ORIGINAL RESEARCH

# Bruce Treadmill $Vo_2$peak Prediction Equations Are Inaccurate for Cancer Survivors

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## ABSTRACT

**Background:** Cardiorespiratory function measured as peak volume of oxygen consumption ($Vo_2$peak) predicts all-cause mortality and dictates exercise prescription for cancer survivors (CS). It is imperative that $Vo_2$peak values are reliable, as using inaccurate values may invalidate the exercise program and is unsafe. The Bruce treadmill protocol is commonly used for $Vo_2$peak testing but may not be accurate for CS because of its higher intensity. A cancer-specific treadmill (CANCER) protocol and corresponding prediction equations has been validated, yet the Bruce protocol is most used, also using estimation equations. It is unknown if the Bruce protocol is appropriate for CS. The purpose of this study was to determine whether the Bruce protocol prediction equations provide accurate estimations of $Vo_2$peak for CS by comparing it against $Vo_2$peak values from the CANCER protocol using gas analysis (CANCERmet) and prediction equations (CANCERest).
**Methods:** Forty-seven subjects completed both CANCER and Bruce protocols 1 week apart in randomized order. Actual and predicted $Vo_2$peak from CANCERmet and CANCERest, respectively, were compared to estimated $Vo_2$peak from the Bruce.
**Results:** $Vo_2$peak values were significantly lower in CANCERmet and CANCERest compared to the Bruce ($P < 0.05$); however, peak heart rate, systolic blood pressure, and rate pressure product were significantly higher using the CANCER protocol ($P < 0.05$).
**Conclusion:** The Bruce protocol and corresponding $Vo_2$peak prediction equations do not appear accurate for CS, as $Vo_2$peak is significantly overpredicted, despite yielding lower physiological values of maximal exertion. The CANCER treadmill protocol should remain the gold standard for assessing cardiorespiratory function in CS. *J Clin Exerc Physiol*. 2022;11(4):132–139.

**Keywords:** cardiorespiratory fitness, oncology, assessment, exercise

## INTRODUCTION

In 2020 approximately 1.8 million new cases of cancer were diagnosed, appending the 16.9 million cancer survivors (CS) currently living in the United States (1). Cancer survivors endure cardiovascular, metabolic, and/or musculoskeletal toxicities culminating in common comorbidities such as hypertension, hyperlipidemia, osteoarthritis, diabetes mellitus, and coronary artery disease (2). Side effects of cancer and its concurrent treatments can linger months to years after treatment is concluded (3). In addition, negative lifestyle factors such as inactivity, poor nutrition, and weight gain are common following cancer diagnosis (4). Collectively, treatment-related toxicities, comorbidities, and poor lifestyle contribute to declinations in cardiorespiratory function (CRF). Cardiorespiratory function, as measured by maximal volume of oxygen consumption ($Vo_2$max), is an independent predictor of all-cause mortality and is recognized as a vital sign which should b routinely assessed in clinical practice (2, 4–11). To combat low CRF, exercise can be prescribed to improve physiological function and reduce treatment effects; and in turn improve mortality rates, prognosis, recurrence, and incidence of certain cancers (10,12,13).

The design of tailored exercise prescriptions requires assessment of CRF yielding accurate $Vo_2$max values (4,9,12,14). A graded exercise test (GXT) performed to volitional fatigue with concurrent gas analysis via a metabolic

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cart is the gold standard method of measurement of $Vo_2$max (15). When conducting GXTs, treadmill protocols are the preferred mode as they demonstrate consistently higher and more accurate $Vo_2$max values compared to cycle ergometry (16–20). The most common treadmill protocol in North America is the Bruce (19,21,22). However, the Bruce's large and abrupt increases in speed and grade can be challenging for participants such as CS who likely present with neuropathy, cachexia, lymphedema, pain, and/or fatigue (1,6–9,23). It has been reported that $Vo_2$max measured by GXT may underestimate CRF in CS most likely because of physiological limitations and reduced confidence to perform maximal effort (14,17). This protocol may specifically contribute to these risks of $Vo_2$max underestimation in CS.

Administration of $Vo_2$max tests are costly, time-consuming, and requires expensive equipment and qualified technicians to perform. To save time and money, peak volume of oxygen consumption ($Vo_2$peak) tests are used in place relying on validated predictive equations to estimate the metabolic cost of exercise dependent on termination time without the use of a metabolic cart (24). Predictive equations are accepted as accurate estimations of $Vo_2$max during steady-state exercise when $Vo_2$max criteria such as $Vo_2$ plateau, lactate, or maximal heart rate (HR) are not measured or cannot be met (24). The American College of Sports Medicine (ACSM) Foster equation for sedentary men, the Pollock equation for active and sedentary women, and the McConnell & Clark equation for cardiac patients and elderly persons are correlated with $Vo_2$max and used to estimate CRF using the Bruce treadmill protocol (24). However, these prediction equations have been reported to underestimate $Vo_2$peak, especially in those with low fitness (19). The standard error of these estimations is ±1 metabolic equivalent of task as reported by Heyward and Gibson or 4 $mL \cdot kg^{-1} \cdot min^{-1}$ as reported by Pollock and colleagues, which is significant in populations with reduced exercise capacity such as CS (19,24).

Currently, there is only 1 cancer-specific (CANCER) treadmill protocol validated for CS (23). To account for cancer-specific toxicities, this treadmill protocol increases in speed and grade gradually with shorter stages, allowing CS suffering from significant and debilitating side effects to progress further in the test, allowing for a greater and more accurate measurement of $Vo_2$peak (20). The ACSM metabolic equations are validated predictive equations for the CANCER treadmill protocol as they yield equivalently accurate $Vo_2$peak values as $Vo_2$max when measured via gas analysis (23).

In summary, a valid, cost effective, and timely method to estimate CRF is needed for clinical and rehabilitative purposes in CS. Although the CANCER treadmill protocol has been established, the Bruce treadmill protocol is commonly used despite lacking validation of its predictive equations in CS. Additionally, the Bruce protocol's inherent difficulty and frequent inaccuracies when estimating $Vo_2$peak in nonathletic populations suggests it may be unsuitable to measure CRF for the cancer population (20). Therefore, the purpose of this study was to compare the Bruce protocol and standard prediction equations to the CANCER protocol using both gas analysis and the validated prediction equations in a group of CS. A secondary purpose investigated systolic cardiovascular work, e.g., peak values of HR, blood pressure (BP), and rate of pressure product between the Bruce and CANCER protocols.

## METHODS

### Subjects

All participants (N = 47) were enrolled in the study upon the completion of a medical history and after signing the informed consent approved by Carroll University's Institutional Review Board. Inclusion criteria included (a) a diagnosis of cancer, (b) at least 18 years of age, and (c) no history of chronic respiratory complications, severe arterial hypertension (resting systolic BP [SBP] > 200 mm Hg, resting diastolic BP > 110 mm Hg, or both), or stroke. Participants were excluded if they had a history of congestive heart failure, a history of myocardial infarction, asthma, significant ambulatory issues, history of coughing up blood, a history of fainting, and/or epilepsy.

### Experimental Design

Participants who qualified for the study completed 2 separate treadmill protocols over the course of 2 weeks. The order of completion was determined by random assignment using the Statistical Analysis System PROC PLAN randomization procedure (v 9.3; SAS, Cary, North Carolina). Tests were performed an average 7.8 ± 0.1 days apart for 2 consecutive weeks. Two $Vo_2$peak treadmill protocols were performed: CANCER and Bruce. Participants were blinded to the name and population-specific indications of the test they performed. Resting BP, HR, and blood oxygen saturation ($Spo_2$) were measured before all tests, along with the subject's body weight. BP was determined using manual auscultation via a BP cuff and stethoscope, HR was determined using a Polar USA HR monitor (Lake Success, New York), and $Spo_2$was determined using a Clinical Guard pulse oximeter (Atlanta, Georgia). During all tests, $Spo_2$ and HR were recorded once every minute, and rating of perceived exertion and BP were recorded every 3 minutes. One clinician was responsible for changing the grade and speed of the treadmill and recording all information during the test, a second technician measured BP, and a third stood behind the treadmill to spot the subject.

In accordance with previous methodology (23), subjects were encouraged to refrain from using the handrails, but if it was deemed necessary because of subject discomfort or increased risk, they were allowed to hold onto the handrails. The tests terminated when the participant felt they reached their maximum threshold of exertion and could not continue any further. Peak HR and BP were recorded as the highest values measured either during or immediately after test termination. The tests also concluded if any of the following criteria were met: SBP failed to increase with increased intensity, diastolic BP wavered more than 10 mm Hg from

resting measure, $Spo_2$ dropped below 80%, and/or verbal consent of the participant to end the test because of any safety issues. A cool down period occurred after completion of every test to confirm that the subject returned to normal physiological parameters. Final HR, BP, $Spo_2$, and treadmill time were recorded.

All participants were given the following verbal instructions prior to each test: (a) a clinician will be measuring your BP once every 3 minutes, (b) another clinician will be recording all physiological data from the test, as well as changing the speed and incline of the treadmill, (c) a pulse oximeter will be placed on your index finger, allowing the clinician to monitor your oxygen saturation at the end of every minute, (d) another clinician will be standing behind the treadmill for spotting purposes, (e) we would like you to exert yourself to what you feel is your maximum exertion; you may stop the test at any point, but we need you to reach the point where you feel it would be physically impossible to continue, (f) it is recommended that you refrain from using the handrails, but you may if you feel it is required, (g) regardless of your choice in handrail usage, this must be maintained for the entire duration of the test, you may not go back and forth, and (h) once you reach perceived maximal exertion, a cool-down will be initiated to lower your vitals close to resting measures.

A test was deemed a valid $Vo_2$peak test if at least 2 of the following criteria were met: (a) participant reached a respiratory exchange ratio ≥ 1.10; (CANCER metabolic cart protocol only), (b) participant terminated test because of perceived maximal effort and fatigue, (c) peak exercise HR was within 5 beats per minute of the individual's estimated maximal HR, and (d) if a subject gave a rating of perceived exertion value ≥ 8 on the modified Borg scale. Two or more maximal criteria must have been met for data inclusion.

## CANCER Protocol

This protocol consisted of 21, 1-minute stages. Speed and/or grade were increased at the completion of each stage. Details of this protocol are presented in Table 1.

Measured $Vo_2$peak during the CANCER protocol (CANCERmet) was obtained using a Cosmed research grade metabolic cart (Cosmed, Chicago, Illinois) Expired gases

TABLE 1. CANCER protocol.

| Stage | Speed, mph | Grade, % | Time, min | Heart Rate | $Spo_2$ | Blood Pressure | RPE |
|---|---|---|---|---|---|---|---|
| 0 | 1.0 | 0 | 1 | | | | |
| 1 | 1.5 | 0 | 1 | | | | |
| 2 | 2.0 | 0 | 1 | | | | |
| 3 | 2.5 | 0 | 1 | | | | |
| 4 | 2.5 | 2 | 1 | | | | |
| 5 | 3.0 | 2 | 1 | | | | |
| 6 | 3.3 | 3 | 1 | | | | |
| 7 | 3.4 | 4 | 1 | | | | |
| 8 | 3.5 | 5 | 1 | | | | |
| 9 | 3.6 | 6 | 1 | | | | |
| 10 | 3.7 | 7 | 1 | | | | |
| 11 | 3.8 | 8 | 1 | | | | |
| 12 | 3.9 | 9 | 1 | | | | |
| 13 | 4.0 | 10 | 1 | | | | |
| 14 | 4.1 | 11 | 1 | | | | |
| 15 | 4.2 | 12 | 1 | | | | |
| 16 | 4.3 | 13 | 1 | | | | |
| 17 | 4.4 | 14 | 1 | | | | |
| 18 | 4.5 | 15 | 1 | | | | |
| 19 | 4.6 | 16 | 1 | | | | |
| 20[a] | 4.7 | 17 | 1 | | | | |
| Cool-Down | …[b] | 0 | …[b] | | | | |

RPE = rating of perceived exertion; $Spo_2$ = oxygen saturation

[a]If a participant was to complete the last stage, the speed would be increased by 0.1 mph and grade by 1% every minute until volitional fatigue achieved.

[b]No standard value and is variable to change dependent on the patient.

were continuously collected where $Vo_2$ and carbon dioxide output were recorded once every 3 seconds. Calibration of the metabolic cart was performed before each test with a 3L syringe and precision gas mixtures. Before each test each subject received an explanation as to how the test was conducted and why the metabolic cart was being used. A respiration mask was attached to the subject's face with tubes connecting the mask and metabolic cart.

Estimated $Vo_2$peak of the CANCER protocol (CANCERest) was calculated using ACSM walking and running equations on the last completed stage of the CANCERmet protocol. This methodology has been previously validated as yielding accurate $Vo_2$peak values (23). The participant was either walking or running by the last completed stage, which determined the specific equation used. If the subject was walking when the test was terminated, the following equation was used: $Vo_2peak = (0.1 \times S) + (1.8 \times S \times G) + 3.5$; where S = speed and G = grade (15). If the subject was holding onto the handrails and walking at the termination of the test, the following correction equation was used: $Vo_2peak = 0.694$ ([0.1 × S] + [1.8 × S × G] + 3.5) + 3.33 (15,25). If the subject was running when the test was terminated, the following equation was used: $Vo_2peak = (0.2 \times S) + (0.9 \times S \times G) + 3.5$ (15). If the subject was running at the end of the test and holding on to the handrails the following correction equation was used: $Vo_2peak = 0.694$ ([0.2 × S] + [0.9 × S × G] + 3.5) + 3.33 (15,25).

### Bruce Protocol

The Bruce protocol is a well-established, widely used treadmill exercise protocol (26) and its predicted $Vo_2$peak equations have been validated extensively (22,27,28). For this study, we followed the standard Bruce protocol as outlined by ACSM Guidelines for Exercise Testing and Prescription widely used in literature (15,17,27), and all references to $Vo_2$peak yielded from the Bruce protocol refer to the estimation. To calculate $Vo_2$peak, the Bruce active and sedentary men and women generalized equations were used. For male participants, the following equation was used: $Vo_2peak = 14.76 - 1.379\ (time) + 0.451\ (time^2) - 0.012\ (time^3)$ (22). If the male participant used handrails, the following equation was used: $Vo_2peak = 0.694\ (14.76 - 1.379\ [time] + 0.451\ [time^2] - 0.012\ [time^3]) + 3.33$ (22,25). For female participants, the following equation was used: $Vo_2peak = 4.38\ (time) - 3.90$ (19). If the female participant used handrails, the following equation was used: $Vo_2peak = 0.694\ (4.38\ [time] - 3.90) + 3.33$ (19,25).

### Statistical Analysis

A power analysis was used to determine the appropriate sample and effect size using the statistical program G-Power (v 3.1; G*Power, Düsseldorf, Germany). Using the standard deviations and differences between the observations, a medium effect size with a confidence level of 95% was used. Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS v 27.0; Chicago, Illinois). All data are presented as mean ± standard deviation (29). A repeated measures ANOVA was used to determine differences in $Vo_2$peak values between the CANCERmet, CANCERest, and Bruce protocols. Post-hoc Tukey pairwise comparisons were conducted on any statistical data requiring follow-up analyses. Pair-wise *t* tests compared differences in mean peak physiological variables, HR, SBP, and rate-pressure product between the CANCER and Bruce protocols. Significance levels were set at $P \leq 0.05$.

## RESULTS

Subject demographics are summarized in Table 2. Participants included 38 females and 9 males; all common cancer types were represented in our sample. There were no significant differences between any resting or descriptive characteristics. All participants were able to achieve $Vo_2$peak

TABLE 2. Patient demographics and treatment characteristics.

| Parameter | Value, N = 47 |
|---|---|
| Participant Characteristics | |
| Age, mean ± SD, y | 61 ± 12 |
| Female, n (%) | 38 (81) |
| Height, mean ± SD, cm | 122 ± 13 |
| Weight, mean ± SD, kg | 74 ± 14 |
| RHR, mean ± SD | 83 ± 15 |
| RSBP, mean ± SD | 122 ± 13 |
| RDBP, mean ± SD | 75 ± 13 |
| Treatment Demographics, n (%) | |
| Surgery only | 12 (26) |
| Radiation only | 2 (4) |
| Surgery and radiation | 6 (13) |
| Radiation and chemotherapy | 1 (2) |
| Surgery and chemotherapy | 9 (19) |
| Surgery, radiation, and chemotherapy | 17 (36) |
| Cancer Types, n (%) | |
| Breast | 11 (23) |
| Liquid | 7 (15) |
| Prostate | 6 (13) |
| Gynecological | 5 (11) |
| Colorectal | 4 (9) |
| Lung | 3 (6) |
| Other, including thyroid, brain, skin, tongue, sarcoma, renal | 11 (23) |
| Cancer Stage, n (%) | |
| I | 15 (32) |
| II | 9 (19) |
| III | 16 (34) |
| IV | 7 (15) |

RHR = resting heart rate; RSBP = resting systolic blood pressure; RDBP = resting diastolic blood pressure.

TABLE 3. Mean peak exercise values for cancer survivors.[a]

| Parameter | CANCERmet | CANCERest | Bruce | *P* Value |
|---|---|---|---|---|
| $Vo_2$ (mL·kg$^{-1}$·min$^{-1}$) | 26.8 ± 7.1 | 27.2 ± 6.5 | 29.2 ± 8.0 | <0.05[b,c] |
| $Vo_2$ (L·min$^{-1}$) | 1.9 ± 0.7 | 2 ± 0.8 | 2.2 ± 0.8 | <0.05 [b,c] |
| METs | 7.6 ± 2 | 7.8 ± 1.8 | 8.4 ± 2.3 | <0.05 [b,c] |
| Treadmill time (min) | 12.6 ± 3 | … | 8.2 ± 2.3 | <0.05 [b,c] |
| RER | 1.21 ± 0.09 | … | … | … |
| HR (beats·min$^{-1}$) | 159 ± 19 | … | 152 ± 20 | <0.05 [b,c] |
| SBP (mm Hg) | 152 ± 13 | … | 149 ± 12 | <0.05 [b,c] |
| DBP (mm Hg) | 79 ± 8 | … | 78 ± 9 | 0.76 |
| RPP | 24,282 ± 3,775 | … | 22,737 ± 4,004 | <0.05 [b,c] |
| RPE | 8.8 ± 1 | … | 8 ± 0.8 | 0.2 |

CANCERest = estimated $Vo_2$peak from cancer-specific metabolic cart treadmill protocol; CANCERmet = cancer-specific metabolic cart treadmill protocol; DBP = diastolic blood pressure; HR = heart rate; METs = metabolic equivalents of task; RER = respiratory exchange ratio; RPE = rating of perceived exertion; RPP = rate pressure product; SBP = systolic blood pressure; $Vo_2$ = volume of oxygen consumption

[a]Data are presented as mean ± SD

[b]denotes a *P* value ≤ 0.05 CANCERmet vs. Bruce

[c]denotes a *P* value < 0.05 CANCERest vs. Bruce

criteria, and no adverse effects were observed during or after any of the tests.

All mean peak exercise values are presented in Table 3. $Vo_2$peak (mL·kg$^{-1}$·min$^{-1}$) was significantly lower in CANCERmet compared to the Bruce (Figure 1), significantly lower in CANCERest compared to the Bruce, and there was no significant difference between CANCERmet and CANCERest).

Mean peak HR and SBP were significantly lower in the Bruce compared to CANCERmet, respectively ($P$ = 0.01). Rate-pressure product, which is the product of both HR and SBP and a reflection of systolic myocardial workload and oxygen consumption, was significantly lower in the Bruce compared to the CANCER protocol (Figure 2). Average total treadmill time was significantly lower on the Bruce compared to the CANCER (Figure 3).

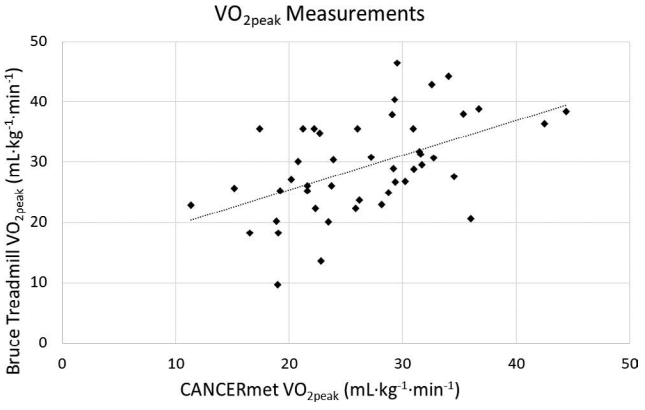


FIGURE 1. Estimated $Vo_2$peak values of the Bruce treadmill protocol and actual $Vo_2$peak of CANCERmet. $Vo_2$peak = peak volume of oxygen consumption; CANCERmet = cancer-specific treadmill protocol using a metabolic cart.

## DISCUSSION

The purpose of this study was to determine whether the Bruce protocol accurately estimates exercise capacity in CS, when compared against the CANCER protocol. Both protocols can obtain $Vo_2$peak using a metabolic cart or estimate $Vo_2$peak through standard prediction equations. The Bruce protocol has several validated prediction equations (22,27,28,30) including the standardized set recommended by ACSM (15). Likewise, the CANCER protocol has also been validated as producing accurate $Vo_2$peak values when using prediction equations in CS, which is confirmed in this work (23). Our principal finding indicated that $Vo_2$peak when estimated using the Bruce is significantly higher than both the actual and estimated values yielded by CANCERmet and CANCERest, respectively. Concerning, this larger estimation of aerobic function did not correspond to peak physiological responses

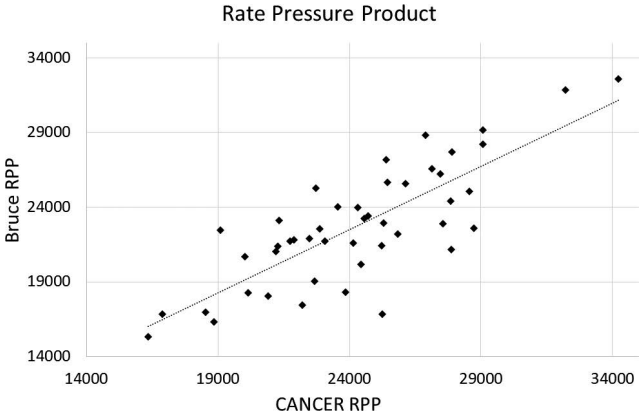


FIGURE 2. Rate pressure product values of the Bruce treadmill protocol and CANCER. CANCER = cancer-specific treadmill protocol.

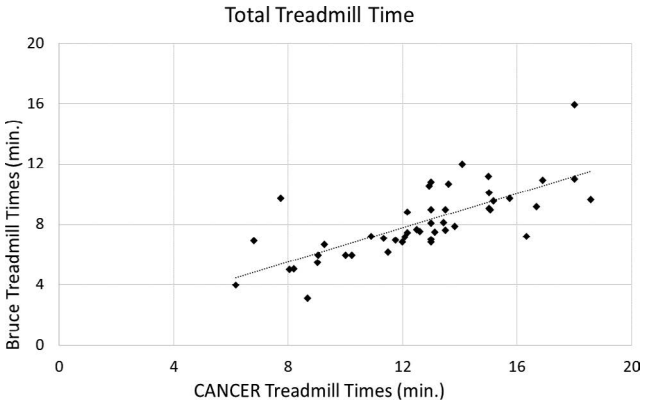


FIGURE 3. Total treadmill time values of the Bruce treadmill protocol and CANCER. CANCER = cancer-specific treadmill protocol; * indicates statistical significance $P < 0.05$.

representative of systolic myocardial work. This suggests that subjects exercised at a higher capacity during the CANCER protocol yet yielded a $Vo_2$peak value significantly lower than those measured by the Bruce. Thus, the Bruce protocol overestimated $Vo_2$peak in this sample of CS.

GXTs require linearly increasing work rates in order to elicit the highest physiological responses to exercise (e.g., HR, BP, rating of perceived exertion, and lactate threshold) and thus corresponds with maximal $Vo_2$ (30,31), Specifically, GXTs rely on the Fick Principle and the relationship between $Vo_2$, cardiac output, and oxygenated arterial-venous difference (17). Gas analysis itself allows measurement of $Vo_2$, while vitals such as HR and BP allow clinicians insight into the linear relationship of cardiac output, the cardiovascular component of the Fick equation. Our results demonstrate that significantly higher HR, SBP, and rate-pressure product values were achieved in the CANCER protocol, reflective of true maximal cardiac output. Of note, 47% of CS exceeded age-predicted HR maximum estimates during the CANCER protocol, in comparison to only 23% during the Bruce. Likewise, treadmill time was greater when subjects completed the CANCER. These outcomes are logical as the CANCER protocol was specifically designed to accommodate treatment-related aftereffects with the design of shorter and less intense stages, allowing the CS to continue further into the protocol and elicit higher physical responses.

Although Bruce $Vo_2$peak values were significantly higher, the protocol yielded significantly lower peak physiological responses compared to the CANCER protocol. These observations suggest that most participants did not reach maximal effort during the Bruce, which may be attributed to the protocol design itself. The Bruce protocol's workload was designed for highly functioning individuals, which has been reported to be too intense for even the average individual to perform (24). Sharp inclines between stages could lead to a greater reliance on anaerobic metabolism, resulting in subjects fatiguing before reaching true maximal volition (32–35). In addition, CS may have cancer cachexia and/or other treatment-related muscular toxicities which may adversely affect systemic mitochondrial function and subsequent adenosine triphosphate generating capacity, which can cause severe fatigue with or without physical exertion (36,37). The higher intensities and more dramatic workload changes of the Bruce protocol may have exacerbated these decrements, resulting in lower physiological responses and early test termination due to muscular fatigue, not cardiovascular fatigue, which is the assumption and goal of a GXT. This response to the Bruce is not exclusive to CS. Others have reported difficulties achieving target HR in a general patient population because of their physical inability to keep up with the large incremental changes in workload (20,38,39). Similarly, Pollock and colleagues demonstrated small but significant differences in $Vo_2$max, HR, and SBP between the Balke-Ware and Bruce treadmill protocols in healthy women (19). Myers and colleagues also reported reduced $Vo_2$peak values as measured by an individualized ramp test, a protocol with gradual work increments, compared to tests using standard increments like the Bruce protocol in patients with reduced oxygen kinetics (20). Likewise, Pollock and colleagues found significant differences between $Vo_2$ as measured by the Balke-Ware, Bruce, Ellestad, and a continuous multistage running protocol in a population of older adults. Despite a lower $Vo_2$ value, the Balke-Ware, the protocol with the most gradual rate of progression in metabolic equivalent of task cost, elicited the maximum physiological responses to exercise as compared to the other 3 protocols (30).

In this study, the Bruce yielded lower peak physiological responses despite estimating higher values of aerobic function, i.e., $Vo_2$peak values. These results agree with other studies which demonstrated that Bruce $Vo_2$peak equations inaccurately estimate CRF in active individuals (17) as well as in sedentary or chronically diseased individuals (14,20,30,35,40). In addition to the design of the Bruce, Aguiar and colleagues reported that the ACSM metabolic equations inaccurately predicted $Vo_2$peak using the Bruce because of the steep increases in workload irrespective of steady-state oxygen consumption necessary for estimation purposes (41). Myers and colleagues similarly demonstrated that the accuracy of estimation of $Vo_2$ from the Bruce is poor in those with heart disease or reduced oxygen kinetics (20). They concluded that protocols with large and unequal increments between stages result in overestimation of $Vo_2$ and greater variability due to a nonlinear relation between oxygen uptake and work rate (20). Our results mirror findings in other chronic diseased populations who performed treadmill protocols with smaller work rate increments and yielded reduced $Vo_2$peak as compared to the Bruce (20). Thus, the CANCER may have yielded a lower, but more accurate $Vo_2$peak compared to the Bruce because of the decreased intensity and shorter stages.

## CLINICAL IMPLICATIONS

Cardiorespiratory fitness is inversely correlated with all-cause mortality and cancer recurrence. A decline in CRF and $Vo_2$peak is commonly observed after cancer treatment because of treatment-related side effects and toxicities on

physiological systems as well as inactivity (8,42,43). Exercise-based rehabilitation programs are becoming more widely used in comprehensive cancer care with the mission to improve physiological functioning, specifically CRF. For this reason, it is imperative that $Vo_2$peak be measured with accuracy so clinicians have confidence in prescribing exercise from these results. GXTs are the most common method of assessing aerobic function, and of these, estimation of $Vo_2$peak from prediction equations is the most economic and feasible way to quantify the result (38). When conducting GXTs, the Bruce protocol and its corresponding prediction equations are used most often, but our data suggests that not only is the Bruce protocol too intense for use in CS but resulted in overestimated and inaccurate $Vo_2$peak values. Any miscalculation of $Vo_2$peak is deleterious when prescribing exercise in this population. Underpredicting $Vo_2$peak could potentially prevent the CS from exercising at the minimum threshold required for improvements in function (14). In contrast, and more concerning, overpredicting $Vo_2$peak could lead to overtraining at too high of an intensity, which could compromise the patient's health and the efficacy of the rehabilitation program (44). Data presented in this study demonstrates that unlike the Bruce, the CANCER protocol provides accurate $Vo_2$peak values, higher physiological responses to exercise, and allows proper CRF assessment in patients who have limited functional capacity. We suggest that clinicians discontinue the use of the Bruce treadmill protocol to measure CRF in CS, as it overestimates $Vo_2$peak and yields lower physical exertion. Instead, we propose that the CANCER protocol be used as the standard method to measure aerobic capacity in the design, implementation, and surveillance of exercise-based rehabilitation programs for CS.

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