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REVIEW

The effects of exercise interventions on fatigue, body composition, physical fitness, and biomarkers in breast cancer patients during and after treatment: a systematic review and meta-analysis of randomized controlled trials

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Abstract

Background Breast cancer is the leading cancer type among women, accounting for 24.5% of female cancer cases worldwide.
Objective The purpose of this study is to systematically review and conduct a meta-analysis to evaluate the effects of exercise interventions on breast cancer patients at different stages of treatment.
Methods Databases including PubMed, Cochrane Library, and Embase were searched for English-language randomized controlled trials (RCTs) published since 2000. The study included data from women aged 18 and above with breast cancer, either undergoing treatment or after treatment. Effect sizes were calculated using the standardized mean difference.
Results Out of 2845 studies, 40 met the inclusion criteria, with 17 studies focusing on patients undergoing treatment and 23 on after treatment patients. Exercise significantly reduced fatigue both undergoing ($d = -0.20$) and after treatment ($d = -1.11$). After treatment exercise interventions resulted in improvements in lean mass ($d = 1.27$), fat mass ($d = -1.33$), percentage body fat ($d = -1.22$), and waist circumference ($d = -0.69$). Additionally, biomarkers such as IL-6, HDL, LDL, glucose, systolic blood pressure (SBP), and diastolic blood pressure (DBP) showed improvements after treatment.
Conclusions Exercise interventions are effective in reducing fatigue and enhancing fitness while undergoing treatment and have positive effects on body composition and biomarkers after treatment. Low-to-moderate intensity exercise is recommended undergoing treatment, while moderate-to-high intensity exercise is beneficial after treatment.
Implications for Cancer Survivors.
Personalized exercise programs should be incorporated as a standard part of care in clinical settings to alleviate fatigue undergoing treatment and improve body composition and biomarkers following treatment.

Keywords Breast cancer · Exercise · Meta-analysis · Fatigue · Body composition · Biomarkers · Personalized exercise programs

Introduction

Breast cancer is the most common cancer among women, accounting for approximately 24.5% of all female cancer cases worldwide [1]. According to the most recent 2022 estimates by GLOBOCAN, breast cancer remains the most prevalent cancer globally, with approximately 2.3 million new cases, emphasizing the urgent need for effective interventions [1]. In addition, breast cancer is the second leading cause of cancer-related deaths among women, with approximately 685,000 global deaths attributed to this cancer in 2020.

Breast cancer stages are categorized based on tumor size, lymph node involvement, and metastasis, with treatment options including chemotherapy, radiation, and immunotherapy [2–4]. The treatment methods, symptoms, and side effects vary by stage. Managing breast cancer during and after treatment to reduce recurrence rates and mitigate side effects is crucial. Breast cancer treatment includes chemotherapy and radiation therapy, with treatment duration ranging from several months to a year, depending on the patient's condition, cancer stage, and medication used.

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Physical fitness is essential for breast cancer patients because it helps them endure the rigors of treatment and recover more effectively. Consequently, personalized exercise programs tailored to each patient's fitness level, health status, and cancer stage are needed to optimize treatment outcomes and improve overall well-being.

Exercise training has been supported by several previous studies for its role in improving health and fitness markers, as well as cancer-related indicators, in breast cancer patients [5–8]. It has been shown to be safe and effective, enhancing physical fitness and quality of life, and reducing cancer-related fatigue among these patients. Previous studies have reported that combining aerobic and resistance exercises during adjuvant chemotherapy can reduce fatigue and improve the quality of life for breast cancer patients [12, 13]. Additionally, research has shown that exercise can mitigate the negative cardiovascular effects of early breast cancer treatment [11]. Weight training, in particular, has been found to significantly improve fitness and reduce fatigue in women at risk of lymphedema post-treatment [12]. Moreover, studies have highlighted that exercise interventions can positively impact body composition and biomarkers associated with breast cancer prognosis [13–16]. Exercise has been linked to reductions in body fat and improvements in lean body mass, both of which are crucial for long-term health outcomes [13, 14]. Furthermore, regular physical activity has been associated with favorable changes in biomarkers, such as insulin, inflammatory markers, and oxidative stress indicators, which play a role in cancer progression and recurrence [15, 16]. The increasing popularity and applicability of exercise among breast cancer survivors emphasize the importance of integrating physical activity into survivorship care plans [5, 6]. Therefore, participating in scientifically evidence-based personalized exercise programs, tailored to address specific needs related to fatigue, body composition, physical fitness, and biomarkers during and after treatment, is essential.

The American College of Sports Medicine (ACSM) [17] provides exercise guidelines for breast cancer patients, recommending 3–5 sessions of aerobic exercise per week at 50–70% of maximum heart rate, lasting 20–60 min, and 2–3 sessions of resistance exercises per week, with 8–15 repetitions and 2–3 sets. However, understanding the specific effects of exercise at different treatment stages and effective exercise programs is necessary. This systematic review and meta-analysis addresses the gap in the current literature regarding the specific effects of exercise interventions at various stages of breast cancer treatment. Understanding how tailored exercise programs can enhance patient outcomes is crucial, as highlighted by previous studies that have demonstrated improvements in fatigue and quality of life through combined aerobic and resistance exercise. Therefore, the purpose of this systematic review and meta-analysis is to evaluate the effects of exercise interventions during the active treatment phase and post-treatment phase in breast cancer patients.

Methods

Search strategy

This meta-analysis adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [18]. A comprehensive search for relevant studies published in English from January 2000 to August 2024 was conducted using PubMed, the Cochrane Library, and EMBASE. The search strategy included the terms "breast cancer," "exercise," and "randomized controlled trial," which were combined to identify pertinent studies. The search was primarily conducted in the titles and abstracts of articles. Additionally, the reference lists of previously published review articles and meta-analyses were scrutinized to identify further relevant studies. Two researchers independently screened and selected relevant articles. Any disagreements during the selection process were resolved through discussion between the researchers.

The terms "during treatment" and "after treatment" are defined as follows: "during treatment" refers to the period when patients are actively receiving chemotherapy or radiation therapy, while "after treatment" refers to the period following the completion of all treatments, typically ranging from several months to years depending on individual recovery and follow-up care. This study employed the Quality Assessment of Controlled Intervention Studies tool to evaluate the methodological quality, focusing on criteria such as random sequence generation, allocation concealment, blinding of participants and personnel, incomplete outcome data, selective reporting, and other potential sources of bias [19]. Additionally, the Cochrane Collaboration's Risk of Bias Tool was used to assess the risk of bias in randomized controlled trials, examining aspects such as selection bias (random sequence generation and allocation concealment), performance bias (blinding of participants and personnel), detection bias (blinding of outcome assessment), attrition bias (incomplete outcome data), reporting bias (selective reporting), and other biases [20].

Inclusion and exclusion criteria

The inclusion criteria focused on randomized controlled trials involving breast cancer patients aged 18 and older, undergoing or having completed treatment, to assess the impact of exercise interventions on physical fitness and biomarkers. The inclusion criteria also required that the outcomes of the intervention be reported with mean ± standard deviation

(SD). Studies were excluded if they were reviews, case–control studies, or did not focus on exercise interventions.

Data extraction

Data extracted and summarized included author, publication year, country and ethnicity of study participants, participant age and number, exercise intervention duration and methods, and main findings (Table 1 for under treatment and Table 2 for after treatment). Data extraction was meticulously performed by two independent reviewers, with discrepancies resolved through consensus discussions to ensure data integrity and reliability.

Statistical analysis

The standardized mean difference statistic that measures the difference between the means of the treatment and control groups divided by the pooled standard deviation was used to compute the effect size for outcome variables that showed comparable results in at least two studies. The interpretation of effect size magnitude was classified as follows: a small effect size ranged from 0.2 to 0.5, a medium effect size from 0.5 to 0.8, and a large effect size was greater than 0.8. Heterogeneity was assessed using the $I2$ statistic, with fixed-effects models applied for $I2$ values $\leq 50\%$ and random-effects models for $I2 > 50\%$, aligning with best practices in meta-analytic methods. Sensitivity analysis systematically excludes specific studies, particularly those of lower quality, to assess their impact on the overall results; this often involves removing studies one at a time or based on quality assessments to see how these exclusions affect conclusions. Funnel plots, meanwhile, are used to detect publication bias by plotting study effect sizes against their standard errors; a symmetrical plot suggests minimal bias, whereas asymmetry may indicate underrepresentation of smaller or negative studies. All analyses were conducted using Comprehensive Meta-Analysis Version 1.25 software (Biostatic Inc, Englewood, NJ, USA). The inter-rater reliability of this study, which describes the level of agreement between two raters on the quality of selected studies, was assessed using Cohen's Kappa coefficient calculated with SPSS software.

Results

A total of 4271 participants were included in this systematic review and meta-analysis. Among them, 2425 participants were undergoing treatment, and 1947 participants had completed treatment. The study included women diagnosed with breast cancer. All participants were over 18 years old. The selection process for this systematic review and meta-analysis is detailed in Fig. 1. From an initial screening of 1506 studies, 40 were included in the analysis: 17 in which participants were undergoing treatment [21–37] and 22 involving patients after treatment [38–59]. The included studies span various countries, primarily in North America and Europe, with participant demographics predominantly comprising women aged 18 and over. Sample sizes ranged from 30 to 300 participants. The methodological quality was assessed using the Quality Assessment of Controlled Intervention Studies tool, as shown in Supplementary Tables 1 and 2, which indicated that the studies met the required standards. Each RCT's quality was further evaluated using the Cochrane Collaboration's Risk of Bias Tool, with detailed assessments provided in Supplementary Fig. 1, confirming that the studies were of high qualitative standards. The analysis yielded a Kappa value of 0.75, indicating substantial agreement between the raters regarding the quality of the selected studies. No adverse side effects were reported for exercise interventions in breast cancer patients undergoing treatment or after treatment. Studies on exercise programs for breast cancer stages were selected for this systematic review and meta-analysis and analyzed separately for patients undergoing treatment or who had completed treatment. Figure 2 shows the effect size of exercise intervention during and after therapy. The forest plot in this study provides a visual representation of the effect sizes and their corresponding confidence intervals for each included study. Statistical significance was assessed by determining whether the confidence intervals crossed zero. Confidence intervals that do not cross zero indicate statistical significance. A p-value of less than 0.05 was considered indicative of statistical significance. No studies were found that excluded based on sensitivity analysis and funnel plot reviews.

Undergoing treatment

Fatigue

Nine studies analyzing the effects of exercise on fatigue in breast cancer patients undergoing treatment showed a significant reduction in fatigue ($d = -0.20$, 95% confidence interval (CI); $-0.32 - -0.08$, $p = 0.00$).

Body composition

To analyze the effects of exercise on body composition during breast cancer treatment, three studies on body mass index (BMI) and four studies on weight were included. Patients undergoing treatment did not show a significant reduction in BMI ($d = -0.17$, 95% CI; $-0.35 - 0.01$, $p = 0.07$) and weight ($d = -0.10$, 95% CI; $-0.27 - 0.06$, $p = 0.22$).

Table 1 Exercise intervention characteristics of selected studies under treatment

First author (year), country	Design, # of participants per group	Participants	Exercise interventions	Control	Adverse side effects of exercise interventions	Outcomes
Ceseiko (2019), Latvia [7]	RCT: training group ($n=27$) vs. control group ($n=28$)	Under chemotherapy, female, stages I ~ III, 18–63 years old	12 weeks, 2 times/week, maximal strength training, 20–min/session, 2 sets of warm-up, 4 sets with 4 reps of MST (applying horizontal dynamic leg press, emphasizing on stopping the eccentric phase with a 90° in the knee joint), start at 85–90% of 1-RM, progressing by 2.5 kg supervised exercise	Followed prescribed treatment without strength training	No adverse side effects of exercise interventions	Weight, muscle strength(1-RM), HRQOL C-30 (global health status/QoL, symptom scales; fatigue, functional scales; physical functioning, role functioning, emotional functioning, cognitive functioning, social functioning), EORTC QLQ-BR23(functional scales; body image, symptoms scales; systemic therapy side effects)
Chung (2022), Taiwan [8]	RCT: exercise group ($n=16$) vs. usual care group ($n=16$)	Under chemotherapy, without radiotherapy, female, stages I ~ III, 30–65 years old	For duration of chemotherapy (start with 1st cycle of therapy), stop during 2nd week of each cycle of therapy 12 weeks, 2–3 sessions/week, 40-min/session of aerobic exercise (stationary ergometer, treadmill), 5-min of warm-up at 50% of HRR or 50–60% of VO_{2paek}, 30-min of moderate-to-high-intensity for 30-min at 70–80% of HRR or 70–75% of VO_{2paek}, 5-min of cool-down at 50% of HRR or 50–60% of VO_{2paek}, 15-min of resistance exercise (with elastic bands with intermediate tension, 2–3 sets, 10–12 reps, targeting upper and lower extremities; elbow flexion, elbow extension, shoulder abduction, squats, hip abduction, hip extension), 5-min of flexibility training (2 sets, 30-s, self-stretched pectoralis muscles, soft tissue mobilization, shoulder mobilization, static stretching of cuff muscles, quadriceps and hamstring muscles) Supervised exercise	Usual care condition	No adverse side effects of exercise interventions	Cardiac function (IVSd, LVIDd, LVPWd, LVIDs, EDV, ESV, LVEF, LVFS, SV, FAC, LVd Mass, LVMI, AoDiam, LADiam, LA/Ao, E velocity, RVs', E/A, DT), cardiopulmonary exercise test(EX time, work, VO_2, HR, RER, METs, VE/VCO_2, VE/VO_2, $PETCO_2$, $PETO_2$, VE/VCO_2 slope)

Table 1 (continued)

First author (year), country	Design, # of participants per group	Participants	Exercise interventions	Control	Adverse side effects of exercise interventions	Outcomes
Courneya (2013), Canada [9]	RCT: STAN ($n=96$) vs. HIGH ($n=101$) vs. COMB ($n=104$)	Under chemotherapy, female, stages I ~ IIIc, ≥ 18 years old	For duration of chemotherapy (start 1–2 weeks after 1st therapy, end 3–4 weeks after last therapy) STAN: 3 days/week, total 75-min/week of vigorous aerobic exercise (cycle ergometer, treadmill, elliptical, rowing ergometer), 25–30 min/day, start at 55–60% of VO_{2peak}, progressing to 70–75% of VO_{2peak} by week 6 HIGH: 3 days/week, total 150-min/week of vigorous aerobic exercise (cycle ergometer, treadmill, elliptical, rowing ergometer), 50–60 min/day, start at 55–60% of VO_{2peak}, progressing to 70–75% of VO_{2peak} by week 6 COMB: 3 days/week, 30–35 min of strength exercise and 25–30 min of aerobic exercise/day, total 75-min/week of vigorous aerobic exercise (cycle ergometer, treadmill, elliptical, rowing ergometer), start at 55–60% of VO_{2peak}, progressing to 70–75% of VO_{2peak} by week 6, 9 strength exercises (leg extension, leg curl, leg press, calf raise, chest press, seated row, triceps extension, biceps curl, modified curl-up), 2 sets, 10–12 reps, 60–75% of estimated 1-RM Supervised exercise	N/A	No adverse side effects of exercise interventions	Physical functioning, role-physical, bodily pain, general health, physical component summary, trial outcome index-fatigue, fatigue symptoms, endocrine symptoms, taxane symptoms, breast cancer symptoms, fitness variables(VO_{2peak}, upper body strength, lower body strength, upper body endurance, lower body endurance, body weight, lean mass, fat mass, body fat)
Husebo (2014), Norway [10]	RCT: exercise intervention group ($n=33$) vs. control group ($n=34$)	Under chemotherapy, female, early stage (stages I ~ III), 18–70 years old	For period of chemotherapy, combined strength (with resistance bands for arms, legs) and aerobic training Strength training: 3 times/week, targeting upper body Aerobic training: daily 30-min of brisk walking (at least moderate intensity) Home-based unsupervised exercise	Usual care condition	$n=2$; knee comfort ($n=1$), syncope ($n=1$)	Cancer-related fatigue (Schwartz Cancer Fatigue Scale-6), physical fitness (6-min walk test), physical activity level (MET-minutes/week),

Table 1 (continued)

First author (year), country	Design, # of participants per group	Participants	Exercise interventions	Control	Adverse side effects of exercise interventions	Outcomes
Kilbreath (2012), Australia [11]	RCT: exercise program ($n=81$) vs. control group ($n=79$)	Under chemotherapy, radiotherapy, female, stages I ~ III, exercise (53.5 ± 12.1 years old), control (51.6 ± 11.0 years old)	8 weeks, 1 times/week, supervised and home-based resistance training (targeting shoulder muscles, free weights, Thera-band, 2 sets, 8–15 reps), 3 passive stretching for shoulder muscles (in supine, each for 5–15 min, shoulder flexion, arm abduction; targeting pectoralis major, arm abduction; targeting pectoralis minor) Supervised exercise	Usual care condition	No adverse side effects of exercise interventions	EORTC-BR23 (BR23 arm symptoms, BR23 breast symptoms), shoulder range of motion(forward flexion, abduction, external rotation, horizontal extension), strength (abduction, forward flexion, horizontal extension, horizontal flexion), swelling(lymphedema; exceeds BIS ratio, interlimb circumference difference, interlimb arm volume ≥ 10% difference)
Ligibel (2016), USA [12]	RCT: exercise ($n=47$) vs. control ($n=51$)	Under radiotherapy, female, early-stage (stages I ~ III), exercise (49.3 ± 9.6 years old), control (50.7 ± 9.4 years old), life expectancy ≥ 12 months, ≤ 150-min/week of recreational physical activity	16 weeks, 150-min/week of moderate-intensity aerobic exercise program, at 55–80% of HR_{max} Unsupervised exercise	Usual care condition	No adverse side effects of exercise interventions	PA (exercise over 16 weeks, min/week), EORTC QLQ-C30 physical functioning, Bruce Ramp Treadmill, 7-day PAR, EORTC QLQ-C30 (global QOL, role functioning, emotional functioning, cognitive functioning, social functioning, fatigue, nausea/vomiting, pain, dyspnea, insomnia, appetite loss, constipation, diarrhea), FACIT (fatigue)
Mijwel (2018), Sweden [13]	RCT: RT-HIIT ($n=74$) vs. AT-HIIT ($n=72$) vs. UC ($n=60$)	Under radiotherapy, female, stages I ~ IIIa, 18–70 years old	16 weeks, 2 times/week, 3 bouts, 3-min of high-intensity interval aerobic exercise at an RPE of 16–18 on the Borg scale, interspersed with ~ 1-min of recovery, 5-min of warm-up (cycle ergometer, treadmill, at RPE of 10–12), 10-min of cooldown (dynamic muscle stretching) RT-HIIT: progressive resistance and high-intensity interval exercise/session, leg press, biceps curls, squat jumps, triceps extensions, lunges, bench press, sit-ups, Russian-weighted abdominal twist, shoulder press, prone-lying back extensions, 2–3 sets, 8–12 reps, at 70–80% of estimated 1-RM AT-HIIT: start from 20-min of moderate-intensity continuous aerobic exercise at RPE of 13–15, cycle ergometer, elliptical ergometer, treadmill Supervised exercise	Usual care condition	No adverse side effects of exercise interventions	Estimated VO_{2peak}, isometric mid-thigh pull, handgrip strength surgery side, handgrip strength non-surgery side, body mass, Hb, PPT(trapezius, gluteus); between receiving taxane- and non-taxane-based treatment

Table 1 (continued)

First author (year), country	Design, # of participants per group	Participants	Exercise interventions	Control	Adverse side effects of exercise interventions	Outcomes
Mijwel (2019), Sweden [14]	RCT: RT-HIIT ($n=79$) vs. AT-HIIT ($n=80$) vs. UC ($n=81$)	Under chemotherapy. female, stages I ~ IIIa, 18–70 years old	16 weeks, 2 times/week, 60-min/session, 3 bouts, 3-min of HIIT at RPE of 16–18 on a cycle ergometer interspersed with 1-min of recovery RT-HIIT: 2–3 sets, 8–12 reps, start from 70% of estimated 1-RM, progressing to 80% of 1-RM AT-HIIT: start from 20-min of moderate-intensity continuous aerobic exercise at RPE of 13–15, cycle ergometer, elliptical ergometer, treadmill Supervised exercise	Usual care condition	High incidence of neuropathies in RT-HIIT group, high incidence of GI side effects in AT-HIIT group reported	Proportion of participants requiring dose reductions, RDI of chemotherapy, hospitalization rates, blood cell concentrations (hemoglobin, lymphocytes, thrombocytes, neutrophils)
Mijwel (2019), Sweden [15]	RCT: RT-HIIT ($n=74$) vs. AT-HIIT ($n=72$) vs. UC ($n=60$)	Under chemotherapy, female, stages I ~ IIIa, 18–70 years old	16 weeks, 2 times/week, 60-min/session, 3 bouts, 3-min of HIIT on a cycle ergometer interspersed with 1 min of recovery RT- HIIT: 2–3 sets, 8–12 reps, start from 70% of estimated 1-RM, progressing to 80% of 1-RM AT-HHIT: start from 20-min of moderate-intensity continuous aerobic exercise, cycle ergometer, elliptical ergometer, treadmill Supervised exercise	Usual care condition	No adverse side effects of exercise interventions	PFS questionnaire (behavior/daily life CRF, emotional/affective CRF, sensory/physical CRF, cognitive CRF, total CRF), EORTC-QLQ-C30(global/quality of life, physical functioning, emotional functioning, role functioning, cognitive functioning, social functioning, fatigue, nausea and vomiting, pain, dyspnea, insomnia, appetite loss, constipation, diarrhea, financial difficulties), MSAS (symptom burden, physical symptoms, psychological symptoms, total symptoms), body mass, BMI, estimated VO_{2peak}, isometric mid-thigh pull, handgrip surgery side, handgrip non-surgery side
Mock (2005), USA [16]	RCT: exercise ($n=60$) vs. usual care ($n=59$)	Under chemotherapy, radiotherapy, female, stages 0 ~ III, 18–70 years old, sedentary	From initiation to cessation of therapy, 6 weeks of RT, 3–6 months of CT, 5–6 times/week, home-based moderate-intensity walking exercise program (50–70% of HR_{max}), 15–30 min of brisk walk Home-based unsupervised exercise	Usual care condition	No adverse side effects of exercise interventions	Fatigue, physical function, 12-min walk, physical activity
Mutrie (2007), Scotland [17]	RCT: exercise group ($n=101$) vs. control group ($n=102$)	Under chemotherapy, radiotherapy, female, stages 0 ~ III, exercise group (51.3 ± 10.3 years old), control group (51.8 ± 8.7 years old)	12 weeks, 2 supervised sessions/week, 45-min in total, 5–10 min of warm-up, 20-min of exercise (walking, cycling, low-level aerobics, muscle strengthening exercises, circuits of specifically tailored exercises; 50–75% of age-adjusted HR_{max}), cool-down and relaxation, 1 home-based additional session/week Supervised exercise, home-based unsupervised exercise	Usual care condition	No adverse side effects of exercise interventions	FACT-G, FACT-GP, FACT-GS, FACT-GE, FACT-GF, FACT-B, FACT-F, FACT-ES, BDI score, PANAS positive, PANAS negative, 12-min walk, SPAQ leisure activity, shoulder mobility score, BMI

Table 1 (continued)

First author (year), country	Design, # of participants per group	Participants	Exercise interventions	Control	Adverse side effects of exercise interventions	Outcomes
Nikander (2012), Finland [18]	RCT: care group ($n=40$) vs. training group ($n=37$)	under chemotherapy, radiotherapy, female, stages I ~ III, 35–68 years old	1 session/week, supervised vigorous aerobic exercise (10 min of warm-up, 30–40 min of effective training; step aerobics, including 100 hops, jumps, 10-min of cool-down, at 80% of HR_{max}, circuit training, 3 rounds, 8–10 movements, rope-jumping, skate jumping, including 100–150 jumps, 20–40 s/movement), additional dumbbell exercises for upper and lower extremity training, 3 sessions/week, home training (modified combination of 100 hops, leaps, jumps, additional brisk endurance training; walking, cycling, swimming), ≥ 150-min of physical activity Supervised exercise, home-based unsupervised exercise	Usual care condition	$n=4$; overuse injuries (joint, muscle pain, muscle stiffness to the lower extremities) No severe adverse events related to the interventions reported	Bond traits (distal tibia, tibial shaft, femoral neck; BMC, total cross-sectional area, cortical area, trabecular density, polar section modulus), body composition (weight, fat, android fat, gynoid fat), physical performance(figure-8 running time, counter-movement jump force, counter-movement jump power, isometric leg extension force, isometric grip strength, 2-km walk time, heart rate at the end of the 2-km walk)
Sanft (2023), USA [19]	RCT: intervention ($n=87$) vs. UC ($n=86$)	Under chemotherapy, female, stages I ~ III, intervention (52.3 ± 11.3 years old), UC (53.3 ± 10.9 years old), < 150-min/week of moderate-to vigorous-intensity PA	1st month: 4 times/week 2nd, 3rd months: 2 times/2 weeks n^{th} months: 1 time/month Aerobic exercise (brisk walking, ≥ 150-min/week of moderate-to vigorous-intensity PA, ≥ 75-in/week of vigorous-intensity PA), progressive strength training program (2 times/week), until the end of chemotherapy Home-based unsupervised exercise	Usual care condition	PRO-CTCAE symptoms	Physical activity (change in PA, meeting PA guidelines, resistance training), diet(change in fruits, vegetables, fiber, healthy eating index), weight, PRO-CTCAE symptoms (severity of dry mouth, difficulty swallowing, mouth/throat sores, problems with tasting, decreased appetite, nausea, vomiting, heartburn, diarrhea, interference of mouth/throat sores, decreased appetite, frequency of nausea, vomiting, heartburn, diarrhea, any NIS), RDI variables (RDI continuous, dose reduction, dose delays, toxicity dose delays, dose reduction, skip, toxicity delays, reasons for toxicity-related changes (neuropathy, infections, hematologic toxicities, mouth sores, diarrhea, constipation, dehydration, nausea/vomiting, fatigue, transaminases, skin toxicities, immune-related toxicities, others), pCR, HR + and HER2-, TNBC, HER2 +

Table 1 (continued)

First author (year), country	Design, # of participants per group	Participants	Exercise interventions	Control	Adverse side effects of exercise interventions	Outcomes
Schmidt (2015), Germany [21]	RCT: EX ($n=52$) vs. RC ($n=49$)	Under chemotherapy, female, stages I ~ IV, ≥ 18 years old, BMI ≥ 18 kg/m^2	12 weeks, 2 times/week, 60-min of 8 progressive resistance exercises (leg extension, leg curl, leg press, shoulder internal and external rotation, seated row, latissimus pull down, shoulder flexion and extension, butterfly and butterfly reverse), at 60–80% of 1-RM, 3 sets, 8–12 reps Supervised exercise	12 weeks, 60-min, 2 times/week, progressive muscle relaxation without any aerobic or muscle strengthening exercise	Potential adverse effects (lymphedema, pain, muscle soreness, nausea, dyspnea, tachycardia) at each session No severe adverse events reported	Fatigue (total fatigue, physical fatigue, affective fatigue, cognitive fatigue), QoL (EORTC QLQ30; global QoL, physical function, emotional function, role function, cognitive function, social function), depression (CES-D), trail-making test, thyroxin use
Schmidt (2016), Germany [20]	RCT: resistance exercise ($n=80$) vs. relaxation control group ($n=80$)	Under radiotherapy, female, stages 0 ~ IIIA, ≥ 18 years old, BMI ≥ 18 kg/m^2	12 weeks, 2 times/week, 60-min of progressive resistance training, 8 resistance exercise (5 upper body; shoulder internal and external rotation, seated row, latissimus pull down, shoulder flexion and extension, butterfly and butterfly reverse, 3 lower body; leg extension, leg curl, leg press), 3 sets, 8–12 reps, at 60–80% of 1-RM, progressing by 5% of weight Supervised exercise	2 times/week, 60-min of progressive muscle relaxation without any aerobic or muscle-strengthening components	No adverse side effects of exercise interventions	IL-6, IL-1ra, fatigue (multidimensional Fatigue Assessment Questionnaire), pain (EORTC QLO-C30), depressive symptoms (CES-D)
Schwartz (2007), USA [22]	RCT: AE ($n=22$) vs. RE ($n=21$) vs. UC ($n=23$)	Under chemotherapy, female, stages I ~ III, AE (48.32 ± 12.6 years old), RE (50.1 ± 8.7 years old), UC (46.26 ± 9.8 years old)	12 weeks Home-based AE: 4 days/week, 15–30 min, walking, jogging, at a symptom-limited, moderate intensity (breathing hard, able to talk) Home-based RE: 4 days/week, 2 sets, 8–10 reps, 8 exercises (4 upper body, 4 lower body), using resistance bands, progressing with greater resistance bands Home-based unsupervised exercise	Usual care condition	No adverse side effects of exercise interventions	Aerobic capacity (12-min walk), muscle strength (overhead press, seated row, leg extension), bone mineral density (BMD L-spine)
Steindorf (2014), Germany [23]	RCT: progressive resistance training ($n=80$) vs. relaxation control ($n=80$)	Under radiotherapy, female, stages 0 ~ III, ≥ 18 years old, BMI ≥ 18 kg/m^2	12 weeks, 2 times/week, 60-min of progressive resistance training, 8 resistance exercise (5 upper body; shoulder internal and external rotation, seated row, latissimus pull down, shoulder flexion and extension, butterfly and butterfly reverse, 3 lower body; leg extension, leg curl, leg press), 3 sets, 8–12 reps, at 60–80% of 1-RM, progressing by 5% of weight Supervised exercise	2 times/week, 60-min of progressive muscle relaxation without any aerobic or muscle-strengthening components	Potential adverse effect recorded at each training session (lymphedema, pain, muscle soreness, nausea, dyspnea, tachycardia) No severe adverse events related to the interventions reported	Fatigue (total fatigue, physical fatigue, affective fatigue, cognitive fatigue), global QoL, EORTC QLQ30 functions (physical function, emotional function, role function, cognitive function, social function0), EORTC QLQ30 symptoms (fatigue, insomnia, dyspnea, nausea and vomiting, pain, appetite loss, constipation, diarrhea, financial difficulties), EORTC BR23 functions (future perspective, body image, sexual functioning and satisfaction), depression (CES-D), cognitive function (trail-making test)

Table 1 (continued)

1-RM 1 repetition maximum, *6MWT* 6-min walking test, *AE* aerobic exercise, *AET* aerobic exercise training, *AoDiam* aortic diameter, BDI Beck Depression Inventory, *BFI* Brief Fatigue Inventory, *BIS* bioimpedance spectroscopy, *BMC* bone mineral content, *BMD* bone mineral density, *CES-D* Center of Diseases Depression Scale, *cIMT* carotid intima media thickness, *COMB* combined of aerobic and resistance exercise, *CON* control group, *CRF* cancer-related fatigue, *cTnT* plasma cardiac TropoNin-T, *DBP* diastolic blood pressure, *DDFS* distant disease-free survival, *DFS* disease-free survival, *Dt* deceleration time, *E velocity* mitral inflow velocity, *E/A* ratio between early and late ventricular filling velocity, *EDV* end-diastolic volume, *EORTC* European Organization for Research and Treatment of Cancer, *ESV* end-systolic volume, *FAC* fractional area change, *FACIT-T*, Functional Assessment of Chronic Illness Therapy-Fatigue Version IV, *FACIT* Functional Assessment of Chronic Illness Therapy, *FACT-An*, the Functional Assessment of Cancer Therapy-Anemia, *FACT-B* Functional Assessment of Chronic Illness Therapy-Best, *FACT-F* Functional Assessment of Chronic Illness Therapy-Fatigue, *FACT* Functional Assessment of Cancer Therapy, *GI side effect* gastrointestinal side effect, *HADS-A* Hospital Anxiety and Depression Scale-Anxiety, *HADS-D* Hospital Anxiety and Depression Scale-Depression, *Hb* hemoglobin levels, *HER2-* human epidermal growth factor receptor 2-negative, *HER2* + human epidermal growth factor receptor 2-positive, *HIIT* high intensity interval training, *HIGH* higher dose of aerobic exercise, *HR* +, hormone receptor-positive, *HRQOL C* −30 health-related quality of life, *HRR* heart rate reserve, *IL-1ra* interleukin-1 receptor antagonist, *IL-6* interleukin-6, *IVSd* interventricular septum thickness at end-diastole, *KPS* Karnofsky Performance Scale, *LA/Ao* ratio of left atrial dimension to aortic annulus dimension, *LADiam* left atrial diameter, *LBM* lean body mass, LV mass at end-diastole, *LVEF*, left ventricle ejection fraction, *LVFS* lv fractional shortening, *LVIDd* left ventricular internal dimension at end-diastole, *LVIDs* left ventricular internal dimension at end-systole, *LVMI* LV mass index, *LVPWd* left ventricular posterior wall thickness at end-diastole, *MET* metabolic equivalent of task, *MST* maximal strength training, *MSAS* Memorial Symptom Assessment Scale, *NIS* nutrition impact symptoms, *NT-proBNP* N-Terminal fragment of the PROhormone Brain-Type Natriuretic Peptide, *OS* overall survival, *PA* physical activity, *PANAS* Positive And Negative Affect Scale, *PAR* physical activity recall, *Pcr* pathologic complete response, *PETCO2* end-tidal carbon dioxide, *PETO2* end-tidal oxygen, *PFS* Piper Fatigue Scale, *PPO* peak power output, *PPT* pressure-pain threshold, *PRO-CTCAE* patient-reported outcomes version of the common terminology criteria for adverse events, *PROs* patient-reported outcomes, *PSQI* Pittsburgh Sleep Quality Index, *QoL* quality of life, *RCT* randomized clinical trial, *RDI* relative dose index, *RE* resistance exercise, *RET* resistance exercise training, *RER* respiratory exchange ratio, *RFI* recurrence-free interval, *RPE* rating of perceived exertion, *RVs'* right ventricular peak systolic tricuspid annulus velocity, *SBP* systolic blood pressure, *SPAQ* Scottish Physical Activity Questionnaire, *STAN* standard dose of aerobic exercise, *SV* stroke volume, *TNBC* triple-negative breast cancer, *TOI-An* Trial Outcome Index-Anemia scale, *UC* usual care control, *VE/VCO2 slope* slope of ventilatory equivalent for carbon dioxide output, *VE/VCO2* minute ventilation relative to CO2 production, *VEVO2* minute ventilation relative to O2 production, *VO2peak* peak oxygen consumption

Physical fitness

Three studies analyzed the effects of exercise on physical fitness in breast cancer patients undergoing treatment. Patients participating in exercise interventions showed a significant improvement in the 12-min walk test ($d = -0.29$, 95% CI; -0.52 – -0.06, $p = 0.01$).

After treatment

Fatigue

Four studies examining the effects of exercise on fatigue in breast cancer patients who completed treatment showed a significant reduction in fatigue ($d = -1.11$, 95% CI; -1.36 – -0.85, $p = 0.00$).

Body composition

To understand changes in body composition after exercise interventions in breast cancer patients after treatment, two studies each on lean mass, fat mass, and % body fat and four studies on waist circumference were included. Participants showed significant improvements in lean mass ($d = 1.27$, 95% CI; 0.96 – 1.59, $p = 0.00$), fat mass ($d = -1.33$, 95% CI; -1.67 – -0.99, $p = 0.00$), % body fat ($d = -1.22$, 95% CI; -1.57 – -0.88, $p = 0.00$), and waist circumference ($d = -0.69$, 95% CI; -0.97 – -0.42, $p = 0.00$).

Physical fitness

Exercise participation in women after breast cancer treatment did not produce significant differences in cardiorespiratory fitness (VO_{2max}, $d = 0.25$, 95% CI; -0.05 – 0.55, $p = 0.10$) or handgrip strength ($d = -0.05$, 95% CI; -0.28 – 0.18, $p = 0.69$).

Biomarkers

The analysis of the effects of exercise on biomarkers in breast cancer survivors after treatment showed significant improvements in IL-6 ($d = -0.95$, 95% CI; -1.31 – -0.59, $p = 0.00$), HDL ($d = 2.16$, 95% CI; 1.80 – 2.52, $p = 0.00$), LDL (d = -1.49, 95% CI; -1.89 – -1.08, $p = 0.00$), glucose ($d = -0.66$, 95% CI; -0.13, $p = 0.00$), systolic blood pressure (SBP, d = -1.23, 95% CI; -1.50 – -0.95, $p = 0.00$), and diastolic blood pressure (DBP, $d = -0.87$, 95% CI; -1.21 – -0.53, $p = 0.00$). However, insulin ($d = 0.24$, 95% CI; -0.04 – 0.52, $p = 0.10$) did not show a significant effect.

Table 2 Exercise intervention characteristics of selected studies after treatment

First author ([], country	Design, # of participants per group	Participants	Exercise interventions	Control	Adverse side effects of exercise interventions	Outcomes
Baruth (2015), USA [24]	RCT: intervention ($n=20$) vs. control ($n=12$)	Post-treatment, female, stages I ~ III, not regularly active (< 5 days/week)	12 weeks, aerobic exercise (walking), if participants could do more, they were encouraged to do so Week 1: 3 days/week, 20-min, moderate-intensity Week 8: 5 days/week, 30–40 min, moderate to vigorous-intensity Home-based unsupervised exercise	Usual care condition	No adverse side effects of exercise interventions	FACT-Fatigue, IBCSG Quality of Life Core Questionnaire, physical well-being (mood, tiredness, appetite, effort in coping, current health, hot flashes, feeling sick, social support, restricted use of arm), SF-36 Quality of Life Questionnaire (physical functioning, role-physical, pain, general health, vitality, social functioning, role-emotional, mental health, physical component scale, mental component scale)
Casla (2015), Spain [25]	RCT: EX ($n=44$) vs. CON ($n=45$)	Post-treatment, female, stages I ~ III, EX (45.91 ± 8.21 years old), CON (51.87 ± 8.21 years old)	12 weeks, 2 times/week, aerobic and resistance exercise, 10 min of warm-up (articular mobilization, walking exercises, running at 50–60% of HRR), 25–30 min of aerobic exercise (dance classes, power circuits, walking-running at 55–70% of HRR), 10–15 min of resistance exercise (shoulder circles, dorsal and chest exercises with elastic bands, 8–15 reps, 2 sets), 10 min of cool-down (whole-body stretching), supervised exercise	Usual care condition	No adverse side effects of exercise interventions	Cardiorespiratory capacity (VO_{2max}), muscle strength (isometric muscle strength, dynamic muscle strength), shoulder range of motion, physical activity (sedentary, low physical activity, medium physical activity, high level), physical variables (physical capacity, IGS, maximal strength chest maximal strength legs, resistance strength chest, resistance strength legs, maximal strength chest/weight, maximal strength legs/weight), body composition (BMI, weight, hip-waist ratio, % body fat mass, lean body mass), QoL (SF36 mental, SF36 physical, physical functioning, role imitation-physical health, bodily pain, general health perception, vitality, social functioning, role limitation-emotional health, mental health)

Table 2 (continued)

First author ([), country	Design, # of participants per group	Participants	Exercise interventions	Control	Adverse side effects of exercise interventions	Outcomes
Courneya (2003), Canada [26]	RCT: exercise ($n=25$) vs. control ($n=28$)	Post-surgery, female, stages I ~ IIIa, $69 \geq P \geq 50$	15 weeks, 3 times/week, 15–35 min, aerobic exercise (recumbent or upright cycle ergometer), at 70–75% of $VO_{2max,}$ supervised exercise	Usual care condition	No adverse side effects of exercise interventions	Cardiopulmonary outcomes (peak oxygen consumption, peak power output, peak respiratory exchange ratio, peak heart rate, ventilatory equivalent for oxygen, power output at the ventilatory equivalent for oxygen, ventilatory equivalent for carbon dioxide, power output at the ventilatory equivalent for carbon dioxide), QoL (FACT-B, TOI, happiness, self-esteem, fatigue, components of FACT-B, physical well-being, functional well-being, emotional well-being, social/family well-being, breast cancer subscale), body composition (body weight, BMI, sum of skinfolds)
Dieli-Conwright (2018), USA [28]	RCT: exercise ($n=50$) vs. usual care ($n=50$)	Post-treatment, female, stages 0 ~ III, BMI ≥ 25.0 kg/m^2, body fat > 30%, waist circumference > 88 cm, nonsmoker, sedentary < 60 min of structured exercise/week	16 weeks, 3 times/week, moderate-to-vigorous (65–85% of HR_{max}) aerobic and resistance exercise, 5-min of aerobic exercise at 40–50% of estimated VO_{2max}, resistance exercises: lower-body exercises (leg press, lunges, leg extension, leg flexion at 80% of 1-RM), upper-body exercises (chest press, seated row, triceps extension, biceps curl at 60% of 1-RM), 10–15 reps, self-selected aerobic exercise session (treadmill walking/running, rowing machine, stationary bicycle) at 65–80% of HR_{max} for 30–50 min, 5-min of cool down at 40–50% of estimated VO_{2max}, supervised exercise	Usual care condition	No adverse side effects of exercise interventions	Metabolic syndrome variables (waist circumference, SBP, DBP, HDL-C, triglycerides, glucose, metabolic syndrome z-score, ATP III score), sarcopenic obesity (appendicular skeletal muscle index), body composition (BMI, weight, hip circumference, lean mass, fat mass, % body fat, trunk fat), serum biomarkers(insulin, HOMA-IR, IGF-1, IGFBP-3, *hs*-CRP, leptin, adiponectin, total cholesterol, IL-6, IL-8, TNF-α, SHBG, estradiol, free testosterone)

Table 2 (continued)

First author ([), country	Design, # of participants per group	Participants	Exercise interventions	Control	Adverse side effects of exercise interventions	Outcomes
Dieli-Conwright (2018), USA [29]	RCT: exercise ($n=50$) vs. control ($n=50$)	Post-treatment, female, stages 0 ~ III, BMI ≥ 25.0 kg/m^2, waist circumference > 88 cm	16 weeks, 3 sessions/week, aerobic exercise: 150 min/week, a 5-min warm-up (40–50% estimated VO_{2max}), 50–80 min of treadmill walking/running, rowing machine, stationary bicycle (65–80% of HR_{max}), 5-min cool-down (40–50% of estimated VO_{2max}), resistance exercise: 2–3 days/week, a 80-min of 60% estimated 1-RM for 4 Upper body resistance exercises (chest press, seated row, triceps extension, biceps curl) and 80% estimated 1-RM for 4 lower body resistance exercises (leg press, lunges, leg extension, leg flexion), 3 sets, 10–15 reps, supervised exercise	Usual care condition	No adverse side effects of exercise interventions	QoL (physical well-being, social well-being, emotional well-being, functional well-being, additional concerns, FACT-general, FACT-breast), health status(physical functioning, role-physical, bodily pain, general health, mental health, rope-emotional, social functioning, vitality, physical component summary, mental component summary, BFI, CES-D) fatigue, depression, physical fitness (estimated VO_{2max}, RHR, muscular strength; leg extension, leg flexion, latissimus pulldown, chest press), bone health (calcium, 25(OH)D, osteocalcin, BSAP: bone-specific alkaline phosphatase, CTX, NTX, RANK, RANKL, whole body BMD, lumbar spine BMD, total hip BMD, trochanter BMD, femoral neck BMD)
Dieli-Conwright (2018), USA [29]	RCT: EX group ($n=10$) vs. CON group ($n=10$)	Post-treatment, female, stages I ~ III, EX (53.0 ± 10.0 years old), CON (55.0 ± 4.5 years old), obese (BMI ≥ 30 kg/m^2), < 60-min of physical activity/week	16 weeks, 3 times/week, progressive, combined aerobic and resistance exercise, 5-min aerobic exercise warm-up at 40–50% estimated VO_{2max}, 2/3 days/week of resistance exercise (3 sets of 10-rep, weight increasing by 10%, reps increasing 10, 12, 15 every 4 weeks, 80% of estimated 1-RM for lower body exercises: leg press, lunges, leg extension, leg flexion, 60% of estimated 1-RM for upper body exercises: chest press, seated row, triceps extension, biceps curl), 150-min/week of moderate-vigorous aerobic exercise (treadmill walking/running, rowing machine, stationary bicycle at 65–80% of HR_{max}), 5-min aerobic exercise cool down at 40–50% estimated VO_{2max}, supervised exercise	Usual care condition	No adverse side effects of exercise interventions	Weight, lean mass, fat mass, % body fat, waist circumference, hip circumference, cardiometabolic profile (glucose, insulin, HOMA-IR, total cholesterol, LDL, HDL, triglycerides, HbA1c), adipose tissue inflammation (CRP, leptin, adiponectin, TNF-α, IL-6, IL-8, M1, M2, IL-12 p40, IL-12 p70)

Table 2 (continued)

First author ([), country	Design, # of participants per group	Participants	Exercise interventions	Control	Adverse side effects of exercise interventions	Outcomes
Dolan (2016), Canada [30]	RCT: AIT ($n=12$) vs. CMT ($n=11$) vs. CON ($n=10$)	Post-treatment, female, stages I ~ IIIA, age 57.2 ± 9 years old, weight 67.6 ± 12 kg	6 weeks, 3 sessions/week AIT: 2–4 min, 95–50%, progressively higher intensity CMT: 2 weeks of introductory intervals at 80% VO_{2max} followed by progressively higher intensity, supervised exercise	Usual care condition	No reporting adverse side effects of exercise interventions	VO_{2max}, weight, circumference (waist, hip, HR_{rest}, strength 1RM), blood (fasting: insulin, glucose, *hs*-CRP, HOMA1-IR, total sessions, total distance, total time, total time > 80% VO_{2max}, average intensity, 3-month follow-up)
Fairey (2005), Canada [31]	RCT: exercise ($n=24$) vs. control ($n=28$)	Post-treatment, female, stages I ~ IIIB, exercise (59 ± 5 years old), control (58 ± 6 years old)	15 weeks, 3 times/week, aerobic exercise (recumbent/upright cycle ergometers) at 70–78% of peak oxygen consumption, 15-min for weeks 1–3, increasing by 5-min every 3 weeks, 35-min for weeks 13–15, 5-min of cycling at 50% of peak oxygen consumption for warm-up and cool-down periods, supervised exercise	Asked not to begin a structured exercise program	No reporting adverse side effects of exercise interventions	Heart rate variables (RHR, HRR), blood pressure (SBP, DBP), lipids (TC, HDL-C, LDL-C, TG, TC:HDL-C ratio), inflammatory biomarker (CRP)
Gal Roxanne (2021), Netherlands [32]	RCT: intervention ($n=68$) vs. control ($n=130$)	Post-treatment, female, stages I ~ III, intervention accepted (56.6 ± 9.8 years old), control (58.3 ± 9.5), physically inactive lifestyle (< 150-min/week performing moderate-to-vigorous leisure time/sports activities)	12 weeks, 2 times/week, 1-h combined aerobic and resistance training, encouraged to be physically active with moderate intensity for at least 30-min/day, supervised exercise	Usual care condition	No adverse side effects of exercise interventions	Physical activity, quality of life, fatigue, anxiety, depression
Jones S.B (2013), USA [33]	RCT: exercise ($n=37$) vs. usual care ($n=38$)	Post-treatment, female, stages 0 ~ IIIA, physically inactive (< 60-min/week of recreational physical activity)	Aerobic exercise (brisk walking, stationary biking, elliptical training, not involve sustained aerobic effort: resistance training, yoga): 150-min of moderate intensity, 3 times of supervised exercises/week, 2 times of unsupervised exercises/week, start at 50% of predicted HR_{max} (220-age), gradually increasing minutes of exercise/week (3 15- min sessions during week 1, building to 5 30-min moderate-intensity sessions by week 5), supervised exercise	Usual care condition	No adverse side effects of exercise interventions	Inflammatory markers (IL-6, CRP, TNF-α)
Lahart (2018), UK [34]	RCT: intervention ($n=40$) vs. control ($n=40$)	Post-treatment, female, stages I ~ III, intervention (52.5 ± 10.7 years old), control (52.0 ± 8.6 years old),	24 weeks Months 1–3: 3–5 days/week, 30-min of moderate-intensity PA (walking, aerobic exercise) Months 3–6: 5–7 days/week, at least 30-min of moderate-intensity PA (walking, aerobic exercise), home-based unsupervised exercise	Usual care condition	No adverse side effects of exercise interventions	VO_{2max}, time to exhaustion, peak HR, resting SBP, resting DBP, resting MAP, mass, total PA, leisure PA, walk PA, moderate PA, vigorous PA, BMI

Table 2 (continued)

First author ([), country	Design, # of participants per group	Participants	Exercise interventions	Control	Adverse side effects of exercise interventions	Outcomes
Lee, K. (2019), USA [35]	RCT: exercise ($n=50$) vs. usual care ($n=50$)	Post-treatment, female, stages I ~ III, BMI ≥ 25.0 kg/m^2, body fat > 30%, waist circumference > 88 cm, sedentary (< 60-min of structured exercise/week)	16 weeks, ≥ 150-min of aerobic exercise (treadmill walking, machine rowing, cycling), 2–3 days of resistance exercise (leg press, leg flexion/extension, chest press, seated row, bicep curl, triceps pulldown at 60–80% of 1-RM)/week, 3 days/week (Day1 and 3: aerobic, resistance exercise for 80-min, Day2: aerobic exercise at 65–980% of HR_{max} for 50-min), supervised exercise	Usual care condition	No adverse side effects of exercise interventions	SBP, HDL-C, LDL-C, diagnosis of diabetes, FRS preset point for SBP/HDL-C/LDL-C/diabetes, total FRS, FRS-predicted 10—y risk
Murtezani (2014), Kosovo [36]	RCT: exercise ($n=30$) vs. control ($n=32$)	Post-treatment, female, early-stage B.C (stages I ~ IIIa)	10 weeks, 3 times/week, 5-min of warm-up (cycling), 3 aerobic exercises (treadmill, stationary bicycle, stair climbing, each for 15-min), 5-min of cool-down (slow walking), 50–75% HRR, 20–45 min/session, supervised exercise	Usual care condition	$n=4$; low back pain ($n=1$), lymphedema ($n=3$)	Overall QoL (FACT-B, FACT-G, physical well-being, functional well-being, emotional well-being, social/family well-being, breast cancer subscale), body composition outcomes, body weight, BMI, 12-MWT
Pinto (2005), USA [37]	RCT: PA group ($n=43$) vs. contact control group ($n=43$)	Post-treatment, female, 58.69 ± 7.5 years old), early-stage B.C (stages 0 ~ II)	12 weeks, from at least 10 min, 2 days/week, to 30-min, 5 days/week, at 55–65% of HR_{max} of moderate-intensity activities (brisk walking, biking, swimming, use of home exercise equipment), home-based unsupervised exercise	Usual care condition	$n=1$; symptoms of chest pain	BMI, percent body fat, 7-day PAR (total weekly energy expenditure, kal/kg/week, moderate-intensity weekly energy expenditure, kcal/kg/week, hard + very hard weekly energy expenditure, kcal/kg/week, total minutes of weekly exercise, total minutes of moderate-intensity exercise, total minutes of hard + very hard intensity exercise), one-mile walk test, minutes, Caltrac, kcal, POMS, BES, fatigue
Pinto (2013), USA [38]	RCT: TC ($n=106$) vs. contact control ($n=86$)	Post-treatment, female, stages 0 ~ IV, PA (56.1 ± 9.9 years old), contact control (55.9 ± 9.9 years old), relatively inactive (< 30-min/week of vigorous-intensity exercise or 90-min/week of moderate-intensity exercise)	12 weeks, start from 10-min/day on at least 2 days/week, end with 30-min/day on at least 5 days/week, moderate-intensity aerobic exercise at 55–65% of HR_{max} (brisk walking, biking, swimming), unsupervised exercise	Usual care condition	$n=2$; sustained minor injuries related to falling off a treadmill	7-day PAR, SF-36 PF, FACT-F

Table 2 (continued)

First author ([), country	Design, # of participants per group	Participants	Exercise interventions	Control	Adverse side effects of exercise interventions	Outcomes
Rogers (2009), USA [39]	RCT: intervention ($n=21$) vs. usual care ($n=20$)	Post-treatment, female, stages I ~ IIIA, intervention (52 ± 15 years old), usual care (54 ± 8 years old), < 60-min/week of vigorous physical activity, < 150-min/week of moderate + vigorous activity	12 weeks, ~ 150-min of moderate walking/week, group and individual sessions, adding flexibility exercises, supervised exercise, and home-based exercise	Usual care condition (only provided materials related to PA obtained from the American Cancer Society)	Changes in endocrine symptoms and joint pains	Activity counts, steps, moderate minutes (≥ hard minutes, ≥ moderate self-report minutes), fitness, right handgrip, left handgrip, back/leg extensors, BIM, waist-to-hip ratio, % body fat, QoL (physical well-being, social well-being, emotional well-being, functional well-being, additional concerns, FACT-G, FACT-B), cognitive function (mental acuity, concentration, memory, verbal fluency, interference in functioning, other people notice deficits, change from previous function, impact on quality of life, total FACT-Cog), sleep dysfunction (sleep quality, sleep latency, sleep duration, sleep efficiency, sleep mediations, daytime dysfunction, total PSQI score), joint symptoms (joint pain, joint stiffness), physical function, WOMAC total
Schmitz (2005), USA [40]	RCT: immediate treatment group ($n=42$) vs. delayed treatment group ($n=43$), delayed treatment group's first 6 months vs. delayed treatment group's last 6 months	Post-treatment, female, stages I ~ III, immediate treatment (53.3 ± 8.7 years old), delayed treatment (52.8 ± 7.6 years old), BMI ≤ 40 kg/m^2, SBP < 160 mm Hg, DBP < 99 mm Hg	48 weeks, 2 sessions/week, ~ 60 min/session, weight training intervention (targeting chest, back, shoulders, arms, buttocks, hips, thighs), first 3 months supervised (2 sessions/week for 13 weeks, 3 sets, 8–10 reps/set), second 3 months supervised (2 sessions/week for 13 weeks, 3 sets, 10, 10, 12 reps for sets 1,2, 3, respectively), stretching exercises before and after each session, upper-body (start from 0–0.5 lb and progressively increasing), lower-body (standard progressive training), last 6 months unsupervised (no call to encourage workout completion), supervised/unsupervised exercise	Usual care condition	Immediate vs. delayed: $n=5$; back injury ($n=4$), shoulder tendonitis ($n=1$) Delayed first 6 months vs. delayed last 6 months: ~ 6 months (n = 1; shoulder tendonitis) 7 ~ 12 months ($n=7$; back injury $n=2$, heel spurs $n=1$, ankle injury $n=3$, rotator cuff injury $n=1$)	Body weight, BMI, body fat, lean mass, waist circumference, glucose, insulin, HOMA, IGF-I, IGF-II, IGFBP-1, IGFBP-2, IGFBP-3

Table 2 (continued)

First author ([), country	Design, # of participants per group	Participants	Exercise interventions	Control	Adverse side effects of exercise interventions	Outcomes
Shobeiri (2016), Iran [41]	RCT: exercise ($n=30$) vs. control ($n=30$)	Post-treatment, female, stages I ~ II, exercise (42.70 ± 9.6 years old), control (43.50 ± 8.60 years old)	10 weeks, F.I.T.T., 2 times/week, 40–60 min, 5–10 min warm-up (slow walking, moderate stretching physical activity), 15 min moderate walking, 15 min stretching physical activity, specific movements of arms and shoulders, 5 min cool-down (slow walking), supervised exercise	Usual care condition	No adverse side effects of exercise interventions	QoL (global health status), functional scales (physical functioning, role functioning, emotional functioning, cognitive functioning, social functioning), symptom scales (fatigue, nausea, vomiting, pain, dyspnea, insomnia, appetite loss, constipation, diarrhea, financial difficulties), components of function (body images, sexual function, sexual pleasure, future prospect, total score of functions), components of symptoms (side effect of treatments, breast symptoms, arm symptoms, worry of hair loss, total score of symptoms)
Sweeney (2019), USA [42]	RCT: EXE intervention ($n=50$) vs. UC ($n=50$)	Post-treatment, female, 53.5 ± 10.4 years old, stages 0 ~ III, BMI ≥ 25.0 kg/m^2, body fat > 30%, waist circumference > 88 cm, sedentary (< 60 min of structured exercise/week)	16 weeks, 3 times/week, 150-min of aerobic and 2/3 days of resistance exercise/week, 80-min of aerobic and resistance exercises for Days 1 and 3, 50-min of aerobic exercise for day 2, progressive, moderated to vigorous, sequenced resistance exercises at 80% of 1-RM for lower body exercises(leg press, lunges, knee extension, knee flexion), 60% of 1-RM for upper body exercises(chest press, seated row, triceps extension, biceps curl), 3 sets, 10–15 reps, self-selected aerobic exercise(treadmill walking/running, rowing machine, stationary bicycle) at 65–80% of HR_{max}, 30–50 min, supervised exercise	Usual care condition	No adverse side effects of exercise interventions	Body structure/function (active range of motion: supine flexion, external rotation at 0°, external rotation at 90°, isometric strength: shoulder flexion, shoulder external rotation, shoulder internal rotation, shoulder horizontal adduction), patient-reported outcome measures (upper limb musculoskeletal disorders: DASH, PSS, PSS pain subscale, PSS satisfaction subscale, PSS function subscale

Table 2 (continued)

First author ([), country	Design, # of participants per group	Participants	Exercise interventions	Control	Adverse side effects of exercise interventions	Outcomes
Twiss (2009), USA [43]	RCT: exercise ($n=110$) vs. comparison ($n=113$)	Post-treatment, female, 53.14 ± 9.70 years old), stages 0 ~ II, ≤ BMD T-score of − 1.0 at any of three sites (hip, spine, forearm)	96 weeks, 2 times/week, 45-min Phase A: home, months 1–2 (2 sets, 8–10 reps, 3 upper extremities exercises: biceps curl, overhead triceps/press, upward row, 3 wrist exercises: curls, extension, ball-gripping, 3 lower extremities exercises: knee extension, side hip raise, hip extension, 2 balance exercises: toe-stand, heel-stand) Phase B: home, months 3–8 (phase A + 2 exercises: overhead press for overhead triceps, diagonal hip raise for side hip raise, 4 supplemental exercises; back extension, abdominal curl, push-up, hip flexion) Phase C: fitness center, months 9–12 (8 exercises on machines: knee extension, overhead press, double leg press, latissimus pull down, leg curl, biceps curl, back extension, abdominal curl, 3 wrist exercises: curls, extension, ball-gripping, 2 balance exercise: toe-stand, heel stand) Phase D: fitness center, months 13–24 (alternate every 2 months between muscle building: 3 sets, 8–12 reps, 1–1.5 min of recovery time and strength building: 3 sets, 8–12 reps, 2–3 min of recovery time, phase C for first week, alternate exercises for variety and muscle load for second week: lunge, pushup on knees, biceps curl with hand held down, pull bar to chest, abdominal floor curl), home-based/fitness exercise, un/supervised exercise	Usual care condition	Temporary muscle soreness for up to 2 days following initiation of exercises or increase in weights lifted, no long-term adverse effects	Muscle strength (hip flexion/extension, knee flexion/extension, wrist flexion/extension), tandem balance (walking backward 20 feet)

Table 2 (continued)

First author ([), country	Design, # of participants per group	Participants	Exercise interventions	Control	Adverse side effects of exercise interventions	Outcomes
Winters-Stone, K.M. (2012), USA [44]	RCT: strength training ($n=52$) vs. flexibility training ($n=54$)	Post-treatment, female, stages 0 ~ IIIa, ≥ 50 years old, non-osteoporotic, < 2, 30-min sessions/week in the past month	1 year, 2 sessions/week, 2-h/session (1-h supervised class, 1-h home-based exercise), progressive, strength training: moderate-intensity resistance + impact training, 1–3 sets of 8–10 exercises (targeting leg, hip, chest, back with dumbells, barbells/resistance bands) for 8–12 reps (60–80% of 1-RM) with 1–2 min rest between sets, flexibility training: low-intensity stretching (a series of whole body stretching, relaxation exercises in a seated/lying position), supervised exercise, home-based unsupervised exercise	Low-intensity stretching	No adverse side effects of exercise interventions	Bench press 1-RM, leg press 1-RM, grip strength left/right hand, chair stand, best 4 m usual walk, 1 leg standing balance-EO, 1 leg standing balance-EC, PPB, SF-36 physical function, LLFDI function upper/lower extremities, LLFDI advanced lower extremities, LLFDI disability limitation score, Schwartz cancer fatigue scale
Zhao, F.Y. (2024), China [45]	RCT: intervention ($n=30$) vs. control ($n=30$)	Post-treatment, female, stages 0 ~ III, 18 to 65 years old, overweight/obese(BMI ≥ 24 kg/m^2) sessions/week in the past month	12 weeks, 5-min warm-up of static stretching, aerobic exercises (1–2/3–5/4–5 days/week, 10–20/15–20/15–30/30–50/40–60 min/day, walking, dancing, jogging, swimming, cycling at 40–60% of reserve HR), resistance exercise with 10-pound elastic bands (2/3 days/week, 1 set of 8–10 reps/1 set of 10–12 reps/1 set of 10–15 reps/2 sets of 10–12 reps/2 sets of 12–15 reps, shoulder pronation, straight arm abduction, arm curl, leg abduction, leg extension, knee lifting), 10-min cooling down of static stretching, monitored exercise by worn exercise bracelet	Usual care condition	No adverse side effects of exercise interventions	Weight, BMI, waist circumference, body composition (%BF, FFM), PAL (PA), aerobic endurance (TMST), lower-body muscular strength (CST), upper-body muscular strength (grip strength-left/right)

25(OH)D 25-hydroxyvitamin D level, *%BF* percent body fat, *6MWT* 6-min walk test, *AIT* aerobic interval training, *ATP* III adult treatment panel III, *BASP* bone-specific alkaline phosphatase, *BES* Body Esteem Scale, *BFI* Brief Fatigue Index, *BMD* bone mineral density, *CFS* Cancer Fatigue Scale, *CES-D* Center for Epidemiologic Studies-Depression Scale, *CES-D* Center for Epidemiological Studies Depression, *CMT* continuous moderate training, *CON* control group, *CRP* C-reactive protein, *CST* Chair-Stand Test, *CTX* C-telopeptide of type 1 collagen, *DASH* disabilities of the arm, shoulder, and hand, *DBP* diastolic blood pressure, *DEG* delayed exercise group, *EC* eyes closed condition, *EO* eyes open condition, *EORTC QLQ BR23* the European Organization for Research and Treatment of Cancer Quality of life Questionnaire Breast Cancer module, *EWB* emotional well-being, *FACT-F/B* Functional Assessment of Cancer Therapy-Fatigue/Breast, *FFM* fat-free mass, *FRAM* Framingham Risk Score, *FWB* functional well-being, *HbA1c* glycated hemoglobin, *HDL-C* high-density lipoprotein cholesterol, *HOMA* HomeOstasis Model Assessment, *hs-CRP* high-sensitivity C-reactive protein, *IEG* immediate exercise group, *IGF* insulin-like growth factor, *IGFBP* insulin-like growth factor binding protein, *IL-6/8* interleukin-6/8, *IMTP* isometric mid-thigh pull, *LLFDI* late life function and disability, *L-Dex* dual energy X-ray absorptiometry extracellular fluid, *LDL-C* low-density lipoprotein cholesterol, *MAP* mean arterial pressure, *NTX* N-telopeptides of type 1 collagen, *PA* physical activity, *PAL* physical activity level, *PAR* physical activity recall, *POMS* profile of mood states, *PSS* Penn Shoulder Scale, *PWB* physical well-being, *QoL* quality of life, *RANK* receptor activator factor-kappa B, *RANKL* receptor activator factor- kappa B ligand, *RCT* randomized clinical trial, *RHR* resting heart rate, *SBP* systolic blood pressure, *SF-36* Short-Form 36, *SF-36 PF* MOS 36-Item Short Form Health Survey Physical Functioning subscale, *SHBG* sex hormone binding globulin, *SHBG* sex hormone-binding globulin, *SPA* social physique anxiety, *SWB* social well-being, *SWLS* Satisfaction With Life Scale, *TC* telephone counseling, *TMST* 2-min step test, *TNF-α* tumor necrosis factor-α, *TOI* trial functional well-being, *TOI* Trial Outcome Index, *WOMAC* The Western Ontario and McMaster Universities Osteoarthritis Index

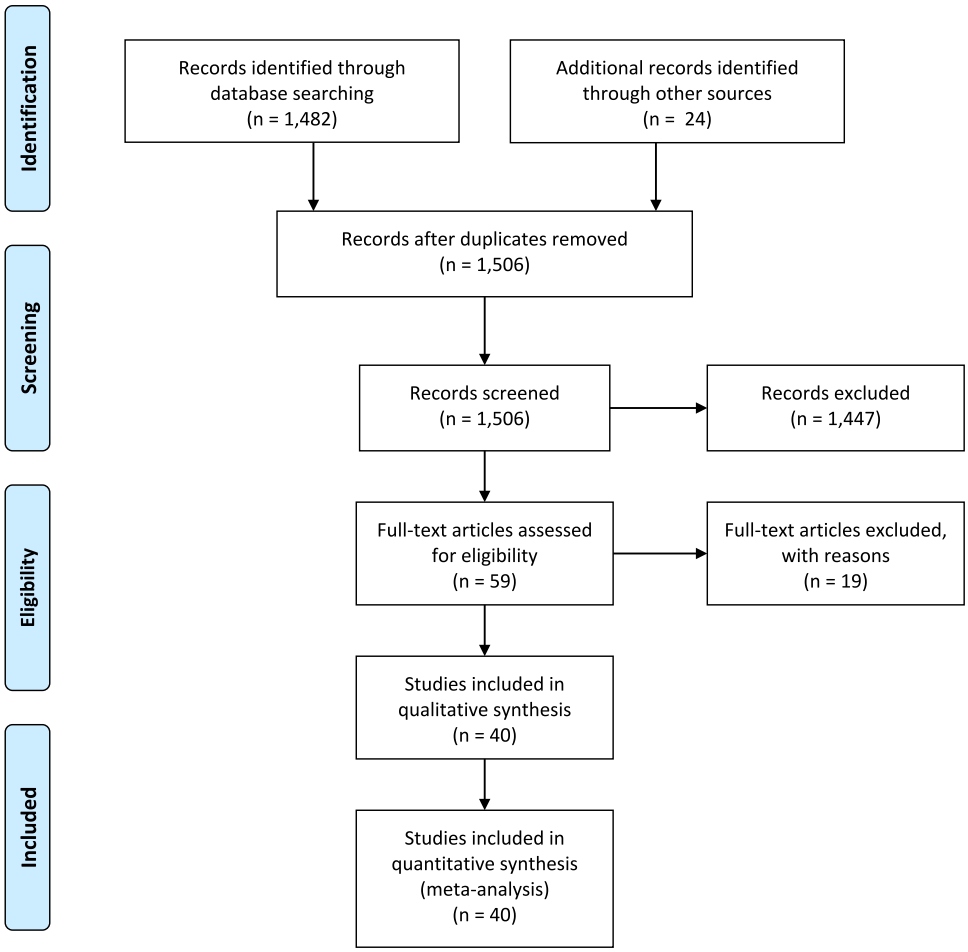


Fig. 1 Selection process flow diagram

Exercise interventions

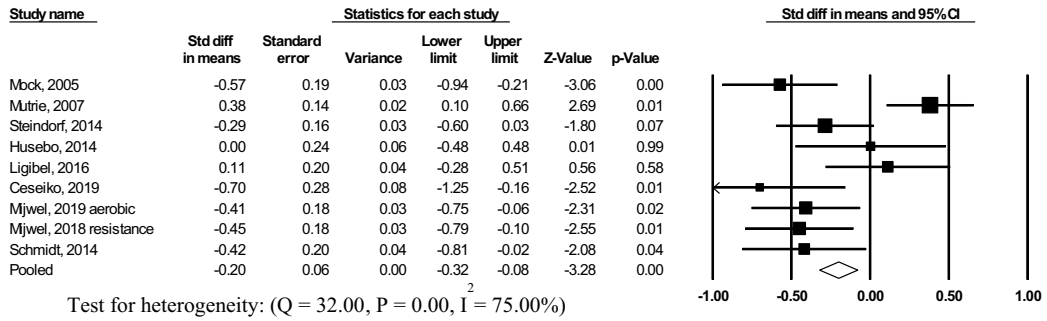
Exercise training protocols for breast cancer patients, primarily inactive women in their 50 s, include those post-treatment and those undergoing treatment. Both protocols include combined aerobic and resistance exercises with progressive intensity. Common aerobic activities include walking, cycling, and treadmill running, and examples of resistance exercises are chest press and leg extension. Training duration is typically 12 weeks during treatment and longer for patients after treatment. Exercise frequency varies, with subjects undergoing treatment often having 1–2 sessions per week for aerobic and 2 days per week for resistance exercises. Patients after treatment are recommended to engage in 2–3 sessions weekly for both types of exercises. Aerobic exercise intensity ranges from 50 to 80% HRmax for subjects undergoing treatment and 55–85% HRmax after treatment. Resistance exercises are performed at 60% of 1-RM for the upper body and 80% for the lower body in both groups. Combined exercise regimens including both aerobic and resistance training are frequently used for enhancing physical health among breast cancer patients.

Discussion

This study systematically analyzed the effects of exercise interventions on breast cancer patients and the effects on fatigue, body composition, physical fitness, and biomarkers during and after treatment. The results demonstrated that exercise significantly reduced fatigue and improved physical fitness during treatment and significantly reduced fatigue, improved physical fitness, and positively affected body composition and biomarkers after treatment.

The main findings indicate that exercise plays a crucial role in alleviating fatigue and enhancing physical fitness in breast cancer patients undergoing treatment. Exercise was shown to significantly reduce fatigue, consistent with the results of previous studies [10, 60]. In addition, exercise significantly improved the results of the 12-min walk test, indicating that breast cancer patients can maintain and improve their physical fitness through exercise during treatment. However, the effect on BMI and weight was not significant, indicating limited effects on body composition. Although similar findings have been reported [61], our study more clearly highlighted the effectiveness of exercise

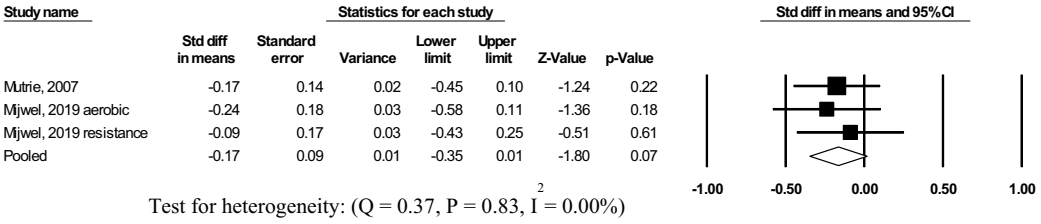
During Treatment



Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Mock, 2005	-0.57	0.19	0.03	-0.94	-0.21	-3.06	0.00
Mutrie, 2007	0.38	0.14	0.02	0.10	0.66	2.69	0.01
Steindorf, 2014	-0.29	0.16	0.03	-0.60	0.03	-1.80	0.07
Husebo, 2014	0.00	0.24	0.06	-0.48	0.48	0.01	0.99
Ligibel, 2016	0.11	0.20	0.04	-0.28	0.51	0.56	0.58
Ceseiko, 2019	-0.70	0.28	0.08	-1.25	-0.16	-2.52	0.01
Mjwel, 2019 aerobic	-0.41	0.18	0.03	-0.75	-0.06	-2.31	0.02
Mjwel, 2018 resistance	-0.45	0.18	0.03	-0.79	-0.10	-2.55	0.01
Schmidt, 2014	-0.42	0.20	0.04	-0.81	-0.02	-2.08	0.04
Pooled	-0.20	0.06	0.00	-0.32	-0.08	-3.28	0.00

Test for heterogeneity: ($Q = 32.00$, $P = 0.00$, $I^2 = 75.00\%$)

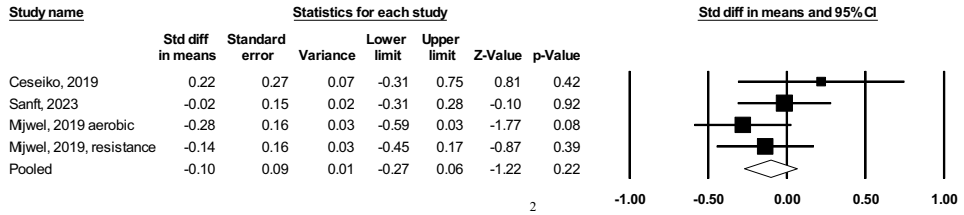
Fatigue



Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Mutrie, 2007	-0.17	0.14	0.02	-0.45	0.10	-1.24	0.22
Mjwel, 2019 aerobic	-0.24	0.18	0.03	-0.58	0.11	-1.36	0.18
Mjwel, 2019 resistance	-0.09	0.17	0.03	-0.43	0.25	-0.51	0.61
Pooled	-0.17	0.09	0.01	-0.35	0.01	-1.80	0.07

Test for heterogeneity: ($Q = 0.37$, $P = 0.83$, $I^2 = 0.00\%$)

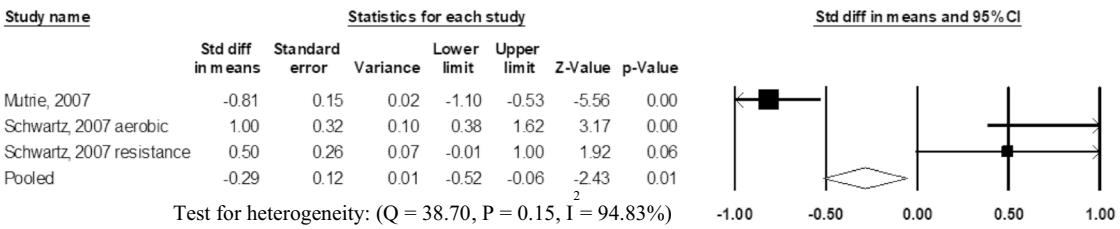
Body Mass Index



Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Ceseiko, 2019	0.22	0.27	0.07	-0.31	0.75	0.81	0.42
Sanft, 2023	-0.02	0.15	0.02	-0.31	0.28	-0.10	0.92
Mjwel, 2019 aerobic	-0.28	0.16	0.03	-0.59	0.03	-1.77	0.08
Mjwel, 2019, resistance	-0.14	0.16	0.03	-0.45	0.17	-0.87	0.39
Pooled	-0.10	0.09	0.01	-0.27	0.06	-1.22	0.22

Test for heterogeneity: ($Q = 3.04$, $P = 0.39$, $I^2 = 1.20\%$)

Weight



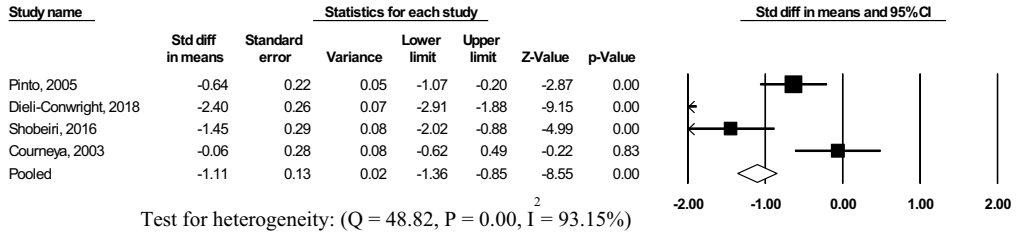
Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Mutrie, 2007	-0.81	0.15	0.02	-1.10	-0.53	-5.56	0.00
Schwartz, 2007 aerobic	1.00	0.32	0.10	0.38	1.62	3.17	0.00
Schwartz, 2007 resistance	0.50	0.26	0.07	-0.01	1.00	1.92	0.06
Pooled	-0.29	0.12	0.01	-0.52	-0.06	-2.43	0.01

Test for heterogeneity: ($Q = 38.70$, $P = 0.15$, $I^2 = 94.83\%$)

12-minute walk

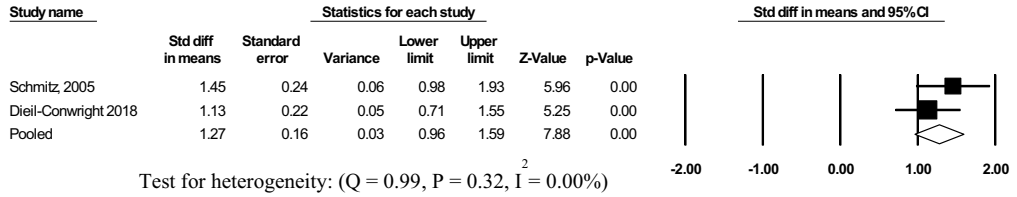
Fig. 2 Effect size of exercise interventions during and after treatment

After Treatment



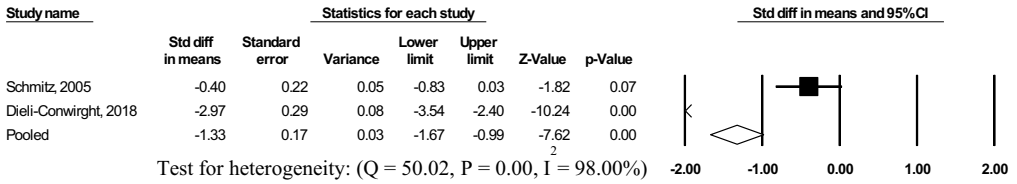
Test for heterogeneity: ($Q = 48.82$, $P = 0.00$, $I^2 = 93.15\%$)

Fatigue



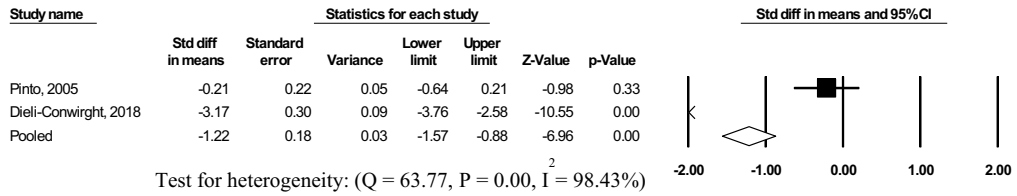
Test for heterogeneity: ($Q = 0.99$, $P = 0.32$, $I^2 = 0.00\%$)

Lean mass



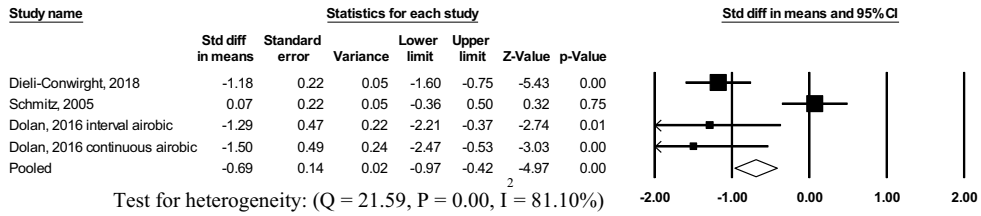
Test for heterogeneity: ($Q = 50.02$, $P = 0.00$, $I^2 = 98.00\%$)

Fat mass (kg)



Test for heterogeneity: ($Q = 63.77$, $P = 0.00$, $I^2 = 98.43\%$)

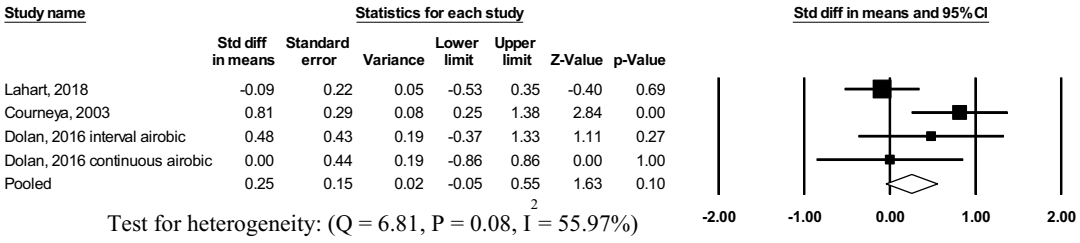
% Body fat



Test for heterogeneity: ($Q = 21.59$, $P = 0.00$, $I^2 = 81.10\%$)

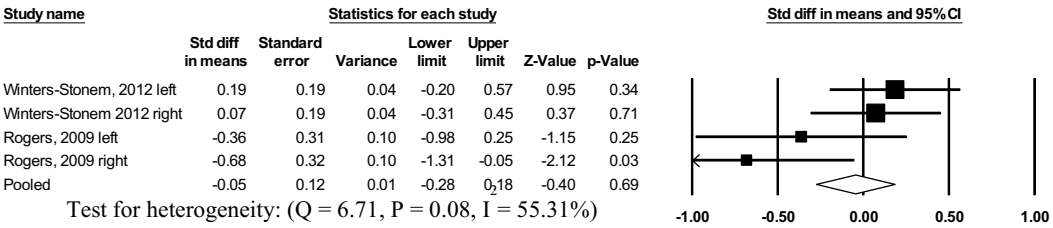
Waist Circumference

Fig. 2 (continued)



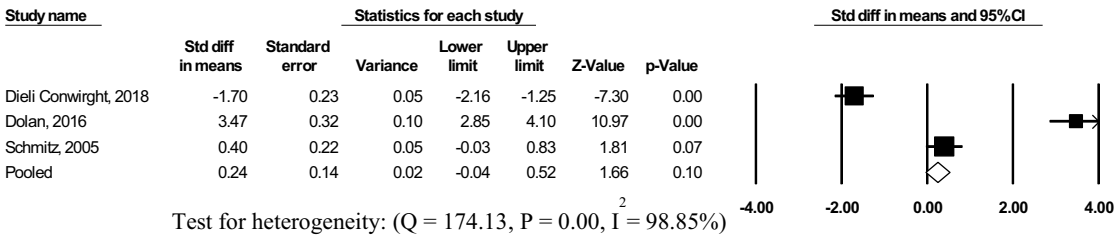
Test for heterogeneity: ($Q = 6.81$, $P = 0.08$, $I^2 = 55.97\%$)

VO_2



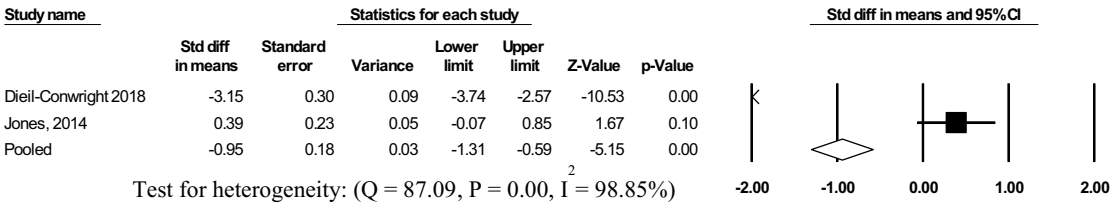
Test for heterogeneity: ($Q = 6.71$, $P = 0.08$, $I^2 = 55.31\%$)

Handgrip Strength



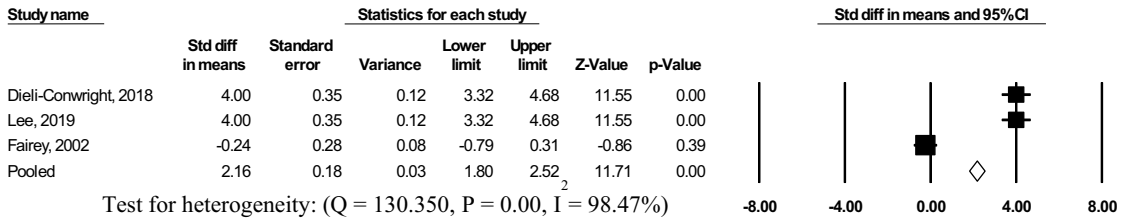
Test for heterogeneity: ($Q = 174.13$, $P = 0.00$, $I^2 = 98.85\%$)

Insulin



Test for heterogeneity: ($Q = 87.09$, $P = 0.00$, $I^2 = 98.85\%$)

IL-6



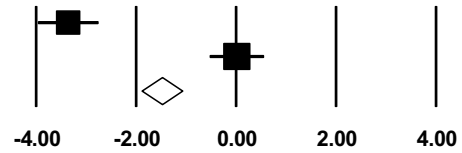
Test for heterogeneity: ($Q = 130.350$, $P = 0.00$, $I^2 = 98.47\%$)

HDL-C

Fig. 2 (continued)

Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Lee, 2019	-3.36	0.31	0.10	-3.97	-2.75	-10.82	0.00
Fairey, 2002	0.01	0.28	0.08	-0.53	0.56	0.05	0.96
Pooled	-1.49	0.21	0.04	-1.89	-1.08	-7.18	0.00

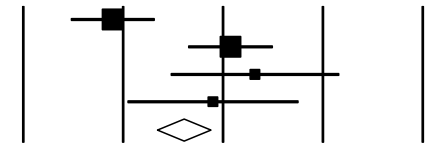
Test for heterogeneity: ($Q = 62.48$, $P = 0.00$, $I^2 = 98.47\%$)



LDL-C

Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Dieli-Conwirght, 2018	-1.10	0.21	0.05	-1.52	-0.68	-5.14	0.00
Schmitz, 2005	0.08	0.22	0.05	-0.35	0.50	0.35	0.73
Dolan, 2016 interval airobic	0.32	0.43	0.19	-0.52	1.16	0.74	0.46
Dolan, 2016 continuous airobic	-0.10	0.44	0.19	-0.96	0.76	-0.23	0.82
Pooled	-0.39	0.14	0.02	-0.66	-0.13	-2.89	0.00

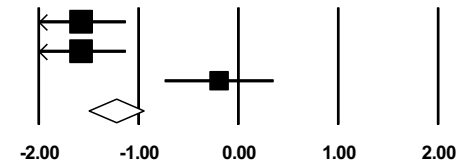
Test for heterogeneity: ($Q = 18.80$, $P = 0.00$, $I^2 = 84.04\%$)



Glucose

Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Dieli-Conwirght, 2018	-1.57	0.23	0.05	-2.02	-1.13	-6.88	0.00
Lee, 2019	-1.57	0.23	0.05	-2.02	-1.13	-6.88	0.00
Fairey, 2002	-0.19	0.28	0.08	-0.74	0.35	-0.69	0.49
Pooled	-1.23	0.14	0.02	-1.50	-0.95	-8.76	0.00

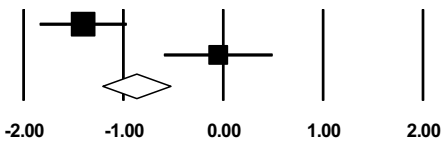
Test for heterogeneity: ($Q = 18.37$, $P = 0.00$, $I^2 = 89.11\%$)



Systolic Blood Pressure

Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Dieli-Conwirght, 2018	-1.40	0.22	0.05	-1.84	-0.97	-6.28	0.00
Fairey, 2002	-0.05	0.28	0.08	-0.60	0.50	-0.18	0.86
Pooled	-0.87	0.17	0.03	-1.21	-0.53	-5.01	0.00

Test for heterogeneity: ($Q = 14.37$, $P = 0.00$, $I^2 = 93.04\%$)



Diastolic Blood Pressure

Fig. 2 (continued)

in reducing fatigue during treatment. Recent research indicates that exercise may reduce inflammation and enhance immune function, contributing to fatigue reduction [62, 63]. Although adverse effects were not reported in our study, recent research indicates that exercise is generally safe and does not cause severe side effects in breast cancer patients [64]. Similar findings emphasize the positive effect of exercise on fatigue and quality of life during breast cancer treatment [65]. Therefore, exercising can be effective in reducing fatigue and enhancing physical fitness in breast cancer patients undergoing or having undergone treatment.

Another significant finding here is the positive effects of exercise on fatigue, body composition, and biomarkers in breast cancer patients after treatment. Similar findings in a previous study also showed exercise interventions significantly reduce fatigue, consistent with previous research [66]. Significant improvements in lean mass, fat mass, % body fat, and waist circumference, as well as in biomarkers such as IL-6, HDL, LDL, glucose, SBP, and DBP, were observed. These results indicate that moderate-to-high-intensity aerobic and resistance exercises are effective in improving body composition, cardiovascular health, and biomarkers in breast cancer patients after treatment. The central message of our findings emphasizes that exercise interventions not only reduce fatigue but also play a significant role in optimizing body composition, particularly by decreasing fat mass and increasing lean muscle mass. This highlights the holistic benefits of exercise beyond mere weight loss. Similar findings were reported in previous research [67], and our updated meta-analysis further supports the effectiveness of exercise interventions. As shown in recent studies, exercise may exert anti-inflammatory effects and enhance insulin sensitivity to positively influence body composition and metabolic health [68, 69]. The meta-analysis revealed significant reductions in fatigue and improvements in biomarkers such as IL-6 and HDL, aligning with previous findings that suggest exercise interventions can effectively manage treatment-related side effects [70]. Similar findings in other studies emphasize the positive effect of exercise on fatigue, body composition, and cardiovascular health in breast cancer survivors after treatment [71]. The improvements in biomarkers such as IL-6 and HDL are clinically relevant as they indicate a reduction in systemic inflammation and improved cardiovascular health, respectively, which are critical for long-term survivorship and reduced cancer recurrence.

This systematic review and meta-analysis provide valuable insights into the effects of exercise interventions for breast cancer patients, comparing the undergoing treatment and after treatment phases. During the undergoing treatment phase, exercise significantly reduced fatigue (effect size $d = -0.20$) and improved physical fitness, as demonstrated by the 12-min walk test ($d = -0.29$). However, changes in body composition, such as BMI and weight, were not statistically significant. In contrast, after treatment exercise interventions showed remarkable improvements across several parameters. There was a substantial reduction in fatigue ($d = -1.11$), along with significant enhancements in body composition, including increases in lean mass ($d = 1.27$) and reductions in fat mass ($d = -1.33$), % body fat ($d = -1.22$), and waist circumference ($d = -0.69$). Additionally, exercise after treatment improved various biomarkers such as IL-6, HDL, and LDL, indicating better metabolic health. Despite these improvements, there were no significant changes in cardiorespiratory fitness and handgrip strength during the after treatment phase. These findings underscore the differential impact of exercise relative to the timing of cancer treatment. While both phases offer benefits, the after treatment phase appears to yield more pronounced improvements in body composition and biomarkers, suggesting that the physiological recovery stage may be more receptive to exercise-induced changes. Therefore, tailored exercise programs should consider these temporal differences to optimize therapeutic outcomes for breast cancer patients. Future research should further explore the mechanisms behind these differential effects and refine exercise recommendations accordingly.

Effective exercise programs for breast cancer patients should be tailored to the treatment phase. For patients undergoing treatment, suitable programs include low-to-moderate-intensity aerobic and resistance exercises, performed 1–2 times per week, with each session comprising 20–40 min of aerobic exercise and 15–20 min of resistance exercises. Aerobic activities may include walking, stationary cycling, and swimming, and resistance exercises may involve light dumbbells or resistance bands [72]. Exercise intensity should be gradually increased based on the patient's fitness and condition. For patients who have completed treatment, suitable programs include moderate-to-high-intensity aerobic and resistance exercises, performed 2–3 times per week, with each session comprising 30–60 min of aerobic exercise and 20–30 min of resistance exercises. Aerobic activities may include jogging, cycling, and high-intensity interval training (HIIT), and resistance exercises may involve weight training or high-intensity resistance bands [73]. Exercise intensity should be gradually increased, focusing on body composition and cardiovascular health.

Previous studies consistently emphasize the efficacy of exercise interventions for breast cancer patients [74–76]. They highlight that circuit training and hybrid training are the most effective for improving cardiometabolic health, reporting that a combination of aerobic and muscle-strengthening exercises positively impacts body composition and health indicators [74]. Furthermore, the combination of high-intensity interval training (HIIT) and resistance training has been concluded to result in significant improvements in muscle strength and body fat

reduction, as well as enhancements in biomarkers related to inflammation and metabolic health [75]. Additionally, a network meta-analysis has confirmed that circuit training is the most efficient exercise type for improving body composition and cardiometabolic health [76]. These findings suggest that exercise interventions play a crucial role in managing fatigue, improving body composition, and enhancing overall physical health in breast cancer patients. Therefore, there is an emphasized need for personalized exercise programs tailored to the treatment and recovery phases of breast cancer patients to optimize both short-term and long-term health outcomes.

The physiological mechanisms through which exercise interventions positively affect fatigue, body composition, and biomarkers in breast cancer patients are diverse. Aerobic exercise improves cardiovascular health and reduces inflammation [77], and resistance exercise enhances muscle strength and maintenance [78]. Exercise also regulates the secretion of cortisol, a stress hormone [79], and enhances immune function, potentially reducing cancer recurrence risk [69]. These physiological mechanisms explain how exercise contributes to overall health improvement in breast cancer patients during and after treatment.

There are several limitations to our systematic review and meta-analysis study. First, despite the promising findings, the systematic review and meta-analysis is constrained by a limited number of studies and variability in intervention protocols, which may impact the generalizability of the result. Future research should include a larger number of studies for more comprehensive meta-analyses. Second, the variability in exercise intervention types, intensities, and durations across studies hindered comparative analyses. Standardized protocols for exercise interventions should be used in future studies to enhance comparability. Third, some heterogeneity existed that may be associated with inconsistent measurement methods. Fourth, a limitation of this systematic review and meta-analysis is the inclusion of only English-language publications, which may exclude relevant studies published in other languages. Finally, this study concentrated on the "under treatment" and "post-treatment" phases, but further studies need to conduct additional analysis on potential moderator variables, such as the duration or type of intervention.

This systematic review and meta-analysis study systematically analyzed the effects of exercise interventions on different stages of breast cancer and the effects on fatigue, body composition, physical fitness, and biomarkers. The findings emphasize the need for personalized exercise programs tailored to the condition of breast cancer patients, supplementing ACSM guidelines with scientific evidence. Future research should investigate the effects of different exercise intensities and modalities on diverse biomarkers and long-term outcomes, as this area remains underexplored.

Implications for practice

This systematic review and meta-analysis presents several critical implications for the practice of implementing exercise interventions among breast cancer patients. Firstly, for effective integration into clinical practice, exercise programs should be personalized according to treatment stages, enhancing both safety and efficacy. Such customization will address the distinct physiological and psychological needs of patients during and after their treatment. Secondly, given the significant reduction in fatigue and improvement in physical fitness and body composition, exercise should be integrated as a standard component of care for breast cancer patients. Healthcare providers should advocate for and facilitate regular physical activity as part of the recovery process. Thirdly, the findings confirm that exercise interventions are generally safe and do not induce significant adverse effects. Practitioners can confidently recommend exercise to breast cancer patients, ensuring that the exercise regimens are appropriately monitored and adjusted as needed. Furthermore, the variability observed in exercise types, intensities, and durations calls for the development of standardized exercise protocols. Standardized guidelines will improve the consistency and comparability of exercise interventions across different clinical settings and studies. Finally, beyond reducing fatigue, exercise interventions have shown improvements in cardiovascular health markers and body composition. These holistic benefits highlight the importance of physical activity not only for immediate recovery but also for long-term health and reduced risk of cancer recurrence.

Conclusions

This systematic review and meta-analysis provides compelling evidence for the beneficial effects of exercise interventions in breast cancer patients. The key findings are that exercise significantly mitigates fatigue during and after breast cancer treatment, enhancing patients' quality of life. Regular exercise leads to improvements in physical fitness, body composition, and cardiovascular health markers, contributing to overall well-being. Exercise interventions are safe for breast cancer patients and can be feasibly incorporated into their treatment and recovery plans. Tailoring exercise programs to the treatment stages and individual needs of patients is essential for maximizing the therapeutic benefits of physical activity. Additionally, there is a need for large-scale, randomized controlled trials involving diverse patient populations to further validate

the specific effects and optimal protocols for exercise interventions in breast cancer care. These conclusions support the integration of exercise into the comprehensive care plan for breast cancer patients, emphasizing its role in improving both short-term and long-term health outcomes.

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Author contribution JL contributed to the study conception and design. Material preparation, data collection and analysis were performed by JL and YSH. The first draft of the manuscript was written by JL and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate Not applicable.

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