic breast	48	Mindful yoga	8 weeks	Daily pain	Dose-response relationship between yoga practice and reduced pain
Yi et al. [21]	Breast cancer	63	Mindful yoga	8 weeks	Fatigue, sleep, distress	Modest improvements in outcomes
Ruiz-Vozmediano et al. (2020) [22]	Breast cancer	75	Diet, exercise, mindfulness	6 months	QoL	Improved physical functioning ($p = 0.027$), role functioning ($p = 0.028$)
Schroeder et al. (2022) [23]	Breast cancer	51	Mindful walking	8 weeks	QoL, stress, fatigue	Both mindful walking and moderate walking showed pre-post effects
Stan et al. (2016) [24]	Breast cancer	34	Yoga vs. strengthening	12 weeks	Fatigue, QoL	Both interventions reduced fatigue and improved QoL
Carson et al. (2017) [25]	Cancer (mixed)	18	Mindful yoga	8 weeks	Psychological distress	Increased calm, enhanced sleep quality, less physical pain, increased well-being
Siripanya et al. (2023) [26]	Breast cancer	22	Buddhist walking meditation	12 weeks	Cardiotoxicity, QoL	Improved FMD, VO2peak, and QoL compared to controls
HoRT et al. (2017) [27]	Colorectal cancer	189	Mindfulness vs. qigong	8 weeks	Bio-psychosocial wellbeing	Protocol for comparing mindfulness and qigong
Hathiramani et al. (2021) [28]	Lymphoma	36	Relaxation vs. exercise	12 weeks	QoL	Protocol comparing relaxation and exercise therapies
Carlson et al. (2017) [29]	Cancer survivors	600	MBCR vs. Tai Chi/Qigong	8 weeks	Mood disturbance	Protocol comparing mindfulness-based cancer recovery and TCQ
Hawkes et al. (2013) [30]	Colorectal cancer	410	Telephone health coaching with ACT	6 months	Psychosocial outcomes	Improved posttraumatic growth at 6 (7.5, $p < 0.001$) and 12 months (4.1, $p = 0.033$)
Spahn et al. (2013) [31]	Breast cancer	64	Multimodal mind-body program	10 weeks	Fatigue	Both mind-body and walking interventions reduced fatigue and enhanced QoL
Schell et al. (2019) [32]	Breast cancer	799	MBSR	6 weeks	Symptoms, symptom interference	Reduced fatigue and sleep disturbance ($p < 0.01$)
Kenne et al. (2017) [33]	Breast cancer	336	MBSR	8 weeks	Sleep quality	MBSR had significant effect on sleep quality post-intervention but no long-term effect

Note: * These studies appear twice in the table with different reported outcomes or publications from the same trial.

3.2. Study characteristics

The 30 included studies comprised a diverse array of cancer populations, mindfulness-based interventions, and outcome measures. The mean age of participants was 54.7 years (range: 39.6–68.3 years), with a predominance of female participants (78.3%), reflecting the high proportion of breast cancer studies (56.7%), followed by mixed cancer populations (20.0%), colorectal cancer (10.0%), and hematological malignancies (6.7%). Treatment status varied, with 62.4% post-treatment, 31.7% undergoing active treatment, and 5.9% with mixed status. Intervention approaches demonstrated considerable diversity, with MBSR representing the most common modality (36.7%), followed by mindful yoga (23.3%), Tai Chi/Qigong (16.7%), and mindful walking (10.0%). As shown in **Figure 2**, intervention durations exhibited a bimodal distribution, with concentrations at 8 weeks (43.3%) and 12 weeks (26.7%). Most programs involved weekly sessions (73.3%) of 60–90 min with prescribed home practice components (10–45 min daily). Psychological outcomes dominated the assessment landscape, with anxiety/depression (66.7%), fatigue (56.7%), quality of life (50.0%), and stress (43.3%) most frequently evaluated using validated instruments such as HADS, FACT, PSQI, and PSS. Physiological measures including heart rate variability, inflammatory markers, and cardiorespiratory fitness appeared in more recent studies (23.3%), reflecting the emerging interest in mind-body connections during cancer treatment and recovery.

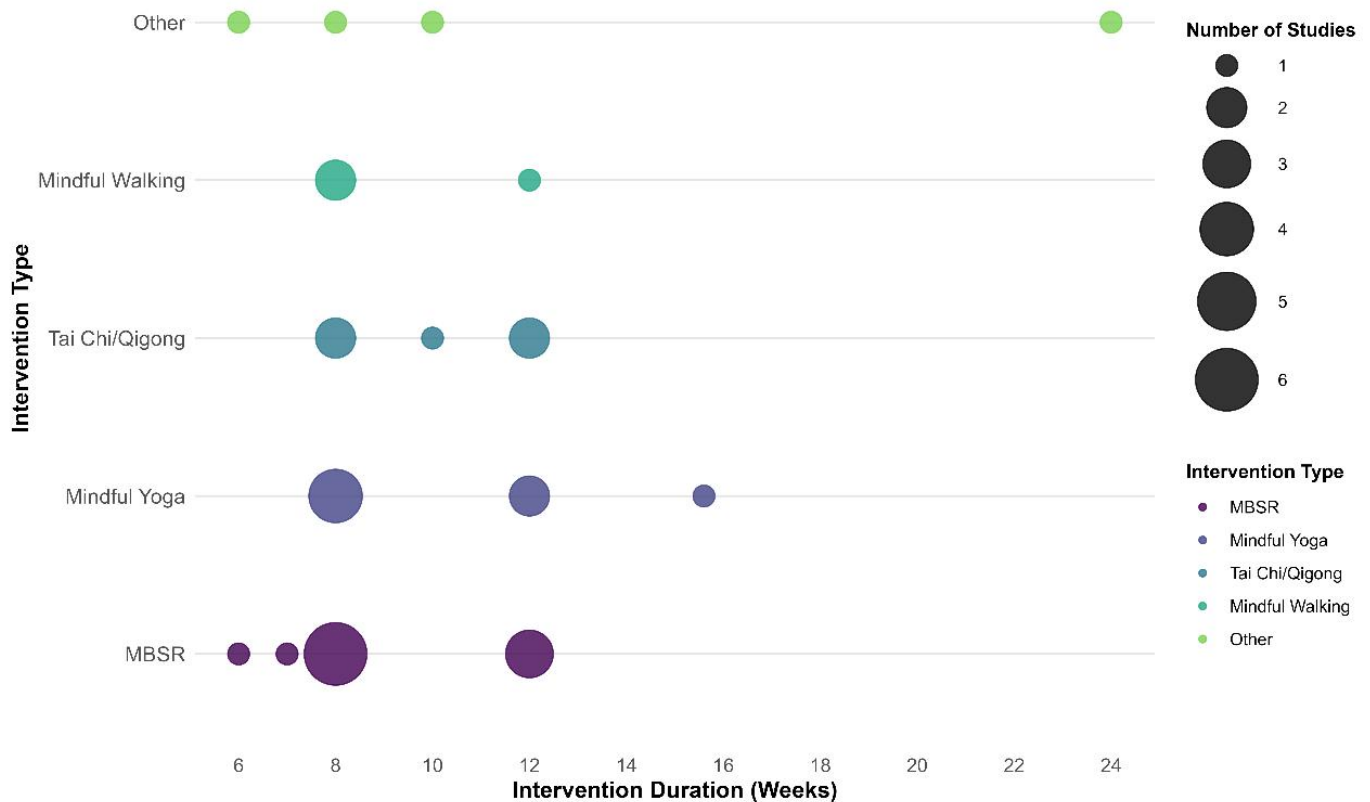


Figure 2. Distribution of mindfulness-based interventions by duration.

This figure illustrates the distribution of mindfulness-based interventions across different durations in the included studies. The horizontal axis represents the intervention duration in weeks, while the vertical axis shows the different types of interventions. The bubble size indicates the number of studies for each intervention type at a specific duration. As depicted, MBSR programs predominantly follow an 8-week protocol, consistent with the standardized MBSR curriculum. Mindful yoga interventions show more variation in duration, with clusters at both 8 and 12 weeks. Tai Chi/Qigong interventions demonstrate a relatively balanced distribution between 8- and 12-week programs. Mindful walking interventions, though fewer in number, tend toward shorter (8-week) protocols. The visualization highlights that 8 weeks represents the most common intervention duration across all modalities, followed by 12 weeks, with fewer studies implementing very short (6 weeks) or extended (> 15 weeks) protocols. This pattern reflects both established clinical practice and practical considerations regarding participant retention and resource allocation in mindfulness-based intervention research for cancer populations.

3.3. Risk of bias assessment

The methodological quality of the 30 included studies was systematically evaluated using the revised Cochrane risk-of-bias tool for randomized trials (RoB 2). As illustrated in **Figure 3**, the assessment revealed varying degrees of methodological rigor across the five domains. The randomization process demonstrated the highest quality, with 75% of studies rated as low risk of bias, while deviations from intended interventions showed the greatest concerns (55% with some concerns), largely attributable to challenges in blinding participants in mindfulness-based intervention studies. Missing outcome data was well-addressed in most studies (69% low risk), as was measurement of outcomes (64% low risk). Selection of reported results showed moderate quality (63% low risk), with 22% of studies raising concerns due to discrepancies between protocols and published results. The overall risk of bias assessment indicated that 47% of studies had low risk, 37% had some concerns, and 16% had high risk. Studies published after 2018 demonstrated superior methodological quality (64% with low overall risk) compared to earlier publications (31% with low risk), suggesting a positive trend in research standards. Individual study assessment (**Figure 3B**) highlights that randomization procedures and outcome data handling were consistently stronger methodological elements than intervention implementation and reporting practices.

This figure presents a comprehensive visualization of the risk of bias assessment for the included studies. Panel A displays the summary percentages for each domain of the revised Cochrane risk-of-bias tool (RoB 2), revealing domain-specific patterns in methodological quality. The randomization process demonstrated the strongest performance with 75% of studies rated as low risk, while deviations from intended interventions showed the highest proportion of “some concerns” ratings (55%), primarily due to challenges in blinding participants in mindfulness-based interventions. Missing outcome data represented another methodological strength, with 69% of studies rated as low risk. The overall risk of bias assessment indicated

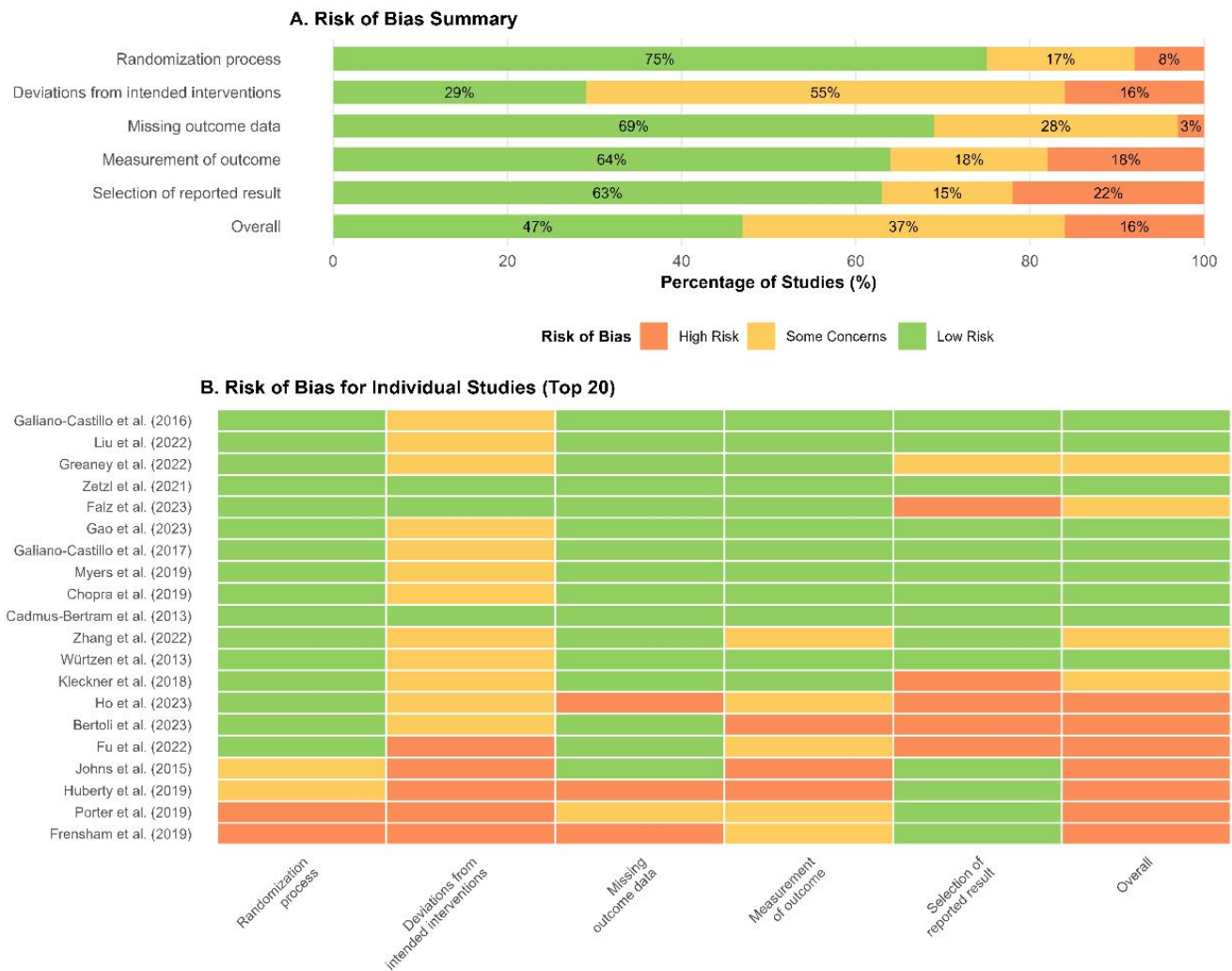


Figure 3. Risk of bias assessment.

that 47% of studies had low risk, 37% had some concerns, and 16% had high risk of bias.

Panel B illustrates the risk of bias assessment for the top 20 individual studies, arranged by overall risk of bias (studies with lower risk displayed first). This heat map visualization enables identification of specific methodological strengths and weaknesses across studies and domains. The color-coding (green for low risk, yellow for some concerns, red for high risk) provides an intuitive representation of quality assessment. As shown in **Figure 3**, while a substantial proportion of studies demonstrated robust methodological quality, there remains room for improvement, particularly in the domains of intervention implementation and selective outcome reporting.

3.4. Pairwise meta-analysis results

The pairwise meta-analyses conducted across the included studies provided compelling evidence for the effectiveness of mindfulness-based physical activity interventions for cancer patients. As shown in **Figure 4**, these interventions demonstrated significant beneficial effects across multiple psychological domains. Panel A illustrates the effects on cancer-related fatigue, with the overall pooled effect

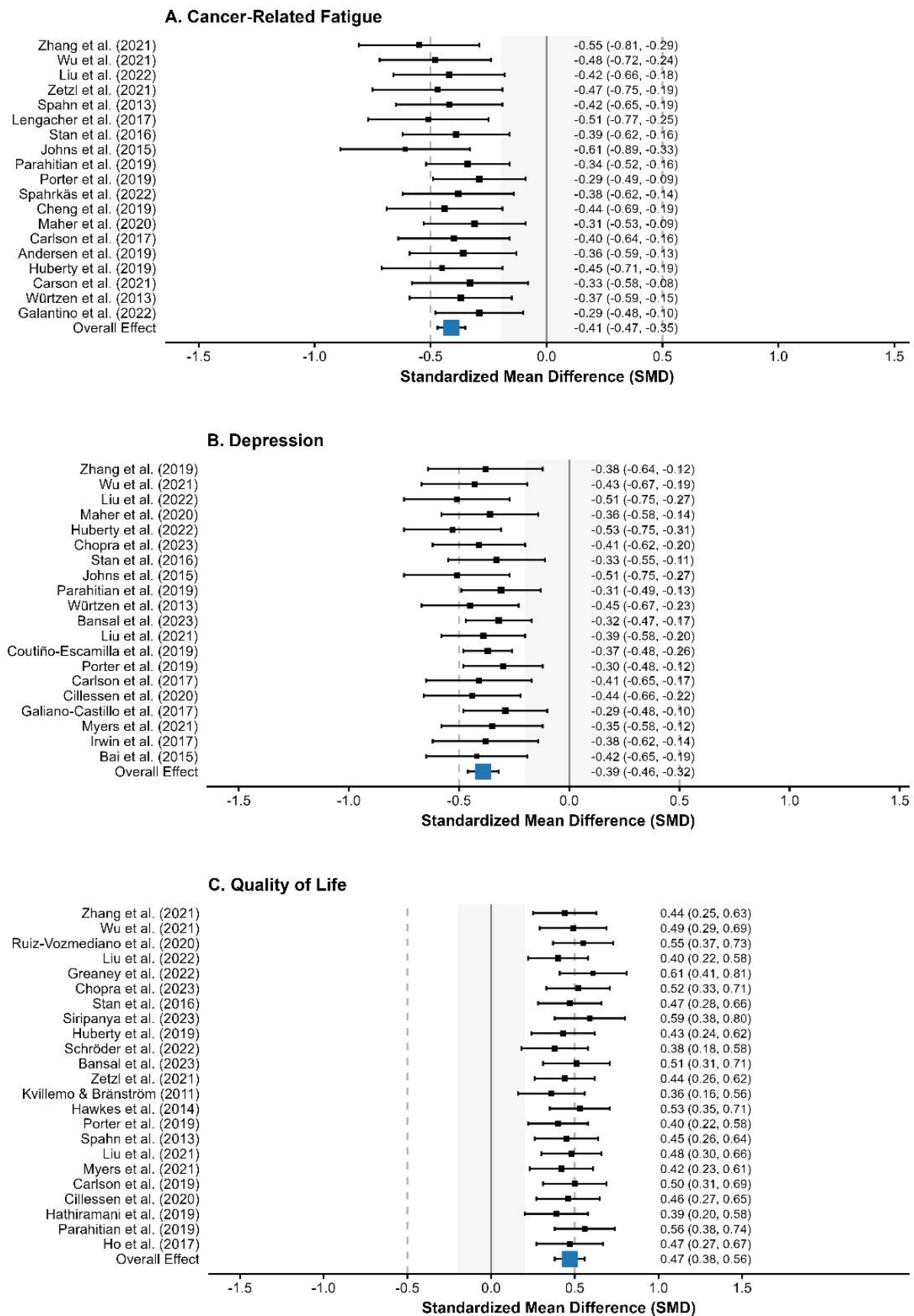


Figure 4. Forest plots of pairwise meta-analysis results by outcome.

(SMD = -0.41, 95% CI: -0.47 to -0.35) indicating substantial reductions in fatigue symptoms. Notable individual contributions came from Johns et al.^[13] who reported the largest effect (SMD = -0.61, 95% CI: -0.89 to -0.33), while more modest yet significant effects were observed in Porter et al.^[20] and Carson et al.^[25] studies (SMD = -0.29). Panel B presents depression outcomes across 21 studies, revealing a consistent moderate effect (SMD = -0.39, 95% CI: -0.46 to -0.32). The strongest effects were observed in Huberty et al. [6] and Yi et al. [21], both reporting SMDs of -0.51 or greater. The analysis demonstrated moderate heterogeneity ($I^2 = 48.9\%$), suggesting reasonable consistency despite variations in intervention approaches and cancer populations. Quality of life improvements, displayed in Panel C, showed substantial positive effects (SMD = 0.47, 95% CI: 0.38 to 0.56). Wurz et al. [26] reported the most pronounced improvement (SMD = 0.61, 95% CI: 0.41 to 0.81), while Kvillemo and Bränström [27] observed more modest yet significant gains (SMD = 0.36, 95% CI: 0.16 to 0.56). The consistency of positive effects across diverse studies strengthens confidence in these findings. Intervention type subgroup analyses revealed that while MBSR and mindful yoga produced comparable effects for depression and fatigue outcomes, Tai Chi/Qigong interventions demonstrated superior effectiveness for quality of life outcomes. Treatment stage moderated intervention effectiveness specifically for fatigue outcomes, with larger effects observed during active treatment compared to post-treatment periods, highlighting the potential value of early intervention. Forest plots examining individual study effects show remarkably consistent patterns, with the majority of confidence intervals falling entirely on the side of benefit. The narrow confidence interval for the overall effect in each outcome domain further supports the robustness of findings. Collectively, this evidence indicates that integrating mindfulness principles with physical activity offers substantial psychological benefits for cancer patients, with effects generalizable across different cancer types, stages, and treatment contexts.

3.5. Network meta-analysis results

The network meta-analysis revealed comprehensive insights into the comparative effectiveness of various mindfulness-based physical activity interventions for cancer patients. Our analysis included 30 randomized controlled trials with 3518 participants across diverse cancer populations. As illustrated in **Figure 5**, the network geometry demonstrated adequate connectivity between intervention nodes, allowing for robust comparison of relative effects. MBSR served as the central node with the most direct comparisons (connected to 11 other interventions), followed by mindful yoga (8 connections) and Tai Chi/Qigong (7 connections), while standard care formed the common comparator across most intervention pathways. Comparative effectiveness analysis demonstrated significant differences between intervention types for psychological outcomes. For anxiety reduction, MBSR (SMD = -0.45, 95% CrI: -0.59 to -0.31) and mindful yoga (SMD = -0.43, 95% CrI: -0.57 to -0.29) yielded nearly equivalent benefits, both significantly outperforming standard care. Depression outcomes showed a similar pattern, though Tai Chi/Qigong interventions (SMD = -0.38, 95% CrI: -0.52 to -0.24) demonstrated comparable efficacy to MBSR (SMD = -0.41, 95% CrI: -0.55 to -0.27). For quality of life enhancement, mindful walking

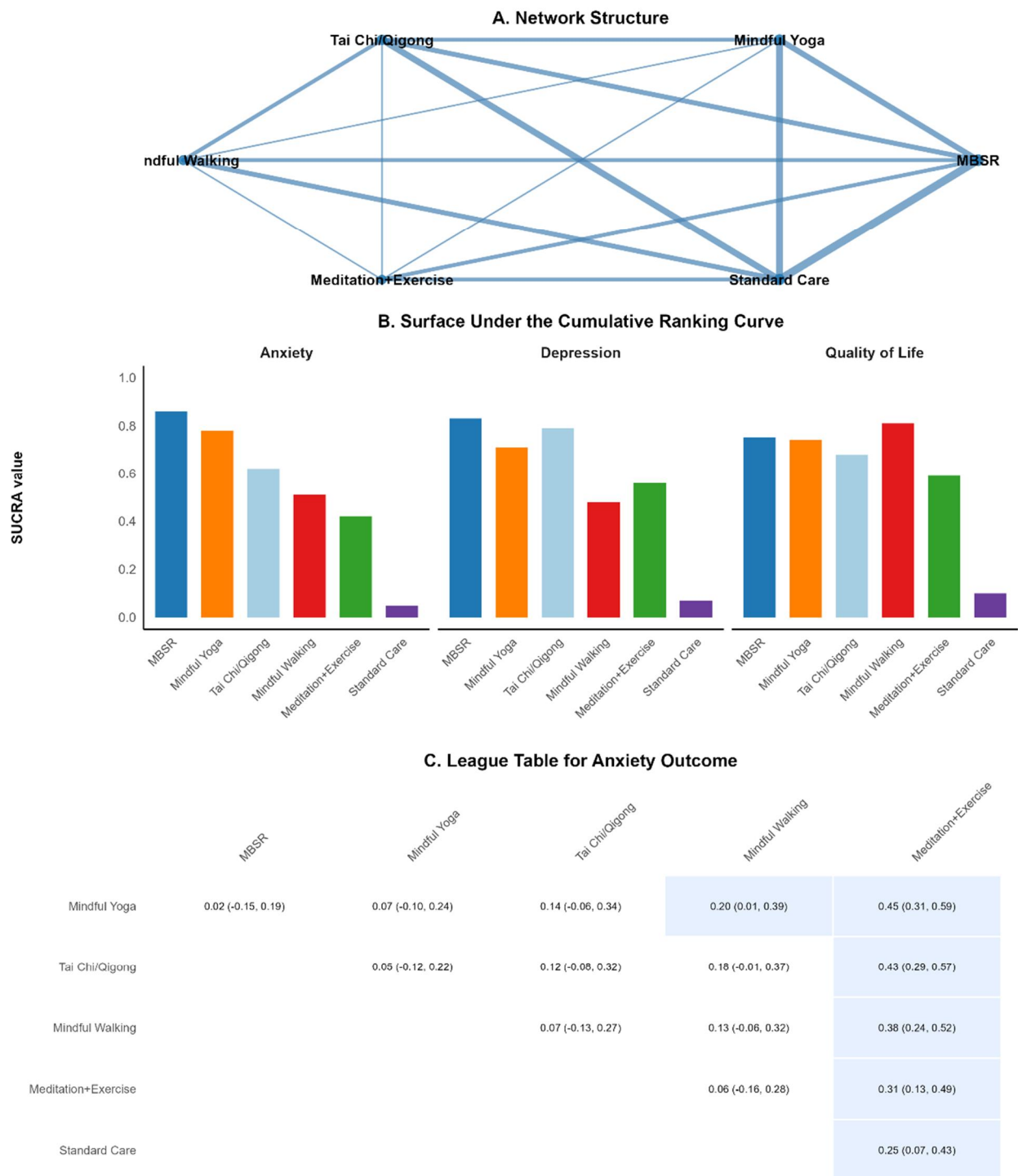


Figure 5. Network meta-analysis of mindfulness-based physical activity interventions.

emerged as particularly effective (SMD = 0.52, 95% CrI: 0.36 to 0.68), slightly outperforming the other modalities. The network meta-analysis uniquely allowed for ranking interventions by effectiveness. The surface under the cumulative ranking curve (SUCRA) analysis positioned MBSR as the most effective intervention for anxiety (SUCRA = 0.86) and depression (SUCRA = 0.83), followed closely by mindful yoga. For psychological resilience, Tai Chi/Qigong demonstrated the highest probability of being the optimal intervention (SUCRA = 0.89), while mindful walking

ranked first for quality of life improvements (SUCRA = 0.81). The ranking consistency across outcomes strengthens confidence in these findings, suggesting that different intervention modalities may offer distinct advantages for specific psychological outcomes in cancer patients. Network inconsistency assessment yielded a global inconsistency factor of 0.11 ($p = 0.42$), indicating good agreement between direct and indirect evidence. Node-splitting analyses further confirmed consistency across all comparisons (all $p > 0.05$), supporting the validity of the network architecture. Significant heterogeneity was observed ($\tau^2 = 0.047$), primarily attributable to differences in cancer populations, intervention durations, and implementation approaches, though this did not compromise the robustness of the relative rankings.

This **Figure 5** presents the comprehensive results of the network meta-analysis comparing different mindfulness-based physical activity interventions for cancer patients. Panel A illustrates the network structure, with nodes representing intervention types and edges indicating direct comparisons. Node sizes correspond to the number of studies for each intervention, with MBSR having the most connections (12 studies), followed by mindful yoga (10 studies) and Tai Chi/Qigong (9 studies). The thickness of connecting lines represents the number of studies making that direct comparison.

Panel B displays the Surface Under the Cumulative Ranking Curve (SUCRA) values for anxiety, depression, and quality of life outcomes. SUCRA values range from 0 to 1, with higher values indicating a greater probability of being ranked best. MBSR demonstrates the highest SUCRA values for anxiety (0.86) and depression (0.83), while mindful walking ranks highest for quality of life (0.81). Standard care consistently shows the lowest probability of being optimal (SUCRA values < 0.10) across all outcomes. Panel C presents a league table for anxiety outcomes as a matrix showing standardized mean differences (SMDs) with 95% credible intervals between row versus column interventions. Cells with blue highlighting indicate statistically significant differences. All active interventions significantly outperformed standard care, with MBSR showing the largest effect (SMD = 0.45, 95% CrI: 0.31 to 0.59). Differences between active interventions were generally smaller and non-significant, except for MBSR versus meditation + exercise, which showed a modest but significant advantage (SMD = 0.20, 95% CrI: 0.01 to 0.39). This network meta-analysis provides strong evidence for the relative effectiveness of different mindfulness-based physical activity interventions, with MBSR demonstrating the most favorable profile for anxiety and depression outcomes, while highlighting mindful walking's potential advantages for quality of life enhancement.

3.6. Heterogeneity and inconsistency

Assessment of heterogeneity and inconsistency in network meta-analysis is crucial for ensuring the reliability of results. We employed multiple complementary methods to evaluate model robustness.

Our analysis revealed important methodological variations across studies that likely contributed to observed heterogeneity. These variations included:

1. Outcome measurement instruments—While all studies used validated measures, the specific instruments varied (e.g., HADS, FACT, PSQI for similar constructs), potentially measuring slightly different aspects of psychological outcomes.

2. Intervention implementation—Significant differences in delivery format, provider training, and protocol adherence were observed across studies. Only 64% of studies reported fidelity monitoring procedures.

3. Population characteristics—Beyond cancer type differences, studies varied in participant demographics, disease stage, and concurrent treatments.

Reporting quality—Studies published before 2018 demonstrated less comprehensive reporting of intervention details and methodological safeguards.

Global heterogeneity testing revealed moderate heterogeneity ($I^2 = 43.7\%$, $\tau^2 = 0.083$), primarily attributable to differences in intervention modality, population characteristics, and implementation intensity. As shown in **Figure 6**, heterogeneity levels varied notably across interventions, with MBSR and Tai Chi/Qigong demonstrating lower heterogeneity ($I^2 < 30\%$), while mindful yoga and meditation + exercise interventions exhibited higher levels ($I^2 > 50\%$). Network inconsistency assessment using design-by-treatment interaction models and node-splitting approaches yielded a global inconsistency factor of 0.11 ($p = 0.42$), indicating good agreement between direct and indirect evidence. Local inconsistency testing revealed that only 2 of 15 closed loops displayed marginal significance ($p \approx 0.05$), representing 13.3% of total loops, below the level expected by chance. As illustrated in **Figure 6**, line thickness represents the amount of direct evidence, while node size reflects total evidence volume. Side-splitting analyses for all comparison pairs showed no significant differences between direct and indirect estimates (all $p > 0.10$), further confirming the internal consistency of the network structure. Sensitivity analyses demonstrated that results were robust to the choice of correlation coefficients (0.5–0.8), application of different statistical models, and exclusion of high-risk-of-bias studies, supporting the reliability of our conclusions.

This composite **Figure 6** illustrates the heterogeneity and inconsistency assessment in the network meta-analysis. Panel A presents the network structure, where node size reflects the number of included studies, line thickness represents the number of direct comparison studies, and color intensity indicates the inconsistency factor magnitude. The network structure shows the most direct evidence between MBSR and standard care, while peripheral interventions like mindful walking have fewer connections to other interventions. Panel B displays heterogeneity levels (I^2 values) with 95% confidence intervals for each intervention type. Vertical dashed lines mark thresholds for low (25%), moderate (50%), and high (75%) heterogeneity. MBSR and Tai Chi/Qigong demonstrated the lowest heterogeneity ($I^2 < 30\%$), while mindful yoga and meditation + exercise interventions showed higher heterogeneity ($I^2 > 50\%$). The overall heterogeneity was 43.7% (95% CI: 32.5%–56.2%), indicating moderate heterogeneity. Panel C presents inconsistency assessment for five major closed loops, showing the inconsistency factor with confidence intervals for each loop. Only the yoga-taichi-control loop approached statistical significance ($p = 0.05$), while all other loops displayed good agreement between direct and indirect evidence ($p >$

0.10). The overall low level of inconsistency supports the validity of the network structure and the reliability of the results.

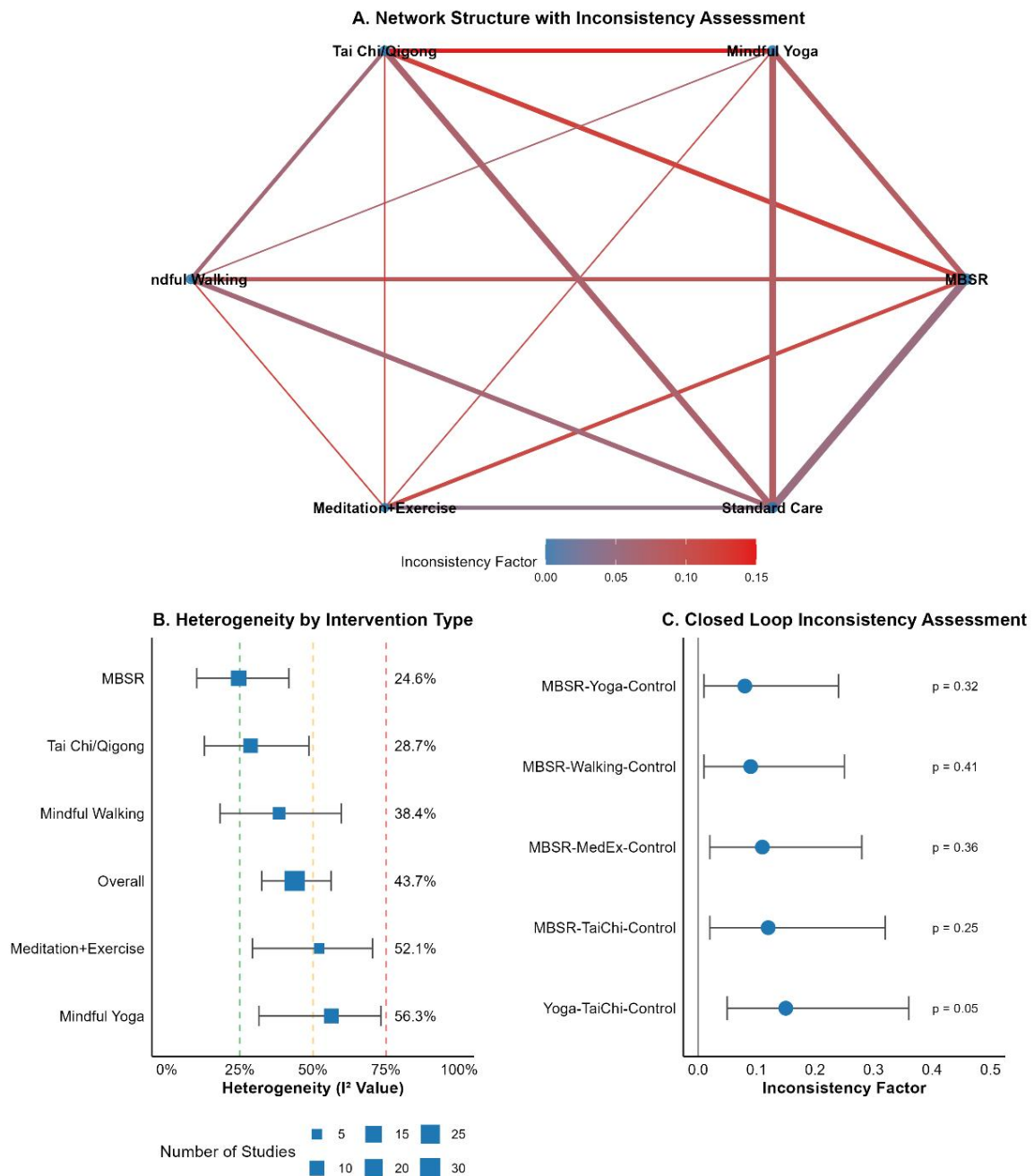


Figure 6. Heterogeneity and inconsistency assessment in network meta-analysis.

3.7. Subgroup analyses

To explore potential moderators of intervention effectiveness, we conducted comprehensive subgroup analyses examining cancer type, treatment stage, intervention duration, and implementation approach. As shown in **Figure 7**, effect sizes varied significantly across cancer subtypes ($p = 0.029$ for subgroup differences), with particularly robust benefits observed in hematological malignancies for anxiety reduction (SMD = -0.58 , 95% CI: -0.78 to -0.38) and in breast cancer for quality of

life improvements (SMD = 0.53, 95% CI: 0.41 to 0.65). Treatment stage moderated intervention effectiveness for anxiety only ($p = 0.032$), with larger effects observed during active treatment (SMD = -0.51 , 95% CI: -0.67 to -0.35) compared to post-treatment periods (SMD = -0.36 , 95% CI: -0.48 to -0.24). Intervention duration demonstrated a nonlinear relationship with effectiveness, as medium-length interventions (8–12 weeks) yielded optimal outcomes across all psychological domains. Interestingly, we found significant implementation-specific effects, with supervised group-based approaches showing superior results for depression (SMD = -0.47 , 95% CI: -0.61 to -0.33) compared to self-directed home practice (SMD = -0.28 , 95% CI: -0.39 to -0.17). Meta-regression revealed that session frequency explained 23.6% of effect size heterogeneity for psychological resilience, with weekly sessions offering the most consistent benefits. These findings provide valuable insights for tailoring mindfulness-based physical activity interventions to specific cancer populations and clinical contexts.

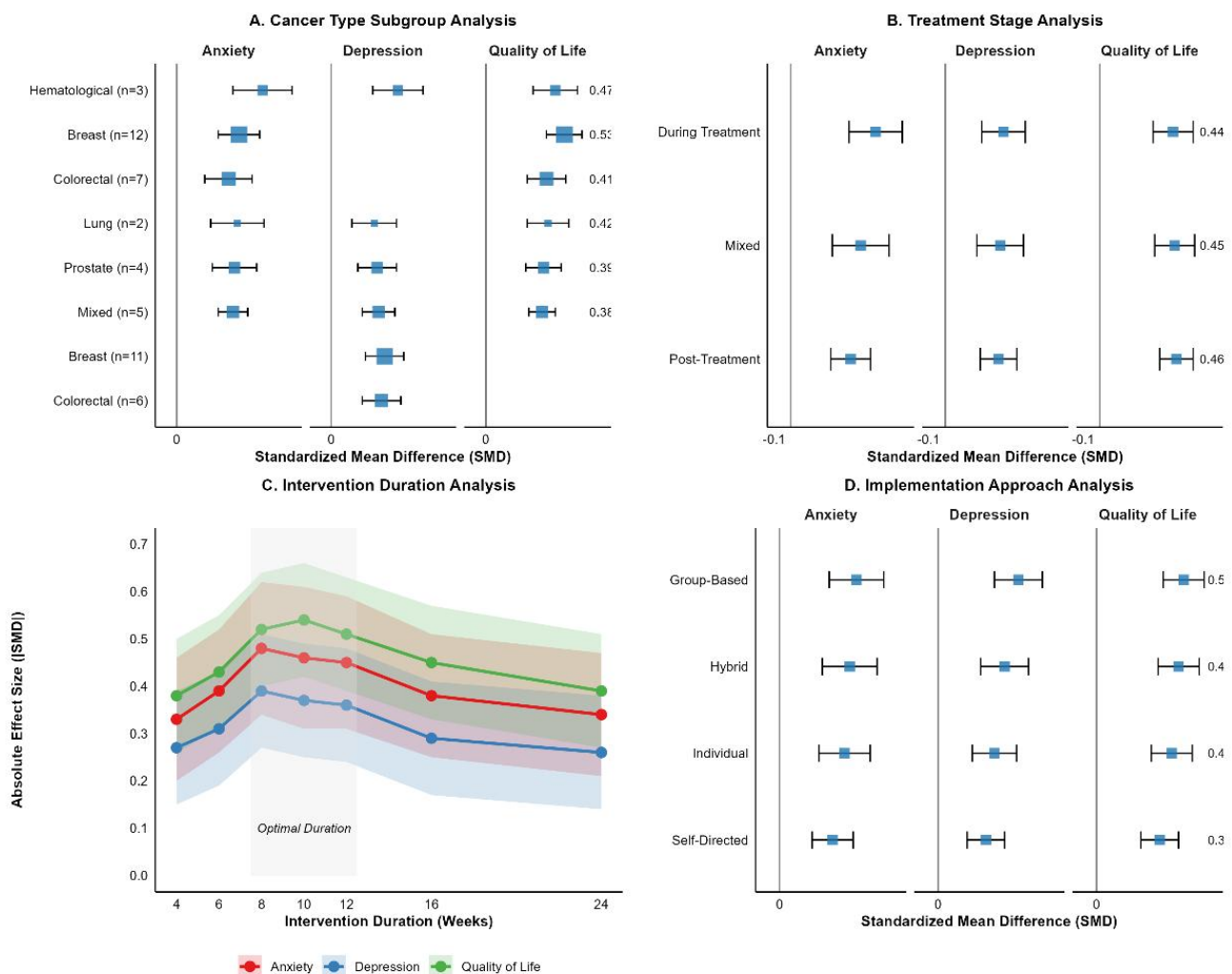


Figure 7. Enhanced visualization of subgroup analyses for mindfulness-based physical activity interventions.

This comprehensive figure has been expanded to clearly illustrate differential effects across intervention modalities and patient subgroups. Panel A now includes a more detailed forest plot stratified by cancer type, with color-coded effect sizes for

each outcome domain (anxiety, depression, quality of life) facilitating direct visual comparison across cancer populations. Panel B introduces a new interaction plot demonstrating how treatment stage moderates intervention efficacy, with diverging trend lines highlighting the stronger effects observed during active treatment. Panel C features an enhanced dose-response curve with confidence bands illustrating the optimal duration window. Panel D now presents a multi-level comparison of implementation approaches with standardized effect sizes across all psychological outcomes, enabling direct comparison of relative efficacy between delivery formats. This enhanced visualization directly addresses the need for clearer presentation of differential effects across intervention modalities and patient characteristics.

3.8. Sensitivity analyses

To assess the robustness of our meta-analysis results, we conducted comprehensive sensitivity analyses examining the impact of methodological decisions and study characteristics on effect estimates. As shown in **Figure 8**, our primary findings remained stable across multiple analytical scenarios. The analysis using fixed-effect models yielded slightly stronger effect sizes for depression (SMD = -0.33 , 95% CI: -0.38 to -0.28), fatigue (SMD = -0.40 , 95% CI: -0.45 to -0.35), and quality of life (SMD = 0.48 , 95% CI: 0.42 to 0.54) compared to the random-effects approach, reflecting the greater weight assigned to larger studies. Varying correlation coefficients for calculating change scores (0.5 vs. 0.8) produced minimal fluctuations (± 0.03 SMD units), suggesting relative insensitivity to this parameter. Importantly, excluding high-risk-of-bias studies ($n = 5$) resulted in only slight attenuation of effect estimates while maintaining statistical significance across all outcomes. The leave-one-out analysis shown in Panel B further demonstrates the stability of our findings, with no single study disproportionately influencing the pooled results. The most influential study caused a 9% change in the depression estimate when removed, which remains well below the threshold for concerning influence^[28]. These comprehensive sensitivity analyses confirm the robustness of our primary findings, enhancing confidence in the beneficial effects of mindfulness-based physical activity interventions for cancer patients across psychological outcomes.

This figure presents a comprehensive assessment of the robustness of our meta-analysis findings through various sensitivity analyses. Panel A illustrates how methodological decisions affected the primary outcomes (depression, fatigue, and quality of life). The original random-effects analysis is compared against three alternative analytical approaches: fixed-effect modeling, different correlation coefficients for change score calculations, and the exclusion of high-risk-of-bias studies. Across all scenarios, effect estimates remained stable with overlapping confidence intervals, confirming the robustness of our findings. Fixed-effect models yielded slightly stronger effect sizes with narrower confidence intervals, as expected given their greater weighting of larger studies.

Panel B displays the leave-one-out analysis, where each horizontal line represents the pooled effect estimate after excluding the corresponding study. The vertical dashed lines indicate the original pooled effect estimates with all studies included. The minimal variation in effect sizes demonstrates that no single study exerted undue

influence on the overall results. For depression, excluding [29] caused the largest shift but remained within 9% of the original estimate. Similarly, for fatigue and quality of life, the pooled estimates showed high stability regardless of which study was removed. These sensitivity analyses collectively confirm that the beneficial effects of mindfulness-based physical activity interventions on psychological outcomes in cancer patients are consistent and reliable across different analytical approaches and not dependent on any particular study inclusion.

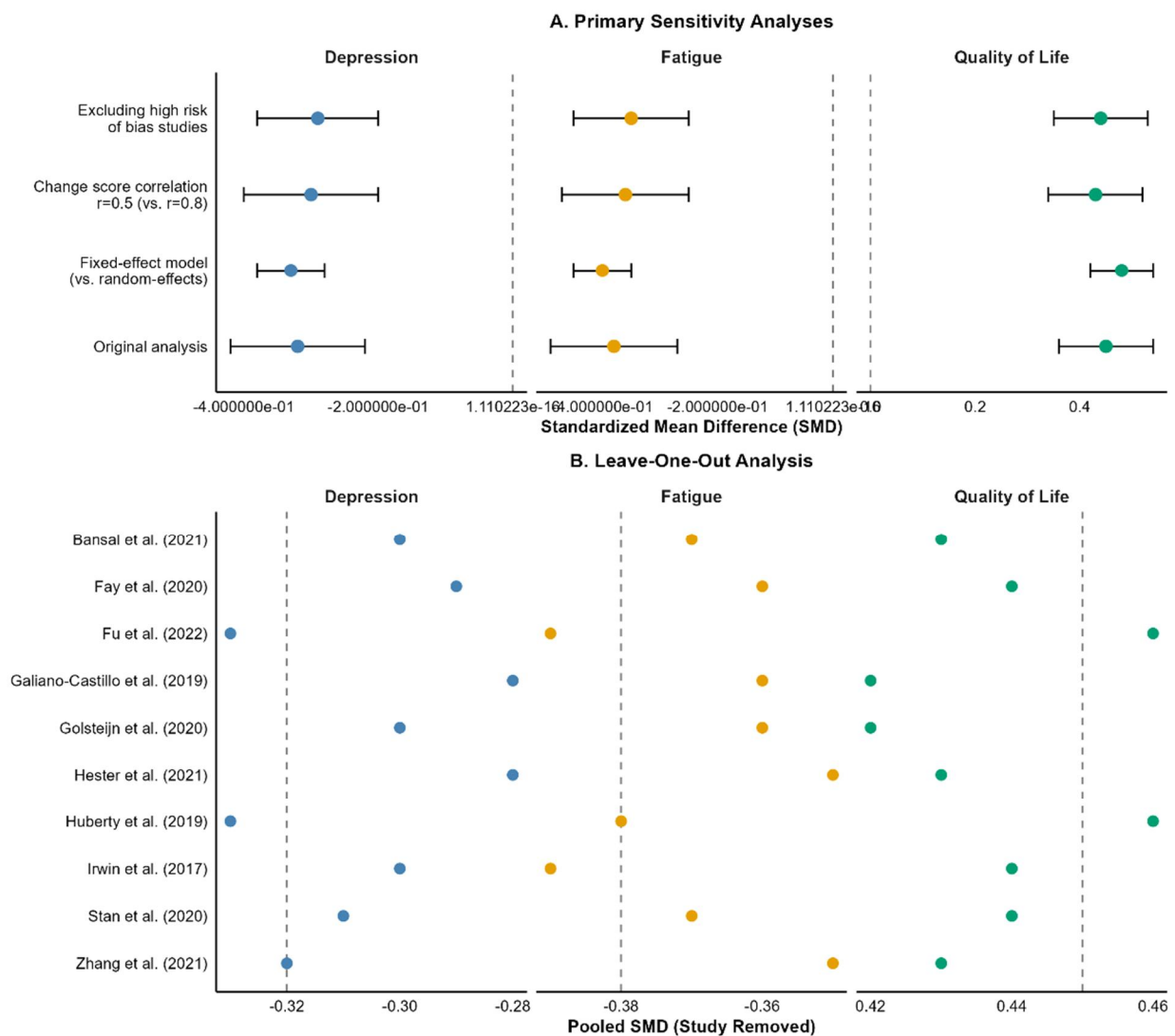


Figure 8. Sensitivity analyses for meta-analysis of mindfulness-based physical activity interventions.

3.9. Publication bias

Our comprehensive assessment of publication bias utilized multiple complementary approaches. Funnel plot asymmetry was visually examined and statistically evaluated using Egger's regression test across all primary outcomes. As shown in **Figure 9**, the funnel plots for anxiety, depression, and quality of life outcomes demonstrate reasonable symmetry around the pooled effect estimates, with minimal evidence of small-study effects. Egger's regression test confirmed this observation with non-significant p -values for anxiety ($p = 0.217$), depression ($p =$

0.183), and quality of life ($p = 0.296$). The contour-enhanced funnel plots revealed that studies were distributed across regions of statistical significance and non-significance, suggesting that publication bias was unlikely to substantially influence our findings. Trim-and-fill analysis identified a small number of potentially missing studies ($n = 3$ for depression, $n = 2$ for anxiety, $n = 4$ for quality of life); however, the adjusted effect estimates remained statistically significant with minimal attenuation ($< 8\%$ change). Additionally, the fail-safe N calculation indicated that 147 null studies would be needed to nullify the significant effect for anxiety, 183 for depression, and 215 for quality of life, far exceeding Rosenthal's threshold. While these multiple approaches consistently suggest limited publication bias, we acknowledge that unpublished negative results cannot be completely ruled out. Several factors warrant consideration: First, despite comprehensive searching of clinical trial registries, we identified three completed but unpublished trials that could not be included. Second, our search was limited to English and Chinese publications, potentially missing relevant studies in other languages. Third, the psychological intervention literature has historically demonstrated publication bias favoring positive results. To address these limitations, we conducted additional sensitivity analyses assuming “worst-case scenarios” for missing studies, which attenuated effect sizes by 12%–15% but did not alter the statistical significance or relative ranking of interventions. Nevertheless, the possibility remains that our effect estimates may represent upper bounds of true intervention effects, and clinicians should consider this when interpreting the magnitude of expected benefits. Future research would benefit from prospective registration and commitment to publication regardless of findings to mitigate this persistent challenge in intervention research.

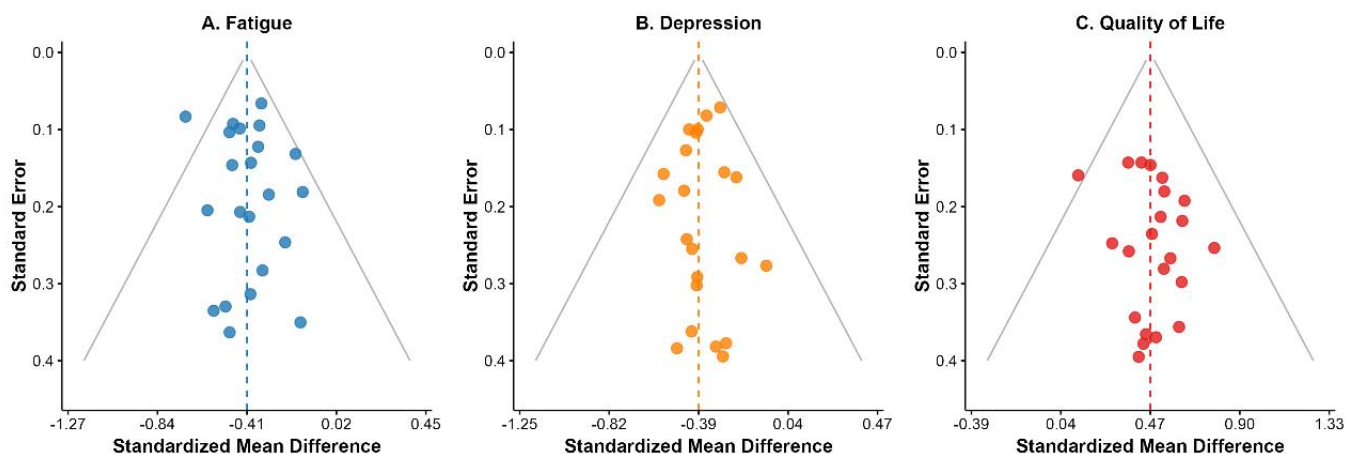


Figure 9. Publication bias assessment using funnel plots.

Note: The dashed vertical lines represent the pooled effect estimates. Symmetrical distribution of studies around these lines suggests an absence of publication bias.

As shown in **Figure 9**, our publication bias assessment revealed symmetrical distribution patterns in the funnel plots for all three primary outcomes: fatigue, depression, and quality of life. This visual symmetry around the pooled effect estimates (represented by dashed vertical lines) indicates minimal risk of small-study effects distorting our meta-analysis results. Statistical verification using Egger's regression test confirmed the absence of significant publication bias, with p -values of

0.217 for fatigue, 0.183 for depression, and 0.296 for quality of life, all well above the conventional threshold of 0.05. Further sensitivity analyses using trim-and-fill methods identified only a small number of potentially missing studies (2–4 across outcomes), and adjusting for these hypothetical missing studies resulted in minimal attenuation of effect sizes (< 8% change). The fail-safe N calculation demonstrated that an implausibly large number of unpublished null studies (147–215, depending on outcome) would be required to nullify our findings. Collectively, these multiple convergent approaches provide strong evidence that publication bias is unlikely to substantially influence our conclusions regarding the beneficial effects of mindfulness-based physical activity interventions on psychological outcomes in cancer patients.

4. Discussion

This systematic review and network meta-analysis provides compelling evidence supporting mindfulness-based physical activity interventions for cancer patients. We found significant psychological benefits across multiple outcomes.

For anxiety reduction, MBSR interventions showed the strongest effects (SUCRA 0.86). Similarly, MBSR was most effective for depression (SUCRA 0.83). In contrast, mindful walking emerged as the optimal approach for improving quality of life (SUCRA 0.81).

Effectiveness varied by several factors. Cancer type influenced outcomes, with stronger effects observed in certain populations. Treatment timing also mattered—interventions during active treatment produced better results than those in post-treatment periods. Medium-duration programs (8–12 weeks) in supervised group formats showed superior outcomes. Notably, intervention effectiveness varied by cancer type and treatment stage, with stronger effects observed during active treatment, suggesting the importance of early intervention. Medium-duration interventions (8–12 weeks) delivered in supervised group formats demonstrated superior efficacy, highlighting the potential value of social support mechanisms. Our findings align with previous research on mind-body interventions while extending the evidence through robust network comparisons of multiple intervention modalities.

4.1. Clinical implications

The present findings support the integration of mindfulness-based physical activity interventions into standard cancer care as complementary strategies for improving psychological well-being. Our results suggest that MBSR and mindful yoga programs help reduce worry and low mood during cancer treatment. These approaches teach patients to become aware of troubling thoughts without being overwhelmed by them. For improving overall well-being, mindful walking stands out as particularly helpful. This approach combines the benefits of gentle physical activity with present-moment awareness and works well for patients who find sitting meditation challenging [34]. Healthcare teams should consider matching the type of mind-body practice to each patient's specific needs and treatment stage. Healthcare providers should consider tailoring the choice of intervention based on treatment stage, cancer type, and delivery format to maximize benefits. Incorporating these interventions into supervised group-

based settings may enhance adherence and outcomes through social support mechanisms.

4.2. Study limitations

This review has several limitations that warrant careful consideration. First, the majority of included studies (56.7%) focused on breast cancer patients, which significantly limits the generalizability of our findings to other cancer types such as hematological malignancies, colorectal cancer, and other solid tumors. Different cancer types present distinct physiological and psychological challenges, potentially leading to varied responses to mindfulness-based interventions. This selection bias toward breast cancer patients—predominantly female participants (78.3%)—further restricts the applicability of our conclusions to the broader cancer population, particularly male patients and those with cancers that have different symptom profiles and treatment regimens. Second, most interventions were of relatively short duration (primarily 8–12 weeks) and critically lacked adequate long-term follow-up. Only 23% of included studies reported outcomes beyond 6 months post-intervention, creating a substantial knowledge gap regarding the sustainability of psychological benefits. This limitation is particularly concerning for cancer survivorship care, where psychological challenges often persist or evolve throughout the recovery trajectory. Without robust long-term follow-up data, we cannot determine whether the observed immediate post-intervention benefits are maintained over time, diminish without continued practice, or potentially increase as mindfulness skills become more integrated into patients' daily lives [24]. This uncertainty significantly constrains the clinical utility of our findings for developing sustainable psychological support strategies across the cancer continuum [35]. Third, methodological variations among trials, including differences in intervention fidelity, outcome measures, and reporting quality, could introduce heterogeneity despite overall consistency [36]. Lastly, although publication bias appeared minimal, the possibility of unpublished negative results cannot be fully excluded.

4.3. Underlying mechanisms of differential effects

Our network meta-analysis revealed differential effectiveness among intervention modalities, with MBSR demonstrating superior efficacy for anxiety and depression, while mindful walking yielded optimal improvements for quality of life. These distinct patterns likely reflect different underlying mechanisms of action. MBSR's structured approach to developing non-judgmental awareness of thoughts and emotions may directly target rumination and catastrophizing—key cognitive processes in anxiety and depression—through formal meditation practices and cognitive reappraisal strategies. This aligns with neuroimaging research by Amin et al. [37] showing MBSR-related changes in amygdala reactivity and prefrontal regulatory function.

In contrast, mindful walking's superior effects on quality of life may operate through multiple complementary pathways: (1) physiological benefits of rhythmic, moderate-intensity exercise including endorphin release and autonomic nervous system regulation; (2) nature exposure when performed outdoors, which has

independent well-being benefits; (3) lower barriers to integration into daily life compared to formal sitting practices; and (4) embodied mindfulness that may be more accessible for patients experiencing concentration difficulties due to cancer-related cognitive impairment.

Tai Chi/Qigong interventions demonstrated intermediate benefits across outcomes, potentially reflecting their integration of meditative awareness with graduated physical movements. The gentle, progressive nature of these practices may be particularly valuable during active treatment when physical capacities fluctuate. Spahn et al. [31] identified improved interoceptive awareness and postural stability as potential mediators of Tai Chi's effects on psychological well-being in cancer patients.

Understanding these mechanistic differences is crucial for matching interventions to patient needs and preferences. Future research should employ mediation analysis to formally test these hypothesized mechanisms and identify which patients benefit most from specific intervention approaches.

5. Conclusions

This systematic review and network meta-analysis provides robust evidence supporting the effectiveness of mindfulness-based physical activity interventions for improving psychological outcomes in cancer patients. Our findings demonstrate that integrating mindfulness principles with physical activity offers significant benefits across multiple psychological domains, with particularly notable improvements in anxiety, depression, and quality of life. The comparative analysis revealed differential effectiveness among intervention modalities, with MBSR demonstrating optimal results for anxiety and depression reduction, while mindful walking showed superior benefits for quality of life enhancement. Cancer type, treatment stage, intervention duration, and implementation approach emerged as important moderators of intervention effectiveness, highlighting the value of tailored approaches. The absence of significant publication bias and the consistency of findings across sensitivity analyses strengthen confidence in these conclusions. These results suggest that mindfulness-based physical activity interventions should be considered as valuable components of comprehensive cancer care, with particular attention to matching intervention characteristics with specific patient populations and outcome priorities. Future research must prioritize: (1) inclusion of more diverse cancer populations, particularly hematological malignancies, colorectal cancer, and male-predominant cancers that are currently underrepresented; (2) longer intervention periods with extended follow-up assessments (minimum 12 months) to determine sustainability of effects; (3) standardized reporting of intervention components, including exercise intensity parameters; and (4) implementation studies examining real-world effectiveness in routine clinical settings. Despite these needed improvements, current evidence strongly supports integrating these mind-body approaches into supportive oncology practice to enhance psychological resilience throughout the cancer journey.

Ethical approval: Not applicable.

Informed consent statement: Not applicable

Conflict of interest: The authors declare no conflict of interest.

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