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Hao Luo
Edith Cowan University

Daniel A. Galvão
Edith Cowan University

Robert U. Newton
Edith Cowan University

Ciaran M. Fairman

Dennis R. Taaffe
Edith Cowan University

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Hao Luo, MEd^{1,2} , Daniel A. Galvão, PhD²,
Robert U. Newton, PhD^{2,3,4} , Ciaran M. Fairman, PhD² ,
and Dennis R. Taaffe, PhD, DSc, MPH^{2,3} 

Abstract

Physical inactivity is a major concern in cancer patients despite the established preventative and therapeutic effects of regular physical exercise for this patient group. Sport not only plays an important role in supporting the development and maintenance of a physically active lifestyle but also is increasingly used as a health promotion activity in various populations. Nevertheless, the potential of sport as an effective strategy in the prevention and management of cancer has gained little attention. Based on the scant evidence to date, participation of cancer patients in supervised, well-tailored sport programs appears to be safe and feasible and is associated with an array of physical and psychological benefits. We propose that sport participation may serve as an alternative strategy in the prevention of cancer and sport medicine in the management of cancer. As with the traditional exercise modes, benefits derived from sport participation will be dependent on the sport undertaken and the physical/physiological, motor, and cognitive demands required. To this end, further work is required to develop a solid evidence base in this field so that targeted sport participation can be recommended for cancer patients.

Keywords

sport medicine, prevention, management, cancer, exercise

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Introduction

Cancer is a worldwide problem and imposes a tremendous disease burden. In 2018, the expected number of new cancer cases globally was 18.1 million.¹ For most cancer patients, the disease and related treatments will have a severe adverse effect on physical, mental, and social health with the most common symptoms being fatigue,^{2,3} pain,^{4,5} nausea,^{6,7} reduced functional capacity,^{8,9} depression,^{10,11} anxiety,^{3,12} and social disconnectedness.^{13,14} In addition, cancer patients are also more vulnerable to other chronic comorbidities such as cardiovascular disease, diabetes, osteoporosis, and sarcopenia.¹⁵⁻¹⁷ Therefore, strategies that can reduce the risk of cancer and mitigate a wide range of health sequelae related to the disease and its treatments are of clinical importance.

Regular physical exercise is associated with a reduced risk of many types of cancers^{18,19} and cancer recurrence²⁰ as well as attenuated treatment-related symptoms in cancer patients.^{15,21,22} However, physical inactivity or an insufficient level of physical activity, irrespective of a cancer diagnosis, remains a major concern. According to data recently published,²³ worldwide 27.5% of adults in 2016 (rising

from 23.3% in 2010) did not meet the World Health Organization recommendations on minimum physical activity for health, that is, at least 150 minutes of moderate-intensity, or 75 minutes of vigorous-intensity physical activity per week, or equivalent combinations. With regard to cancer patients in developed countries, the prevalence of a sedentary lifestyle is much higher. The National Cancer Institute recently reported²⁴ that 34.8% of adult cancer patients engaged in no physical activity in 2016. In addition, an estimated 88% of prostate cancer patients in Australia do not meet the recommended physical activity level, of which 47.5% are totally inactive²⁵; while in

¹Guangdong Vocational Institute of Sport, Guangzhou, Guangdong, China

²Edith Cowan University, Joondalup, Western Australia, Australia

³University of Queensland, Brisbane, Queensland, Australia

⁴The University of Hong Kong, Hong Kong

Corresponding Author:

Dennis R. Taaffe, Exercise Medicine Research Institute, Edith Cowan University, 270 Joondalup Drive, Joondalup, Western Australia 6027, Australia.

Email: d.taaffe@ecu.edu.au



Canada, only 21% of cancer patients were considered active in 2005,²⁶ with similar results also reported in the 2009-2010 National Health Survey round.²⁷

Sport participation is commonly advocated by policy makers to facilitate the development and maintenance of an active lifestyle in the general public. As suggested by Khan and colleagues,²⁸ sport contributes to a healthier nation through improved physical activity level of the population. Individuals who play sports are more likely to meet the recommended physical activity level for health than those who are not active in sport.²⁹ Sport, through varied forms of interactive (such as partnered-based and group-based activity) and match/contest play, may have the potential to increase participation rate and maintain exercise continuance in various populations.^{30,31}

In recent years, a range of sports as a health promotion activity has been examined in the noncancer populations. A period of participation in organized sport activities were reported to result in a broad spectrum of cardiometabolic and musculoskeletal benefits in both the apparently healthy population and patients with common chronic diseases such as diabetes, hypertension, and osteoporosis.^{32,33} In addition, sport participation is often associated with a wide array of psychological benefits including enhanced self-esteem and self-efficacy and a general feeling of well-being.³⁴ However, the potential of sport as an effective intervention in the management of cancer has gained little attention. This may be partially related to a prevailing dogma that vigorous exercise, which would include a wide range of sport activities, may increase the risk of immunosuppression thereby compromising the immune system against tumor cells. However, a recent review by Campbell and Turner³⁵ dispelled such a misconception and concluded that acute vigorous exercise may actually enhance immunological health.

To date, there is no definitive evidence that would preclude sport participation in cancer patients. On the contrary, a recent review by Ruiz-Casado et al³⁶ synthesizing numerous preclinical and human mechanistic studies concluded that an active lifestyle (and this could be achieved through exercise and sport) through multiple biological mechanisms (such as vascular normalization, myokine secretion, etc) may potentially exert an antitumorigenic effect. In addition, emerging clinical trials^{37,38} have showed preliminary efficacy of prescribed sport activities (such as soccer, triathlon, wall climbing, and dragon boat racing) in patients with common types of cancers (predominantly prostate and breast cancers) on a variety of supportive care outcomes. Therefore, we propose that participating in structured sport programs may serve as an alternative strategy to conventional clinic-based and community-based physical exercise programs and could be implemented more widely in the prevention and management of cancer. In this review, we discuss the positive association between sport participation and the risk of cancer and cancer-specific and overall

mortality, present studies reporting sport activities in the management of cancer, provide initial recommendations on sport participation for cancer patients, and finally discuss future opportunities for research in this emerging field of oncology.

In order to facilitate discussion on this topic, in this article sport is defined as an activity requiring physical effort and skills with predetermined rules and objectives, which typically requires multifaceted physical and physiological demands depending on various factors such as movement components and forms of play.^{39,40} Evidence regarding sport participation for cancer management in this review was obtained through a systematic literature search. Briefly, electronic searching was undertaken in PubMed, Web of Science, SPORTDiscus, PsycINFO, and Google Scholar databases using keywords for population (cancer OR tumor OR malignancy) AND keywords for intervention (sport OR individual sports OR team sports OR specific sport disciplines based on the current list of Summer and Winter Olympics), with databases searched up until May 2019. In addition, the reference lists of relevant primary and secondary studies (review articles, commentaries, and editorials) were also checked to identify potential eligible studies. Due to the limited evidence on sports for cancer management, studies on exercise programs primarily composed of sport-related activities (including sport skills practice and targeted physical training preparation for a specific sport such as triathlon) in cancer patients were also included in this review.

Sport, Cancer Risk, and Cancer Mortality

It is well established that sport participation reduces the risk of all-cause mortality and improves life expectancy in various populations.⁴¹⁻⁴⁴ In the cancer context, individuals repeatedly exposed to sports (including the general public, amateur/collegiate athletes, and professional/elite athletes) also have decreased risk of cancer and cancer-related death, although disparity exists in their training levels and physical condition. An early observational study⁴⁵ suggested that regular sport participation led to a lower rate of cancer incidence in middle-aged and older men. In a similar fashion, life-time sport-active adult women have a reduced incidence of breast cancer (>50% reduction) compared with age-matched nonactive women with stronger protective effects observed in those with earlier sport engagement and higher activity level.⁴⁶ In amateur/collegiate athletes with higher training volume and intensity, a lower rate of cancer risk has also been observed. An early large-scale survey⁴⁷ in 5398 female former collegiate athletes and nonathletes indicated that long-term participation in organized sport activities was associated with a reduced risk of not only breast cancer but also gynecologic cancers; while a 15-year follow-up⁴⁸ of these subjects also indicated that previous

Table 1. Summary of Benefits of Sport Participation in Untrained, Healthy/Asymptomatic Individuals and Noncancer Patients.

Increased	Decreased
Muscle mass ^{54,60-62}	Body fat ^{54,56,58,60-63}
Bone mineral density ^{59,61,62,64}	Heart rate ^{55,56,61-63}
Cardiorespiratory fitness ^{42,54-58,60-62,64}	Blood pressure ^{55-58,60,61}
Muscular strength ^{42,63}	Blood glucose ^{42,58,60}
Functional capacity ^{42,63}	Insulin resistance ^{58,63}
Physical performance ^{61,62}	Plasma triglycerides ^{58,60,61,63}
Mental wellness ^{42,62}	Low-density lipoprotein cholesterol ^{60,63}
	Proinflammatory cytokines ^{54,58}
	Stress and anxiety ⁴²

college sports experience conferred a life-time prophylactic effect against breast cancer. Recently, a retrospective study⁴⁹ in French athletes demonstrated that the longer life expectancy in elite athletes of numerous sports was primarily attributed to the lower risk of cancer.

Regarding cancer mortality, several cohort studies⁵⁰⁻⁵² and a meta-analysis⁵³ have demonstrated that, in comparison with the general population, elite professional athletes and Olympians (mostly men) have fewer cancer-specific deaths. As reported in the meta-analysis,⁵³ the pooled standard mortality ratio for cancer was 0.60 (95% confidence interval = 0.38-0.94) in professional or Olympic-level athletes. Therefore, encouraging evidence suggests that engagement in sports may be conducive in reducing cancer incidence and cancer-specific and overall mortality in adult men and women with varied sport training backgrounds, which may be attributable to a healthier lifestyle including less smoking and more physical activity in sport active people.⁵⁰

Sport and Cancer Management

Work to date indicates that sport participation as a health promotion activity has a broad spectrum of physical and psychological benefits in not only healthy/asymptomatic individuals but also clinical populations with common cardiometabolic comorbidities including hypertension, diabetes, and obesity regardless of age, sex, and socioeconomic background. A summary of beneficial effects resulting from a period of participation in individual and team-based sport activities including golf,⁴² rugby,^{54,55} soccer,⁵⁶⁻⁶⁰ basketball,⁶¹ handball,⁶² and floorball^{63,64} in untrained, healthy/asymptomatic individuals and noncancer patients is presented in Table 1. Likewise, a small but growing number of studies⁶⁵⁻⁷⁹ have shown that regular participation in individual and team-based sports (including triathlon, wall climbing, dragon boat racing, and soccer) is also effective as an exercise therapy for persons previously diagnosed with cancer (mostly breast and prostate cancer) in alleviating disease-related and treatment-related adverse effects on physical, physiological, and psychological function (Tables 2 and 3).

Physical and Physiological Benefits

Positive adaptations in physical performance, functional ability, cardiovascular fitness, and body composition have been observed in cancer patients following short-term to long-term participation in structured soccer and dragon boat (team paddling in a heavy, dragon-shaped boat) programs with some of the changes more notable than those engaging in other fitness activities (Table 2). For example, a short-term (8-week) program of dragon boating resulted in significant improvement in muscular strength and aerobic capacity in adult cancer patients.⁷¹ In middle-aged and older breast cancer (BCa) patients,⁷⁵ cardiac diastolic function substantially improved following long-term (48 months) participation in dragon boating compared with healthy women undertaking predominantly traditional cardiorespiratory activities including running, cycling, and swimming. In addition, BCa patients engaged in a twice-weekly dragon boat program for over 6 months had lower lymphedema incidence than a comparison group undertaking other forms of aerobic exercise including Pilates, yoga, tai-chi, jogging, and walking.⁷⁷ A randomized controlled trial (RCT) demonstrated that recreational soccer training up to 32 weeks in duration induced marked improvement in lean body mass,⁷³ bone mineral density,⁷⁶ and lower limb muscle strength and function⁷⁶ in men with locally advanced or metastatic prostate cancer (PCa) undergoing androgen deprivation therapy. In a subsequent 5-year follow-up,⁷⁸ the beneficial effects on the skeleton were maintained through regular participation in self-organized recreational soccer games with significant improvement observed in femoral neck bone mineral density compared with those undergoing resistance training, aerobic exercise, and yoga.

Beyond soccer and dragon boat racing, other sports including triathlon and wall climbing (adapted indoor rock climbing), albeit less examined in cancer patients, have also shown initial efficacy in improving physical functioning (Table 2). For instance, a 14-week program culminating with participation in a sprint distant triathlon (800-m swimming, 20-km cycling, and 5-km running), which comprised

Table 2. Physical and Physiological Benefits of Sport Participation in Cancer Patients.

Author (Year)	Study Design	Participants (Number, Cancer Status, Gender, Mean Age)	Activity	Training Program (Duration, Frequency, Session Duration)	Changes for Intervention/ Sport Participation Group
Carter et al ⁷¹ (2012)	NRCT	INT = 68, adult cancers, 53.8 years COMP = 52, adult cancers, 58.2 years	Dragon boat paddling Group-based walking	3 rounds, 8 weeks/round, 2/week, 60 min/session NR	Upper-limb strength ↑ ^{a,b} Aerobic capacity ↑ ^a Lower-limb strength ↑ ^a
Uth et al ⁷³ (2014) ^c	RCT	INT = 29, PCa, male, 67.1 years	Recreational soccer	12 weeks, 2-3/week, 45-60 min/session	LBM ↑ ^b
Stefani et al ⁷⁵ (2015)	Intervention study comparison with healthy controls	CON = 28, PCa, male, 66.5 years INT = 55, BCa, female, 57 years COMP = 36, healthy, female	No activity prescribed Dragon boat Running (21), cycling (2), tennis (5), canoeing (1), riding (1), scuba diving (1), swimming (3), and fitness (2)	48 months, 2/week, 120 min/session 48 months, 3/week, ≥ 120 min/session	A peak ↑ ^{a,b} IVRT ↑ ^{a,b} E _s ↑ ^a
Uth et al ⁷⁶ (2016) ^c	RCT	As above (see Uth et al, 2014)	As above (see Uth et al, 2014)	32 weeks, 2-3/week, 45-60 min/session	(R) Total hip BMD ↑ ^b Stair climbing ↓ ^{a,b} IRM ↑ ^a Sit-to-stand ↑ ^a
Ng et al ⁸⁰ (2017)	SAT	21, BCa, female, 48 years	Team triathlon training with additional home-based program	Triathlon training: 14 weeks, 2/week, 90 min/session; home-based program: 14 weeks, 3-4 (3-7 hours)/week	6-minute walk test ↑ ^a VO _{2max} ↑ ^a
Crawford et al ⁸¹ (2017)	RCT	INT = 24, GCa, female, 52.5 years CON = 11, GCa, female, 54.1 years	Wall climbing No activity prescribed	8 weeks, 2/week, 120 min/session	6-minute walk test ↑ ^{a,b} Hand-grip strength ↑ ^{a,b} 30-second arm curls ↑ ^{a,b} 30-second chair stands ↑ ^{a,b} Sit-and-reach ↑ ^{a,b} 8-foot up-and-go ↑ ^{a,b} Lymphedema ↓ ^a
Iacorossi et al ⁷⁷ (2019)	OS	Group A = 50, BCa, female Group B = 50, BCa, female	Dragon boat Compression therapy, lymphatic drainage, Pilates/yoga/tai-chi, jogging/walking Self-organized recreational soccer	> 6 months, 2/week > 6 months, 2/week	
Uth et al ⁷⁸ (2018) ^c	NRCT	INT = 11, PCa, male, 71.3 years CON = 11, PCa, male, 71.3 years	Resistance training, aerobic exercises and yoga	5 years of follow-up with no specific prescription 5 years of follow-up with no specific prescription	(R) Femoral neck BMD ↑ ^b Resting HR ↓ ^a

Abbreviations: ↑, increase; ↓, decrease; A peak, peak mitral annular velocity during late diastole; BCa, breast cancer; BMD, bone mineral density; CON, control group; COMP, comparison group; Ea, the time to onset of early diastolic velocity of the mitral annulus; F, female; GCa, gynecologic cancer; HR, heart rate; INT, intervention group; IVRT, isovolumic relaxation time; LBM, lean body mass; min, minute; NR, not reported; NRCT, nonrandomized controlled trial; OS, observational study; PCa, prostate cancer; R, right; RCT, randomized controlled trial; RM, repetition maximum; SAT, single-arm trial; VO_{2max}, maximum oxygen uptake.

^aStatistically significant from baseline.

^bStatistically significant from control/comparison group.

^cSame trial with different intervention duration and outcomes reported.

Table 3. Psychological Benefits of Sport Participation in Cancer Patients.

Author (Year)	Study Design	Qualitative Data Collection	Participants (Number, Gender, Mean Age/Age Range)	Activity	Conclusion/Changes
Mitchell et al ⁶⁵ (2002)	ROS	Open-ended interviews	6, BCa, female, 43-75 years	Dragon boating	Enhancement of well-being for BCa patients through participating in dragon boating.
Unruh et al ⁶⁶ (2004)	ROS	Semistructured interviews	3, BCa, female, early 50s	Dragon boating	Dragon boating was associated with improved emotional well-being and energy for BCa patients.
Culos-Reed et al ⁶⁷ (2005)	POS	—	109, BCa, female, 52.9 years	Dragon boating	BCa patients participating in dragon boating experienced comparable improvement in team cohesion and health-related QoL with subclinical population and healthy women, respectively.
Sabiston et al ⁶⁸ (2007)	ROS	Semistructured interviews	20, BCa, female, 58.7 years	Dragon boating	Dragon boating was psychologically beneficial for BCa patients in facilitating social support and regaining personal control.
Mitchell et al ⁶⁹ (2007)	POS	Semistructured and open-ended interviews	10, BCa, female, 35-70 years	Dragon boating	BCa patients experienced improved wellness and posttreatment QoL.
McDonough et al ⁷⁰ (2011)	POS	Semistructured interviews	17, BCa, female, 51.2 years	Dragon boating	Participating in dragon boating is effective in developing social relationships and support for BCa patients.
Carter et al ⁷¹ (2012)	NRCT	—	INT = 68, adult cancers, 53.8 years COMP = 52, adult cancers, 58.2 years	Dragon boating	Team cohesion ^{↑a} QoL ^{↑b}
Ray et al ⁷² (2013)	Mixed-methods sequential explanatory study	Semistructured interviews	Quantitative analysis = 100, BCa, female Qualitative analysis = 15, BCa, female	Group-based walking Dragon boating	Emotional well-being ^{↑b} Social well-being ^{↑b} Spiritual well-being ^{↑b} Health-related QoL ^{↑b}
Bruun et al ⁷⁴ (2014)	POS	Focus group interviews	26, PCa, male, 67.1 years	Recreational soccer	Recreational football may facilitate physical exercise participation and adherence in PCa patients.
Robinson et al ⁸⁶ (2016) ^c	SAT	Participants observation Focus group interviews Individual phone interviews	11, BCa, female, 50.9 years	Team triathlon training with additional home-based program	Team participation in a supportive environment was crucial in exercise initiation and maintenance in BCa patients.
Ng et al ⁸⁰ (2017) ^c	SAT	—	21, BCa, female, 48 years	Team triathlon training with additional home-based program	QoL ^{↑b} Barriers to physical activity ^{↓b}
Iacorossi et al ⁷⁷ (2018)	ROS	—	Group A = 50, BCa, female Group B = 50, BCa, female	Dragon boating Compression therapy, lymphatic drainage, Pilates/yoga/tai-chi, jogging/walking	QoL ^{↑a,b}
Bjerre et al ⁷⁹ (2019)	pRCT	—	INT = 109, PCa, male, 67.8 years CON = 105, PCa, male, 69 years	Recreational soccer Physical activity advice and rehabilitation	Mental health ^{↑a}

Abbreviations: [↑], increase; [↓], decrease; BCa, breast cancer; COMP, comparison group; CON, control group; INT, interventional group; NRCT, nonrandomized controlled trial; PCa, prostate cancer; POS, prospective observational study; pRCT, pragmatic randomized controlled trial; QoL, quality of life; ROS, retrospective observational study; SAT, single-arm trial.

^aStatistically significant from control/comparison group.

^bStatistically significant from baseline.

^cSame trial with different data collection and outcomes reported.

twice-weekly team triathlon training and 3 to 7 hours per week home-based exercise, significantly increased maximal oxygen uptake in BCa patients.⁸⁰ In addition, in undertaking an 8-week wall climbing program (including various specific skills practice and climbing strategy drills) in gynecologic cancer patients, significant improvement was observed in aerobic capacity, muscular strength, agility, dynamic balance, and flexibility.⁸¹

The improvements observed in cancer patients are possibly related to the physical and physiological demands of the respective sport activity. Soccer is a lower limb-driven intermittent locomotor activity with various vigorous, high-impact movements,⁸² which predominantly results in adaptations in cardiorespiratory and lower body musculoskeletal systems. Dragon boat racing, like most paddle sports (such as canoeing and rowing), is a non-weight-bearing, upper limb-driven endurance activity, which predominantly may result in changes in the cardiovascular system and upper body muscle endurance.⁸³ Triathlon is a multisport endurance event consisting of 3 continuous and sequentially performed races including swimming, road cycling, and distance running.⁸⁴ Wall climbing, which is adapted from an outdoor sport—rock climbing, primarily requires muscular strength/power, aerobic endurance, flexibility, and balance in climbers.⁸⁵

Psychological and Social Benefits

In addition to physical and physiological endpoints, participation in sports are accompanied by psychological and social benefits in cancer patients with the most frequently reported positive findings being enhanced psychological well-being and quality of life (QoL; Table 3). For instance, various dimensions of psychological well-being (such as emotional, social, and spiritual well-being) in adult BCa patients were enhanced through participating in dragon boat racing.^{65,66,72} In addition, health-related QoL was also improved in BCa patients^{67,69,72,80} and other unspecified adult cancer patients⁷¹ after a period of dragon boating or triathlon training; and the improvement in BCa patients was comparable with age-matched healthy women.⁶⁷ A recent retrospective study⁷⁷ indicated that BCa patients who participated in a short-term low-frequency dragon boat program had better QoL compared with a group undertaking commonly used therapies (such as compression therapy and lymphatic drainage) and aerobic exercise including Pilates, yoga, tai-chi, jogging, and walking. Regaining of social support and personal control was also observed in middle-aged BCa patients following long periods (19 months to 8 years) of engagement in dragon boat programs.^{68,70} Moreover, both observational⁶⁷ and intervention-based⁷¹ studies indicate that adult cancer patients (mainly BCa) within a team format developed strong cohesiveness after a period of dragon boating, which was at a higher

level compared with those undertaking other group-based activity (eg, walking)⁷¹ and comparable with those in female sport teams,⁶⁷ and was crucial to exercise initiation and maintenance.⁸⁶ Last, it has been reported that participation in small-sided soccer games by men with PCa is accompanied by improved mental health.⁷⁹

Aside from the studies dedicated to a specific sport program mentioned above, cross-sectional studies^{87,88} also indicate that participation in a range of sports (such as golf, swimming, hockey, tennis, etc) after a cancer diagnosis is associated with improved psychosocial outcomes in patients. The mechanisms underlying the improvements in psychosocial functioning in cancer patients participating in sports are possibly related to the social/interactive, supportive, and enjoyable/challenging environment featured in sports and in particular team sports.^{34,89,90} In team-based sports, participants are required to work closely toward a common goal, which tends to generate greater bonding among team peers compared with undertaking other exercise modalities. In addition, there is also evidence that cancer patients consider peer support and shared experience with co-participants as motivational factors in their sport participation.^{86,91,92}

Safety and Feasibility

In undertaking sport activities, the cancer patient's safety needs to be ensured. With regard to exercise in general, the Exercise and Sports Science Australia (ESSA) position stand⁹³ and the American College of Sports Medicine (ACSM) roundtable statement on exercise for cancer patients²² concluded that exercise training is well tolerated during and after cancer treatment and is safe in patients of common cancers. In addition, numerous systematic reviews and meta-analyses⁹⁴⁻¹⁰⁵ published within the past decade further support this conclusion, adding that resistance-based and aerobic-based exercises, irrespective of mode, intensity, duration, frequency, and supervision, are safe in common adult and pediatric cancer patients at different stages or having received different therapies, with either no adverse events or only minor exercise-related injuries (such as muscle soreness, sprains, and strains) and discomforts observed.

Similar findings were also reported in patients with breast, gynecologic, and prostate cancers undertaking varied sport programs, although the incidence and frequency of adverse events or injuries were not always explicitly reported by the investigators (Table 4). For example, in nonmetastatic BCa patients following intensive treatments, no adverse events and only one case of a non-training-related injury were reported in a 4-year supervised dragon boat program⁷⁵ and a 14-week team triathlon training program,⁸⁰ respectively. Similarly, in an 8-week wall climbing program in 24 gynecologic cancer survivors,⁸¹ only one participant suffered a leg scratch during training. Even in

Table 4. Safety and Feasibility Outcomes of Sport Participation in Cancer Patients.

Author (Year)	Sport Participants (Number, Sex, Mean Age/Age Range, Cancer Type, Mean Diagnosed Years, Ongoing/Received Treatments)	Training Period, Frequency, Session Duration	Adverse Events (Incidence, Severity/Nature)	Feasibility Outcomes (Recruitment, Retention, Attendance Rate)
Carter et al ⁷¹ (2012)	Dragon boating = 68, male and female, 53.8 years, mostly (~85%) stage I-IV adult cancers (BCa, PCa, and other unspecified types), 4.4 years after diagnosis, mostly (75%) after cancer treatments.	3 rounds, 8 weeks/round, 2/ week, 60 min/session	NR	Higher average attendance than the controls undertaking group-based walking (12.7 vs 10.8, <i>P</i> = .002).
Uth et al ⁷² (2014) ^a	Soccer = 29, male, 67.1 years, advanced or locally advanced PCa (including those with bone metastasis), over 1 year after diagnosis, ADT > 1 year.	12 weeks, 2-3/week, 45-60 min/session	Five participants (~17%) had musculoskeletal injuries including fibular fracture (<i>n</i> = 2), partial Achilles tendon rupture (<i>n</i> = 1), ankle sprain (<i>n</i> = 1), quadriceps muscle strain (<i>n</i> = 1), but most recovered after conservative treatment and resumed training	Attendance rate = 76.5%; ~85% HRmax.
Stefani et al ⁷⁵ (2015)	Dragon boating = 55, female, 57 years, nonmetastatic BCa, 1 year after diagnosis and treatments (total mastectomy, quadrantectomy, chemotherapy, and radiotherapy).	48 months, 2/week, 120 min/ session	No adverse events	NR
Uth et al ⁷⁶ (2016) ^a	As above (see Uth et al. 2014).	32 weeks, 2-3/week, 45-60 min/session	As above (see Uth et al. 2014).	Attendance rate = 46.2%
Ng et al ⁸⁰ (2017)	Triathlon = 21, female, 48 years, stage 0-III BCa, 4 years post treatments (surgery, chemotherapy, radiotherapy, and hormonal therapy).	14 weeks, 2/week, 90 min/ session	Unspecified non-training-related injury (<i>n</i> = 1)	Retention rate = 84%
Crawford et al ⁸¹ (2017)	Wall climbing = 24, female, 52.5 years, localized or metastatic GCa (cured or in remission), mostly (67%) less than 2 years of diagnosis, intensive treatments completed (including surgery, radiotherapy, and chemotherapy).	8 weeks, 2/week, 120 min/ session	Leg scratch (<i>n</i> = 1, no medical care and training discontinuation required)	Attendance rate = 84%
Uth et al ⁷⁸ (2018) ^a	Soccer = 11 (only 9 reported their attendance and injury incidence), male, 71.3 years, advanced or locally advanced PCa, over 1 year after diagnosis, 45% of the participants with ADT.	5 years of self-organized, unsupervised soccer training	Unspecified sport-related injury (<i>n</i> = 2)	Average weekly attendance = 1.7 times; mostly >80% HRmax (based on monitoring in 3 selected sessions)
Bjerre et al ⁷⁹ (2019)	Soccer = 109, male, 67.8 years, early-stage and advanced PCa (including bone metastasis), 3 year after diagnosis, intensive treatments completed (including prostatectomy, chemotherapy, and radiotherapy) and 56% on ADT.	6 months, 2/week, 60 min/ session	Equivalent or even less adverse events observed in the soccer training compared with in the controls (in total, soccer vs controls = 23:30), including falls (soccer vs controls = 10:6), fracture (soccer vs controls = 1:1), hospitalization (soccer vs controls = 11:22), and cancer-specific death (soccer vs controls = 1:1); soccer-related injuries (<i>n</i> = 60, minor injuries such as muscle strain and sprains accounting for 97% of the total injuries).	Recruitment rate = 90%; retention rate = 98% (12 weeks) and 95% (6 months); attendance rate = 64% (12 weeks) and 59% (6 months)

Abbreviations: ADT, androgen deprivation therapy; BCa, breast cancer; GCa, gynecologic cancer; HRmax, maximum heart rate; NR, not reported; PCa, prostate cancer.

^aSame trial with different intervention duration and outcomes reported.

more advanced ($\geq T3n$) PCa patients (including those with bone metastases) undergoing androgen deprivation therapy, the incidence of adverse events was not severe with only 5 of the 29 participants experiencing a musculoskeletal injury in a 32-week supervised trial^{73,76} and 2 of 11 soccer participants suffering an injury in 5 years of unsupervised soccer training.⁷⁸ Moreover, in a recent large-scale RCT in men with early-stage and advanced PCa⁷⁹ participating in 6 months of twice-weekly supervised soccer, the injury rate in the soccer players was equivalent to that in the control group receiving exercise instruction by telephone and rehabilitative therapy, with the vast majority of injuries minor including muscle strain or sprains. Although participating in soccer games appears to be associated with a risk of injury, men with PCa might instead perceive the risk a positive reinforcement of their masculinity.¹⁰⁶

In addition to the safety profile, the feasibility outcomes observed in various cancer patients undertaking sport-based programs also appears promising (Table 4). For instance, in the wall climbing program in women diagnosed with gynecologic cancer, on average 13.5 out of 16 sessions were attended.⁸¹ Similarly, in the 14-week, twice-weekly team triathlon program for BCa patients, 21 out of 25 participants completed the training program and assessments.⁸⁰ Carter et al reported that adult cancer patients undertaking dragon boating on average attended more sessions than controls performing group-based walking over an 8-week period.⁷¹ However, attendance may alter with program duration as evidenced in the soccer program by Uth and colleagues, with attendance of ~77% at 12 weeks⁷³ but only 46% at 32 weeks.⁷⁶ Last, in a 6-month soccer trial with early-stage and advanced PCa patients,⁷⁹ 214 out of 238 eligible participants were recruited with a retention rate of 95% and attendance of 59% at 6 months.

Therefore, the preliminary evidence suggests that participation in supervised, well-tailored sport programs by cancer patients is feasible and is of low risk, and may only result in mild sport injuries that are common for people engaging in any form of physical exercise. Nevertheless, additional studies are necessary to develop this evidence base.

Opportunities and Recommendations for Sport Programs in Cancer

Classification of sports based on the principle of specificity is an essential prerequisite underpinning the effectiveness of a sport program for cancer management, as sport activities with homogeneous physical and physiological profiles will result in similar responses and adaptations for the participants. Almost all sports require a combination of coordination, strength/power, speed, and aerobic and anaerobic fitness. In accordance with the predominant characteristics involved in a particular sport and the potential physiological loads imposed by motor activity and movement

demands,¹⁰⁷⁻¹⁰⁹ sport disciplines can be divided into 4 categories, that is, skill-dominant/precision sports, strength/power-dominant sports, endurance-dominant sports, and mixed sports. However, it should be noted that there are multiple ways to categorize sports.¹¹⁰ Although sport activities within a category share a similar profile, variability in the demands of different energy systems and movement components may still exist across the different sports within a category due to intrinsic patient-centered characteristics, such as skill level and motivation, and extrinsic factors such as skills/competitiveness of the opponent/competitors or fellow team members and environmental factors.

- *Skill-dominant/precision sports.* We define skill-dominant/precision sports as activities requiring a higher level of bodily coordination and skills to achieve a precise execution of movement (eg, golf, table tennis, gymnastics, diving, and archery). In general, skill-dominant sports include only a short bout of action that predominantly requires cognitive function, body control, quick reaction, and physical strength with only modest stress to the cardiorespiratory system.
- *Strength/power-dominant sports* are activities requiring a higher level of physical strength and power output (eg, weightlifting, speed skating, shotput, sprinting, and triple jump). In general, strength/power-dominant sports include rapid forceful motion against body weight and/or an external resistance, which predominantly requires a higher rate of force development.
- *Endurance-dominant sports* are activities requiring both cardiorespiratory and muscle endurance (eg, canoeing, road cycling, swimming, rowing, and orienteering). In general, endurance-dominant sports basically involve cyclic motion that requires sustained, repeated contraction of large muscle groups and maximum involvement of the cardiorespiratory system with comparatively lower demands on muscle strength and power.
- *Mixed sports.* We define mixed sports as activities requiring involvement of a wide range of systems with nearly equal demands in technical skills, strength/power, speed, aerobic, and anaerobic fitness (eg, soccer, basketball, ice/field hockey, rugby, and boxing). In general, mixed sports include an assortment of repetitive dynamic movement components such as jogging, sprinting, acceleration, deceleration, stopping and cutting, jumping, and so on.

Evidence indicates that people participating in different types of sport demonstrate different physical and physiological adaptations. For example, a cross-sectional study¹¹¹ in frail older women indicated that participating in table

tennis resulted in better cognitive function than nonparticipants. In addition, older golfers showed better balance control than age-match nongolfers.¹¹² Male and female athletes in higher resistance and impact-loading sports consisting mainly of strength/power-dominant (such as judo and karate) and mixed sports (such as soccer) show greater muscle mass and bone density compared with non-weight-bearing or low-impact sports (such as swimming and water polo) with more increases observed in athletes of longer participation and at sites of more intensive stress.¹¹³⁻¹¹⁶ In a similar fashion, sport activities with higher aerobic components (such as swimming) elicit more improvement in cardiopulmonary function.¹¹⁷

Accordingly, along with the aforementioned positive changes in cancer patients undertaking various sport-based programs,^{71,73,75-78,80,81} we propose that sport activities with similar profiles and comparable exercise load stimulus would also result in similar beneficial effects in cancer patients. Specifically, cancer patients participating in endurance-dominant sports would predominantly improve cardiovascular fitness, and cancer patients participating in strength/power-dominant sports would predominantly gain lean mass, muscular strength, endurance, and bone density. For mixed sports, positive adaptations in circulatory and respiratory systems as well as in body composition and functional ability would be elicited. In addition, cancer patients with treatment-related cognitive deficit would benefit from undertaking skill-dominant/precision sports. However, as variability of demands in the body systems exist across sports within a category, substantial secondary adaptations would also be possible in cancer patients through regular participation.

Given the paucity of evidence with regard to sport participation for cancer management as well as the diversified characteristics across sports, specific recommendations on dosage for a particular sport in cancer patients still remains impractical. However, the general guidelines for physical exercises proposed by ACSM²² and ESSA⁹³ could be considered as a basis for dosage prescription (ie, weekly 60-150 minutes of exercise at a moderate to vigorous intensity).

Additional Considerations

Several other factors should be taken into account when planning and implementing a sport program for cancer patients. First, a sport program should always be practical for cancer patients. To this end, it is vital to simplify technical skills, reduce exercise load, and avoid high-risk activity components (such as body contact) of a sport activity according to participant's physical capacity at different phases of treatment.¹¹⁸ For example, in mixed sport events (such as soccer and basketball), playing rules, field-of-play, number of players per side, and game duration can be adjusted to manage the training load and avoid risk factors.

Second, a selected sport activity should appeal to potential participants. In this regard, the participant's personal preference and previous experience in sport participation should be taken into consideration when prescribing sport programs.¹¹⁸⁻¹²¹ Third, a separate familiarization period before regular sport participation may be required for participants to learn and acquire the necessary skills related to the subsequent sport program, which should also be regarded as an indispensable part of a sport program to further ensure safety and maintain the participant's playing interest and enjoyment as well as facilitate exercise continuance. Finally, in order to increase the participation rate of cancer patients in a sport program, the prevalence of different sport events within a region and availability of facilities should be considered.¹²² For example, rugby is one of the most played and widely watched sports in Australia among men and women across all age groups, while basketball is one of the most popular sports in the United States. However, apart from referring to sport popularity and facility availability, provision of a list of sport program options for cancer patients may assist in contributing to a higher sport uptake and adherence rate.¹²³

Despite all these considerations, a cautious attitude should still be taken when implementing sport programs in cancer patients. Overall, for health and fitness, it is highly recommended for practitioners who are interested in conducting sport medicine programs in cancer patients to follow the general contraindications and reasons for starting and stopping exercise proposed in the ACSM roundtable statement.²² In addition, special attention needs to be attached to patients undergoing active treatments and when implementing sport programs outdoors.

Perspectives and Future Directions

Although the benefits of physical exercise for cancer management has been well established, insufficient engagement and low adherence rate in cancer patients often compromise the beneficial effects of regular exercise training. Evidence to date indicates that in cancer patients the lack of ability and motivation, as well as the tedious and repetitive nature of exercise, are among the frequently reported barriers to regular exercise participation.¹²⁴⁻¹²⁸ Conversely, a supportive environment during exercise is a facilitator to regular engagement in physical exercise.^{124,128,129} Sport participation is recognized as an enjoyable experience and intrinsically involves many motivational aspects such as personal challenge, competitive climate, and goal orientation, and may facilitate exercise participation and adherence in cancer patients.

Sport participation is associated with lower risk of cancer and cancer-related death. Based on preliminary evidence, participating in sport activities is feasible and can be well tolerated by cancer patients. In addition, sport

participation can play a vital role in countering a range of physical and psychological adverse effects related to the cancer and its treatments. Therefore, sport participation could be considered as an alternative strategy to frequently used fitness exercises in the prevention and management of cancer. We believe that sport participation as adjunct therapy for cancer management would especially appeal to those with previous and current experiences in sport including sports fans as well as retired professional/recreational athletes. In general, cancer patients are encouraged to participate in different types of sports according to their personal circumstance and preference.

Although there is a developing body of evidence that sport participation can enhance physical and psychosocial functioning in cancer patients, it needs to be recognized that the evidence base contains few RCTs with only a few sports investigated and is dominated by pilot studies with only small sample sizes. Therefore, at this stage, the efficacy of sport participation in cancer management should be interpreted with caution, and further work in this field is required to develop the evidence base. Robust RCTs are required to investigate the effectiveness of different sport activities in cancer patients at different stages of the cancer continuum and while receiving different treatments. In addition, sport-specific guidelines and practical strategies in planning sport programs are warranted. At present, only a handful of sports have been examined in cancer management with the majority being team-based. Therefore, comparative studies on the beneficial effects between individual, partner-based, and team-based sports are also required.

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ORCID iDs

Hao Luo  <https://orcid.org/0000-0001-5181-7529>

Robert U. Newton  <https://orcid.org/0000-0003-0302-6129>

Ciaran M. Fairman  <https://orcid.org/0000-0001-8834-9669>

Dennis R. Taaffe  <https://orcid.org/0000-0001-6381-1597>

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