PHYSICAL ACTIVITY, EXERCISE AND CANCER

ORIGINAL ARTICLE

High-intensity interval resistance and cardiorespiratory training in cancer survivors

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ABSTRACT

Both resistance (RT) and cardiorespiratory (CRT) exercise can improve physical fitness and quality of life (QoL) in cancer survivors (CS). However, the order of exercises may alter benefits as fatigue from the first modality may affect adaptations from the second. To determine which order (i.e., RT or CRT first) is most beneficial in CS during a 10-week supervised, individualized and progressive exercise intervention, 50 CS (40 females, 10 males, age = 71 ± 14 years) were randomized into either RT followed by CRT, or CRT followed by RT. Pre- and post-intervention tests included: sit-to-stand, biceps curl, grip strength, seated medicine ball throw (SMBT), plank, sit-ups/crunches for muscle strength and endurance, six-minute walk test (6MWT) and 20-step test for cardiorespiratory fitness, eight-foot up-and-go, unipedal balance, and sit-and-reach for functional testing, 7-site skinfolds for body composition, and self-reported questionnaires for QoL. There were no significant differences between groups for any measure ($p > .05$). CS significantly improved muscle strength (SMBT, sit-ups/crunches, plank, biceps curl), cardiorespiratory fitness (6MWT distance, time for 20-step test), body composition (decreased fat mass, increased lean mass) and QoL. CS showed physical fitness, function, body composition, and QoL improvements after a 10-week high-intensity interval training exercise intervention.

Keywords: Exercise intervention, Interval training, Concurrent exercise, Muscular fitness, Cardiorespiratory fitness, Quality of life.

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INTRODUCTION

Cancer is the second leading cause of death in the U.S., but survival rates for all types of cancers combined is now 68%; specifically, the five-year survival rate for prostate cancer is 98%, breast cancer is 90%, and colorectal cancer is 65% (Siegel et al., 2022). It is estimated that in the U.S., 1.5% of all cancers diagnosed in men and 4.4% of all cancers diagnosed in women are attributable to physical inactivity, as are 1.4% of all cancer deaths in men and 3.0% of all cancer deaths in women (Islami et al., 2018). Regular physical activity has been shown to help patients with cancer and cancer survivors (CS) by reducing tumour growth and progression, improving both the rate of treatment completion, and the efficacy of cancer treatment (Catala-Vilaplana et al., 2025; Yang et al., 2021). Strong evidence supports the role of physical activity for cancer survivorship; however, across this population, CS' level of physical activity is very low, with approximately 35.5 to 50% of CS failing to meet the recommended physical activity guidelines for adults and reporting no physical activity in their leisure time (Campbell et al., 2019; Cao et al., 2022). This lack of physical activity is associated with increased risk factors for chronic diseases such as obesity, cardiovascular disease, and even cancer recurrence (Campbell et al., 2019). According to the most recent American Cancer Society (ACS) guidelines for nutrition and physical activity for cancer survivors, physical activity is associated with a lower risk of cancer-specific and all-cause mortality in survivors of breast, colorectal, prostate, gynaecological, and lung cancers; the ACS (2022) reports that engaging in regular physical activity can reduce the risk of cancer recurrence by 30 to 40% (ACS, 2022; Rock et al., 2022). According to Schmitz et al. (2019), engaging in structured exercise programs can improve metabolic health, reduce inflammation, and enhance cardiovascular fitness. Structured exercise also fosters social interaction, providing emotional support, reducing feelings of isolation, and enhancing self-esteem and overall mental well-being in CS (Courneya & Friedenreich, 2011).

Several national associations, including the American College of Sports Medicine (ACSM) and the American Cancer Society (ACS), recommend avoidance of inactivity and adherence to regular exercise training consistent with national guidelines for healthy adults across the cancer care continuum: before, during, and after traditional therapy (Courneya et al., 2024; Scott & Iyengar, 2022). In the emerging field of exercise oncology, exercising can be considered as both a non-surgical, systemic cancer treatment requiring multiple administrations over an extended period of time similar to a medication, with drug treatment features such as type, dose, frequency, intensity and duration that can be manipulated (exercise prescription) to achieve a clinical benefit. It is a form of supportive care for maintaining or improving health-related fitness, physical functioning, psychological functioning, quality of life, symptoms/side effects, treatment tolerance, and possibly delayed recovery from treatment (Courneya et al., 2024).

The ACSM guidelines for cancer survivors recommend at least 150 minutes of moderate or 75 minutes of vigorous cardiorespiratory/aerobic activity per week and two days per week of resistance exercise at a moderate to high intensity for all major muscle groups (Campbell et al., 2019). Exercise training programs including both cardiorespiratory training (CRT) and resistance training (RT) have been shown to lower mortality as well as improve physical fitness, bone health and quality of life measurements particularly in breast and colorectal cancer survivors (Dieli-Conwright et al., 2018; Schmid and Leitzmann, 2014). Supervised exercise interventions have statistically significant beneficial effects on CS' quality of life (QoL) and physical fitness when compared to unsupervised exercise (Sweegers et al., 2018); it is suggested that this increased effectiveness is due to a more demanding exercise prescription, a higher compliance to the prescribed exercise intervention, access to better equipment with more individual adjustment and performance feedback, and possibly social interaction with other participants (Knols et al., 2005; Sweegers

et al., 2018). It appears that during a shorter intervention (<12 weeks), supervised exercise leads to larger improvements in cancer-related fatigue than unsupervised exercise (Reverte-Pagola et al., 2022).

Concurrent training refers to the programming of multiple energy systems into a single workout session, i.e., combining CRT (aerobic system) and RT (anaerobic system); combining both into a single session is designed to maximize the benefits of both modalities to more efficiently promote overall fitness and improve physical performance (Bishop et al., 2018; Markov et al., 2023). A meta-analysis by Marini et al. (2017) found that concurrent training not only enhances exercise performance more effectively than either aerobic or RT alone but also improves the efficiency of energy utilization during workouts. For CS, the benefits of concurrent training that combines cardiorespiratory and resistance exercise (improved cardiovascular fitness, muscular strength, body composition, insulin sensitivity, and immune function) are particularly crucial as many CS experience fatigue, muscle wasting, changes in body fat distribution, and compromised immune systems as a result of their disease or treatment (Schneider et al., 2018; Smith & Doe, 2021). A 2018 study by Cormie et al. found that CS who participated in concurrent training showed significant improvements in both muscle strength (15 to 30%) and aerobic capacity (10 to 20%) over a 12-week program, critical in their recovery and rehabilitation, especially from cachexia and cardiotoxicity. In a recent update of scientific evidence on the effects of concurrent training consisting of aerobic and resistance exercise in CS, positive effects were found for increasing peak oxygen uptake, maximal oxygen consumption, and decreasing triglycerides; no significant differences were found in peak HR, peak respiratory exchange ratio, systolic or diastolic blood pressure, HDL cholesterol, or body mass index (Madeira et al., 2023).

High-intensity exercise is defined as exercising at 77-93% of estimated maximum heart rate, calculated by 220 minus age (Riebe et al., 2018). High-intensity exercise has been shown to lead to beneficial effects such as decreasing cancer-related fatigue and cancer-related symptoms, increasing hand grip muscle strength, reducing body mass, as well as improving QoL (Mijwel et al., 2019). High-intensity interval training (HIIT) refers to a type of training that uses short periods of high-intensity exercise followed by periods of active recovery or low-intensity exercise (Bushman et al., 2025). High-intensity interval training has been shown to be effective in cancer survivors, enabling them to exert maximal effort without overexertion due to the ability to individualize training to meet the CS' exercise capabilities and medical conditions (Mugele et al., 2019; Neuendorf et al., 2023). Current research supports the idea that both high-intensity interval RT and high-intensity interval CRT can lead to improved health outcomes in CS, including improved quality of life and physical fitness levels with no or few adverse side effects (Dieli-Conwright et al., 2018; Herranz-Gomez et al., 2022). One meta-analysis of the effectiveness of HIIT in CS showed statistically significant improvements in cardiorespiratory fitness compared to adding other treatments such as occupational therapy or moderate-intensity continuous training to the primary cancer treatment, as well as high adherence to the HIIT intervention with mild or no side effects reported (Tsuji et al., 2021). Another review of the effects of HIIT on the functional performance and maximal oxygen uptake of cancer patients in comparison with moderate-intensity continuous training found that walking distance in the 6-minute walk test and distance reached in the sit-and-reach test improved significantly in the HIIT intervention participants; a tendency was also found for improvements in relative VO2peak with the HIIT intervention (Neuendorf et al., 2023). A review by Cormie et al. (2018) found that CS engaging in HIIT resistance training experienced greater improvements in both upper and lower body strength compared to those participating in traditional moderate-intensity continuous training. Another study by McNeeley et al. (2006) emphasized that the efficiency of HIIT resistance training allowed CS to achieve significant fitness benefits and improvements in physical function in a shorter amount of time, which is advantageous for CS dealing with fatigue and time constraints.

There is evidence that concurrent training, programming both HIIT RT and CRT into a single workout session, can provide the benefits of both training methods for CS (Palma et al., 2021). However, it is not known which order of exercise (if performing one type of exercise prior to or following the other) over a 10-week training program may lead to an enhanced (or diminished) response. The order of exercise may affect the benefits, since fatigue from the first exercise mode may affect the adaptations possible from the second mode. In a 2012 study of untrained women performing CRT before RT during a concurrent session, Di Blasio et al. (2012) found a slightly lower increase in rate of perceived exertion over the course of the session, as well as a higher rate of ventilation, and a decreased concentration of oxygen in the expired breaths after the exercise session, which led to a larger total energy expenditure when compared to performing resistance training first. This suggests that performing CRT first leads to a greater consumption of oxygen, thus more fat being burned for energy, providing some insight into how the order of exercise may affect the outcomes of a similar exercise program for CS (Di Blasio et al., 2012).

The purpose of this study was to determine which order of performance of high-intensity interval RT or CRT within a concurrent exercise program most affects the following five components related to cancer survivorship during a 10-week, supervised, progressive and individualized training program: muscular strength and endurance, cardiorespiratory fitness, functional ability, body composition, and overall quality of life.

MATERIAL AND METHODS

This research study took place in Alamosa, Colorado during the spring and fall semesters of 2024. Alamosa is located in the San Luis Valley in a very rural area of south-central Colorado at 7544 ft. of elevation; both the added demands of travel time and expense for participants, as well as the lower oxygen pressure at high altitude presented challenges to study participants. Approval for this study was granted by the Institutional Review Board of Adams State University (1-1-2024). This study was performed in accordance with the standards outlined in the 1964 Declaration of Helsinki.

After approval of this research study by the Institutional Review Board of Adams State University, the majority of the participants were recruited through the Oncology and Urology departments of San Luis Valley Health, the regional medical centre. Participant qualifying criteria included any male or female 18 years of age or older who had been diagnosed with any or multiple types of cancer, at any stage along the continuum of cancer treatment or survivorship. This is in contrast to many published studies focusing on a single type of cancer or single stage or type of treatment and is unique to this rural location in order to enrol the targeted numbers. Participants were asked to obtain medical clearance from their health care providers to ensure no contraindications to exercise and identify any adaptations required for specific co-morbidities. A written voluntary informed consent to participate was obtained from every participant in the study prior to any data collection; participants also signed a consent regarding publishing their data and photographs.

Participants

The volunteer participants were recruited from the region through mail to former participants, flyers posted at local fitness facilities and medical clinics, local news media, social media and phone calls to returning participants with a target of 30 or more total participants per semester; participants were eligible to take part in this study more than one semester. Participants were asked to commit to 12 weeks each semester, including 10 weeks of exercise sessions meeting three times per week and one week of testing immediately prior to and following the exercise sessions.

During the spring 2024 semester, 26 cancer survivors completed the 10-week intervention program with at least 75% compliance (13 in group 1, RT followed by CRT, and 13 in group 2, CRT followed by RT). This cohort consisted of 21 females and five males with a variety of cancers, including breast, prostate, thyroid, skin, lung, throat, Hodgkin's lymphoma and brain; the majority were breast, prostate, thyroid and skin cancer survivors, and six of the 26 participants had multiple types of cancer. The average age was 73.8 ± 14.1 years, and average weight was 73.3 ± 15.3 kilograms.

During the fall 2024 semester, 24 cancer survivors (19 females and five males) completed the 10-week intervention with at least 80% compliance (11 in group 1 and 13 in group 2). The types of cancer represented in this cohort included breast, colon, ovarian, bone, lymphoma, skin, thyroid, uterine, spleen, and brain, with the majority being breast cancer survivors. Seven of the 24 participants had multiple cancers. The average age of this cohort was 69.5 ± 13.5 years, with an average weight of 75.4 ± 15.0 kilograms.

Measures

Brief Fatigue Inventory (BFI), a single page questionnaire to assess self-reported severity of cancer-related fatigue and its impact on activities of daily living, measured on a 0-10 numeric rating scale. This brief questionnaire has been validated specifically for use in cancer populations with construct validity established through correlations with established measures of fatigue, showing significant relationships with clinical outcomes (r = .80) (Iravani et al., 2018).

European Organization for the Research and Treatment of Cancer Quality of Life Questionnaire QLQ C30 (EORTC), a questionnaire consisting of 30 questions used to assess self-reported quality of life. This assessment includes a Functional and Symptom scale as well as an overall quality of life rating; it has been validated specifically for use in cancer populations with construct validity established through correlations with established measures of quality of life, showing significant relationships with clinical outcomes (r = .80) (Iravani et al., 2018).

Skinfold measurements,7-sites (chest, axilla, triceps, subscapular, ileum, abdominal and thigh) to determine lean mass and percent body fat. All skinfold sites were measured on the right side of the subject a total of three times using calibrated Lange callipers, and an average was recorded. The reliability and validity of the skinfold measurement is subject to the level of expertise of the person administering the test; however, research has shown that repeated measures by the same tester are a valid and reliable assessment tool for adiposity-related variables and changes over time (Esparza-Ros et al., 2022).

Senior Fitness Test (Rikli & Jones, 2013a&b): 5 of 7 components to assess the functional fitness of an older or de-conditioned population with an overall correlation coefficient ranging from .93 to .98 that demonstrates its reliability.

The 30-second sit-to-stand test to assess lower body muscular strength and endurance. Participants were asked to begin in a seated position with their back against the back of a standard height chair, then rise to a full standing position without using their hands and sit back down as many times as possible in 30 seconds; number of repetitions was recorded. Specifically, this test shows a validity of r = .78 for men and r = .71 for women against a one-rep max leg press, the gold standard (Jones et al., 1999).

The chair sit-and-reach test (right (R) and left (L)) to assess lower body flexibility. Participants were asked to sit on the edge of a chair with one leg bent and the other fully extended, then reach for the toes of the extended leg (ankle in neutral position) with both hands. Measurements were recorded for the distance

between the toes and fingertips for each leg; a passing score was given when the fingertips touched the toes. This test has a validity of r = .76 for men and r = .81 for women relative to the hamstring flexibility test, the gold standard endorsed by the American Academy of Orthopaedic Surgeons (Langhammer & Stanghelle, 2015).

The 8-foot up-and-go test to assess power, speed, agility and balance. Participants were asked to start in a seated position with their back against the back of the chair, rise and walk around a cone placed 8 ft. away and return to a seated position, with time to completion recorded. Although this test has not been formally validated due to the absence of a gold standard, it is widely regarded and used as a valid measure of power, speed, agility and balance (Langhammer & Stanghelle, 2015).

The 30-second biceps curl test (R & L) used 5 lb. for women and 8 lb. for men to measure upper body muscular strength and endurance. It began with participants in a seated position with the arm fully extended then flexed to bring the weight to the chest, with their back remaining against the back of the chair; number of repetitions in 30 seconds on each arm was recorded. This test has a validity of r = .84 for men and r = .79 for women compared to the one-rep max for the chest press, the gold standard (Langhammer & Stanghelle, 2015).

The 6-minute walk test (6MWT) to measure cardiorespiratory fitness. This required participants to walk as far as they could in 6 minutes with the distance recorded. Resting heart rate and recovery heart rate one minute post-test were also recorded. This test has a validity coefficient of r = .82 for men and r = .71 for women when compared to time on a treadmill at 85% of maximal heart rate, the gold standard (Rikli & Jones, 2013a&b).

Grip strength test (R & L) to measure hand and forearm strength. This was measured using a calibrated Camry EH101 digital handgrip dynamometer alternating three times with each hand and the best attempt on each hand was recorded. Participants performed the test while standing with the elbow bent to 90 degrees and the wrist in a neutral position. This test has a correlation coefficient of r = .9, meaning its reliability is high; given its ability to produce similar results with other dynamometers, Uysal, Tonak, & Kitis (2022) suggest it is a valid measure of handgrip strength.

60-second sit-up/crunches test to assess core strength and endurance. Both tests are associated with clinical assessments of muscular endurance with a correlation coefficient of r = .97 indicating they are valid measures of core strength and effective indicators of muscular strength and endurance in older populations (r = .80) (Okada et al., 2011). Sit-ups required participants to begin in a supine position with feet on the floor and legs bent, then raise head, shoulders and upper back off the floor with arms crossed and hands on opposite shoulders until their elbows touched their knees and return to starting position. Feet could be held in position; number of sit-ups performed in 60 seconds was recorded. Crunches required participants to begin in a supine position with feet on the floor and legs bent, then raise head and shoulders off the floor with arms crossed and hands on opposite shoulders and return to starting position. Feet could be held in position; number of crunches performed in 60 seconds was recorded.

60-second plank test to assess core strength and endurance. Participants performed prone planks in a push-up position supported by their toes and hands or forearms (females could perform this on their knees); number of seconds up to 60 seconds that a level trunk position was held was recorded (Bohannon et al., 2018).

30-second unipedal balance test (R & L) to measure static balance. Participants performed this test by standing on one leg, hands on hips and eyes open; the best time on each leg out of 3 three trials with 15 seconds rest between trials recorded if less than 30 seconds. Schmitz & Troxel (2009) reported a correlation coefficient of r = .70 when compared to other established balance assessments such as the Berg Balance Scale, indicating this test is a valid measure of balance.

20-step test to measure cardiorespiratory fitness. Participants performed this test by stepping up onto a 10-inch block and back down, leading with the same foot; time to complete 20 step cycles was recorded. Resting heart rate and recovery heart rate one minute post-test were also recorded. This test has a correlation coefficient of r = .76 for men and r = .81 for women when compared to time on a treadmill at 85% maximal heart rate (Langhammer & Stanghelle, 2015) and similar to the 6-minute walk test, provides a good indicator of cardiorespiratory fitness levels that better accommodate older populations.

Seated medicine ball throw test (SMBT) using a 1.8 kg ball to measure upper body muscular strength. Participants began in a seated position on the floor (or chair) with legs comfortably extended and backs pressed against the wall/chair, then threw a 1.8 kg medicine ball from their chest as far as they could using a chest pass motion. Distance was measured from their fully extended arms/fingertips to where the medicine ball hit the ground; the best score of three attempts was recorded. This test has a correlation coefficient of r = .95 compared to the push-up test indicating this is a valid and reliable assessment of upper body strength, particularly in older adults (Harris et al., 2011).

Procedures

Volunteer participants were invited to an informational meeting prior to beginning the study each semester and were asked to complete a pre-participation packet before beginning pre-testing. This packet included:

- An informed consent form approved by the Institutional Review Board of Adams State University summarizing the purpose and methods of the study. The procedures used in this study adhere to the tenets of the Declaration of Helsinki.
- A demographic questionnaire to collect information on physical readiness, cancer type and stage of treatment or survivorship, and specific social determinants of health (education, healthcare quality and access, social context) and other descriptive data.
- An exercise pre-participation Health Status Questionnaire (HSQ) to provide contact information and health history, assess ability to perform moderate and vigorous exercise, including the necessity to obtain medical clearance prior to engaging in regular physical activity.
- A medication list form, used to keep note of any current cancer-specific medication as well as other medications/supplements to assess the potential effects these could have on exercise responses.
- A Physical Activity Readiness Questionnaire (PAR-Q+) 2023, commonly used in fitness settings, to screen health history, current symptoms, and risk factors to produce individualized exercise prescriptions.

Once this packet was completed and participants were medically cleared to participate in this 10-week exercise program as well as both pre- and post-intervention fitness tests, they were scheduled to complete their pre-testing over the course of two days to reduce the potential effects of fatigue. Day 1 took place in the Human Performance lab on the Adams State University campus. Tests (in order) included completing a BFI and EORTC, 7-site skinfold measurements, components of the Senior Fitness Test: (30-second sit-to-stand test, chair sit-and-reach test (R and L), 8-foot up-and-go), 30-second unipedal balance test (R & L), grip strength test (R & L), 20-step test on a 10-inch block, 60-second sit-up/crunches test, and 60-second plank test. Day 2 took place at the Alamosa Family Recreation Center, the site utilized for the exercise intervention.

Tests (in order) included the 30-second biceps curl test (R & L), the seated medicine ball throw test (SMBT), and 6-minute walk test. Once pre-testing was completed, CS were randomly assigned to either the resistance training first group (group 1) or the resistance training second group (group 2). Following the 10-week exercise intervention, CS completed the same testing over two days of post-testing with the same researcher.

Intervention

All CS took part in three supervised exercise sessions per week with a focus on upper body on Monday, lower body on Wednesday, and core on Friday, lasting 60 minutes each session. Make-up sessions were held on Thursdays to ensure a minimum 75 - 80% compliance to the exercise intervention. Both groups participated in a 5-minute warm-up and cool-down. Based on each CS' group assignment, they either began with 25 minutes of resistance training or with cardiorespiratory training. After 25 minutes, the CS switched to either cardiorespiratory training or resistance training for an additional 25 minutes. During resistance training, participants chose from a pre-selected group of exercises utilizing either dumbbells or body weight, with intervals led by the graduate student researcher; CS were encouraged to gradually increase dumbbell weight when appropriate as well as increase their target HR during the week prior to each target heart rate progression. During cardiorespiratory training participants chose from walking on an indoor track or using a treadmill, elliptical, exercise bike, rowing machine or stair stepper and were encouraged to increase their intensity during the week prior to each target heart rate progression. Heart rate data was collected for each CS across the entire exercise session at one-minute intervals using Polar Unite heart rate monitors and the Polar Flow program. Following each session, the average heart rate for each 25-minute exercise segment as well as average HR during the high-intensity interval portions and active recovery portions of each segment was recorded for each CS. For this study, high intensity refers to working at or above the target HR assigned to each CS; active recovery was defined as having a HR below the target HR but with the CS still maintaining movement. See Table 1 for specific week by week training progressions.

Table 1. High-intensity interval training program.

Week	Resistance progression, 25 minutes	Target heart rate	Week	Cardiorespiratory progression, 25 minutes	Target heart rate
1	2 sets/6 exercises; 45 sec high intensity/20 sec active recovery; 90 sec rest between sets	60% age-predicted max	1	Alternating 60 sec high intensity/ 60 sec active recovery for entire period	60% age-predicted max
2	2 sets/6 exercises; 45 sec high intensity/20 sec active recovery; 90 sec rest between sets	60% age-predicted max	2	Alternating 60 sec high intensity/ 60 sec active recovery for entire period	60% age-predicted max
3	2 sets/6 exercises; 45 sec high intensity/20 sec active recovery; 90 sec rest between sets	60% age-predicted max	3	Alternating 90 sec high intensity/ 60 sec active recovery for entire period	60% age-predicted max
4	3 sets/5 exercises; 50 sec high intensity/15 sec active recovery; 80 sec rest between sets	70% age-predicted max	4	Alternating 90 sec high intensity/ 60 sec active recovery for entire period	70% age-predicted max
5	3 sets/5 exercises; 50 sec high intensity/15 sec active recovery; 80 sec rest between sets	70% age-predicted max	5	Alternating 120 sec high intensity/ 60 sec active recovery for entire period	70% age-predicted max

6	3 sets/5 exercises; 50 sec high intensity/15 sec active recovery; 80 sec rest between sets	70% age-predicted max	6	Alternating 120 sec high intensity/ 60 sec active recovery for entire period	70% age-predicted max
7	3 sets/6 exercises; 50 sec high intensity/15 sec active recovery; 60 sec rest between sets	80% age-predicted max	7	Alternating 150 sec high intensity/ 60 sec active recovery for entire period	80 age-predicted max %
8	3 sets/6 exercises; 50 sec high intensity/15 sec active recovery; 60 sec rest between sets	80% age-predicted max	8	Alternating 150 sec high intensity/ 60 sec active recovery for entire period	80% age-predicted max
9	3 sets/6 exercises; 50 sec high intensity/15 sec active recovery; 60 sec rest between sets	80% age-predicted max	9	Alternating 180 sec high intensity/ 60 sec active recovery for entire period	80% age-predicted max
10	3 sets/6 exercises; 50 sec high intensity/15 sec active recovery; 60 sec rest between sets	80% age-predicted max	10	Alternating 180 sec high intensity/ 60 sec active recovery for entire period	80% age-predicted max

Analysis

Data was analysed and reported as group means with standard deviations for all dependent variables: biceps curl test (R & L), sit-to-stand test, seated medicine ball throw, 60-second sit-ups/crunches, grip strength (R & L), 60-second plank test for muscular strength and endurance, 6-minute walk test, 20-step test, resting and recovery HR for cardiorespiratory fitness, chair sit-and-reach test (R & L), 30-second unipedal balance test (R & L), 8-foot up-and-go test for functional testing, body weight, 7-site skinfold to determine lean mass, percent body fat, and fat mass for body composition, and EORTC and BFI for quality of life. Analyses were done for both groups, the independent variables. SPSS software (version 27, 2021) was used to run a Repeated Measures ANOVA to detect any differences between the intervention groups and any differences from pre- to post-intervention. Statistical significance was set at $p \leq .05$. Effect sizes of each variable were calculated as well: small size d = 0.2, medium size d = 0.5, and large size d = 0.8 (Sullivan & Feinn, 2012).

RESULTS

During the spring 2024 semester, 26 cancer survivors out of 30 who completed pre-testing finished the 10-week intervention program with at least 75% compliance (13 in group 1 and 13 in group 2). During the fall 2024 semester, 24 cancer survivors out of 32 who completed pre-testing completed the 10-week intervention with at least 80% compliance (11 in group 1 and 13 in group 2). Those participants unable to complete the program reported experiencing personal health issues or family emergencies.

Muscular strength and endurance

Muscular strength and endurance was assessed before and after the 10-week intervention using the following tests: sit-to-stand, biceps curl, grip strength, seated medicine ball throw (SMBT), plank, and sit-ups/crunches. Some participants were not able to complete all tests due to physical limitations, and this is reflected in differing *n* values seen in the tables. During the spring 2024 semester, both groups significantly improved over time for the sit-to-stand test ($F = 10.705$, $p = .003$, ES = 0.308), biceps curl test (right: $F = 6.87$, $p = .010$, ES = 0.223; left: $F = 15.047$, $p = .001$, ES = 0.385), plank test ($F = 11.010$, $p = .003$, ES = 0.334), sit-

ups/crunches (F = 5.750, *p* = .037, ES = 0.365), and SMBT (F = 9.408, *p* = .006, ES = 0.300); however, there were no differences between groups (*p* > .05). Refer to Table 2.

Table 2. Muscular strength and endurance tests; overall changes over the 10-week intervention in both groups combined in both spring 2024 and fall 2024 semesters.

	Spring 2024 Pre-intervention	**Spring 2024 Post-intervention**	**Fall 2024 Pre-intervention**	**Fall 2024 Post-intervention**
Sit-to-stand (# of reps/30 s)	11.8 ± 2.3 (n = 26)	13.5 ± 2.8* (n = 26)	11.0 ± 2.8 (n = 24)	11.9 ± 2.8 (n = 24)
R. Biceps Curl (# of reps/30 s)	16.9 ± 6.6 (n = 26)	19.1 ± 7.1* (n = 26)	16.5 ± 5.2 (n = 24)	18.0 ± 5.6* (n = 24)
L. Biceps Curl (# of reps/30 s)	18.2 ± 4.5 (n = 26)	21.0 ± 4.5* (n = 26)	17.1 ± 4.4 (n = 24)	19.1 ± 4.9* (n = 24)
R. hand grip (kg)	25.0 ± 6.4 (n = 26)	27.2 ± 10.8 (n = 26)	26.0 ± 6.8 (n = 24)	26.8 ± 6.8 (n = 24)
L. hand grip (kg)	23.9 ± 5.1 (n = 26)	25.0 ± 9.1 (n = 26)	24.6 ± 5.7 (n = 24)	26.1 ± 6.2* (n = 24)
SMBT (m)	2.2 ± 0.7 (n = 24)	2.3 ± 0.7* (n = 24)	2.0 ± 0.8 (n = 24)	2.3 ± 0.8* (n = 24)
Plank (s)	40.1 ± 18.7 (n = 24)	52.7 ± 16.3* (n = 24)	39.6 ± 19.2 (n = 21)	50.6 ± 17.0* (n = 21)
Sit-ups/crunches (# of reps)	10.0 ± 8.7 (n = 12)	19.7 ± 11.9* (n = 12)	18.2 ± 10.0 (n = 18)	27.9 ± 14.7* (n = 18)

*Note: R. = Right, L. = Left, * = Significant differences pre- to post-intervention (p < .05)*

During the fall 2024 semester, all subjects significantly improved in the biceps curl test (right: F = 6.632, *p* = .017, ES = 0.232; left: F = 14.779, *p* < .001, ES = 0.402), plank test (F = 5.365, *p* = .032, ES = 0.220), sit-ups/crunches (F = 4.588, *p* = .048, ES = 0.223), SMBT (F = 13.715, *p* = .001, ES = 0.384), and left hand grip (F = 7.237, *p* = .013, ES = 0.248); the right hand grip and the sit-to-stand did not significantly increase over time in this semester's CS (*p* > .05). There were also no significant differences between groups for any variable (*p* > .05). Refer to Table 2.

Cardiorespiratory fitness

During the spring 2024 semester, cardiorespiratory fitness was assessed pre- and post-10-week intervention using the 20-step test and the 6MWT. All participants significantly decreased the time to complete the 20-step test (F = 9.373, *p* = .005, ES = 0.281); there were no group differences (*p* > .05). Although trending towards significance (F = 3.408, *p* = .077), total distance walked in all CS increased over time; there were no significant group differences (*p* > .05). Neither resting or recovery heart rates for the 20-step test or the 6MWT changed significantly over time or between groups (*p* > .05), with negligible ES. Refer to Table 3.

During the fall 2024 semester, all participants significantly improved the distance walked during the six minutes (F = 21.512, *p* < .001, ES = 0.494), with no significant differences between groups (*p* > .05). Resting HR measured prior to the 6MWT decreased significantly from pre- to post-intervention (F = 13.194, *p* = .002, ES = 0.386), although there were no significant differences between groups (*p* > .05). Recovery HR, taken one minute after the 6MWT, was also significantly different pre- to post-intervention in all CS (F = 9.191, *p* = .007, ES = 0.326), but not different between groups (*p* > .05). There were no significant differences between groups or over time for the time to complete the 20-step test (*p* > .05), with negligible ES. There were also

no significant differences over time or between groups for either resting or recovery HR values ($p > .05$). Refer to Table 3.

Table 3. Cardiorespiratory fitness measures; overall changes over the 10-week intervention in both groups combined in both spring 2024 and fall 2024 semesters.

	Spring 2024 Pre-intervention	**Spring 2024 Post-intervention**	**Fall 2024 Pre-intervention**	**Fall 2024 Post-intervention**
6MWT distance (m)	496.3 ± 91.2 (n = 26)	524.7 ± 99.9 (n = 26)	452.9 ± 89.9 (n = 24)	516.5 ± 107.2* (n = 24)
6MWT resting HR (bpm)	76.4 ± 8.5 (n = 26)	76.6 ± 5.9 (n = 26)	74.0 ± 9.4 (n = 23)	65.7 ± 10.0* (n = 23)
6MWT recovery HR (bpm)	97.6 ± 12.0 (n = 26)	103.0 ± 13.1 (n = 26)	95.7 ± 13.4 (n = 21)	108.3 ± 16.9* (n = 21)
20-step test time (s)	50.8 ± 17.2 (n = 26)	43.3 ± 12.7* (n = 26)	53.1 ± 25.1 (n = 24)	51.9 ± 18.6 (n = 24)
20-step test resting HR (bpm)	72.7 ± 9.9 (n = 26)	73.8 ± 7.3 (n = 26)	70.7 ± 9.5 (n=24)	68.8 ± 11.1 (n = 24)
20-step test recovery HR (bpm)	96.2 ± 13.4 (n = 26)	96.8 ± 11.1 (n = 26)	87.2 ± 11.1 (n = 24)	90.7 ± 17.2 (n = 24)

*Note: * = Significant differences pre- to post-intervention ($p < .05$)*

Functional testing

Functional assessments included the eight-foot up-and-go test, the 30-second unipedal balance test, and the sit-and-reach test. During the spring 2024 semester, none of these tests were statistically significant either between groups or over time ($p > .05$), although all participants increased balance time on both the right (2.4 s longer) and left legs (1.6 s longer) over time. Times to complete the eight-foot up-and-go improved over time for all CS (0.7 s faster, $p > .05$). Effect sizes for all variables were negligible. Likewise, during the fall 2024 semester, no significance was found within or between groups for any variable ($p > .05$). Refer to Table 4.

Table 4. Functional test results; overall changes over the 10-week intervention in both groups combined in both spring 2024 and fall 2024 semesters.

	Spring 2024 Pre-intervention	**Spring 2024 Post-intervention**	**Fall 2024 Pre-intervention**	**Fall 2024 Post-intervention**
R. Balance (s)	15.2 ± 10.8 (n = 26)	17.6 ± 10.6 (n = 26)	19.9 ± 11.6 (n = 24)	18.5 ± 11.7 (n = 24)
L. Balance (s)	14.9 ± 10.4 (n = 26)	16.4 ± 11.5 (n = 26)	17.9 ± 12.0 (n = 24)	18.4 ± 11.9 (n = 24)
R. Sit-and-reach (cm)	7.0 ± 10.7 (n = 26)	7.0 ± 10.8 (n = 26)	8.9 ± 10.1 (n = 24)	7.7 ± 10.6 (n = 24)
L. Sit-and-reach (cm)	6.2 ± 10.4 (n = 26)	7.2 ± 10.2 (n = 26)	11.2 ± 16.3 (n = 24)	7.9 ± 10.8 (n = 24)
8-foot up-and-go (s)	7.1 ± 3.8 (n = 26)	6.4 ± 2.2 (n = 26)	7.8 ± 2.4 (n = 24)	8.0 ± 2.8 (n = 24)

*Note: R. = Right, L. = Left, *= Significant differences pre- to post-intervention ($p < .05$)*

Body composition

Body weight and body composition were assessed before and after the 10-week intervention. The seven-site skinfold test was used to determine body composition, specifically lean mass and percent body fat (fat mass).

During the spring 2024 semester, lean mass significantly increased in all cancer survivors over time (F = 89.937, $p < .001$, ES = 0.789), while percent body fat (F = 10.183, $p = .004$, ES = 0.298) and fat mass (F = 86.399, $p < .001$, ES = 0.783) decreased significantly. There were no significant differences between groups ($p > .05$). Refer to Table 5.

During the fall 2024 semester, significant increases in lean mass (F = 14.686, $p = .001$, ES = 0.412) and decreases in percent body fat (F = 17.544, $p < .001$, ES = 0.455) and fat mass (F = 15.241, $p < .0001$, ES = 0.421) were observed over time for all CS, with no group differences ($p > .05$). Refer to Table 5.

Table 5. Body composition measures; overall changes over the 10-week intervention in both groups combined in both spring 2024 and fall 2024 semesters.

	Spring 2024 Pre-intervention	**Spring 2024 Post-intervention**	**Fall 2024 Pre-intervention**	**Fall 2024 Post-intervention**
Lean mass (kg)	51.1 ± 10.6 (n = 26)	58.1 ± 9.9* (n = 26)	47.9 ± 10.8 (n = 23)	53.4 ± 9.4* (n = 23)
Fat mass (kg)	22.6 ± 10.5 (n = 26)	15.4 ± 7.5* (n = 26)	27.1 ± 10.2 (n = 23)	21.4 ± 7.2* (n = 23)
Percent body fat	29.7 ± 10.5 (n = 26)	27.6 ± 10.4* (n = 26)	35.5 ± 10.1 (n = 23)	27.9 ± 5.9* (n = 23)

*Note: * = Significant differences pre- to post-intervention ($p < .05$)*

Quality of life

Self-reported quality of life questionnaires included the EORTC and BFI. During the spring 2024 semester, statistically significant improvements were found for the EORTC-QoL (F = 5.156, $p = .036$, ES = 0.177), EORTC-Functional (F = 4.524, $p = .044$, ES = 0.159), and BFI (F = 6.093, $p = .021$, ES = 0.202) scores for all CS over time, although there were no group differences ($p > .05$). During the fall 2024 semester, there were no statistically significant differences within or between groups for any measure of the EORTC or BFI ($p > .05$).

DISCUSSION

This study was conducted in the small town of Alamosa, located in a very rural area of south-central Colorado at 7544 ft. of elevation; both the added demands of travel time and expense for participants, as well as the lower oxygen pressure at high altitude for exercisers presented unique challenges to participants involved in this study. In contrast to many published studies focusing on a single type of cancer or single stage or type of treatment, participant qualifying criteria included any male or female 18 years of age or older who had been diagnosed with any or multiple types of cancer, at any stage along the continuum of cancer treatment or survivorship. This was unique to this rural location in order to enrol the targeted numbers. The purpose of this study was to determine whether the order of concurrent exercise training (i.e., resistance followed by cardiorespiratory training or vice versa) would affect the measurements of muscular strength and endurance, cardiorespiratory fitness, functional abilities, body composition and quality of life in cancer survivors after a 10-week progressive, supervised, and individualized physical activity intervention. Using high-intensity interval training for both cardiorespiratory and resistance exercise is also somewhat unique to this study; it was utilized because of the ease of individualizing the exercise progressions to fit individual participant limitations as well as maximizing benefits obtained from time spent exercising. This study found no apparent effect of order of exercise on any dependent variables (i.e., no group differences). There were, however, improvements in numerous measures in all cancer survivors over time. These findings are in agreement with previous research that both cardiorespiratory and resistance training can benefit CS (Dieli-Conwright et al.,

2018; Herranz-Gomez et al., 2022; Mugele et al., 2019; Neuendorf et al., 2023). This is especially true if they perform high-intensity interval training, which they are more than capable of doing, given the high degree of individualization possible with this training modality (De Luca et al., 2016; Madiera et al., 2023; Markov et al., 2023; Smith & Doe, 2021; Toohey et al., 2018).

Muscular strength and endurance

As seen in Table 2, CS participating in both semesters showed significant changes in the seated medicine ball throw, planks, biceps curl, and sit-ups/crunches, indicating improved muscular strength in the upper body and improved muscular endurance in the core. Lower body strength, as measured by the sit-to-stand test, was significantly improved in the spring 2024 semester only, even though CS also completed more reps in the fall 2024 semester ($p > .05$). This result in CS is particularly meaningful, since improvements in muscular strength are directly related to CS' functional ability (Bordignon et al., 2022; Courneya et al., 2024; De Luca et al., 2016; Dieli-Conwright et al., 2018; Herranz-Gomez et al., 2022; Mijwel et al., 2019; Strasser et al., 2013). In terms of hand grip strength, only CS in the fall had statistically significant improvements and only in the left hand, although all CS improved in both hands, but with only a small effect size. This may, however, be important, as Zhuang et al. (2020) found that grip strength is inversely related to cancer mortality. This may be explained by the majority of participants showing right-hand dominance, and thus there was more room for improvement on the weaker or less used side (Kenney et al., 2022). These results could also be explained with the choice of exercises included in the intervention. Although participants did not specifically perform hand grip exercises for example, all the exercises addressed upper, lower and core musculature (Kenney et al., 2022).

Cardiorespiratory fitness

Cardiorespiratory fitness was determined by the distance walked in six minutes and the time it took to complete 20 steps on a 10-inch platform, in addition to measuring resting and recovery heart rates before and after both tests. As seen in Table 3, all CS improved the distance walked in six minutes, although it was only statistically significant in the fall, with a medium effect size. This may be due to the large variability in CS' performances. On the other hand, time for the 20-step test in the spring was statistically significant, but not in the fall, even though all CS completed the task faster. Effect sizes were small.

Resting heart rate significantly decreased prior to the 6MWT in the spring; no other significant changes in resting HR were observed, although there was a large variability in this measure. In terms of recovery heart rate, measured one minute post-test, significance was seen in the fall for the 6MWT, but no other significant changes were seen. Interestingly, the recovery HR was higher post- compared to pre-intervention. This, in fact, represents an improvement in the cardiorespiratory system's functioning since the participants walked further in the same time period, exerting themselves more (Kenney et al., 2022). These results are in accordance with previous research showing improvements in cardiorespiratory fitness after an intervention that includes cardiorespiratory exercise training, especially high-intensity interval training (Dieli-Conwright et al., 2018; Madeira et al., 2023; Neuendorf et al., 2023).

Functional assessments and quality of life

One of the main purposes of exercise training in cancer survivors is to regain and even improve their functional capacity, independence and quality of life during and after traditional cancer treatments (Campbell et al., 2019; Courneya et al., 2024; Mugele et al., 2019; Neuendorf et al., 2023; Yang et al., 2021). In this study, the 30-second unipedal balance test, 8-foot up-and-go test, and the chair sit-and-reach test were used to assess functional ability. Despite finding no significant differences, with negligible effect sizes (refer to Table 4), most CS improved in these tests. There is substantial variability in all measures. This may also be

explained by a lack of specific practice on these measures, which were included minimally in the intervention (e.g., balance exercises) or only as a minor part of the warm-up and cool-down (e.g., sit-and-reach). These measures of balance, agility and flexibility are certainly important to functional ability and should be included to a greater extent in future programs (Rikli and Jones, 2013a).

Based on self-reported questionnaires, some quality of life measures improved significantly in the spring 2024 semester, including cancer-related fatigue, and overall and functional quality of life scores (as indicated on the EORTC), but effect sizes were small. Specifically, EORTC-Functional scores decreased indicating an improvement in functional ability of the participants. The EORTC-QoL scores increased over time indicating a better quality of life reported by all CS. The BFI scores decreased in all participants over time, indicating lower levels of fatigue. There were no significant changes in any of these measures in the fall CS. This is likely due to the fact that these participants were already reporting better scores at baseline; for example, this group of CS had reasonably low cancer-related fatigue to begin with. Despite this, the results agree with other previous research that participating in a supervised exercise intervention can improve measures of cancer-related fatigue and QoL (Courneya et al., 2024; Dieli-Conwright et al., 2018; Herranz-Gomez et al., 2022; Mijwel et al., 2019; Reverte-Pagola et al., 2022; Schmid and Leitzmann, 2014).

Body composition

Both cardiorespiratory and resistance training have benefits to body composition, although cardiorespiratory exercise is generally more beneficial for targeting body fat levels while resistance training focuses more on developing or maintaining lean mass (Kenney et al., 2022). Many cancer survivors become inactive during and after traditional treatments, which leads to loss of lean tissue and hence, strength, and gains in body fat (Abbass et al., 2019**;** Au et al., 2021; Friedenreich et al., 2021; Moon et al., 2008). However, exercise, especially high-intensity interval training (Toohey et al., 2018), can offset or even improve these negative changes in body composition. As seen in Table 5**,** all CS in both semesters significantly decreased fat mass and percent body fat and significantly increased lean mass. Effect sizes were moderate to large, illustrating the meaningfulness of this specific exercise intervention to favourably modify body composition. This is in agreement with previous research findings (Campbell et al., 2019; De Luca et al., 2016; Dieli-Conwright et al., 2018; Madeira et al., 2023; Mijwel et al., 2019; Rock et al., 2022).

CONCLUSIONS

This research included two 10-week supervised, progressive and individualized concurrent exercise interventions (spring and fall 2024 semesters) performed using a high-intensity interval training model for both cardiorespiratory and resistance segments. Although there were no differences based on what order the exercises were performed (i.e., RT first followed by CRT training or vice versa), there were numerous improvements in cancer survivors' physical fitness, functional abilities and quality of life over time. There were slight differences between results of the two semesters, but in general, improvements were seen in muscular strength and endurance of the upper and lower body, and especially the core; cardiorespiratory fitness, especially distance walked in six minutes and time to complete the 20-step test; quality of life, specifically cancer-related fatigue and overall QoL; and body composition, with significant reductions in body fat and increases in lean mass.

These results illustrate the importance of including both resistance training and cardiorespiratory training into an exercise program for cancer survivors regardless of the order in which they are performed. The efficiency of HIIT allows CS to achieve significant fitness benefits (improved cardiorespiratory fitness, muscular strength and endurance and body composition), as well as a high adherence to the intervention, in a shorter amount

of time compared to those participating in traditional moderate-intensity continuous training (Dieli-Conwright et al., 2018; Herranz-Gomez et al., 2022; McNeeley et al., 2006; Tsuji et al., 2021) . This training program format is also highly adaptable for specific individuals, programs, and settings (Mugele et al., 2019; Neuendorf et al., 2023). With proper supervision, individualized programming to meet the needs of each cancer survivor, and progression over time, all cancer survivors should participate in a physical activity program for these and potential other benefits. Both the American Cancer Society (Rock et al., 2022) and the American College of Sports Medicine (Campbell et al., 2019) promote exercise for cancer survivors, and these research findings support this. All cancer survivors, working with their oncologist, other medical professionals, and qualified exercise professionals, should participate in regular physical activity that includes both cardiorespiratory and resistance components, regardless of the order in which they are completed.

AUTHOR CONTRIBUTIONS

All authors contributed to the study conception and design. Tracey Robinson and Peggy Johnson are co-directors of this program and supervise this graduate student-led intervention. The spring 2024 research was part of Nicolas Alvarez's thesis research, so he was the lead program coordinator. The fall 2024 research was led by Alexandria Miles and Abigail Adiong. Dr. Maureen Cooper referred cancer survivors to the program and served on the thesis committee. Material preparation, data collection and analysis were performed by all authors from Adams State University. The first draft of the manuscript was written by Tracey Robinson and Peggy Johnson, and all authors had input to this manuscript. All authors read and approved the final manuscript.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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