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The Impact of Exercise on Cancer Mortality, Recurrence, and Treatment-Related Adverse Effects

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The combination of an increasing number of new cancer cases and improving survival rates has led to a large and rapidly growing population with unique health-care requirements. Exercise has been proposed as a strategy to help address the issues faced by cancer patients. Supported by a growing body of research, major health organizations commonly identify the importance of incorporating exercise in cancer care and advise patients to be physically active. This systematic review comprehensively summarizes the available epidemiologic and randomized controlled trial evidence investigating the role of exercise in the management of cancer. Literature searches focused on determining the potential impact of exercise on 1) cancer mortality and recurrence and 2) adverse effects of cancer and its treatment. A total of 100 studies were reviewed involving thousands of individual patients whose exercise behavior was assessed following the diagnosis of any type of cancer. Compared with patients who performed no/less exercise, patients who exercised following a diagnosis of cancer were observed to have a lower relative risk of cancer mortality and recurrence and experienced fewer/less severe adverse effects. The findings of this review support the view that exercise is an important adjunct therapy in the management of cancer. Implications on cancer care policy and practice are discussed.

exercise; oncology; physical activity; policy; supportive care; survivorship

Abbreviation: RCT, randomized controlled trial.

INTRODUCTION

Improvements in screening, diagnosis, and treatments of cancer have resulted in an exponential increase in the number of cancer survivors alive in the United States and other industrialized nations. Within the United States, it is estimated that there are 15 million cancer survivors (1). Within Australia, the estimate is 340,000 (2). In both countries, the estimate is that there will be a substantive increase in this number over the coming years. For example, in the United States, it is anticipated that there are currently 14.5 million cancer survivors (1). To put this in context, it is estimated that there are currently 21 million Americans diagnosed with diabetes (3).

Within the growing population of cancer survivors, there are 2 major categories of health concerns. The first is the concern regarding cancer recurrence and mortality. The second category includes the persistent adverse effects of cancer treatment. Multiple observational and interventional trials have been undertaken to evaluate the potential efficacy of exercise training to improve outcomes relevant to cancer recurrence and mortality, as well as persistent adverse effects of treatment. Below, we review the effects of exercise on the 2 most important categories of outcomes among cancer survivors. In section 1, we review the evidence that exercise has a meaningful impact on cancer recurrence and mortality. In section 2, we review the evidence that exercise has a meaningful impact on cancer morbidity resulting from the adverse effects of cancer treatment. During the final section, we comment on policy and practice issues to address the needs for exercise programming for cancer survivors in both the United States and Australia. The goal of the review is to place in context the breadth and depth of the efforts to address these needs among survivors, with a conclusion that suggests possible next steps toward the shared goal of improving outcomes in this growing chronic disease population.

METHODS

Search strategy

This study was conducted in accordance with the Preferred Reporting Items of Systematic Reviews and Meta-analyses (PRISMA) statement (4). Two separate literature searches were conducted to evaluate the impact of exercise following a cancer diagnosis on 1) cancer mortality and recurrence (review 1) and 2) the adverse effects of cancer and its treatment (review 2). Searches were carried out in August 2016 by using PubMed, MEDLINE, and Cochrane Central Register of Controlled Trials databases, as well as reviewing reference lists for additional potentially relevant articles. Web Table 1 (available at http://aje.oxfordjournals.org/) details the full listing of search terms used for the 2 literature searches.

Inclusion and exclusion criteria

Participants included adults diagnosed with any form of cancer, and articles published in the English language from all available years through to August 2016 were considered for inclusion for review 1. Review 1 included epidemiologic studies, interventional trials, and systematic reviews/meta-analyses that evaluated associations between exercise behavior and cancer mortality and/or cancer recurrence. Studies that reported all-cause mortality but did not independently report cancer-specific mortality were excluded, as were studies that did not report exercise behavior independent of other exposures/lifestyle behaviors. Additionally, studies were excluded if they did not report exercise levels postcancer diagnosis. Publications with any length of follow-up were considered for eligibility. Review 2 included randomized controlled trials (RCTs) and systematic reviews/meta-analyses that evaluated associations between exercise behavior and persistent adverse effects of cancer and its treatment. Interventions of all lengths were included. Given our prior meta-analyses on this topic (5, 6), we excluded RCTs and meta-analyses published before 2011 or that had fewer than 50 participants per group. We also chose a specific grouping of adverse effects on which to focus, and if the effects of exercise on the adverse effect were included in a meta-analysis, the RCTs on that outcome were not reviewed.

Outcomes

The primary outcomes for review 1 included risk of cancer-specific mortality and risk of cancer recurrence expressed as a hazard ratio or relative risk with 95% confidence interval. The secondary outcome was all-cause mortality expressed as a hazard ratio or relative risk with 95% confidence interval. These data were reported for comparisons between a reference group who performed no/less exercise versus a comparator group who performed a greater volume, frequency, and/or intensity of exercise. The primary outcomes for review 2 were distinct for the randomized control trials and the meta-analyses. For the RCTs, outcomes included bone health, cognitive function, sexuality, treatment-related symptoms, urinary incontinence, anemia, nausea/vomiting, and dyspnea. For the meta-analyses, outcomes included psychosocial health parameters (e.g., anxiety, depression, psychosocial distress, emotional well-being, mental health, and stress); body image; fatigue; lymphedema; physical function; physical health; quality of life; shoulder disability; and sleep. These data were reported for comparisons between cancer survivors randomized to an exercise intervention and cancer survivors who did not perform an exercise intervention.

Data extraction

Titles and abstracts of the initial search return were assessed for eligibility by E.M.Z. (review 1) and X.Z. (review 2). Duplicates were removed, and articles that were outside the scope of the reviews were excluded (Figures 1 and 2). Full-text articles were assessed for eligibility by E.M.Z. and P.C. for review 1 and by X.Z. and K.H.S. for review 2. Any discrepancies regarding inclusion and exclusion criteria were resolved by consensus. Characteristics of eligible studies were extracted, and data were reported in line with the purpose of each review.

Study quality assessment

The quality and risk of bias of each study were assessed by using 1 of 2 tools in line with the study design: the Cochrane Collaboration's tool for assessing risk of bias in randomized trials (7) and the Newcastle-Ottawa quality assessment scale for cohort studies (8). The Cochrane Collaboration's tool evaluates the bias of interventional trials on the basis of 6 domains—selection, performance, detection, attrition, reporting, and other—and is scored on the basis of high, low, or unclear risk-of-bias categories (7). The Newcastle-Ottawa scale assesses the quality of epidemiologic/observational studies by using 3 domains—selection, comparability, and outcome—and is scored on a scale from 0 to 9 points, with higher scores representing better quality studies (8). Study quality assessments were conducted by E.M.Z. (review 1) and X.Z. (review 2) and reported in Web Table 2.

Data analysis

Meta-analyses were not performed, and a narrative synthesis was conducted instead because of the heterogeneity in participant characteristics, exercise measures and interventions, and the broad variety of outcomes for review 2, as well as the analytical strategies applied to the trials within these reviews. However, a systematic search of previously published meta-analyses was conducted, and the results of these meta-analyses have been included within the narrative synthesis. Results of the narrative synthesis are summarized in Tables 1–5 and Web Table 3, with studies presented according to cancer type and sample size in descending order.

RESULTS

Study selection

The literature search for review 1 (cancer mortality and recurrence) identified 5,258 articles with an additional 4 articles identified from reference lists (Figure 1). After

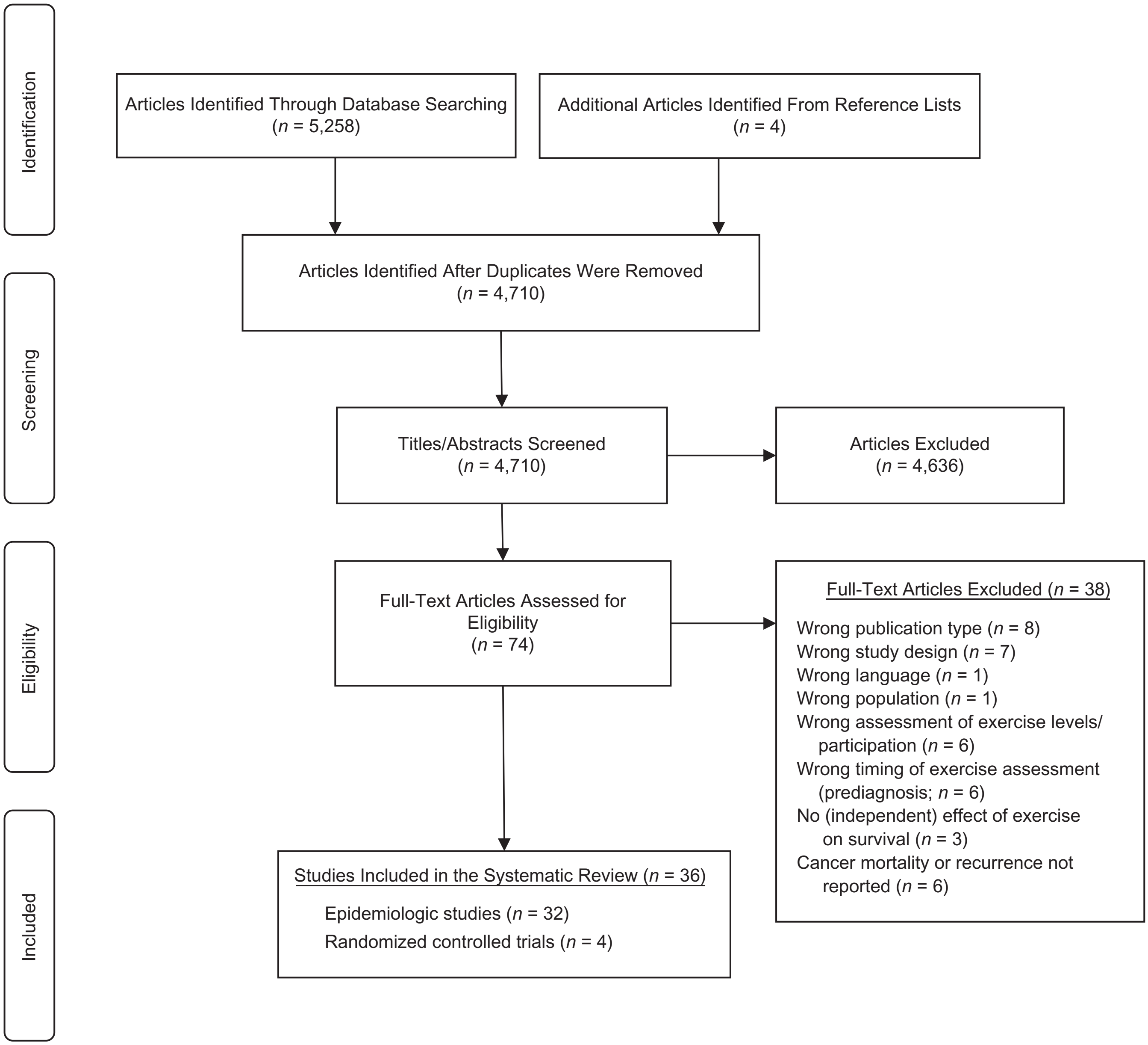

Figure 1. Preferred Reporting Items of Systematic Reviews and Meta-analyses (PRISMA) flow diagram for systematic review addressing the impact of exercise on cancer mortality and recurrence.

duplicates were removed and titles and abstracts were screened, 74 full-text articles were assessed for eligibility. Thirty-eight articles were excluded for not meeting the eligibility criteria, leaving 36 articles included within review 1. The literature search for review 2 (adverse effects of cancer and its treatment) identified 3,066 articles (Figure 2). After duplicates were removed and titles and abstracts were screened, 667 full-text articles were assessed for eligibility; 603 articles were excluded for not meeting the eligibility criteria, leaving 40 meta-analyses and 24 articles representing 23 RCTs included within review 2. Therefore, this systematic review included a total of 100 studies.

Study characteristics and quality

Review 1 included 32 prospective cohort studies with follow-up spanning from ~2 to 20 years (9–40) and 4 RCTs with experimental follow-up between ~1 and 7 years (41–44). There were a total of 68,285 participants involved in these studies comprising mainly patients with breast cancer (66%), colorectal cancer (15%), and prostate cancer (14%). Risk of cancer-specific mortality was reported by 85% of the studies, with 36% of the studies reporting risk of cancer recurrence and 89% of the studies reporting all-cause mortality risk. Among the epidemiologic studies, exercise levels were

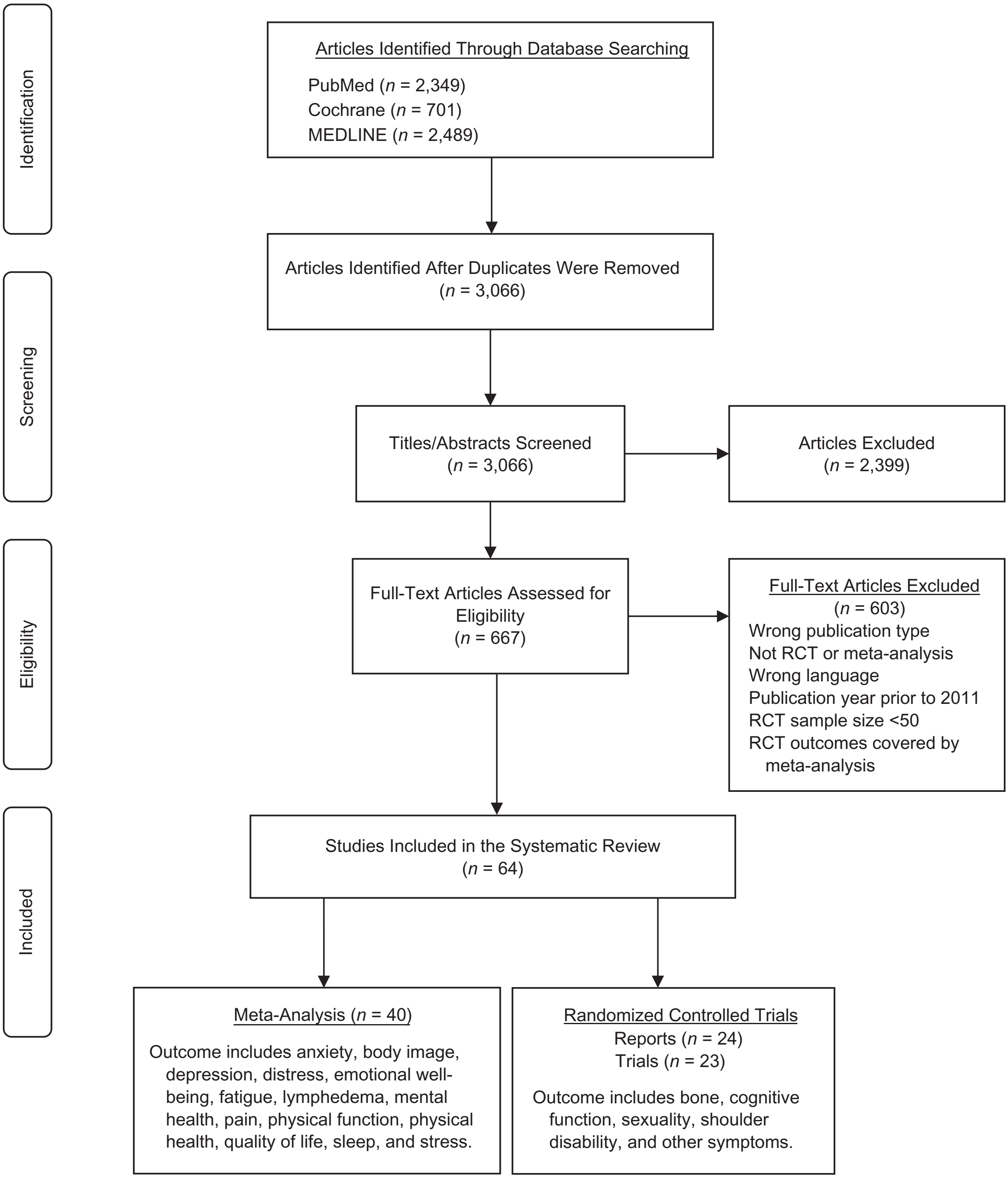

Figure 2. Preferred Reporting Items of Systematic Reviews and Meta-analyses (PRISMA) flow diagram for systematic review addressing the impact of exercise on cancer treatment-related adverse effects. RCT, randomized controlled trial.

assessed by using a variety of self-report and interview-administered questionnaires that evaluated a range of domains of exercise behaviors. The majority of these studies reported the dosage of exercise based on the number of metabolic equivalent hours per week, but a range of other analysis methods to quantify exercise levels was also utilized. Within the intervention trials, exercise behavior was compared between groups of patients who were randomized into a supervised exercise intervention versus a control condition not involving any structured exercise program (Table 1).

Review 2 included 23 RCTs with interventions that lasted between 4 weeks and 12 months (45–68). There were a total

Table 1. Summary of Systematic Reviews Evaluating the Association Between Exercise Behavior and Cancer Mortality and Recurrence

First Author, Year (Reference No.)	Sample Size	Exercise Level	Time Since Diagnosis[a]	Cancer-Specific Mortality			Cancer Recurrence			All-Cause Mortality		
				Effect Estimate, HR	95% CI	*P* Value	Effect Estimate, HR	95% CI	*P* Value	Effect Estimate, HR	95% CI	*P* Value
Breast Cancer												
Beasley, 2012 (12)	13,302	<10 vs. ≥10 MET-hours/week	Range, 18–48 months	0.75	0.65, 0.85	<0.001	0.96	0.86, 1.06	0.600	0.73	0.66, 0.82	<0.001
Nechuta, 2016 (36)[b]	6,295	<4.9 vs. 4.9–17.4 MET-hours/week	Mean = 2 years				0.93	0.76, 1.13	0.270	0.81	0.71, 0.93	<0.001
		<4.9 vs. ≥17.4 MET-hours/week					0.89	0.73, 1.09		0.71	0.61, 0.82	
Chen, 2011 (19)	4,826	0 vs. <8.3 MET-hours/week	6, 18, and 36 months	0.60	0.46, 0.78	0.006				0.81	0.63, 1.05	<0.001
		0 vs. >8.3 MET-hours/week		0.59	0.45, 0.76					0.65	0.51, 0.84	
Holick, 2008 (23)	4,482	<2.8 vs. 2.8–7.9 MET-hours/week	Median, 2 years	0.65	0.39, 1.08	0.050				0.58	0.45, 0.76	<0.001
		<2.8 vs. 8.0–20.9 MET-hours/week		0.59	0.35, 1.01					0.53	0.40, 0.69	
		<2.8 vs. ≥21.0 MET-hours/week		0.51	0.29, 0.89					0.44	0.32, 0.60	
Holmes, 2005 (24)	2,987	<3 vs. 3–8.9 MET-hours/week	Median, 38 months	0.80[c]	0.60, 1.06	0.004	0.83[c]	0.64, 1.08	0.050	0.71[c]	0.56, 0.89	0.003
		<3 vs. 9–14.9 MET-hours/week		0.50[c]	0.31, 0.82		0.57[c]	0.38, 0.85		0.59[c]	0.41, 0.84	
		<3 vs. 15–23.9 MET-hours/week		0.56[c]	0.38, 0.84		0.66[c]	0.47, 0.93		0.56[c]	0.41, 0.77	
		<3 vs. ≥24 MET-hours/week		0.60[c]	0.40, 0.89		0.74[c]	0.53, 1.04		0.65[c]	0.48, 0.88	
Irwin, 2011 (26)	2,910	0 vs. ≤3 MET-hours/week	Median, 1.8 years	0.77	0.43, 1.38	0.049				0.72	0.48, 1.07	<0.001
		0 vs. 3.1–8.9 MET-hours/week		0.30	0.09, 0.99					0.42	0.21, 0.82	
		0 vs. ≥9 MET-hours/week		0.61	0.35, 0.99					0.54	0.38, 0.79	
Bertram, 2011 (13)	2,361	<10 vs. ≥10 MET-hours/week	Range, 0–4 years				0.89	0.70, 1.14	0.360	0.65	0.47, 0.91	0.010
Sternfeld, 2009 (38)	1,970	<1 hour vs. 1–3 hours moderate PA/week	Mean = 1.9 years	0.51	0.29, 0.89	0.070	0.76	0.53, 1.09	0.050	0.71	0.48, 1.06	0.040
		<1 hour vs. 3–6 hours moderate PA/week		0.69	0.42, 1.13		0.80	0.56, 1.13		0.66	0.44, 1.00	
		<1 hour vs. ≥6 hours moderate PA/week		0.56	0.32, 0.98		0.66	0.44, 0.97		0.66	0.42, 1.03	
Bradshaw, 2014 (17)	1,423	0 vs. 0.1–0.9 MET-hours/week	Range, 1–6 years	0.24	0.07, 0.65	NR				0.43	0.20, 0.84	NR
		0 vs. >9.0 MET-hours/week		0.27	0.15, 0.46					0.33	0.22, 0.48	
Borch, 2015 (15)	1,327	PA level 5–6 vs. PA level 7–8	Mean = 3.1 years	0.75	0.47, 1.17	NR				0.74	0.50, 1.09	<0.001
		PA level 5–6 vs. PA level 9–10		0.50	0.15, 1.62					0.46	0.17, 1.28	
Williams, 2014 (39)	986	Walking <1.07 vs. 1.07–1.79 MET-hours/day	Mean = 7.9 years	1.20	0.48, 3.01	0.690						
		Walking <1.07 vs. 1.8–3.59 MET-hours/day		0.94	0.38, 2.35	0.900						
		Walking <1.07 vs. ≥3.6 MET-hours/day		1.17	0.32, 3.61	0.790						

Table continues

Table 1. Continued

First Author, Year (Reference No.)	Sample Size	Exercise Level	Time Since Diagnosis[a]	Cancer-Specific Mortality			Cancer Recurrence			All-Cause Mortality		
				Effect Estimate, HR	95% CI	P Value	Effect Estimate, HR	95% CI	P Value	Effect Estimate, HR	95% CI	P Value
		Running <1.07 vs. 1.07–1.79 MET-hours/day		0.56	0.10, 2.46	0.450						
Irwin, 2008 (27)	688	0 vs. >0–8.9 MET-hours/week	Median, 2.5 years	0.72	0.28, 1.85	0.460				0.36	0.17, 0.73	0.046
		0 vs. ≥9 MET-hours/week		0.65	0.23, 1.87					0.33	0.15, 0.73	
Borugian, 2004 (16)	603	None vs. exercise ~once a week	2 months postsurgery	1.3[c]	0.7, 2.3	NR						
		None vs. exercise >once a week		1.0[c]	0.6, 1.6							
Bao, 2015 (11)[b]	518	0 vs. <7.6 MET-hours/week	6, 18, 36, and 60 months	0.64	0.39, 1.07	0.010				0.79	0.50, 1.27	0.020
		0 vs. ≥7.6 MET-hours/week		0.54	0.35, 0.84					0.61	0.41, 0.91	
De Glas, 2014 (21)	435	≤21.0 vs. 21.1–40.0 MET-hours/week	1 and 2 years	0.44	0.15, 1.35	0.950	0.54	0.23, 1.29	0.790	0.43	0.19, 0.94	0.340
		≤21.0 vs. 40.1–65.5 MET-hours/week		1.00	0.13, 1.32		0.97	0.44, 2.13		0.60	0.29, 1.24	
		≤21.0 vs. 65.6–258 MET-hours/week		0.77	0.28, 2.12		0.90	0.39, 2.10		0.57	0.26, 1.40	
Prostate Cancer												
Bonn, 2015 (14)	4,623	<5 vs. ≥5 total MET-hours/day	Range, 5–10 years	0.78	0.55, 1.11	NR				0.63	0.52, 0.77	NR
		<20 vs. ≥20 minutes/day walking/bicycling		0.61	0.43, 0.87					0.70	0.57, 0.86	
		<1 vs. ≥1 hours/week exercise		0.68	0.48, 0.94					0.74	0.61, 0.90	
Kenfield, 2011 (28)	2,705	<3 vs. 3 to <9 MET-hours/week	Median, 18 months	0.91	0.48, 1.73	0.040				0.80	0.61, 1.06	<0.001
		<3 vs. 9 to <24 MET-hours/week		0.60	0.32, 1.11					0.69	0.53, 0.90	
		<3 vs. 24 to <48 MET-hours/week		0.83	0.44, 1.55					0.65	0.49, 0.86	
		<3 vs. ≥48 MET-hours/week		0.42	0.20, 0.88					0.38	0.27, 0.53	
Richman, 2011 (37)	1,455	<3 vs. ≥3 hours/week of slow walking	Median, 27 months				1.05	0.65, 1.70	0.050			
		<3 hours/week of slow walking vs. <3 hours/week of fast walking					0.62	0.36, 1.05				
		<3 hours/week of slow walking vs. ≥3 hours/week of fast walking					0.43	0.21, 0.91				
Friedenreich, 2016 (20)	830	≤42 vs. >42 to ≤73 MET-hours/week/year	Mean = 2.5, 4.7, and 6.8 years	0.66	0.42, 1.05	0.400	0.80[d]	0.56, 1.15	0.800	0.72	0.56, 0.93	<0.001
		≤42 vs. >73 to ≤119 MET-hours/week/year		1.02	0.64, 1.61		0.84[d]	0.59, 1.21		0.74	0.57, 0.97	
		≤42 vs. >119 MET-hours/week/year		0.65	0.37, 1.13		0.94[d]	0.65, 1.34		0.58	0.42, 0.79	
Colorectal Cancer												
Baade, 2011 (10)	1,825	0 vs. <150 minutes/week	5 and 12 months	0.90	0.69, 1.17	0.585				0.72	0.57, 0.91	0.007
		0 vs. >150 minutes/week		0.88	0.68, 1.15					0.75	0.60, 0.94	

Table continues

Table 1. Continued

First Author, Year (Reference No.)	Sample Size	Exercise Level	Time Since Diagnosis[a]	Cancer-Specific Mortality			Cancer Recurrence			All-Cause Mortality		
				Effect Estimate, HR	95% CI	*P* Value	Effect Estimate, HR	95% CI	*P* Value	Effect Estimate, HR	95% CI	*P* Value
Campbell, 2013 (18)	1,800	<3.5 vs. 3.5–8.75 MET-hours/week	Mean = 1.7 years	1.0[d]	0.64, 1.56	NR				0.78[d]	0.60, 1.00	NR
		<3.5 vs. ≥8.75 MET-hours/week		0.87[d]	0.61, 1.24					0.58[d]	0.47, 0.71	
Arem, 2015 (9)	1,759	0 vs. <1 hour/week	Median, 4.2 years	0.98	0.53, 1.81	0.041				1.00	0.72, 1.39	0.006
		0 vs. 1 to <4 hours/week		0.96	0.57, 1.62					0.88	0.65, 1.19	
		0 vs. 4 to <7 hours/week		0.69	0.36, 1.29					0.66	0.46, 0.94	
		0 vs. ≥7 hours/week		0.53	0.27, 1.03					0.69	0.49, 0.98	
Meyerhardt, 2006 (33)	832	<3 vs. 3–8.9 MET-hours/week	Median, 7 months	0.87	0.58, 1.29	0.010	0.86	0.57, 1.30	0.030	0.85	0.49, 1.49	0.010
		<3 vs. 9–17.9 MET-hours/week		0.90	0.57, 1.40		0.89	0.55, 1.42		0.71	0.36, 1.41	
		<3 vs. 18–26.9 MET-hours/week		0.51	0.26, 0.97		0.51	0.26, 1.01		0.71	0.32, 1.59	
		<3 vs. ≥27 MET-hours/week		0.55	0.33, 0.91		0.60	0.36, 1.01		0.37	0.16, 0.82	
Meyerhardt, 2009 (32)	661	<3 vs. 3–8.9 MET-hours/week	Median, 15 months	1.06	0.55, 2.08	0.002				1.00	0.68, 1.48	<0.001
		<3 vs. 9–17.9 MET-hours/week		1.30	0.65, 2.59					1.12	0.74, 1.70	
		<3 vs. 18–26.9 MET-hours/week		0.76	0.33, 1.77					0.74	0.46, 1.20	
		<3 vs. ≥27 MET-hours/week		0.47	0.24, 0.92					0.59	0.41, 0.86	
Kuiper, 2012 (29)	606	0 vs. >0–2.9 MET-hours/week	Median, 1.5 years	0.49	0.21, 1.14	0.020				0.71	0.40, 1.30	0.005
		0 vs. 3.0–8.9 MET-hours/week		0.30	0.12, 0.73					0.42	0.23, 0.77	
		0 vs. 9.0–17.9 MET-hours/week		0.53	0.22, 1.25					0.57	0.31, 1.07	
		0 vs. ≥18.0 MET-hours/week		0.29	0.11, 0.77					0.41	0.21, 0.81	
Yamauchi, 2013 (40)[b]	605	<6.4 vs. 6.4–18.4 MET-hours/week	Median, 17 months	0.42	0.24, 0.75	0.001				0.76	0.54, 1.06	0.022
		<6.4 vs. 18.6–46.5 MET-hours/week		0.54	0.32, 0.91					0.62	0.44, 0.88	
		<6.4 vs. ≥47.1 MET-hours/week		0.29	0.15, 0.56					0.61	0.43, 0.87	
Meyerhardt, 2006 (31)	554	<3 vs. 3–8.9 MET-hours/week	Median, 22 months	0.92	0.50, 1.69	0.008				0.77	0.48, 1.23	0.003
		<3 vs. 9–17.9 MET-hours/week		0.57	0.27, 1.20					0.50	0.28, 0.90	
		<3 vs. ≥18 MET-hours/week		0.39	0.18, 0.82					0.43	0.25, 0.74	
Morikawa, 2011 (35)	497	– CTNNB1 status <18 vs. ≥18 MET-hours/week	Median, 17 months	0.33	0.13, 0.81	0.050				0.68	0.42, 1.09	0.470
		+ CTNNB1 status <18 vs. ≥18 MET-hours/week		1.07	0.50, 2.30					0.86	0.55, 1.34	
Meyerhardt, 2009 (34)[b]	484	<18 vs. ≥18 MET-hours/week	Median, 17 months	0.64	0.33, 1.23	NR				0.60	0.41, 0.86	NR
Hanyuda, 2016 (22)[b]	371	–IRS1 expression <18.3 vs. ≥18.3 MET-hours/week	Median, 17 months	0.15	0.02, 1.38	0.005				0.53	0.20, 1.39	0.140
		Low IRS1 expression <18.3 vs. ≥18.3 MET-hours/week		0.45	0.19, 1.03					0.71	0.46, 1.11	

Table continues

Table 1. Continued

First Author, Year (Reference No.)	Sample Size	Exercise Level	Time Since Diagnosis[a]	Cancer-Specific Mortality			Cancer Recurrence			All-Cause Mortality		
				Effect Estimate, HR	95% CI	*P* Value	Effect Estimate, HR	95% CI	*P* Value	Effect Estimate, HR	95% CI	*P* Value
		High IRS1 expression <18.3 vs. ≥18.3 MET-hours/week		1.32	0.50, 3.53					0.77	0.45, 1.32	
Other Cancer Types												
Inoue-Choi, 2013 (25)[e]	2,017	Low vs. moderate PA levels	Median, 8.6 years	0.61	0.42, 0.91	0.040				0.62	0.48, 0.79	<0.001
		Low vs. high PA levels		0.72	0.47, 1.10					0.62	0.47, 0.83	
Lee, 2014 (30)[e]	1,021	<2,100 vs. 2,100–4,199 kJ/week PA	Median, 6 years	0.89[c]	0.62, 1.29	0.010				0.77[c]	0.60, 0.97	<0.001
		<2,100 vs. 4,200–8,399 kJ/week PA		0.77[c]	0.55, 1.06					0.74[c]	0.60, 0.91	
		<2,100 vs. 8,400–12,599 kJ/week PA		1.03[c]	0.73, 1.47					0.76[c]	0.60, 0.97	
		<2,100 vs. ≥12,600 kJ/week PA		0.62[c]	0.44, 0.87					0.52[c]	0.42, 0.65	
Experimental Follow-up of Randomized Controlled Trials												
Courneya, 2014 (41)[e]	242	No supervised exercise vs. supervised exercise (3 sessions/week during chemotherapy; moderate intensity aerobic/resistance exercise)	During first-line adjuvant chemotherapy				0.68	0.37, 1.24	0.210	0.60	0.27, 1.33	0.210
Courneya, 2015 (42)[e]	122	No supervised exercise vs. supervised exercise (3 sessions/week for 12 weeks; moderate intensity aerobic exercise)	Mean = 29.2 months				0.70	0.35, 1.39	0.310			
Wiskemann, 2015 (43)[e]	103	No supervised exercise vs. supervised exercise (2–3 sessions/week during allogenic HSCT treatment; moderate intensity aerobic/resistance exercise)	During allogeneic HSCT				0.71[c]	NR	0.293	0.67[c]	NR	0.112
Rief, 2016 (44)[e]	60	No exercise vs. resistance exercise (3–5 sessions/week for 6 months; supervised and home based; moderate intensity resistance exercise)	During radiation therapy	30 vs. 42[f]		0.303	73 vs. 90[f]		0.095	57 vs. 63[f]		0.688

Abbreviations: CI, confidence interval; CTNNB1, cadherin-associated protein β1; HR, hazard ratio; HSCT, hematopoietic stem cell transplantation; IRS1, insulin receptor substrate 1; MET, metabolic equivalent of task; NR, not reported in original publication; PA, physical activity.

[a] Time since diagnosis when exercise level was evaluated.

[b] Data that have not been included within any meta-analyses to date.

[c] Relative risk instead of hazard ratio reported.

[d] Categories of exercise level differ for recurrence analysis: ≤98 vs. >98 to ≤145 MET-hours/week/year; ≤98 vs. >145 to ≤199 MET-hours/week/year; ≤98 vs. >199 MET-hours/week/year.

[e] Inoue-Choi (25) (various cancers), Lee (30) (various cancers), Courneya (41) (breast cancer), Courneya (42) (lymphoma), Wiskemann (43) (allogenic stem cell transplant patients), and Rief (44) (various advanced cancers).

[f] Proportion (%) of patients reported rather than hazard ratio or relative risk.

Table 2. Summary of Previously Published Meta-Analyses Evaluating the Association Between Exercise Behavior and Cancer Mortality and Recurrence Data Presented for Participants With the Highest Physical Activity Level Compared With Participants With the Lowest Physical Activity (Unless Otherwise Noted)

First Author, Year (Reference No.)	No. of Studies Reviewed	Reference No. of Reviewed Studies	Sample Size	Cancer-Specific Mortality				Cancer Recurrence				All-Cause Mortality			
				Effect Estimate		95% CI	*P* Value	Effect Estimate		95% CI	*P* Value	Effect Estimate		95% CI	*P* Value
				HR	RR			HR	RR			HR	RR		
Breast Cancer															
Zhong, 2014 (118)	4	12, 23, 26, 27	23,360		0.71	0.58, 0.87	0.168						0.57	0.45, 0.72	0.006
Lahart, 2015 (113)	9	13, 17, 19, 23, 24, 26, 27, 38, 39	21,647	0.59		0.45, 0.78	<0.001	0.79		0.63, 0.98	0.03	0.52		0.43, 0.64	<0.001
Schmid, 2014 (116)	5	12, 16, 23, 26, 27	21,382		0.72	0.60, 0.85	NR						0.52	0.42, 0.64	
Ibrahim, 2011 (111)	4	23, 24, 27, 38	8,146	0.66		0.57, 0.77	<0.001	0.76[a]		0.66, 0.87	<0.001	0.59		0.53, 0.65	<0.001
Colorectal Cancer															
Wu, 2016 (117)	7	9, 10, 18, 29, 31–33	10,457		0.56	0.38, 0.83	0.096						0.58	0.49, 0.68	0.355
Des Guetz, 2013 (109)	6	10, 18, 28, 29, 32, 33	7,530	0.61		0.44, 0.86	<0.001					0.61		0.52, 0.72	<0.001
Je, 2013 (112)	6	10, 18, 29, 31–33	6,348		0.65	0.47, 0.92	0.001						0.61	0.52, 0.71	<0.001
Schmid, 2014 (116)	6	10, 18, 29, 31–33	6,278		0.61	0.40, 0.92	NR						0.58	0.48, 0.70	NR
Otto, 2015 (115)	2	10, 31	2,379	0.70[b]		0.55, 0.85	0.101					0.75[b]		0.62, 0.87	0.055
Any Cancer															
Li, 2016 (114)	16	10, 12, 17, 18, 23, 24, 26, 28, 29, 31, 32, 35, 38	69,011	0.60		0.50, 0.71	0.006								
Friedenreich, 2016 (110)	26	9, 10, 12–21, 23–30, 32, 33, 37–39, 41	38,560		0.63	0.54, 0.73	NR		0.65	0.56, 0.75	NR				

Abbreviations: CI, confidence interval; HR, hazard ratio; NR, not reported in original publication; RR, relative risk.

[a] Data are presented for participants with the highest physical activity level compared with participants with the lowest physical activity level (unless otherwise noted).

[b] Data presented for participants that increased/maintained their physical activity during cancer treatment compared with the reference of reduced physical activity.

Table 3. Summary of Previously Published Meta-analyses Evaluating the Impact of Exercise on the Adverse Effects of Cancer and Its Treatment

Cancer-Related Adverse Effect and Cancer Site	First Author, Year (Reference No.)	Sample Size, no.	No. of RCTs	Timing	No. of Studies	No. of Patients		I^2, %	Effect Estimate	95% CI	*P* Value
						Exercise	Control				
Fatigue											
Breast	Zhu, 2016 (70)	2,659	33	Mixed[a]	10	841	800	83	0.3	−1.16, 1.75	0.69
	van Vulpen, 2016 (71)	784	6	During treatment	4	N/A	N/A	N/A	−0.22	−0.38, −0.05	N/A
	Meneses-Echavez, 2015 (73)	1,156	9	Mixed	9	N/A	N/A	75	−0.51	−0.81, −0.21	0.001
	Zou, 2014 (76)	1,014	12	During treatment	6	N/A	N/A	88.6	−0.82	−1.04, −0.60	0.001
	Carayol, 2013 (77)	1,380	17	Mixed	11	N/A	N/A	72	−0.284	−0.54, −0.03	0.03
	Duijts, 2011 (78)	N/A	56	Mixed	10	N/A	N/A	N/A	−0.31	−0.53, −0.10	0.004
Colorectal cancer	Cramer, 2014 (106)	157	3	Posttreatment	3	91	66	27	0.18	−0.22, 0.59	0.38
Hematological malignancy	van Haren, 2013 (103)	734	11	Mixed	2	57	58	0	0.53	0.16, 0.91	0.005
	Persoon, 2013 (102)	472	8	Mixed	4	122	116	0	0.53	0.27, 0.79	<0.0001
Various	Tian, 2016 (97)		26	Mixed	26	N/A	N/A	N/A	−0.22	−0.39, −0.04	0.01
	Dennett, 2016 (86)	3,336	33	Mixed	33	N/A	N/A	82	0.32	0.13, 0.52	N/A
	Meneses-Echavez, 2015 (90)	1,530	11	Mixed	11	N/A	N/A	99	−1.69	−2.99, −0.39	N/A
	Meneses-Echavez, 2015 (91)	772	9	Mixed	9	N/A	N/A	46.7	−0.23	−0.37, −0.09	0.001
	Strasser, 2013 (96)	1,167	11	Mixed	4	225	212	0	1.86	−0.03, 3.75	0.05
	Cramp, 2012 (85)	4,068	56	Mixed	38	N/A	N/A	N/A	−0.27	−0.37, −0.17	N/A
	McMillan, 2011 (89)	1,426	16	Mixed	16	759	667	26	0.28	0.17, 0.38	<0.0001
	Brown, 2011 (80)	3,254	44	Mixed	44	N/A	N/A	50	0.31	0.22, 0.4	
	Tomlinson, 2014 (98)	N/A	72	Mixed	56	4,000		71	−0.45	−0.57, −0.32	<0.001
	Mishra, 2014 (93)	3,694	33	Mixed	N/A	N/A	N/A	N/A	−0.82	−1.50, −0.14	<0.05
	Puetz, 2012 (94)	4,881	70	During treatment	43	N/A	N/A	48.4	0.32	0.21, 0.43	N/A
				Posttreatment	27	N/A	N/A-	60.7	0.38	0.21, 0.54	N/A
	Fong, 2012 (87)	N/A	34	Mixed	3	N/A	N/A	0	−1.0	−1.8, −0.1	N/A
	Buffart, 2012 (82)	N/A	13	Mixed	7	N/A	N/A	43.5	−0.51	−0.79, −0.22	0.001
	Mishra, 2012 (92)	3,694	40	Mixed	10	380	365	94	−0.82	−1.50, −0.14	0.019
	Bradt, 2011 (79)	207	3	Mixed	2	N/A	N/A	N/A	−0.36	−1.26, 0.55	N/A
Quality of life											
Breast	Paramamamda, 2014 (75)	1,091	11	Mixed	6	N/A	N/A	N/A	0.34	0.09, 0.58	<0.05
	Cheema, 2014 (74)	1,652	15	Mixed	7	N/A	N/A	47	0.17	−0.03, 0.38	N/A
	Carayol, 2013 (77)	1,380	17	Mixed	9	N/A	N/A	73	0.34	0.07, 0.62	0.015
	Duijts, 2011 (78)	N/A	56	Mixed	12	N/A	N/A	N/A	0.30	0.12, 0.48	0.001

Table continues

Table 3. Continued

Cancer-Related Adverse Effect and Cancer Site	First Author, Year (Reference No.)	Sample Size, no.	No. of RCTs	Timing	No. of Studies	No. of Patients		I^2, %	Effect Estimate	95% CI	*P* Value
						Exercise	Control				
Prostate	Bourke, 2016 (100)	1,574	16	Mixed	7	N/A	N/A	46	0.13	−0.08, 0.34	0.23
Colorectal cancer	Cramer, 2014 (106)	157	3	Posttreatment	3	91	66	59	0.18	−0.39, 0.76	0.53
Lung	Cavalheri, 2013 (105)	178	3	Posttreatment	3	72	75	24	0.17	−0.16, 0.49	0.32
Hematological malignancy	van Haren, 2013 (103)	734	11	Mixed	3	74	74	0	8.72	3.13, 14.31	0.002
	Persoon, 2013 (102)	472	8	Mixed	5	146	148	0	0.41	0.18, 0.64	0.0005
Gynecological cancer	Smits, 2015 (108)	153	3	Posttreatment	N/A	80	73	0	2.48	−4.63, 9.58	0.49
Various	Gerritsen, 2016 (88)	N/A	16	Mixed	16	877	858	N/A	5.55	3.19, 7.90	<0.001
	Zeng, 2014 (99)	592	13	Mixed	5	200	205	95	7.99	4.07, 11.91	<0.001
	Mishra, 2014 (93)	3,694	33	Mixed	N/A	N/A	N/A	N/A	0.48	0.16, 0.81	<0.05
	Buffart, 2012 (82)	N/A	13	Mixed	7	N/A	N/A	84.5	0.88	0.25, 1.5	0.006
	Mishra, 2012 (92)	3,694	40	Mixed	11	434	392	78	0.48	0.16, 0.81	0.0032
Distress, various	Buffart, 2012 (82)	N/A	13	Mixed	7	N/A	N/A	80.8	−0.95	−1.49, −0.49	<0.001
Anxiety											
Breast	Zhu, 2016 (70)	2,659	33	Mixed	5	341	361	0	−3.17	−4.76, −1.58	<0.01
	Carayol, 2013 (77)	1,380	17	Mixed	8	N/A	N/A	91	−0.52	−1.01, 0.02	0.06
Various	Mishra, 2014 (93)	3,694	33	Mixed	N/A	N/A	N/A	N/A	−0.26	−0.44, −0.07	<0.05
	Buffart, 2012 (82)	N/A	13	Mixed	7	N/A	N/A	91.5	−1.25	−1.93, −0.56	<0.001
	Mishra, 2012 (92)	3,694	40	Mixed	4	223	232	0	−0.26	−0.07, −0.44	0.0059
	Bradt, 2011 (79)	207	3	Mixed	2	N/A	N/A	N/A	0.21	−0.09, 0.51	N/A
Depression											
Breast	Zhu, 2016 (70)	2,659	33	Mixed	6	378	373	2	−2.08	−3.36, 0.80	0.001
	Carayol, 2013 (77)	1,380	17	Mixed	9	N/A	N/A	39	−0.27	−0.457, −0.09	0.003
	Duijts, 2011 (78)	N/A	56	Mixed	5	N/A	N/A	N/A	−0.26	−0.476, −0.05	0.016
Prostate	Newby, 2015 (101)	N/A	11	Mixed	4	N/A	N/A	0	−0.90	−2.04, 0.24	0.124
Various	Craft, 2012 (84)	N/A	15	Mixed	15	N/A	N/A	N/A	−0.22	−0.43, −0.09	0.04
	Brown, 2012 (81)	2,929	40	Mixed	40	N/A	N/A	54.7	−0.13	−0.26, −0.01	<0.001
	Tomlinson, 2014 (98)	N/A	72	Mixed	20	1,658		71	−0.41	−0.63, −0.19	<0.001
	Fong, 2012 (87)	N/A	34	Mixed	4	N/A	N/A	47	−4.1	−6.5, −1.80	N/A
	Buffart, 2012 (82)	N/A	13	Mixed	7	N/A	N/A	93.3	−1.49	−2.42, −0.53	0.002
	Mishra, 2012 (92)	3,694	40	Mixed	12	355	352	53	−0.41	−0.65, −0.17	0.00075
	Bradt, 2011 (79)	207	3	Mixed	2	N/A	N/A	N/A	0.02	−0.28, 0.32	N/A
Stress, various	Bradt, 2011 (79)	207	3	Mixed	2	N/A	N/A	N/A	−0.18	−0.48, 0.12	N/A

Table continues

Table 3. Continued

Cancer-Related Adverse Effect and Cancer Site	First Author, Year (Reference No.)	Sample Size, no.	No. of RCTs	Timing	No. of Studies	No. of Patients		I^2, %	Effect Estimate	95% CI	*P* Value
						Exercise	Control				
Emotional well-being, breast	Zhu, 2016 (70)	2,659	33	Mixed	8	343	316	2	0.27	0.12, 0.43	0.0006
Mental health, breast	Zhu, 2016 (70)	2,659	33	Mixed	4	125	116	18	1.4	0.09, 2.00	0.03
Body image											
Breast	Duijts, 2011 (78)		56	Mixed	6	N/A	N/A	N/A	0.28	0.08, 0.48	0.007
Various	Mishra, 2012 (92)	3,694	40	Mixed	5	117	116	16	−0.5	−0.8, −0.2	0.001
	Bradt, 2011 (79)	207	3	Mixed	2	N/A	N/A	N/A	−0.13	−0.61, 0.34	N/A
Sleep dysfunction											
Breast	Zhu, 2016 (70)	2,659	33	Mixed	4	64	62	0	0.32	−0.82, 1.46	0.58
Various	Chiu, 2015 (83)	599	9	Mixed	9	N/A	N/A	61	−0.52	−0.79, −0.25	N/A
	Tomlinson, 2014 (98)	N/A	72	Mixed	17	1,125	32		−0.27	−0.43, −0.12	<0.001
	Buffart, 2012 (82)	N/A	13	Mixed	4	N/A	N/A	0	−0.26	−0.53, 0.02	0.07
	Mishra, 2012 (92)	3,694	40	Mixed	8	222	216	41	−0.46	−0.72, −0.2	0.0005
Physical function											
Hematological malignancy	Persoon, 2013 (102)	472	8	Mixed	5	146	148	0	0.38	0.15, 0.61	N/A
Various	Fong, 2012 (87)	N/A	34	Mixed	2	N/A	N/A	0	3.0	0.7, 5.3	N/A
	Buffart, 2012 (82)	N/A	13	Mixed	6	N/A	N/A	87.5	0.6	−0.05, 1.25	0.07
	Mishra, 2012 (92)	3,694	40	Mixed	15	446	432	70	0.36	0.09, 0.64	0.009
Physical health											
Lung	Ni, 2016 (104)	350	8	Mixed	4	N/A	N/A	0	3	0.81, 5.2	0.007
Various	Scott, 2013 (95)	N/A	12	Mixed	5	N/A	N/A	N/A	2.22	0.12, 4.31	0.04
Shoulder disability, head and neck	Carvalho, 2012 (107)	104	3	Mixed	2	35	34	0	−8.48	−14.1, −1.88	0.012
Lymphedema, breast	Paramamamda, 2014 (75)	1,091	11	Mixed	8	N/A	N/A	0	−0.09	−0.23, 0.05	0.2
	Rogan, 2016 (69)	N/A	4	Posttreatment	4	N/A	N/A	0	−0.49	−0.86, −0.11	0.011
	Singh, 2016 (72)	283	11	Posttreatment	11	N/A	N/A	0	−0.1	−0.3, 0.4	0.34
Pain											
Breast	Zhu, 2016 (70)	2,659	33	Mixed	3	106	97	98	2.58	−2.65, 7.81	0.33
Head and neck	Carvalho, 2012 (107)	104	3	Mixed	2	35	34	0	−6.26	−12.2, −0.3	0.039
Various	Mishra, 2012 (92)	3,694	40	Mixed	4	145	144	15	−0.29	−0.55, −0.04	0.025

Abbreviations: CI, confidence interval; N/A, not available; RCT, randomized controlled trial.
[a] Mixed, before, during, and after treatment.

Table 4. Summary of Results From Randomized Controlled Trials on the Adverse Effects of Cancer Treatment[a]

Cancer Site	Randomized Controlled Trial Data With Outcomes Not Previously the Subject of a Meta-analysis													
	Treatment Symptoms		Bone Health		Cognitive Health		Sexual Health		Bladder and Bowel Health		Hot Flashes		Anemia	
	No. of Significant Trials	No. of Total Trials	No. of Significant Trials	No. of Total Trials	No. of Significant Trials	No. of Total Trials	No. of Significant Trials	No. of Total Trials	No. of Significant Trials	No. of Total Trials	No. of Significant Trials	No. of Total Trials	No. of Significant Trials	No. of Total Trials
Breast	2	4	1	4	1	3	2	3	1	1	1	2	0	1
Prostate	0	2	1	2	N/A	N/A	1	2	1	3	N/A	N/A	N/A	N/A
Lung	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Colon	0	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Gynecological cancer	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Mixed	0	1	1	1	1	2	N/A	N/A	0	1	N/A	N/A	1	1
Overall	2	7	3	7	2	5	3	5	2	5	1	2	1	2

Abbreviation: N/A, not available.
[a] Number of significant trials/total number of trials.

of 3,735 participants involved in the 23 trials comprising mainly patients with breast cancer (85%) and prostate cancer (10%). The remaining 5% were a mix of other less common cancer sites. Of the 23 RCTs, 43% were conducted during active treatment, 22% were conducted during the posttreatment period, 17% were conducted in prostate cancer patients during androgen deprivation therapy, and the remainder did not clarify the timing of the intervention with regard to treatment. Changes in persistent adverse treatment effects were compared between groups of patients who were randomized into an exercise intervention versus a control condition not involving any structured exercise program (Web Table 3).

The 40 meta-analyses in review 2 included 257 reported studies with 9,126 patients who participated in RCTs. Ten (25%) of the meta-analyses focused on breast cancer survivors (69–78), 21 (45%) included trials with a broad variety of cancer diagnoses (79–99), and there were 2 meta-analyses each that focused on the adverse effects among prostate (100, 101), hematological (102, 103), and lung (104, 105) malignancies. Finally, there was 1 meta-analysis each that focused specifically on the adverse effects of treatment among colorectal (106), head and neck (107), and gynecological cancer survivors (108). The most common outcomes examined were fatigue (24 meta-analyses) (70, 71, 73, 76–80, 82, 85–87, 89–94, 96–98, 102, 103, 106), quality of life (15 meta-analyses) (74, 75, 77, 78, 82, 88, 92, 93, 99, 100, 102, 103, 105, 106, 108), and depression (11 meta-analyses) (70, 77–79, 81, 82, 84, 87, 92, 98, 101).

Cancer mortality and recurrence

Data synthesized in review 1 suggest a consistent trend for reduced risk of cancer-specific mortality, cancer recurrence, and all-cause mortality in patients who have superior exercise behaviors (Table 1). Significantly lower risk of cancer-specific mortality was observed for patients with higher exercise levels in 17 of the 30 studies reporting cancer-specific mortality (9, 11, 12, 19, 22–26, 28–32, 35, 36, 40). Studies reporting a statistically significant association between exercise level and cancer mortality involved patients with breast (11, 12, 19, 23, 24, 26), colorectal (9, 22, 29, 31–33, 35, 40), and prostate (28) cancer, as well as evaluations involving patients with groups of various cancers combined (25, 30). Significantly lower risk of cancer recurrence was observed for patients with higher exercise levels in 4 of the 9 studies reporting cancer recurrence (24, 33, 37, 38). Studies reporting a statistically significant association between exercise level and cancer recurrence involved patients with breast (24, 38), colorectal (33), and prostate (37) cancer. Of the 25 studies reporting all-cause mortality, 22 reported significantly lower risk of all-cause mortality among patients with higher exercise levels (9–13, 15, 19, 20, 23–33, 36, 38, 40). It is unclear from this review if there is any variation in the magnitude of protective effect against cancer-specific mortality, cancer recurrence, and/or all-cause mortality according to the type of cancer or the exercise dosage (modality, volume, intensity, frequency). There was considerable variability in the time since diagnosis at which exercise levels were assessed (refer to Table 1). Although the vast majority of studies excluded deaths that occurred early in the follow-up

Table 5. Summary of Results From Meta-analyses Reviewing the Impact of Exercise on the Adverse Effects of Cancer Treatment[a]

Cancer Site	Adverse Effects																	
	Fatigue		Quality of Life		Psychosocial Distress		Body Image		Sleep		Physical Function		Physical Health		Lymphedema		Shoulder Dysfunction	
	No. of Significant Trials	No. of Total Trials	No. of Significant Trials	No. of Total Trials	No. of Significant Trials	No. of Total Trials	No. of Significant Trials	No. of Total Trials	No. of Significant Trials	No. of Total Trials	No. of Significant Trials	No. of Total Trials	No. of Significant Trials	No. of Total Trials	No. of Significant Trials	No. of Total Trials	No. of Significant Trials	No. of Total Trials
Breast	5	6	3	4	3	4	1	1	0	1	N/A	N/A	N/A	N/A	1	3	N/A	N/A
Prostate	N/A	N/A	0	1	0	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lung	N/A	N/A	0	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1	1	N/A	N/A	N/A	N/A
Colon	0	1	0	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Gynecological cancer	N/A	N/A	0	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hematological malignancies	2	2	2	2	N/A	N/A	N/A	N/A	N/A	N/A	1	1	N/A	N/A	N/A	N/A	N/A	N/A
Head and neck	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1	1
Mixed	15	15	5	5	7	8	1	2	3	4	2	3	1	1	N/A	N/A	N/A	N/A
Overall	22	24	5	15	10	13	2	3	3	5	3	4	2	2	1	3	1	1

Abbreviation: N/A, not available.

[a] Number of meta-analyses reporting a significant effect/total number of meta-analyses that examined that outcome.

phase, it is unclear from this review if the timing of assessment influenced the observed relationship between exercise levels and cancer progression. All but 3 studies (17, 30, 39) reported that they controlled for cancer stage or grade, making it difficult to draw any conclusions regarding the potential influence of stage/grade on exercise levels and/or cancer outcomes.

Studies involving experimental follow-up of RCTs did not report any statistically significant associations between exercise levels and cancer-specific mortality, cancer recurrence, or all-cause mortality (41–44). However, these studies were not designed or powered to evaluate any of these endpoints and involved a relatively low number of participants (n = 60–242). Rather, the primary endpoints for these trials were quality of life (41), physical function (42), fatigue (43), and bone density (44). Data reported in Table 1 are based on exploratory follow-ups probing any interaction between exercise levels and cancer recurrence, cancer mortality, and/or all-cause mortality.

Results of the previously published meta-analyses evaluating cancer mortality and recurrence have been summarized in Table 2 (109–118). These analyses report that patients diagnosed with cancer who were more physically active had a lower relative risk of breast cancer mortality (pooled hazard ratios range from 0.71 to 0.59), colorectal cancer mortality (pooled hazard ratios range from 0.70 to 0.56), and cancer-specific mortality from a variety of cancer types (pooled hazard ratios range from 0.63 to 0.60). Patients who were more physically active also had a lower relative risk of breast cancer recurrence (pooled hazard ratios range from 0.79 to 0.76). Furthermore, cancer patients with more positive exercise behaviors are observed to have a lower relative risk of all-cause mortality (pooled hazard ratios range from 0.75 to 0.52). Web Table 4 specifies which original data sets were included within each of the meta-analyses reviewed in this article. This article reviews data from 5 original studies that have not been included in any previous meta-analysis (11, 22, 34, 36, 40). These new data continue to support the findings of prior meta-analyses, reporting lower relative risk of cancer recurrence, cancer mortality, and all-cause mortality in people with breast (11, 36) and colorectal (22, 34, 40) cancer who are more physically active. These new data have expanded into new areas not previously investigated by exploring the relationship between exercise and cancer outcomes based on variations in factors that have been implicated in cancer progression (e.g., estrogen receptor status, cyclooxygenase 2 status).

Effects of exercise on adverse treatment effects

Data synthesized in review 2 suggest variability in the efficacy of exercise to improve adverse treatment effects by adverse effect, tumor site, intervention, and timing of the intervention with regard to treatment (Web Table 3).

Treatment symptoms. The effects of exercise interventions on treatment symptoms (e.g., breast, endocrine, taxane related, arm, or general treatment-related symptoms) were evaluated in 7 recent randomized trials (48–50, 54, 59, 61): 4 in breast cancer (50, 54, 59, 61), 2 in prostate cancer (48, 49), and 1 in breast and colorectal cancers (46). Statistically significant improvements in treatment-related symptoms were noted in 2 of the 7 studies, both with breast cancer survivors and conducted during chemotherapy (46, 50). One of these studies prescribed 10,000 steps of walking daily and noted that breast symptoms were reduced by half in the exercise group, compared with a small increase in the control group (46). In the other study, the significant effects were noted in comparing a lower with a higher intensity exercise program, with significant treatment effects on reducing symptoms only among women in the higher intensity aerobic exercise program, or the higher intensity program that combined aerobic and resistance exercise (50).

Bone health. The effects of exercise training on bone health outcomes were evaluated in 7 trials (56, 58, 60, 64–68): 4 in breast cancer (60, 64, 65, 67, 68), 2 in prostate cancer, (56, 66), and 1 focused on bony metastases in the spine (58). All 4 of the studies in breast cancer survivors were conducted posttreatment, and only 1 showed any significant effect on bone outcomes (64). Winters-Stone et al. (64) showed that an exercise intervention that focused on resistance training combined with impact exercise can stabilize spinal bone mineral density when compared with a control group ($P < 0.01$). Winters-Stone et al. (66) observed a very similar result in prostate cancer survivors undergoing androgen deprivation therapy. The other trial in prostate cancer survivors did not observe any significant effect of high load strength training 3 times weekly during androgen deprivation therapy (56). Finally, thrice weekly resistance training during 6 months of radiotherapy for metastases to the spine resulted in significantly improved spine bone density compared with passive physical therapy (58).

Sexual health. Sexual health outcomes were examined in 5 studies: 3 in breast cancer (52, 59, 62) and 3 in prostate cancer (48, 49, 53). Among breast cancer patients, combined cognitive behavioral therapy and a 12-week home-based exercise program conducted posttreatment improved scores related to sexual activity and sexual pleasure (52). No significant effect was seen in an intervention for breast cancer patients undertaken during radiotherapy or an intervention undertaken once weekly, after treatment (59, 62). Among prostate cancer patients receiving androgen deprivation therapy, a 3-month program including aerobic and resistance exercise improved sexual function scores on the prostate cancer-specific quality-of-life survey of the European Organization for Research and Treatment for Cancer (EORTC QLQ-PR25) (48). By contrast, 5 supervised walking sessions per week had no effect on sexual health among prostate cancer patients postsurgery (53).

Cognitive health. Cognitive health was an outcome in 5 trials (46, 47, 55, 59, 61), all of which included breast cancer patients, 3 of which focused exclusively on breast cancer (47, 59, 61). Two of the 5 observed significant improvements in cognitive function, including an 8-week thrice weekly aquatic exercise program conducted posttreatment with breast cancer survivors (47) and a 4-week once weekly cycle ergometry program that included breast and prostate cancer patients (55).

Bowel and bladder function. Five RCTs evaluated the effects of exercise on bowel and bladder function after cancer (46, 48, 49, 57, 63). Exercise resulted in significant improvements in bowel and bladder outcomes in 2 of these trials, including a 6-week yoga intervention that improved constipation in breast cancer survivors posttreatment (63) and a twice weekly resistance, flexibility, and kegel exercise intervention in postsurgical prostate cancer survivors (57).

Hot flashes and anemia. There were 2 trials each that addressed hot flashes (52, 61) and anemia (45, 51). For each of these symptoms, there was 1 trial that showed a positive effect (45). There was no evidence that exercise impacts nausea and vomiting or dyspnea in the 1 trial that examined these outcomes (46).

There were 40 meta-analyses identified as having been published between 2011 and 2016 that examined the effects of exercise interventions on adverse treatment effects among adults diagnosed with cancer. Web Table 5 specifies which original data sets were included within each of the meta-analyses reviewed in this section. The outcomes explored in these meta-analyses included fatigue, quality of life, psychosocial distress, body image, sleep, physical function, physical health, lymphedema, and shoulder dysfunction (Tables 3–5).

Fatigue. Of the 24 meta-analyses that examined the effects of exercise on fatigue (70, 71, 73, 76–80, 82, 85–87, 89–94, 96–98, 102, 103, 106), all but 2 (70, 106) observed a statistically significant effect. Five meta-analyses focused on studies in breast cancer survivors, 1 meta-analysis in colorectal cancer survivors, and the remainder grouped survivors from a variety of cancers. Three of the meta-analyses focused on the effects of exercise during chemotherapy; all 3 observed significant effects (71, 76, 94).

Quality of life. The second most common outcome evaluated in these meta-analyses was quality of life (15 publications) (74, 75, 77, 78, 82, 88, 92, 93, 99, 100, 102, 103, 105, 106, 108). Of these, 5 included a variety of cancer types (82, 88, 92, 93, 99), 4 focused on breast cancer (74, 75, 77, 78), 2 focused on hematological malignancies (102, 103), and 1 each focused on prostate, colorectal, lung, and gynecological cancers (100, 105, 106, 108). The meta-analyses in a variety of cancers, 3 of the 4 meta-analyses in breast cancer, and both focused on hematological malignancies reported significant improvements in quality of life for cancer survivors who exercised compared with those randomized to a comparison group (75, 77, 78, 102, 103). Evidence did not support a positive effect of exercise on quality of life in prostate, lung, colorectal, or gynecological cancer survivors (100, 105, 106, 108).

Psychosocial distress. Psychosocial distress-related outcomes (e.g., psychosocial distress, anxiety, depression, stress, emotional well-being, mental health) were examined in 12 meta-analyses, including 3 focused on breast cancer (70, 77, 78), 8 that included a variety of diagnoses (79, 81, 82, 84, 87, 92, 93, 98), and 1 that focused on prostate cancer survivors (101). Ten of these showed significant improvements in 1 or more of the above-noted psychosocial outcomes among cancer survivors randomized to exercise compared with those randomized to a comparison group (70, 77, 78, 81, 82, 84, 87, 92, 93, 98). The exceptions included a small meta-analysis that included only 2 randomized trials with multiple cancer diagnoses (79) and another meta-analysis that focused on the effects of exercise on depression specifically among prostate cancer survivors (101).

Body image, sleep, physical function, and more. For the remaining outcomes, there were from 1 to 5 meta-analyses that sought to summarize the RCT evidence that exercise training results in improved body image, sleep, physical function, physical health, and shoulder dysfunction. With few exceptions, the conclusions of these meta-analyses are that exercise does have a significant positive effect on these outcomes. The outcomes from meta-analyses regarding the effects of exercise on lymphedema outcomes are complicated by the possibility that the favorable outcome is no harm (null findings) (69, 72, 75). Of the 3 meta-analyses that examined this relationship, 2 observed no harm or benefit, and 1 observed that exercise reduces edema (69).

DISCUSSION

Findings from this comprehensive review of observational studies, interventional trials, and meta-analyses support the view that exercise is an important adjunct therapy in the management of cancer. Specifically, this review confirms that cancer patients involved in greater levels of exercise have a lower relative risk of cancer mortality and a lower relative risk of cancer recurrence, and they experience fewer and/or less severe treatment-related adverse effects.

Cancer mortality and recurrence

Engaging in exercise following the diagnosis of cancer was observed to have a protective effect against cancer-specific mortality, cancer recurrence, and all-cause mortality. Based on the 11 meta-analyses that have evaluated these outcomes to date, the magnitude of effect was observed to be considerable (109–118). Specifically, superior levels of exercise following a cancer diagnosis were associated with a 28%–44% reduced risk of cancer-specific mortality, a 21%–35% lower risk of cancer recurrence, and a 25%–48% decreased risk of all-cause mortality (Table 2). These data quantify trends seen across the 36 studies investigating post-diagnosis exercise levels in over 68,000 cancer patients (9–44). Although the majority of these studies are observational and therefore cannot infer causation, the apparent protective effect of exercise was observed in multivariable-adjusted analyses that account for a range of clinically relevant covariates associated with cancer progression (e.g., cancer stage, treatments, smoking status, body mass index, comorbidities, and so on). Most evaluations to date have involved breast (n > 45,000), colorectal (n ~ 10,000), and prostate (n > 9,500) cancer patients. As such, it is unclear whether exercise is associated with improved disease outcomes in patients diagnosed with other types of cancer. Insufficient data exist to determine if the degree of apparent protection varies according to cancer type, stage, and/or treatment regimen. Furthermore, knowledge is lacking regarding the influence of exercise dosage on the magnitude of potential survival benefit; thus, it is currently unclear what modality, volume, intensity, or frequency of exercise shows the most promise for improving disease outcomes.

A range of potential factors and mechanisms may contribute to the relationship observed between exercise behavior and cancer progression. Exercise may reduce the risk of cancer mortality and recurrence by enhancing the ability of patients to physically tolerate greater dosages of cancer treatment (119, 120). Exercise may reduce the rate and magnitude of anticancer therapy dose modifications by increasing functional capacity and attenuating the severity of treatment-related adverse effects, therefore allowing for higher treatment completion rates (119, 120). Similarly, improved fitness has been associated with enhanced surgical outcomes including less complications and morbidity (121–123). There is also the possibility that exercise may improve the effectiveness of anticancer treatments by normalizing the tumor microenvironment and potentially increasing transport of systemic therapies to cancer cells (124). Another possible contributing factor is the potential of more active patients being diagnosed with less aggressive tumors (125). A range of biological mechanisms has been proposed to mediate the protective effect of exercise on cancer outcomes. Specifically, exercise may elicit positive changes in inflammation, immunity, and oxidative stress, as well as in metabolic and sex hormones, all of which are factors believed to contribute to cancer progression (124, 126, 127). Emerging research suggests that exercise-induced epigenetic modifications concordant with health-enhancing phenotypic adaptations may also play a role in enhancing survival outcomes for cancer patients (128, 129). Furthermore, regular exercise is an established prophylactic measure that reduces the risk of developing comorbid conditions, such as heart disease, hypertension, diabetes, and osteoporosis. Although these factors may represent some potential pathways, precise mechanisms underlying the protective effect of exercise on cancer outcomes are yet to be elucidated (126, 127).

A series of limitations exist that must be considered when interpreting the results of this component of the review. Inherent in the nature of epidemiologic investigations is the inability to infer direct causality between exercise behavior and cancer outcomes. Although this review also contains RCTs incorporating experimental follow-up periods, these trials were neither designed nor powered to investigate survival or recurrence endpoints (41–44). It is possible that observations of the protective effect of exercise may reflect reverse causality rather than a physiological effect. Specifically, better outcomes may be reported for more active patients because they are less encumbered by advanced or aggressive disease and/or severe symptomology rather than exercise-induced adaptations that slow cancer progression. Additionally, the time at which assessment of exercise levels was conducted may contribute considerably to reverse causality; studies that assessed exercise levels during treatment and/or close to the end of treatment may be particularly susceptible to reverse causality. Furthermore, changes in other health behaviors or variation in clinical factors over the follow-up period may have influenced the observed associations. Considerable heterogeneity exists in the participant characteristics, study designs, follow-up periods, assessment tools, analysis techniques, and subsequent findings of the individual studies and meta-analyses contained within this review. Although robust adjustments were typically factored into analyses, the potential impact of confounding by unmeasured factors and/or residual confounding cannot be excluded. Additionally, bias may be introduced by the use of self-report exercise behavior assessment techniques that are prone to measurement error. Interpretation of information arising from the summary of meta-analyses is limited by the fact that these meta-analyses are at times based on the same original data (Tables 2 and 3; Web Tables 4 and 5) and do not always represent independent patient populations.

Managing treatment-related adverse effects

To assist with interpreting the results reviewed herein in a manner intended to be useful to clinicians, policy makers, and patients, we have created 2 tables that summarize the findings (Tables 4 and 5). The first, most obvious observation in summarizing the results on treatment-related adverse effects is that there are many understudied tumor sites. Every site other than breast cancer is understudied. However, studies of the benefits of exercise on adverse treatment effects are particularly scarce among head and neck, hematological, gynecological, colon, and lung cancers. The extent to which it is safe and appropriate to extrapolate results from studies of patients with other tumor types is unknown. That said, in the absence of significant risk, there is sufficient evidence that exercise is of general health value and that it could do more harm than good to wait to prescribe exercise to these less studied populations until further research is complete.

Our review included a review of RCTs for outcomes for which there were no meta-analyses, including breast cancer treatment symptoms; sexual, bone, and cognitive health; bladder and bowel health; anemia; and hot flashes. Results from studies examining the effects of exercise interventions on these outcomes are insufficiently consistent to warrant any policy statements overall or for any particular tumor site. Further research is needed to examine the effects of exercise on treatment symptoms; bone, cognitive, and sexual health; bladder and bowel health; hot flashes; and anemia. A limitation of this conclusion is that this review collates trials that were conducted both during and posttreatment. For some outcomes, a lack of detrimental change/maintenance of current condition might be the best possible outcome during treatment (e.g., maintenance of sexual well-being during prostate cancer treatment). There may be specific elements of exercise interventions that need to be examined more fully to discern the outcome. For example, there are 2 randomized trials in which bone health outcomes are significantly improved after an intervention that includes impact exercises to load the bones (65, 66, 68). Further research is warranted to discern whether focusing on impact exercise would make the results of exercise interventions on bone health outcomes more consistently positive.

For the outcomes examined more thoroughly in prior studies and for which there are recent meta-analyses, there are 2 outcomes with particularly strong evidence. These include fatigue and psychosocial distress. This is consistent with the National Comprehensive Cancer Network guidelines for managing fatigue, which recommend exercise as the number 1 approach for managing cancer-related fatigue (130). For physical function, sleep, body image, and physical health, the majority of the meta-analyses conclude that there is a positive effect of exercise, but that the number of studies or meta-analyses is less compelling than for fatigue or psychosocial distress. Finally, it is of interest that this review cannot conclude that exercise has a significant effect on quality of life, given that prior reviews have concluded otherwise. One possible explanation for this observation could be that the studies in tumor types other than breast were small and underpowered. Clearly, sample sizes of the individual studies, as well as varying intensity and quality of exercise interventions, could have influenced study results and our subsequent interpretation.

Another important adverse effect of cancer therapies is cardiotoxicity (131). Breast cancer patients are more likely to die of heart disease than of breast cancer after 9 years of survivorship (132). RCTs to prevent, attenuate, or reverse the cardiotoxic effect of cancer treatments and to prevent cardiovascular mortality are sorely needed.

Implications on policy and practice

The review of scientific evidence on the effectiveness of exercise interventions to prevent recurrence and to improve adverse effects of cancer treatments has implications for policy and practice. A range of organizations has endorsed exercise guidelines for people with cancer, including the American Cancer Society, National Comprehensive Cancer Network, American Society of Clinical Oncology, American College of Sports Medicine, Exercise and Sports Science Australia, and British Association of Sport and Exercise Science (133–138). These guidelines largely mirror general exercise guidelines for healthy adults, recommending that people with cancer avoid inactivity and participate in regular, moderate-intensity aerobic and resistance exercise. The guidelines also stipulate exercise programming adaptations based on cancer and treatment-related adverse effects. Despite these recommendations, the majority of people diagnosed with cancer are not sufficiently active, and it is anticipated that most patients do not participate in the high-quality exercise programs that are observed to elicit significant benefit (139–141). Thus, there is great potential to improve outcomes for patients and potentially to reduce health system expenditure (i.e., reduce the need to manage/treat some adverse treatment-related effects) through improved implementation of exercise within cancer care. To realize this potential, strategies to further develop policy and practice beyond the general exercise guidelines currently available are required. There is solid evidence that exercise is an effective treatment for cancer-related fatigue during and after treatment and for a broad variety of cancer types. Given that cancer-related fatigue is ubiquitous during treatment and can persist long term in a subset of patients (142), the practice of clinical oncology should include recommendations for exercise during and after treatment. There are already policies in place on this topic, most notably the guidelines for managing fatigue from the National Comprehensive Cancer Network in the United States (130). Similarly, the evidence for the effectiveness of exercise for improving psychosocial outcomes is also clear and consistent. There is a requirement of the American College of Surgeons Commission on Cancer accreditation that psychosocial distress be evaluated often among cancer patients (143). Further, if the results of that evaluation indicate the need for intervention, there must be a referral to effective treatment. Despite this, there are no policies, guidelines, or statements of major national organizations that point to exercise as a means of improving psychosocial outcomes. This could be low hanging fruit for organizations that produce such statements and policies, including the National Comprehensive Cancer Network, the American Cancer Society, and the Clinical Oncology Society of Australia. Given the increasing research efforts in the field, such statements should be refined and updated as the evidence base grows. Notably, the implementation of such policies and enacting on calls within position statements will need to occur to increase access to exercise advice and programs within cancer care.

Conclusions

Findings of this comprehensive review support the view that exercise is an important adjunct therapy for the management of cancer. A considerable body of literature now exists that provides convincing evidence of the beneficial impact of exercise on disease and patient outcomes. However, these data need to be interpreted carefully as considerable heterogeneity exists in the nature and quality of study designs, interventions, assessments, and subsequent findings. Despite existing limitations, the evidence to date substantiates recommendations for people with cancer to avoid inactivity and to engage in regular exercise. This includes participating in moderate to vigorous intensity aerobic and resistance exercise as endorsed by leading international organizations (133–135, 137, 138). For the potential of exercise to be realized, considerable effort and efficient investment are required to strengthen evidence-based policy and practice. Effectively implementing exercise within the cancer treatment paradigm is likely to contribute to a reduction in the burden of cancer.

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REFERENCES

1. American Cancer Society. *Cancer Facts & Figures 2016*. Atlanta, GA: American Cancer Society; 2016.
2. Australian Bureau of Statistics. *National Health Survey: Summary of Results Australia 2004–05*. Canberra, Australia: Australian Bureau of Statistics; 2005.
3. Centers for Disease Control and Prevention. *National Diabetes Statistics Report: Estimates of Diabetes and Its Burden in the United States, 2014*. Atlanta, GA: Department of Health and Human Services; 2014.
4. Moher D, Liberati A, Tetzlaff J, et al. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *BMJ*. 2009;339:b2535.
5. Schmitz KH, Holtzman J, Courneya KS, et al. Controlled physical activity trials in cancer survivors: a systematic review and meta-analysis. *Cancer Epidemiol Biomarkers Prev*. 2005;14(7):1588–1595.
6. Speck RM, Courneya KS, Masse LC, et al. An update of controlled physical activity trials in cancer survivors: a systematic review and meta-analysis. *J Cancer Surviv*. 2010; 4(2):87–100.
7. Higgins JP, Altman DG, Gotzsche PC, et al. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. *BMJ*. 2011;343:d5928.
8. Wells GA, Shea B, O'Connell D, et al. The Newcastle-Ottawa Scale for assessing the quality of nonrandomized studies in meta-analysis. http://www.ohri.ca/programs/clinical_epidemiology/oxford.asp. Published 2011. Accessed September 2016.
9. Arem H, Pfeiffer RM, Engels EA, et al. Pre- and postdiagnosis physical activity, television viewing, and mortality among patients with colorectal cancer in the National Institutes of Health-AARP Diet and Health Study. *J Clin Oncol*. 2015;33(2):180–188.
10. Baade PD, Meng X, Youl PH, et al. The impact of body mass index and physical activity on mortality among patients with colorectal cancer in Queensland, Australia. *Cancer Epidemiol Biomarkers Prev*. 2011;20(7):1410–1420.
11. Bao PP, Zhao GM, Shu XO, et al. Modifiable lifestyle factors and triple-negative breast cancer survival: a population-based prospective study. *Epidemiology*. 2015; 26(6):909–916.
12. Beasley JM, Kwan ML, Chen WY, et al. Meeting the physical activity guidelines and survival after breast cancer: findings from the After Breast Cancer Pooling Project. *Breast Cancer Res Treat*. 2012;131(2):637–643.
13. Bertram LA, Stefanick ML, Saquib N, et al. Physical activity, additional breast cancer events, and mortality among early-stage breast cancer survivors: findings from the WHEL Study. *Cancer Causes Control*. 2011;22(3):427–435.
14. Bonn SE, Sjölander A, Lagerros YT, et al. Physical activity and survival among men diagnosed with prostate cancer. *Cancer Epidemiol Biomarkers Prev*. 2015;24(1):57–64.
15. Borch KB, Braaten T, Lund E, et al. Physical activity before and after breast cancer diagnosis and survival—the Norwegian Women and Cancer Cohort Study. *BMC Cancer* 2015;15:967.
16. Borugian MJ, Sheps SB, Kim-Sing C, et al. Insulin, macronutrient intake, and physical activity: are potential indicators of insulin resistance associated with mortality from breast cancer? *Cancer Epidemiol Biomarkers Prev*. 2004; 13(7):1163–1172.
17. Bradshaw PT, Ibrahim JG, Khankari N, et al. Post-diagnosis physical activity and survival after breast cancer diagnosis: the Long Island Breast Cancer Study. *Breast Cancer Res Treat*. 2014;145(3):735–742.
18. Campbell PT, Patel AV, Newton CC, et al. Associations of recreational physical activity and leisure time spent sitting with colorectal cancer survival. *J Clin Oncol*. 2013;31(7): 876–885.
19. Chen X, Lu W, Zheng W, et al. Exercise after diagnosis of breast cancer in association with survival. *Cancer Prev Res (Phila)*. 2011;4(9):1409–1418.

20. Friedenreich CM, Wang Q, Neilson HK, et al. Physical activity and survival after prostate cancer. *Eur Urol*. 2016; 70(4):576–585.
21. de Glas NA, Fontein DB, Bastiaannet E, et al. Physical activity and survival of postmenopausal, hormone receptor-positive breast cancer patients: results of the Tamoxifen Exemestane Adjuvant Multicenter Lifestyle Study. *Cancer*. 2014;120:2847–2854.
22. Hanyuda A, Kim SA, Martinez-Fernandez A, et al. Survival benefit of exercise differs by tumor IRS1 expression status in colorectal cancer. *Ann Surg Oncol*. 2016;23(3):908–917.
23. Holick CN, Newcomb PA, Trentham-Dietz A, et al. Physical activity and survival after diagnosis of invasive breast cancer. *Cancer Epidemiol Biomarkers Prev*. 2008;17(2):379–386.
24. Holmes MD, Chen WY, Feskanich D, et al. Physical activity and survival after breast cancer diagnosis. *JAMA*. 2005; 293(20):2479–2486.
25. Inoue-Choi M, Robien K, Lazovich D. Adherence to the WCRF/AICR guidelines for cancer prevention is associated with lower mortality among older female cancer survivors. *Cancer Epidemiol Biomarkers Prev*. 2013;22(5):792–802.
26. Irwin ML, McTiernan A, Manson JE, et al. Physical activity and survival in postmenopausal women with breast cancer: results from the Women's Health Initiative. *Cancer Prev Res (Phila)*. 2011;4(4):522–529.
27. Irwin ML, Smith AW, McTiernan A, et al. Influence of pre- and postdiagnosis physical activity on mortality in breast cancer survivors: the Health, Eating, Activity, and Lifestyle Study. *J Clin Oncol*. 2008;26(24):3958–3964.
28. Kenfield SA, Stampfer MJ, Giovannucci E, et al. Physical activity and survival after prostate cancer diagnosis in the Health Professionals Follow-Up Study. *J Clin Oncol*. 2011; 29(6):726–732.
29. Kuiper JG, Phipps AI, Neuhouser ML, et al. Recreational physical activity, body mass index, and survival in women with colorectal cancer. *Cancer Causes Control*. 2012;23(12): 1939–1948.
30. Lee IM, Wolin KY, Freeman SE, et al. Physical activity and survival after cancer diagnosis in men. *J Phys Act Health*. 2014;11(1):85–90.
31. Meyerhardt JA, Giovannucci EL, Holmes MD, et al. Physical activity and survival after colorectal cancer diagnosis. *J Clin Oncol*. 2006;24(22):3527–3534.
32. Meyerhardt JA, Giovannucci EL, Ogino S, et al. Physical activity and male colorectal cancer survival. *Arch Intern Med*. 2009;169(22):2102–2108.
33. Meyerhardt JA, Heseltine D, Niedzwiecki D, et al. Impact of physical activity on cancer recurrence and survival in patients with stage III colon cancer: findings from CALGB 89803. *J Clin Oncol*. 2006;24(22):3535–3541.
34. Meyerhardt JA, Ogino S, Kirkner GJ, et al. Interaction of molecular markers and physical activity on mortality in patients with colon cancer. *Clin Cancer Res*. 2009;15(18): 5931–5936.
35. Morikawa T, Kuchiba A, Yamauchi M, et al. Association of CTNNB1 (beta-catenin) alterations, body mass index, and physical activity with survival in patients with colorectal cancer. *JAMA*. 2011;305(16):1685–1694.
36. Nechuta S, Chen WY, Cai H, et al. A pooled analysis of post-diagnosis lifestyle factors in association with late estrogen-receptor-positive breast cancer prognosis. *Int J Cancer*. 2016; 138(9):2088–2097.
37. Richman EL, Kenfield SA, Stampfer MJ, et al. Physical activity after diagnosis and risk of prostate cancer progression: data from the cancer of the prostate strategic urologic research endeavor. *Cancer Res*. 2011;71(11): 3889–3895.
38. Sternfeld B, Weltzien E, Quesenberry CP Jr, et al. Physical activity and risk of recurrence and mortality in breast cancer survivors: findings from the LACE Study. *Cancer Epidemiol Biomarkers Prev*. 2009;18(1):87–95.
39. Williams PT. Significantly greater reduction in breast cancer mortality from post-diagnosis running than walking. *Int J Cancer*. 2014;135(5):1195–1202.
40. Yamauchi M, Lochhead P, Imamura Y, et al. Physical activity, tumor PTGS2 expression, and survival in patients with colorectal cancer. *Cancer Epidemiol Biomarkers Prev*. 2013;22(6):1142–1152.
41. Courneya KS, Segal RJ, McKenzie DC, et al. Effects of exercise during adjuvant chemotherapy on breast cancer outcomes. *Med Sci Sports Exerc*. 2014;46(9):1744–1751.
42. Courneya KS, Friedenreich CM, Franco-Villalobos C, et al. Effects of supervised exercise on progression-free survival in lymphoma patients: an exploratory follow-up of the HELP Trial. *Cancer Causes Control*. 2015;26(2):269–276.
43. Wiskemann J, Kleindienst N, Kuehl R, et al. Effects of physical exercise on survival after allogeneic stem cell transplantation. *Int J Cancer*. 2015;137(11):2749–2756.
44. Rief H, Bruckner T, Schlampp I, et al. Resistance training concomitant to radiotherapy of spinal bone metastases—survival and prognostic factors of a randomized trial. *Radiat Oncol*. 2016;11(1):97–107.
45. Andersen C, Rorth M, Ejlertsen B, et al. The effects of a six-week supervised multimodal exercise intervention during chemotherapy on cancer-related fatigue. *Eur J Oncol Nurs*. 2013;17(3):331–339.
46. Backman M, Wengstrom Y, Johansson B, et al. A randomized pilot study with daily walking during adjuvant chemotherapy for patients with breast and colorectal cancer. *Acta Oncol*. 2014;53(4):510–520.
47. Cantarero-Villanueva I, Fernandez-Lao C, Cuesta-Vargas AI, et al. The effectiveness of a deep water aquatic exercise program in cancer-related fatigue in breast cancer survivors: a randomized controlled trial. *Arch Phys Med Rehabil*. 2013; 94(2):221–230.
48. Cormie P, Galvao DA, Spry N, et al. Can supervised exercise prevent treatment toxicity in patients with prostate cancer initiating androgen-deprivation therapy: a randomised controlled trial. *BJU Int*. 2015;115(2):256–266.
49. Cormie P, Newton RU, Taaffe DR, et al. Exercise maintains sexual activity in men undergoing androgen suppression for prostate cancer: a randomized controlled trial. *Prostate Cancer Prostatic Dis*. 2013;16(2):170–175.
50. Courneya KS, McKenzie DC, Mackey JR, et al. Effects of exercise dose and type during breast cancer chemotherapy: multicenter randomized trial. *J Natl Cancer Inst*. 2013; 105(23):1821–1832.
51. Dolan LB, Gelmon K, Courneya KS, et al. Hemoglobin and aerobic fitness changes with supervised exercise training in breast cancer patients receiving chemotherapy. *Cancer Epidemiol Biomarkers Prev*. 2010;19(11):2826–2832.
52. Duijts SF, van Beurden M, Oldenburg HS, et al. Efficacy of cognitive behavioral therapy and physical exercise in alleviating treatment-induced menopausal symptoms in patients with breast cancer: results of a randomized, controlled, multicenter trial. *J Clin Oncol*. 2012;30(33): 4124–4133.
53. Jones LW, Hornsby WE, Freedland SJ, et al. Effects of nonlinear aerobic training on erectile dysfunction and cardiovascular function following radical prostatectomy for

clinically localized prostate cancer. *Eur Urol*. 2014;65(5): 852–855.
54. Kilbreath SL, Refshauge KM, Beith JM, et al. Upper limb progressive resistance training and stretching exercises following surgery for early breast cancer: a randomized controlled trial. *Breast Cancer Res Treat*. 2012;133(2): 667–676.
55. Miki E, Kataoka T, Okamura H. Feasibility and efficacy of speed-feedback therapy with a bicycle ergometer on cognitive function in elderly cancer patients in Japan. *Psychooncology*. 2014;23(8):906–913.
56. Nilsen TS, Raastad T, Skovlund E, et al. Effects of strength training on body composition, physical functioning, and quality of life in prostate cancer patients during androgen deprivation therapy. *Acta Oncol*. 2015;54(10):1805–1813.
57. Park SW, Kim TN, Nam JK, et al. Recovery of overall exercise ability, quality of life, and continence after 12-week combined exercise intervention in elderly patients who underwent radical prostatectomy: a randomized controlled study. *Urology*. 2012;80(2):299–305.
58. Rief H, Petersen LC, Omlor G, et al. The effect of resistance training during radiotherapy on spinal bone metastases in cancer patients—a randomized trial. *Radiother Oncol*. 2014; 112(1):133–139.
59. Saarto T, Penttinen HM, Sievanen H, et al. Effectiveness of a 12-month exercise program on physical performance and quality of life of breast cancer survivors. *Anticancer Res*. 2012;32(9):3875–3884.
60. Saarto T, Sievanen H, Kellokumpu-Lehtinen P, et al. Effect of supervised and home exercise training on bone mineral density among breast cancer patients. A 12-month randomised controlled trial. *Osteoporos Int*. 2012;23(5): 1601–1612.
61. Spahn G, Choi KE, Kennemann C, et al. Can a multimodal mind-body program enhance the treatment effects of physical activity in breast cancer survivors with chronic tumor-associated fatigue? A randomized controlled trial. *Integr Cancer Ther*. 2013;12(4):291–300.
62. Steindorf K, Schmidt ME, Klassen O, et al. Randomized, controlled trial of resistance training in breast cancer patients receiving adjuvant radiotherapy: results on cancer-related fatigue and quality of life. *Ann Oncol*. 2014;25(11):2237–2243.
63. Vardar Yagli N, Sener G, Arikan H, et al. Do yoga and aerobic exercise training have impact on functional capacity, fatigue, peripheral muscle strength, and quality of life in breast cancer survivors? *Integr Cancer Ther*. 2015;14(2): 125–132.
64. Winters-Stone KM, Dobek J, Nail L, et al. Strength training stops bone loss and builds muscle in postmenopausal breast cancer survivors: a randomized, controlled trial. *Breast Cancer Res Treat*. 2011;127(2):447–456.
65. Winters-Stone KM, Dobek J, Nail LM, et al. Impact + resistance training improves bone health and body composition in prematurely menopausal breast cancer survivors: a randomized controlled trial. *Osteoporos Int*. 2013;24(5):1637–1646.
66. Winters-Stone KM, Dobek JC, Bennett JA, et al. Skeletal response to resistance and impact training in prostate cancer survivors. *Med Sci Sports Exerc*. 2014;46(8):1482–1488.
67. Winters-Stone KM, Laudermilk M, Woo K, et al. Influence of weight training on skeletal health of breast cancer survivors with or at risk for breast cancer-related lymphedema. *J Cancer Surviv*. 2014;8(2):260–268.
68. Winters-Stone KM, Leo MC, Schwartz A. Exercise effects on hip bone mineral density in older, post-menopausal breast cancer survivors are age dependent. *Arch Osteoporos*. 2012; 7:301–306.
69. Rogan S, Taeymans J, Luginbuehl H, et al. Therapy modalities to reduce lymphoedema in female breast cancer patients: a systematic review and meta-analysis. *Breast Cancer Res Treat*. 2016;159(1):1–14.
70. Zhu G, Zhang X, Wang Y, et al. Effects of exercise intervention in breast cancer survivors: a meta-analysis of 33 randomized controlled trails. *Onco Targets Ther*. 2016;9: 2153–2168.
71. van Vulpen JK, Peeters PH, Velthuis MJ, et al. Effects of physical exercise during adjuvant breast cancer treatment on physical and psychosocial dimensions of cancer-related fatigue: a meta-analysis. *Maturitas*. 2016;85:104–111.
72. Singh B, Disipio T, Peake J, et al. Systematic review and meta-analysis of the effects of exercise for those with cancer-related lymphedema. *Arch Phys Med Rehabil*. 2016;97(2): 302–315.
73. Meneses-Echavez JF, Gonzalez-Jimenez E, Ramirez-Velez R. Effects of supervised exercise on cancer-related fatigue in breast cancer survivors: a systematic review and meta-analysis. *BMC Cancer*. 2015;15:77.
74. Cheema BS, Kilbreath SL, Fahey PP, et al. Safety and efficacy of progressive resistance training in breast cancer: a systematic review and meta-analysis. *Breast Cancer Res Treat*. 2014;148(2):249–268.
75. Paramanandam VS, Roberts D. Weight training is not harmful for women with breast cancer-related lymphoedema: a systematic review. *J Physiother*. 2014;60(3):136–143.
76. Zou LY, Yang L, He XL, et al. Effects of aerobic exercise on cancer-related fatigue in breast cancer patients receiving chemotherapy: a meta-analysis. *Tumour Biol*. 2014;35(6): 5659–5667.
77. Carayol M, Bernard P, Boiche J, et al. Psychological effect of exercise in women with breast cancer receiving adjuvant therapy: what is the optimal dose needed? *Ann Oncol*. 2013; 24(2):291–300.
78. Duijts SF, Faber MM, Oldenburg HS, et al. Effectiveness of behavioral techniques and physical exercise on psychosocial functioning and health-related quality of life in breast cancer patients and survivors—a meta-analysis. *Psychooncology*. 2011;20(2):115–126.
79. Bradt J, Goodill SW, Dileo C. Dance/movement therapy for improving psychological and physical outcomes in cancer patients. *Cochrane Database Syst Rev*. 2011;10:CD007103.
80. Brown JC, Huedo-Medina TB, Pescatello LS, et al. Efficacy of exercise interventions in modulating cancer-related fatigue among adult cancer survivors: a meta-analysis. *Cancer Epidemiol Biomarkers Prev*. 2011;20(1):123–133.
81. Brown JC, Huedo-Medina TB, Pescatello LS, et al. The efficacy of exercise in reducing depressive symptoms among cancer survivors: a meta-analysis. *PLoS One*. 2012;7(1): e30955.
82. Buffart LM, van Uffelen JG, Riphagen II, et al. Physical and psychosocial benefits of yoga in cancer patients and survivors, a systematic review and meta-analysis of randomized controlled trials. *BMC Cancer*. 2012;12:559.
83. Chiu HY, Huang HC, Chen PY, et al. Walking improves sleep in individuals with cancer: a meta-analysis of randomized, controlled trials. *Oncol Nurs Forum*. 2015; 42(2):E54–E62.
84. Craft LL, Vaniterson EH, Helenowski IB, et al. Exercise effects on depressive symptoms in cancer survivors: a systematic review and meta-analysis. *Cancer Epidemiol Biomarkers Prev*. 2012;21(1):3–19.

85. Cramp F, Byron-Daniel J. Exercise for the management of cancer-related fatigue in adults. *Cochrane Database Syst Rev*. 2012;11:CD006145.
86. Dennett AM, Peiris CL, Shields N, et al. Moderate-intensity exercise reduces fatigue and improves mobility in cancer survivors: a systematic review and meta-regression. *J Physiother*. 2016;62(2):68–82.
87. Fong DY, Ho JW, Hui BP, et al. Physical activity for cancer survivors: meta-analysis of randomised controlled trials. *BMJ*. 2012;344:e70.
88. Gerritsen JK, Vincent AJ. Exercise improves quality of life in patients with cancer: a systematic review and meta-analysis of randomised controlled trials. *Br J Sports Med*. 2016; 50(13):796–803.
89. McMillan EM, Newhouse IJ. Exercise is an effective treatment modality for reducing cancer-related fatigue and improving physical capacity in cancer patients and survivors: a meta-analysis. *Appl Physiol Nutr Metab*. 2011;36(6): 892–903.
90. Meneses-Echavez JF, Gonzalez-Jimenez E, Ramirez-Velez R. Effects of supervised multimodal exercise interventions on cancer-related fatigue: systematic review and meta-analysis of randomized controlled trials. *Biomed Res Int*. 2015;2015: 328636.
91. Meneses-Echavez JF, Gonzalez-Jimenez E, Ramirez-Velez R. Supervised exercise reduces cancer-related fatigue: a systematic review. *J Physiother*. 2015;61(1):3–9.
92. Mishra SI, Scherer RW, Geigle PM, et al. Exercise interventions on health-related quality of life for cancer survivors. *Cochrane Database Syst Rev*. 2012;8:CD007566.
93. Mishra SI, Scherer RW, Snyder C, et al. Are exercise programs effective for improving health-related quality of life among cancer survivors? A systematic review and meta-analysis. *Oncol Nurs Forum*. 2014;41(6):E326–E342.
94. Puetz TW, Herring MP. Differential effects of exercise on cancer-related fatigue during and following treatment: a meta-analysis. *Am J Prev Med*. 2012;43(2):e1–e24.
95. Scott DA, Mills M, Black A, et al. Multidimensional rehabilitation programmes for adult cancer survivors. *Cochrane Database Syst Rev*. 2013;3:CD007730.
96. Strasser B, Steindorf K, Wiskemann J, et al. Impact of resistance training in cancer survivors: a meta-analysis. *Med Sci Sports Exerc*. 2013;45(11):2080–2090.
97. Tian L, Lu HJ, Lin L, et al. Effects of aerobic exercise on cancer-related fatigue: a meta-analysis of randomized controlled trials. *Support Care Cancer*. 2016;24(2):969–983.
98. Tomlinson D, Diorio C, Beyene J, et al. Effect of exercise on cancer-related fatigue: a meta-analysis. *Am J Phys Med Rehabil*. 2014;93(8):675–686.
99. Zeng Y, Luo T, Xie H, et al. Health benefits of qigong or tai chi for cancer patients: a systematic review and meta-analyses. *Complement Ther Med*. 2014;22(1):173–186.
100. Bourke L, Smith D, Steed L, et al. Exercise for men with prostate cancer: a systematic review and meta-analysis. *Eur Urol*. 2016;69(4):693–703.
101. Newby TA, Graff JN, Ganzini LK, et al. Interventions that may reduce depressive symptoms among prostate cancer patients: a systematic review and meta-analysis. *Psychooncology*. 2015;24(12):1686–1693.
102. Persoon S, Kersten MJ, van der Weiden K, et al. Effects of exercise in patients treated with stem cell transplantation for a hematologic malignancy: a systematic review and meta-analysis. *Cancer Treat Rev*. 2013;39(6):682–690.
103. van Haren IE, Timmerman H, Potting CM, et al. Physical exercise for patients undergoing hematopoietic stem cell transplantation: systematic review and meta-analyses of randomized controlled trials. *Phys Ther*. 2013;93(4): 514–528.
104. Ni HJ, Pudasaini B, Yuan XT, et al. Exercise training for patients pre- and postsurgically treated for non-small cell lung cancer: a systematic review and meta-analysis [published online ahead of print May 5, 2016]. *Integr Cancer Ther*. (doi: 10.1177/1534735416645180).
105. Cavalheri V, Tahirah F, Nonoyama M, et al. Exercise training undertaken by people within 12 months of lung resection for non-small cell lung cancer. *Cochrane Database Syst Rev*. 2013;7:CD009955.
106. Cramer H, Lauche R, Klose P, et al. A systematic review and meta-analysis of exercise interventions for colorectal cancer patients. *Eur J Cancer Care (Engl)*. 2014;23(1):3–14.
107. Carvalho AP, Vital FM, Soares BG. Exercise interventions for shoulder dysfunction in patients treated for head and neck cancer. *Cochrane Database Syst Rev*. 2012;4:CD008693.
108. Smits A, Lopes A, Das N, et al. The effect of lifestyle interventions on the quality of life of gynaecological cancer survivors: a systematic review and meta-analysis. *Gynecol Oncol*. 2015;139(3):546–552.
109. Des Guetz G, Uzzan B, Bouillet T, et al. Impact of physical activity on cancer-specific and overall survival of patients with colorectal cancer. *Gastroenterol Res Pract*. 2013;2013: 340851.
110. Friedenreich CM, Neilson HK, Farris MS, et al. Physical activity and cancer outcomes: a precision medicine approach. *Clin Cancer Res*. 2016;22(19):4766–4775.
111. Ibrahim EM, Al-Homaidh A. Physical activity and survival after breast cancer diagnosis: meta-analysis of published studies. *Med Oncol*. 2011;28(3):753–765.
112. Je Y, Jeon JY, Giovannucci EL, et al. Association between physical activity and mortality in colorectal cancer: a meta-analysis of prospective cohort studies. *Int J Cancer*. 2013; 133(8):1905–1913.
113. Lahart IM, Metsios GS, Nevill AM, et al. Physical activity, risk of death and recurrence in breast cancer survivors: a systematic review and meta-analysis of epidemiological studies. *Acta Oncol*. 2015;54(5):635–654.
114. Li T, Wei S, Shi Y, et al. The dose-response effect of physical activity on cancer mortality: findings from 71 prospective cohort studies. *Br J Sports Med*. 2016;50(6):339–345.
115. Otto SJ, Korfage IJ, Polinder S, et al. Association of change in physical activity and body weight with quality of life and mortality in colorectal cancer: a systematic review and meta-analysis. *Support Care Cancer*. 2015;23(5):1237–1250.
116. Schmid D, Leitzmann MF. Association between physical activity and mortality among breast cancer and colorectal cancer survivors: a systematic review and meta-analysis. *Ann Oncol*. 2014;25(7):1293–1311.
117. Wu W, Guo F, Ye J, et al. Pre- and post-diagnosis physical activity is associated with survival benefits of colorectal cancer patients: a systematic review and meta-analysis. *Oncotarget*. 2016;7(32):52095–52103.
118. Zhong S, Jiang T, Ma T, et al. Association between physical activity and mortality in breast cancer: a meta-analysis of cohort studies. *Eur J Epidemiol*. 2014;29(6):391–404.
119. Courneya KS, Segal RJ, Mackey JR, et al. Effects of aerobic and resistance exercise in breast cancer patients receiving adjuvant chemotherapy: a multicenter randomized controlled trial. *J Clin Oncol*. 2007;25(28):4396–4404.
120. van Waart H, Stuiver MM, van Harten WH, et al. Effect of low-intensity physical activity and moderate- to high-intensity physical exercise during adjuvant chemotherapy on

physical fitness, fatigue, and chemotherapy completion rates: results of the PACES randomized clinical trial. *J Clin Oncol*. 2015;33(17):1918–1927.
121. Moran J, Wilson F, Guinan E, et al. Role of cardiopulmonary exercise testing as a risk-assessment method in patients undergoing intra-abdominal surgery: a systematic review. *Br J Anaesth*. 2016;116(2):177–191.
122. Santa Mina D, Scheede-Bergdahl C, Gillis C, et al. Optimization of surgical outcomes with prehabilitation. *Appl Physiol Nutr Metab*. 2015;40(9):966–969.
123. Carli F, Zavorsky GS. Optimizing functional exercise capacity in the elderly surgical population. *Curr Opin Clin Nutr Metab Care*. 2005;8(1):23–32.
124. Pedersen L, Christensen JF, Hojman P. Effects of exercise on tumor physiology and metabolism. *Cancer J*. 2015;21(2): 111–116.
125. Courneya KS, Friedenreich CM. Physical activity and cancer: an introduction. *Recent Results Cancer Res*. 2011; 186:1–10.
126. Betof AS, Dewhirst MW, Jones LW. Effects and potential mechanisms of exercise training on cancer progression: a translational perspective. *Brain Behav Immun*. 2013; 30(suppl):S75–S87.
127. Ballard-Barbash R, Friedenreich CM, Courneya KS, et al. Physical activity, biomarkers, and disease outcomes in cancer survivors: a systematic review. *J Natl Cancer Inst*. 2012; 104(11):815–840.
128. Zeng H, Irwin ML, Lu L, et al. Physical activity and breast cancer survival: an epigenetic link through reduced methylation of a tumor suppressor gene *L3MBTL1*. *Breast Cancer Res Treat*. 2012;133(1):127–135.
129. Denham J, Marques FZ, O'Brien BJ, et al. Exercise: putting action into our epigenome. *Sports Med*. 2014;44(2):189–209.
130. Berger AM, Mooney K, Alvarez-Perez A, et al. Cancer-related fatigue, version 2.2015. *J Natl Compr Canc Netw*. 2015;13(8):1012–1039.
131. Yu AF, Jones LW. Breast cancer treatment-associated cardiovascular toxicity and effects of exercise countermeasures. *Cardiooncology*. 2016;2:1–12.
132. Patnaik JL, Byers T, DiGuiseppi C, et al. Cardiovascular disease competes with breast cancer as the leading cause of death for older females diagnosed with breast cancer: a retrospective cohort study. *Breast Cancer Res*. 2011;13(3):R64.
133. Schmitz KH, Courneya KS, Matthews C, et al. American College of Sports Medicine roundtable on exercise guidelines for cancer survivors. *Med Sci Sports Exerc*. 2010;42(7): 1409–1426.
134. Rock CL, Doyle C, Demark-Wahnefried W, et al. Nutrition and physical activity guidelines for cancer survivors. *CA Cancer J Clin*. 2012;62(4):242–274.
135. Ligibel JA, Denlinger CS. New NCCN guidelines for survivorship care. *J Natl Compr Canc Netw*. 2013;11(5 suppl):640–644.
136. American Society of Clinical Oncology. *Providing High Quality Survivorship Care in Practice: An ASCO Guide*. Alexandria, VA: American Society of Clinical Oncology; 2014.
137. Campbell A, Stevinson C, Crank H. The BASES Expert Statement on exercise and cancer survivorship. *J Sports Sci*. 2012;30(9):949–952.
138. Hayes SC, Spence RR, Galvao DA, et al. Australian Association for Exercise and Sport Science position stand: optimising cancer outcomes through exercise. *J Sci Med Sport*. 2009;12(4):428–434.
139. Eakin EG, Youlden DR, Baade PD, et al. Health behaviors of cancer survivors: data from an Australian population-based survey. *Cancer Causes Control*. 2007;18(8):881–894.
140. Short CE, James EL, Girgis A, et al. Main outcomes of the Move More for Life Trial: a randomised controlled trial examining the effects of tailored-print and targeted-print materials for promoting physical activity among post-treatment breast cancer survivors. *Psychooncology*. 2015;24 (7):771–778.
141. Galvão DA, Newton RU, Gardiner RA, et al. Compliance to exercise-oncology guidelines in prostate cancer survivors and associations with psychological distress, unmet supportive care needs, and quality of life [published online ahead of print June 18, 2015]. *Psychooncology*. (doi:10.1002/pon.3882).
142. Berger AM, Gerber LH, Mayer DK. Cancer-related fatigue: implications for breast cancer survivors. *Cancer*. 2012;118(8 suppl):2261–2269.
143. American College of Surgeons Commission on Cancer. *Cancer Program Standards 2012: Ensuring Patient-Centered Care*. Chicago, IL: American College of Surgeons; 2011.