Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Medicine and Health Sciences
Department of Neuromedicine and Movement Science

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Validity of the Ekblom-Bak Cycle Ergometer Test in Adult Patients with Cardiovascular Disease

Master's thesis in Physical Activity and Health (Exercise Physiology)
Supervisor: Marius Steiro Fimland
Co-supervisor: Jon Arne Sandmæl & Harald Engan
May 2022

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Infographic

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Exercise testing for assessing cardiorespiratory fitness (CRF) is recommended both before and after cardiac rehabilitation. CRF measured as peak oxygen consumption ($\dot{V}O_2$peak) is a key predictor of physical performance and all-cause mortality. The Ekblom-Bak test has shown to accurately estimate $\dot{V}O_2$peak in healthy adults, but its accuracy in patients with cardiovascular disease (CVD) remains uncertain.

Aim: To validate the Ekblom-Bak test´s estimation of $\dot{V}O_2$peak in CVD patients admitted to cardiac rehabilitation.

26 patients recruited from cardiac rehabilitation at Unicare Røros performed two exercise tests

19 men, 7 women

62 ± 10 years

90.9 ± 15.6 kg

Ekblom-Bak Cycle Ergometer Test	VS	Maximal Cardiopulmonary Exercise Treadmill Test
2.69 ± 0.57 L/min		2.29 ± 0.56 L/min
29.5 ± 4.6 mL/kg/min		25.2 ± 4.3 mL/kg/min

The Ekblom-Bak test overestimated V̇O2peak by ~17%

Conclusion:
The Ekblom-Bak test does not seem to accurately estimate V̇O2peak in patients with CVD. It is however easily administered, time-efficient and not dependent on expensive, specialized equipment. No adverse effects were observed during the Ekblom-Bak test, so it seems to be safe for CVD patients. Thus, the Ekblom-Bak test may be a feasible alternative for exercise testing when a maximal CPET is not possible.

Abstract

Background: The objective of the present study was to validate the Ekblom-Bak cycle ergometer test in patients with cardiovascular disease (CVD) admitted to cardiac rehabilitation, by comparing estimated peak oxygen consumption ($\dot{V}O_2$peak) from the Ekblom-Bak test to directly measured $\dot{V}O_2$peak from a maximal treadmill cardiopulmonary exercise test (CPET).

Methods: Patients attending cardiac rehabilitation, performed two exercise tests on two separate days. First, they performed a maximal CPET by walking on a treadmill. On the following day, ≥ 24 hours after the maximal CPET, they performed the Ekblom-Bak test. Pearson's correlation coefficient (r) was used to establish the correlation between estimated and measured $\dot{V}O_2$peak, and Bland-Altman plots with limits of agreement (LoA) was used to determine the bias between the two tests.

Results: Twenty-six patients were included in the final analysis. The Ekblom-Bak test overestimated $\dot{V}O_2$peak in CVD patients by 17.5% ($p < 0.05$) and 17.1% ($p < 0.05$) for absolute and relative $\dot{V}O_2$peak, respectively. The agreement between estimated and measured $\dot{V}O_2$peak was: bias = 0.40 L/min (LoA: -0.35 – 1.16 L/min) for absolute $\dot{V}O_2$peak, and bias = 4.3 mL/kg/min (LoA: -4.0 – 12.6 mL/kg/min) for relative $\dot{V}O_2$peak. There was a statistically significant strong correlation between estimated and measured $\dot{V}O_2$peak for both absolute ($r = 0.769$) and relative ($r = 0.544$) $\dot{V}O_2$peak.

Conclusion: The Ekblom-Bak test does not seem to accurately estimate $\dot{V}O_2$peak in patients with CVD. It is however easily administered, time-efficient and not dependent on expensive, specialized equipment. No adverse effects were observed during the Ekblom-Bak test, so it seems to be safe for CVD patients. Thus, the Ekblom-Bak test may be a feasible alternative for exercise testing when a maximal CPET is not possible.

Keywords: Cardiac Rehabilitation, Ekblom-Bak Test, Cardiorespiratory Fitness, Validation

Abstrakt

Hensikt: Målet med denne studien var å validere Ekblom-Bak testen for pasienter i hjerterehabilitering med hjerte- og karsykdommer, ved å sammenligne estimert peak oksygenopptak (V̇O2peak) fra Ekblom-Bak testen mot direkte målt V̇O2peak fra en maksimal kardiopulmonal belastningstest (CPET).

Metode: Deltagere på hjerterehabilitering utførte to kondisjonstester på to separate dager. Først gjennomførte de en maksimal CPET ved å gå på en tredemølle. Dagen etter, ≥ 24 timer etter deres maksimale CPET, utførte de Ekblom-Bak testen. Pearsons korrelasjonskoeffisient (r) ble brukt for å finne korrelasjonen mellom estimert og målt V̇O2peak, og Bland-Altman plott med Limits of Agreement (LoA) ble brukt for å finne differansen mellom de to testenes resultater.

Resultat: Tjueseks pasienter ble inkludert i den endelige analysen. Ekblom-Bak testen overestimerte V̇O2peak for hjerterehabiliteringsdeltagerne med 17,5% ($p < 0,05$) og 17,1% ($p < 0,05$) for absolutt og relativ V̇O2peak, henholdsvis. Differansen mellom estimert og målt V̇O2peak var: bias = 0,40 L/min (LoA: -0,35 – 1,16 L/min) for absolutt V̇O2peak, og bias = 4,3 mL/kg/min (LoA: -4,0 – 12,6 mL/kg/ min) for relativ V̇O2peak. Det ble observert en statistisk signifikant, sterk korrelasjon mellom estimert og målt V̇O2peak for både absolutt ($r = 0,769$) og relativ ($r = 0,544$) V̇O2peak.

Konklusjon: Ekblom-Bak testen ser ikke ut til å estimere V̇O2peak nøyaktig for pasienter med hjerte- og karsykdommer. Den er imidlertid enkel å administrere, tidseffektivt og man er ikke avhengig av dyrt, spesialisert utstyr. Det ble ikke observert noen negative effekter under Ekblom-Bak testen, så det kan se ut til at den er trygg å utføre for pasienter med hjerte- og karsykdommer. Dermed kan det tenkes at Ekblom-Bak testen kan være et godt alternativ for kondisjonsstesting når en maksimal CPET ikke er gjennomførbar.

Nøkkelord: Hjerterehabilitering**,** Ekblom-Bak test**,** Kondisjon**,** Validering

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Introduction

Cardiovascular diseases (CVD) refers to diseases affecting the heart and blood vessels (e.g., coronary heart disease, myocardial infarction, arrhythmias, stroke, etc.), and is one of the major causes of health-related disability and death worldwide (WHO, 2022). CVD accounts for substantial societal and economical costs with regard to both leave of absence, treatment, and mortality (Liu et al., 2002; Timmis et al., 2018; Virani et al., 2021). Admission to cardiac rehabilitation is highly recommended, as it has shown to improve exercise capacity, cardiovascular risk factors, quality of life and mortality rates for patients with various CVD diagnoses (Dibben et al., 2021; Lawler et al., 2011; Wenger, 2008). Assessment of cardiorespiratory fitness (CRF) by use of exercise testing is recommended both before and after cardiac rehabilitation (Thomas et al., 2019). CRF is a key predictor of physical performance and has been established as a strong independent predictor of health outcomes, longevity, and all-cause mortality in both the general population and people with CVD (Kaminsky et al., 2019; Kodama et al., 2009). Some studies suggest that CRF may be a stronger predictor of mortality than well-known CVD risk factors, such as smoking, type 2 diabetes, hypertension, and high cholesterol (Myers et al., 2002; Ross et al., 2016). Direct measurements of CRF, assessed as peak oxygen consumption ($\dot{V}O_2$peak) enables assessment of prognosis and risk stratification for several CVD diagnosis, by comparison to established $\dot{V}O_2$peak reference values (Kavanagh et al., 2002; Stelken et al., 1996). $\dot{V}O_2$peak also provides a beneficial framework for determination of optimal aerobic exercise intensity, and the American Heart Association has stated that CRF should be used as a clinical evaluation tool (Kaminsky et al., 2013; Mann et al., 2013).

The gold standard method for testing CRF is to measure $\dot{V}O_2$peak during a maximal cardiopulmonary exercise test (CPET), where the test subject performs a gradual incremental exercise effort until exhaustion (Albouaini et al., 2007). For achieving accurate $\dot{V}O_2$peak measurements, it is recommended to perform CPET on a treadmill, as tests performed on cycle ergometers has been shown to report lower $\dot{V}O_2$peak values (Hermansen & Saltin, 1969; Shephard, 1984). CPET is a relatively time-consuming method of exercise testing, that requires use of expensive equipment for analyzation of expired air in a controlled lab environment, and proper interpretation of results is dependent on a certain degree of physiological expertise (American Thoracic Society [ATS], 2002). CPET also requires the test subject to perform a maximal exercise effort, which may not be possible for certain populations due to symptom specific contraindications (Fletcher et al., 2013). Patients with CVD may be unable to perform maximal efforts, because of symptoms like unstable angina, arrhythmias, palpitations, dizziness, and dyspnea (Albouaini et al., 2007; Arena & Sietsema, 2011; Fletcher et al., 2013). Psychological barriers related to fear of their own safety and the possibility of acute cardiac events, may also cause CVD patients to be scared of performing efforts leading to maximal exertion (Spaderna et al., 2020).

When a maximal CPET is not feasible due to a lack of resources, expertise, or because of patients having contraindications for maximal exercise efforts, one could consider performing a submaximal exercise test. Submaximal testing of CRF commonly predicts $\dot{V}O_2$peak from the heart rate (HR) response to submaximal work, with either regression modeling or extrapolation to supposed maximal levels (Noonan & Dean, 2000; Swain et al., 2004). $\dot{V}O_2$peak estimations are commonly based on the rather linear relationship between HR and power output up to maximum, and the fact that oxygen consumption can be estimated from power output with acceptable precision (Ekblom-Bak et al., 2014; Hawley & Noakes, 1992). However, estimation of $\dot{V}O_2$peak seems to be an inaccurate method, so if you are to obtain meaningful results from submaximal testing it is crucial to choose a test with sufficient reliability and validity (Brown et al., 1985; Shephard, 1984). Some of the most used submaximal tests for estimation of $\dot{V}O_2$peak includes the 6-minute walk test (ATS, 2002), the Rockport Fitness Test (Kline et al., 1987), the Modified Shuttle Walking Test (Singh et al., 1992, 1994), and the Åstrand & Ryhming Cycle Ergometer Test (Åstrand test) (I. Åstrand, 1960; P. O. Åstrand & Ryhming, 1954). The Åstrand test predicts $\dot{V}O_2$peak by use of extrapolation from steady-state HR achieved after 6 minutes at an individually chosen work rate, and is one of the most commonly used submaximal cycle ergometer tests (I. Åstrand, 1960; Noonan & Dean, 2000; Swain et al., 2004). Fitness

facilities have frequently been using the Åstrand test as part of fitness evaluations, and to aid the development and evaluation of training plans (Wisén & Wohlfart, 1995). Additionally, the Åstrand test has recently been used as a substitute for the maximal CPET in several Scandinavian studies investigating CRF related outcomes (Ekblom-Bak et al., 2019, 2021; Eriksson et al., 2021).

The Ekblom-Bak Cycle Ergometer Test (Ekblom-Bak test) is a relatively new submaximal exercise test for estimation of $\dot{V}O_2$peak, that has shown a strong correlation to directly measured $\dot{V}O_2$peak from maximal treadmill CPET in healthy adults, with improved precision compared to the commonly used Åstrand test. (Björkman et al., 2016; Ekblom-Bak et al., 2014; Väisänen et al., 2020). The Ekblom-Bak test equations were further updated by Björkman et al. (2016), and $\dot{V}O_2$peak estimations are calculated from sex specific formulas incorporating the subject´s age and HR response between two work rates, rather than the single work rate used in the Åstrand test. The revised version of the Ekblom-Bak test is considered to provide valid estimations of $\dot{V}O_2$peak for a wide variety of both age (20 – 86 years) and fitness levels (19 – 76 mL/kg/min) within the healthy adult population (Björkman et al., 2016). The Ekblom-Bak test seems to be able to detect changes in $\dot{V}O_2$peak over time, and has recently been utilized as the main method of $\dot{V}O_2$peak estimation in a study investigating CRF in Swedish adolescents (Björkman et al., 2021; Kjellenberg et al., 2021).

The Ekblom-Bak test is easily administered, time-efficient and seems to carry relatively low risk, meaning it might be suitable for use in rehabilitation settings if a maximal CPET is not feasible (Björkman et al., 2016; Ekblom-Bak et al., 2014). However, the evidence regarding the validity of the Ekblom-Bak test in patient populations are scarce, with only one study attempting to validate the $\dot{V}O_2$peak estimation´s accuracy in a group of breast cancer patients undergoing chemotherapy (Mijwel et al., 2016). Since there is no evidence of the Ekblom-Bak test´s accuracy in estimating $\dot{V}O_2$peak for CVD patients, its applicability for use in cardiac rehabilitation settings remain uncertain. Thus, the objective of the present study was to validate the Ekblom-Bak test in CVD patients admitted to cardiac rehabilitation, by comparing estimated VO2peak from the Ekblom-Bak test to directly measured VO2peak from a maximal treadmill CPET.

Methods

Participants

Participants were recruited from patients taking part in an inpatient cardiac rehabilitation program (Unicare Røros, Norway). Patients answered a series of categorical answer mode questionnaires as part of their rehabilitation, where they self-reported information on demographics, physical function, quality of life, and anxiety and depression. Information on disease history, diagnosis and medication was collected through the center´s patient journals. This study used a convenience sample approach, meaning that every patient willing to participate was included, provided they were medically cleared by the cardiologist at the center. Every patient was given oral information about the project during a plenary meeting on their first day at the center. Further information was provided both written and orally for the patients interested in participating in an additional meeting on the second day of their rehabilitation stay. Every participant provided written consent before commencement of the Ekblom-Bak test. Data was collected in accordance with the requirements of the Declaration of Helsinki, and the present study was approved by the Norwegian Regional Ethical Committee South-East B (Project ID: 281364).

Test information

The maximal CPET is part of the clinical routine of the cardiac rehabilitation, and every patient performs the test during the first three days of their stay. The same pre-test instructions were given for both the maximal CPET and the Ekblom-Bak test. This included abstaining from food intake, nicotine, and consuming other fluids than water on the last 2 hours before the test, as well as not performing any vigorous physical activity during the last 24 hours prior to the test. To accommodate this, the test schedule was designed so that the Ekblom-Bak test was performed on the day after the maximal CPET, with at least 24 hours interval between the two tests. Instructions on Borg´s scale was given prior to both tests, as the present clinical routines of the

maximal CPET, and the specific protocol of the Ekblom-Bak test operated with different versions. The Borg Category Ratio 10 scale (Borg CR10) ranging from 0 – 10+, and Borg´s Rating of Perceived Exertion (Borg RPE) ranging from 6 – 20, were utilized for the maximal and submaximal test, respectively (Borg, 1982). Participant's weight used for calculating relative $\dot{V}O_2$peak (ml/kg/min), was registered to the nearest 0.1 kg prior to both tests, in case of any substantial changes that might influence the results.

Maximal CPET

Participants performed a maximal incremental walking protocol on a treadmill (Woodway PPS 55 Med, Waukesha, WI, USA). During the test, participants were fitted with a face mask of appropriate size (Hans Rudolph, Germany), connected to an inspiratory flow meter that linked to the Vyntus CPX (Vyaire medical, Hoechberg, Germany). Vyntus CPX measured oxygen consumption through breath-by-breath analyzation of the gas exchange between CO_2 and O_2. The volume of the inspiratory flow meter and gas were calibrated by the Vyntus CPX´s automatic procedures prior to each test, using a calibration gas (5.00 ± 0.01% CO_2 and 16.00 ± 0.01% O_2, (Vyaire medical, Hoechberg, Germany)) and ambient indoor air. Prior to the test, participants were instructed on test procedures and Borg CR10, and their height and waist circumference were measured to the nearest cm. Participants were connected to a 12-lead ECG-recording (Custo cardio 300BT_A, Ottobrunn, Germany) and a blood pressure measurement device (Tango M2, SunTech Medical, Morrisville, NC, USA). Resting ECG and resting blood pressure was recorded from a seated position before the maximal CPET was initiated. ECG-readings were continuously monitored by a cardiologist throughout the test, while blood pressure was measured every 3 minutes, and at the cessation of the test. Concurrently with blood pressure measurements, participants were asked to report their subjective feeling of exertion according to BORG CR10.

Testing was performed using specifically developed walking protocols for patients with CVD (Appendix A), which was created by a hospital specializing in treatment and rehabilitation of cardiac patients (Feiringklinikken, Feiring, Norway). Four ramping protocols was programmed in the Sentrysuite test software (Vyaire medical, Hoechberg, Germany), and increments were automatically controlled by the software. Protocols differed in both initial (1.6 – 3.5 km/h), and final (4.0 – 6.0 km/h) walking velocity, with maximal velocity occurring after ~9 minutes. Every protocol started at 0% inclination, with a slow gradual increase to 4% inclination during the first ~9 minutes. This was followed by larger increases for the remainder of the test, with increments up to a maximum of 20% inclination occurring after ~15 minutes. The protocol was chosen by the test administrator, based on the participant´s self-reported physical activity level over the last couple of months, history of disease, severity of- and time since cardiac event, and observation of gait. No warm-up period was performed prior to testing, as the slow ramping during the first minutes of the protocols served this purpose. Participants were instructed to avoid holding on to the handrails if not absolutely necessary throughout the entire test, and to relax their arm during blood pressure measurements for ensuring optimal recordings. If a participant seemed to have been assigned a suboptimal protocol, the workload was manually adjusted to ensure that maximal exhaustion was obtained. Tests were terminated when participants reached voluntary exhaustion in form of e.g., dyspnea or leg fatigue, or if any of the indications for test termination listed by the American Heart Association were observed (Gibbons et al., 1997). Test results are not deemed maximal oxygen consumption ($\dot{V}O_2$max) as CVD patients rarely are able to attain common criteria used for establishing $\dot{V}O_2$max (Arena et al., 2007). Contrary, results were deemed $\dot{V}O_2$peak, which is more commonly used clinically and expresses the highest oxygen consumption during exercise to voluntary exhaustion (Arena et al., 2007). Absolute $\dot{V}O_2$peak (L/min) was calculated from the relative $\dot{V}O_2$peak (mL/kg/min) value reported by the Sentrysuite test software, using the formula: $\dot{V}O_2$peak (L/min) = (($\dot{V}O_2$peak (mL/kg/min) × weight))/1000.

Submaximal test

Test procedures for the Ekblom-Bak test are described by Ekblom-Bak et al. (2014), and the full protocol (Appendix B) can be found at the homepage of The Swedish School of Sport and Health Sciences (Ekblom-Bak, 2012). The test was performed on an electronically braked cycle ergometer (Monark model 928E, Vansbro, Sweden), and participants were equipped with a HR-monitor (Polar model H7, Kempele, Finland). The test administrator ensured that the participant had complied with the pretest criteria and provided instructions on test procedures and Borg RPE. Participants were instructed to pedal with a cadence of 60 revolutions per minute, and not speak or adjust their position during the test. Total test duration was ~8 minutes, with the first 4 minutes being performed at a fixed work rate of 30 watts (W). This was directly followed by 4 minutes at a higher predetermined individualized work rate. The test leader chose the higher work rate based on gender, body size, training background, training status, and information on disease, aiming to achieve a work rate corresponding to Borg RPE ≈ 14. After the first minute of the higher work rate, participants were asked to assess their current Borg RPE. If Borg RPE were less than 12, the work rate was further increased by 30 W, and the final 4-minute period was restarted. If Borg RPE were higher than 16, the test was terminated, and the participant was given a 20-minute rest-period before commencement of a new test. Finally, participants were asked to assess Borg RPE for the 4 minutes at the higher work rate, to ensure that the work rate corresponded to Borg RPE ≈ 14.

The Ekblom-Bak test equations use the difference in HR between the standard and higher work rate, relative to the increase in power output (PO) to calculate $\dot{V}O_2$peak. It is also dependent of the sex and age of the subject, as well as the absolute HR at the standard and higher work rate. HR was registered every 15 seconds during the last minute of each work rate (3:15, 3:30, 3:45, and 4:00), and the calculated average of these recordings was used as the mean HR for the standard and higher work rate. The calculations of estimated $\dot{V}O_2$peak for the Ekblom-Bak test was performed by use of an Excel-sheet provided by The Swedish School of Sport and Health Sciences, which included the formula for the latest update of the gender specific equations (Ekblom-Bak, 2012). For women, the equation used was: $\dot{V}O_2peak = 1.84390 - 0.00673\ (age) - 0.62578\ (\Delta HR/\Delta PO) + 0.00175\ (\Delta PO) - 0.00471\ (HR\ at\ standard\ work\ rate)$, and for men the equation was: $\dot{V}O_2peak = 2.04900 - 0.00858\ (age) - 0.90742\ (\Delta HR/\Delta PO) + 0.00178\ (\Delta PO) - 0.00290\ (HR\ at\ standard\ work\ rate)$(Björkman et al., 2016).

Statistical analysis

All statistical analyses were performed with SPSS statistical software version 27.0 (SPSS Inc, Chicago, IL, USA). Descriptive data was controlled for normal distribution by use of normality plots and the Shapiro-Wilk test. All parameters were normally distributed and are presented as mean ± Standard deviation (SD), unless otherwise mentioned. To establish the correlation between the two tests, Pearson's correlation coefficient (r) was calculated between the estimated $\dot{V}O_2$peak from the Ekblom-Bak test and the directly measured $\dot{V}O_2$peak from the maximal CPET. Pearson's r was classified as weak (< 0.10), modest (0.1 – 0.3), moderate (0.3 – 0.5), strong (0.5 – 0.8), or very strong (0.8 – 1.0). Standard error of estimate was derived from a linear regression model to show the variation around the regression line. The variation in relation to its mean for the difference between estimated and measured $\dot{V}O_2$peak was determined by the coefficient of variation. The coefficient of variation was calculated by dividing the SD of the difference between estimated and measured $\dot{V}O_2$peak by the mean of the measured $\dot{V}O_2$peak. Bland-Altman plot analysis with limits of agreement (LoA), were performed to find the bias between the Ekblom-Bak test and the maximal CPET. The bias was determined by calculating the mean difference between estimated and measured $\dot{V}O_2$peak, and one sample t-test was used to detect whether the two tests were significantly different from each other. LoA were calculated with the equation: mean difference between estimated and measured $\dot{V}O_2$peak ± 1.96 multiplied by the SD of difference between estimated and measured $\dot{V}O_2$peak. The LoA are expected to include 95% of the differences between the tests. Analysis was performed for the full sample, and for subgroups based on participants´ sex and betablocker medication status. Two-tailed significance level were set at $p < 0.05$, for all statistical analysis.

Results

The process of recruitment and exclusion is presented in figure 1. The sample included in the final analysis, consisted of 26 participants, including 7 women and 19 men with mean age 62 years and mean BMI 29.4. Complete characteristics of these participants are presented in table 1.

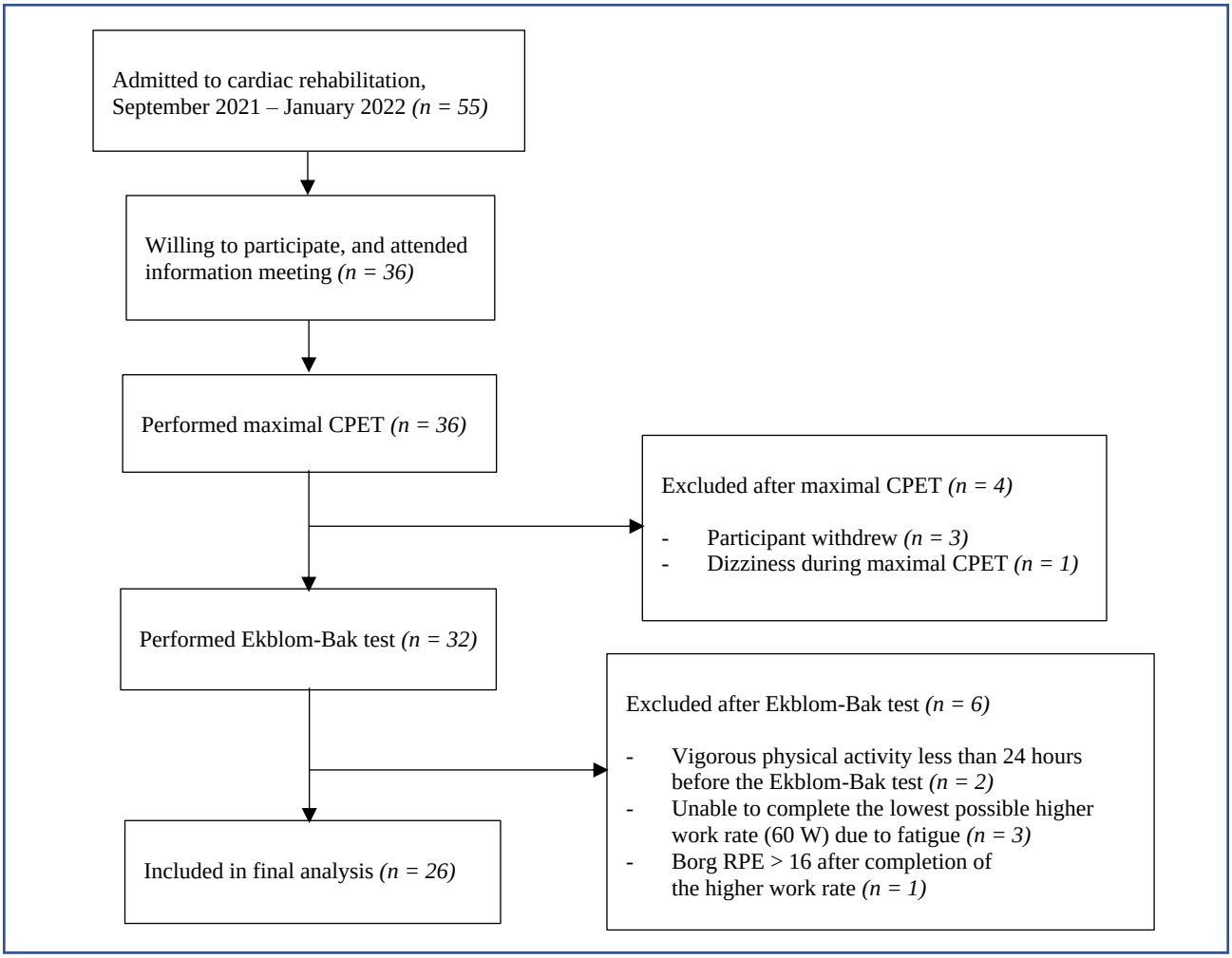

Figure 1: *Flowchart describing the recruitment and exclusion process. CPET = cardiopulmonary exercise test; RPE = rating of perceived exertion*

Table 1: *Characteristics of the sample included in the final analysis (mean ± standard deviation)*

	All *(n = 26)*	Women *(n = 7)*	Men *(n = 19)*
Age (years)	62 ± 10	54 ± 10	65 ± 9
Height (cm)	175 ± 9	165 ± 6	180 ± 6
Weight (kg)	90.9 ± 15.6	81.2 ± 14.9	94.5 ± 14.6
BMI	29.4 ± 4.9	30.0 ± 5.1	29.1 ± 5.0
HRmax (beats/min)	150 ± 20	147 ± 20	151 ± 21
Resting Systolic BP (mmHg)	137 ± 18	123 ± 14	143 ± 16
Resting Diastolic BP (mmHg)	86 ± 11	79 ± 11	88 ± 11
Using beta blockers	n = 10	n = 3	n = 7

HRmax = maximal heart rate; BP = blood pressure

The higher work rate for the Ekblom-Bak test ranged from 60 – 150W in the present study, and mean Borg RPE for the higher work rate was 14 ± 1. Relevant variables from the Ekblom-Bak test and maximal CPET are presented in table 2. For absolute $\dot{V}O_2$peak, the estimated $\dot{V}O_2$peak was 17.5% ($p < 0.05$) higher compared to measured $\dot{V}O_2$peak. Estimated $\dot{V}O_2$peak was 16.7% ($p < 0.05$) and 17.8% ($p < 0.05$) higher than measured $\dot{V}O_2$peak in women and men, respectively. In patients using betablockers, the Ekblom-Bak test overestimated $\dot{V}O_2$peak by 26.1% ($p < 0.05$), while in the subgroup not taking betablockers, estimated $\dot{V}O_2$peak was 13% ($p < 0.05$) higher than measured $\dot{V}O_2$peak.

Analysis of relative $\dot{V}O_2$peak, showed that estimated $\dot{V}O_2$peak was 17.1% ($p < 0.05$) higher compared to measured $\dot{V}O_2$peak. Estimated $\dot{V}O_2$peak was 14.6% ($p < 0.05$) and 18% ($p < 0.05$) higher than measured $\dot{V}O_2$peak in women and men, respectively. In patients using betablockers, the Ekblom-Bak test overestimated $\dot{V}O_2$peak by 25.7% ($p < 0.05$). For the subgroup not taking betablockers, estimated $\dot{V}O_2$peak was 12% ($p < 0.05$) higher than measured $\dot{V}O_2$peak. Estimated $\dot{V}O_2$peak had a strong correlation to measured $\dot{V}O_2$peak in all subgroups, except for a very strong correlation of absolute $\dot{V}O_2$peak in patients using betablockers, and a moderate correlation of relative $\dot{V}O_2$peak in the unmedicated patients. Correlation between the two tests was consistently higher for the absolute $\dot{V}O_2$peak than the relative $\dot{V}O_2$peak across all subgroups, and every Pearson´s R was statistically significant ($p < 0.05$).

Table 2: *Results from the Ekblom-Bak test and the maximal cardiopulmonary exercise test*

	All *(n = 26)*	Women *(n = 7)*	Men *(n = 19)*	Using Betablockers *(n = 10)*	Not using Betablockers *(n = 16)*
Estimated $\dot{V}O_2$peak					
Absolute L/min; mean ± SD	2.69 ± 0.57	2.24 ± 0.41	2.85 ± 0.54	2.66 ± 0.74	2.70 ± 0.46
Relative mL/kg/min; mean ± SD	29.5 ± 4.6	27.5 ± 3.1	30.2 ± 4.9	30.3 ± 5.9	28.9 ± 3.6
Measured $\dot{V}O_2$peak					
Absolute L/min; mean ± SD	2.29 ± 0.56	1.92 ± 0.32	2.42 ± 0.58	2.12 ± 0.60	2.39 ± 0.53
Relative mL/kg/min; mean ± SD	25.2 ± 4.3	24.0 ± 4.6	25.6 ± 4.3	24.1 ± 3.9	25.8 ± 4.6
Between-test difference					
Absolute L/min; mean [95% CI]	0.40 [0.25, 0.56]	0.32 [0.08, 0.56]	0.43 [0.23, 0.64]	0.55 [0.32, 0.77]	0.31 [0.09, 0.53]
Relative mL/kg/min; mean [95% CI]	4.3 [2.6, 6.0]	3.5 [0.4, 6.6]	4.6 [2.4, 6.8]	6.2 [3.5, 8.9]	3.1 [0.9, 5.4]
Correlation coefficient					
Absolute; r	0.769	0.775	0.711	0.910	0.670
Relative; r	0.544	0.686	0.502	0.777	0.496
Coefficient of variation					
Absolute; %	17.0	13.5	17.8	14.8	17.1
Relative; %	16.9	13.9	17.9	15.8	16.3
SEE					
Absolute; L/min	0.37	0.22	0.42	0.27	0.40
Relative; mL/kg/min	3.7	3.7	3.8	2.6	4.1

$\dot{V}O_2$peak = peak oxygen consumption; SD = standard deviation; CI = confidence interval; SEE = standard error of estimate

The agreement between estimated $\dot{V}O_2$peak from the Ekblom-Bak test and measured $\dot{V}O_2$peak from the maximal CPET was: bias = 0.40 L/min (LoA: -0.35 – 1.16 L/min), and bias = 4.3 mL/kg/min (LoA: -4.0 – 12.6 mL/kg/min) for absolute and relative $\dot{V}O_2$peak, respectively. Figure 2 illustrates agreement between estimated and measured $\dot{V}O_2$peak for subgroups divided by sex (A & B) and betablocker medication status (C & D) for both absolute (A & C) and relative (B & D) $\dot{V}O_2$peak. Agreement for absolute $\dot{V}O_2$peak was: bias = 0.32 L/min (LoA: -0.19 – 0.83 L/min), and bias = 0.43 L/min (LoA: -0.40 – 1.26 L/min) for women and men, respectively (Fig. 2A). For the relative $\dot{V}O_2$peak, agreement was: bias = 3.5 mL/kg/min (LoA: -3.0 – 10.1 mL/kg/min) for women, and bias = 4.6 mL/kg/min (LoA: -4.4 – 13.6 mL/kg/min) for men (Fig. 2B). Agreement for absolute $\dot{V}O_2$peak in patients using betablockers was: bias = 0.55 L/min (LoA: -0.07 – 1.17 L/min) compared to: bias = 0.31 L/min (LoA: -0.49 – 1.10 L/min) in those not using betablockers (Fig. 2C). For relative $\dot{V}O_2$peak, patients using betablockers had: bias = 6.2 mL/kg/min (LoA: -1.3 – 13.6 mL/kg/min), while the patients not using medication had: bias = 3.1 mL/kg/min (LoA: -5.1 – 11.3 mL/kg/min) (Fig. 2D).

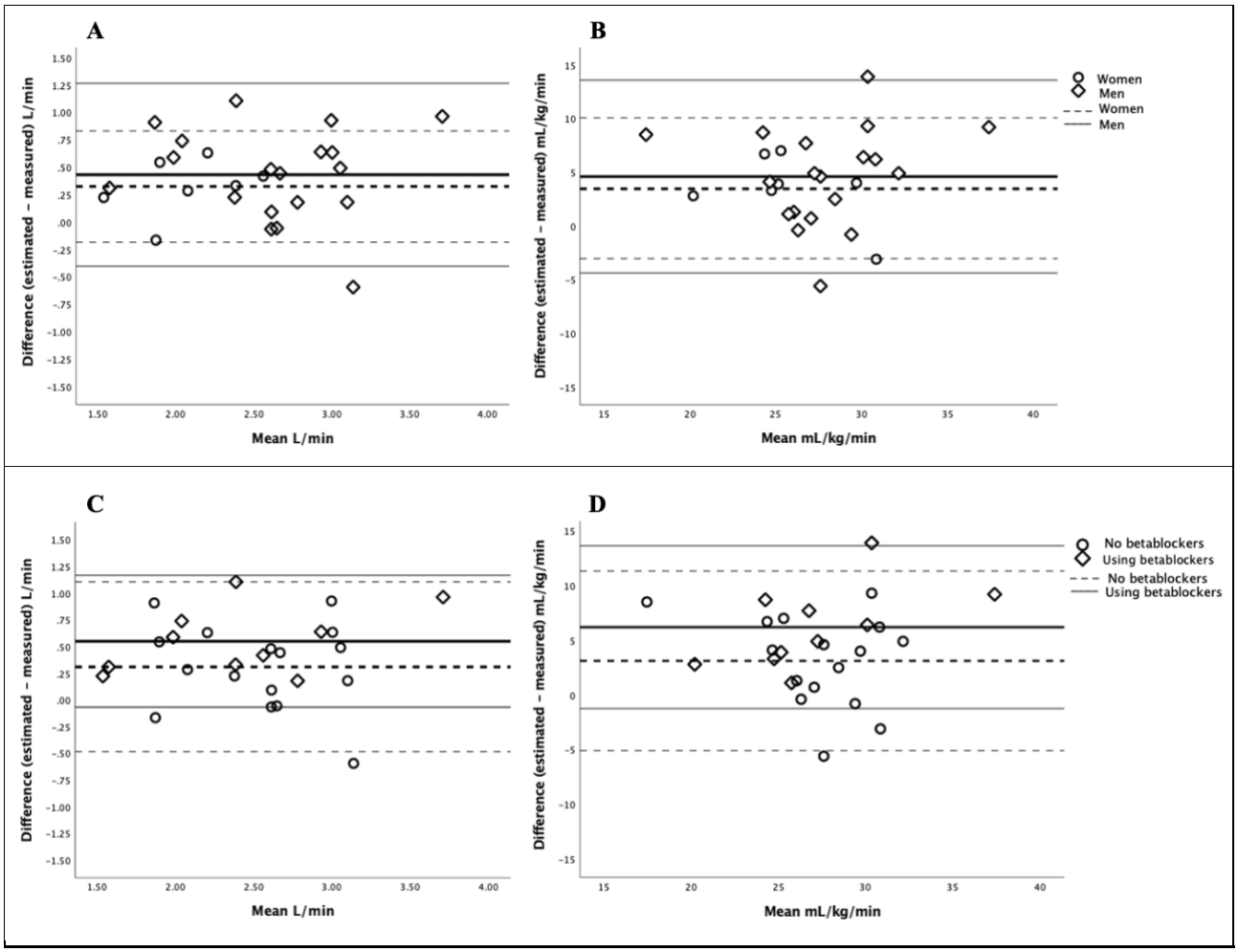

Figure 2: *Bland Altman plots, including limits of agreement for estimated and measured $\dot{V}O_2$peak in subgroups divided by sex (A & B) and betablocker medication status (C & D) for absolute (A & C) and relative (B & D) $\dot{V}O_2$peak. Thick line = mean difference; Thin line = upper and lower limits of agreement.*

Discussion

The objective of the present study was to validate the Ekblom-Bak test in CVD patients admitted to cardiac rehabilitation, by comparing estimated VO2peak from the Ekblom-Bak test to directly measured VO2peak from a maximal treadmill CPET. Thereby, contributing to determine whether the Ekblom-Bak test provides sufficiently accurate estimates of $\dot{V}O_2$peak in this population, for it to be applicable for use in cardiac rehabilitation. The main findings suggest that the Ekblom-Bak test systematically overestimates $\dot{V}O_2$peak in CVD patients for both absolute (2.69 vs. 2.29 L/min, 17.5%), and relative (29.5 vs. 25.2 mL/kg/min, 17.1%) $\dot{V}O_2$peak. Additional findings across subgroups, suggest that the accuracy of $\dot{V}O_2$peak estimations is independent of the patients´ sex. However, there seems to be a greater overestimation of $\dot{V}O_2$peak in patients prescribed to betablockers. The betablocker subgroup also had the strongest correlation between the two $\dot{V}O_2$peak measurements, indicating that there is a systematic error of the Ekblom-Bak test overestimating $\dot{V}O_2$peak within this group. Additionally, 3 participants were not able to complete the Ekblom-Bak test at the lowest possible higher work rate due to fatigue. This might indicate that for individuals with low CRF, the increase from standard to higher work rate may be too much for them to cope with.

Compared to previous validation studies conducted in healthy populations, it seems the Ekblom-Bak test is less accurate in estimating $\dot{V}O_2$peak in the CVD patient population. While the present study reported an overestimation of estimated $\dot{V}O_2$peak, by 0.40 L/min (r = 0.769) and 4.3 mL/kg/min (r = 0.544), previous validation studies of the Ekblom-Bak test in healthy individuals, have shown more accurate estimations when compared to maximal CPET. In the study where Björkman et al. (2016) updated the equations for $\dot{V}O_2$max estimation, they found the Ekblom-Bak test to underestimate $\dot{V}O_2$max by -0.01 L/min in both men and women. They concluded that their new equation was valid for estimating $\dot{V}O_2$max in healthy individuals with age 20 – 86 years, and CRF levels of 19 – 76 mL/kg/min. The updated equation has been used in studies conducted later than 2016, as it has replaced the original version created by Ekblom-Bak et al. (2014). This includes studies validating the Ekblom-Bak test in age specific populations, both adolescents and elderly. Björkman et al. (2018) validated $\dot{V}O_2$max estimations among adolescents aged 10 – 15 years and found the Ekblom-Bak test to overestimate $\dot{V}O_2$max by 0.09 L/min (r = 0.86), concluding that the Ekblom-Bak test has reasonable validity for estimating $\dot{V}O_2$max in adolescents. Validation in an elderly population aged 65 – 75 years by Väisänen et al. (2020), found accurate estimations of $\dot{V}O_2$max from the Ekblom-Bak test, with only minor overestimations of 0.02 L/min (r = 0.88) and 0.19 mL/kg/min (r = 0.77) for absolute and relative $\dot{V}O_2$max, respectively. In a recent study, Björkman et al. (2021) investigated the Ekblom-Bak test´s ability to detect longitudinal changes of $\dot{V}O_2$max over a period of 5 – 8 years. They reported an underestimation of -0.17 L/min at the follow up test, and an underestimation of -0.08 L/min at baseline testing. This was accompanied by a strong correlation of the estimation error between baseline- and follow up testing (r = 0.84). One additional validation study by Schultz et al. (2020), found the Ekblom-Bak test to significantly underestimate $\dot{V}O_2$max by -0.48 L/min (r = 0.968) and 6.17 mL/kg/min (r = 0.980) for absolute and relative $\dot{V}O_2$max, respectively. These findings are however derived from a relatively small sample size (n = 15), with a wide variety in key characteristic, like age (25 – 75 years) and activity levels.

Prior to the present study, Mijwel et al. (2016) has performed the only validation study of the Ekblom-Bak test in a patient population. They investigated the accuracy of $\dot{V}O_2$peak estimations in 8 women with breast cancer undergoing chemotherapy and found the Ekblom-Bak test to overestimate $\dot{V}O_2$peak by 0.79 L/min (r = 0.21). These findings along with the results of the present study may suggest that the Ekblom-Bak test is not valid in patient populations. However, due to the relatively small sample size, there is reason to believe this could be a random finding. In the forementioned validation studies, everyone except Mijwel et al. (2016) and Schultz et al. (2020) reported LoA containing the value of zero difference, indicating satisfactory accuracy of the Ekblom-Bak test´s $\dot{V}O_2$peak estimations in the general healthy population. This is also the case in the present study, with LoA ranging from -0.35 to 1.16 L/min and -4.0 to 12.6 mL/kg/min for absolute and relative $\dot{V}O_2$peak, respectively. However, due to the relatively wide interval of the LoA and the

degree of skewness towards $\dot{V}O_2$peak overestimation, I would suggest the present study indicates the Ekblom-Bak test is not able to accurately estimate $\dot{V}O_2$peak in CVD patients.

The Ekblom-Bak test´s overestimation of $\dot{V}O_2$peak in the present study, may be due to disease-specific characteristics of the CVD patients in cardiac rehabilitation. CVD patients generally have lower levels of CRF, either because of current cardiovascular limitations or because of recent severe events like e.g., myocardial infarctions or strokes. Most participants in the present study had $\dot{V}O_2$peak values near the lower part of the $\dot{V}O_2$peak-range in which the Ekblom-Bak test equation has previously been validated. I believe people with lower $\dot{V}O_2$peak will have a higher HR relative to their maximal HR at the standard work rate of the Ekblom-Bak test. This may result in a smaller HR increase between the standard and higher work rate, which would lead to an overestimation of $\dot{V}O_2$peak. Many CVD patients are also prescribed to betablockers, which inhibits HR response to exercise and limits maximal HR (Priel et al., 2021). Analysis in the subgroup using betablockers showed an almost twice as large overestimation of $\dot{V}O_2$peak compared to the subgroup not using betablockers. These findings can probably be explained by the inhibitory nature of betablockers, which may cause a limitation in the HR response when workload is increased. Also, Väisänen et al. (2020) found that the Ekblom-Bak equation is more likely to overestimate $\dot{V}O_2$peak in individuals with low maximal HR.

There are several limitations in the present study. Firstly, we used the alternative method of the Ekblom-Bak test, meaning that the test was performed using an electronically braked cycle ergometer, rather than the mechanically braked cycle ergometer used to develop the Ekblom-Bak test (Ekblom-Bak, 2012). The alternative method uses the same test protocol and equations for estimating $\dot{V}O_2$peak, but workload is measured with W rather than kilopond. Increments of 30 W between the different higher work rates were used, as this corresponds to approximately 0.5 kilopond when pedaling at a frequency of 60 revolutions per minute. It is important to consider that using an electronical braked cycle ergometer may influence the workload added when increasing the work rate, thus probably causing a variation in the subject´s HR response to the higher work rate. The alternative method of the Ekblom-Bak test has not been validated and may lead to different estimation errors than what has been reported for the original method (Ekblom-Bak, 2012). This makes it hard to conclude whether the differences reported in the present study are because of specific characteristics of the CVD patients, or if it's due to the use of a different cycle ergometer.

Inclusion of an even larger sample size would probably have helped avoiding potential random errors in the present study to an even larger degree. Even though the sample size is large enough to provide significant results regarding the correlation between the Ekblom-Bak test and the maximal CPET, an even larger body of data would further increase the statistical power of the findings. Björkman et al. (2021) suggests that one should include up to 50 participants to properly analyze the agreement between the two tests by use of Bland Altman plots with LoA. This proposed number is however only a recommendation and not a requirement for performing meaningful analysis, so I would argue the results of the present study carry sufficient validity and reliability. This is further evident by the fact there is no extreme outliers present in the between-test difference variable. The main reason for not recruiting more participants, was because the study was conducted as part of a master's degree, where the time available for collecting data was limited. Additionally, the data collection period had to be postponed due to the COVID-19 pandemic.

Performance of the two tests required in the present study, was integrated in the clinical routines of a cardiac rehabilitation program. This led to certain necessary considerations in the study design, particularly for the time schedule of the two tests. As the maximal CPET was part of the clinical routine, the time for testing was predetermined for every patient attending rehabilitation. The maximal CPET was scheduled to the start of their rehabilitation-stay, with the first patient being tested in the morning of their first full day at the center. To ensure the strain of performing a maximal CPET would not influence their HR response during the Ekblom-Bak test, participants were given minimum 24 hours rest between the tests. Thus, the Ekblom-Bak

test was scheduled to the day after the maximal CPET. This differed from the study designs used in the development of the Ekblom-Bak test and in previous validation studies, where the Ekblom-Bak test has been performed prior to the maximal CPET during a single day test-session (Björkman et al., 2016, 2018; Ekblom-Bak et al., 2014; Väisänen et al., 2020). One could argue that such a distinction from previously used study designs may impact the findings of the present study, and its basis for comparison to previous findings. The maximal CPET was scheduled from Wednesday through Friday during the first week of the rehabilitation stay. Due to the present study design, the patients performing their maximal CPET on Friday, had to perform the Ekblom-Bak test on the following Saturday. This unfortunate timeslot was the reason for 3 withdrawals, as the patients in question was not present during the time of their Ekblom-Bak test. Ideally, testing should have been organized in a similar way to previous validation studies. Then some of the difficulties regarding patients not following pretest criteria and the withdrawals because of undesirable timeslots for testing could probably have been avoided. This would also make the results more comparable to previously reported findings in similar validation studies. However, I would argue that the considerations and actions taken to accommodate the required changes, should not impact the results. The study design ensured each patient got sufficient rest prior to their Ekblom-Bak test according to the pretest criteria, and the ~24-hour interval in-between tests should be short enough that no significant changes in the patients´ CRF would occur.

This is the first study to investigate the Ekblom-Bak test´s validity in CVD patients admitted to cardiac rehabilitation. I would suggest conducting more validation studies in similar populations in the future, in order to further increase the body of evidence regarding the Ekblom-Bak test´s validity. Considering 3 participants in the present study was not able to complete the Ekblom-Bak test due to fatigue, I would suggest looking in to whether the increments in workload from the standard to the higher work rate could be altered to make the test even more suitable for persons with low CRF. I also believe it would be interesting to investigate the Ekblom-Bak test´s sensitivity to detecting minor changes in $\dot{V}O_2$peak as a result of training interventions, like e.g., in cardiac rehabilitation. In the present study, there was also an indication that the Ekblom-Bak test overestimated $\dot{V}O_2$peak to an even larger degree in persons using betablockers. These findings are however derived from a relatively small sample, so I would suggest more research on the Ekblom-Bak test´s validity in persons using betablockers should be carried out in the future.

Conclusion

Based on the findings of the present study, it seems the Ekblom-Bak test is not able to accurately estimate $\dot{V}O_2$peak in patients with CVD. It may however be accurate enough to detect wide differences in CRF, if this should be of interest. The Ekblom-Bak test is easily administered, time-efficient and not dependent on expensive, specialized equipment. When also taking into consideration that no adverse effects were observed during the Ekblom-Bak test in the present study, it seems to be relatively safe for CVD patients. Thus, the Ekblom-Bak test may be a feasible alternative for exercise testing when a maximal CPET is not possible.

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Appendices

Appendix A: CPET walking protocols

14:23:46 — Protokoll: MOD_FK-1 — Side 1

Fase/ Trinn	Trinn tid	Hastigh. (km/t)	Helling (%)	12 avl. rapport Første	12 avl. rapport Gjenta	Median rapport Første	Median rapport Gjenta	BT Første	BT Gjenta	Lagre Median Første	Lagre Median Gjenta
FØR TEST		Ramping:	av								
OPPVARM.	99:00	1.6	0.0	---	---	---	---	---	---	---	---
ARBEID		Ramping:	på								
TRINN 1	03:00	1.6	0.0	02:50	03:00	---	---	01:20	---	02:50	03:00
TRINN 2	02:00	2.0	1.0	01:50	02:00	---	---	01:20	---	01:50	02:00
TRINN 3	02:00	2.5	2.0	01:50	02:00	---	---	---	---	01:50	02:00
TRINN 4	01:00	3.0	3.0	00:50	01:00	---	---	00:20	---	00:50	01:00
TRINN 5	01:00	3.5	4.0	00:50	01:00	---	---	---	---	00:50	01:00
TRINN 6	01:00	4.0	5.0	00:50	01:00	---	---	---	---	00:50	01:00
TRINN 7	01:00	4.0	6.0	00:50	01:00	---	---	00:20	---	00:50	01:00
TRINN 8	01:00	4.0	8.0	00:50	01:00	---	---	---	---	00:50	01:00
TRINN 9	01:00	4.0	10.0	00:50	01:00	---	---	---	---	00:50	01:00
TRINN 10	01:00	4.0	12.0	00:50	01:00	---	---	00:20	---	00:50	01:00
TRINN 11	01:00	4.0	14.0	00:50	01:00	---	---	---	---	00:50	01:00
TRINN 12	01:00	4.0	16.0	00:50	01:00	---	---	---	---	00:50	01:00
TRINN 13	99:00	4.0	18.0	00:50	01:00	---	---	00:20	03:00	00:50	01:00
ETTER ARB.		Ramping:	av								
	99:00	1.6	0.0	00:50	01:00	---	---	00:01	03:00	00:50	01:00

14:23:04 — Protokoll: MOD_FK2 — Side 1

Fase/ Trinn	Trinn tid	Hastigh. (km/t)	Helling (%)	12 avl. rapport Første	12 avl. rapport Gjenta	Median rapport Første	Median rapport Gjenta	BT Første	BT Gjenta	Lagre Median Første	Lagre Median Gjenta
FØR TEST		Ramping:	av								
OPPVARM.	99:00	2.4	0.0	---	---	---	---	---	---	---	---
ARBEID		Ramping:	av								
TRINN 1	03:00	2.4	0.0	02:50	03:00	---	---	01:20	---	02:50	03:00
TRINN 2	02:00	3.0	1.0	01:50	02:00	---	---	01:20	---	01:50	02:00
TRINN 3	02:00	3.6	2.0	01:50	02:00	---	---	---	---	01:50	02:00
TRINN 4	01:00	4.2	3.0	00:50	01:00	---	---	00:20	---	00:50	01:00
TRINN 5	01:00	4.8	4.0	00:50	01:00	---	---	---	---	00:50	01:00
TRINN 6	01:00	4.8	6.0	00:50	01:00	---	---	---	---	00:50	01:00
TRINN 7	01:00	4.8	8.0	00:50	01:00	---	---	00:20	---	00:50	01:00
TRINN 8	01:00	4.8	10.0	00:50	01:00	---	---	---	---	00:50	01:00
TRINN 9	01:00	4.8	12.0	00:50	01:00	---	---	---	---	00:50	01:00
TRINN 10	01:00	4.8	14.0	00:50	01:00	---	---	00:20	---	00:50	01:00
TRINN 11	01:00	4.8	16.0	00:50	01:00	---	---	---	---	00:50	01:00
TRINN 12	99:00	4.8	18.0	00:50	01:00	---	---	01:20	03:00	00:50	01:00
ETTER ARB.		Ramping:	av								
	99:00	2.4	0.0	00:50	01:00	---	---	00:01	03:00	00:50	01:00

14:22:15 Protokoll: MOD_FK3 Side 1

Fase/ Trinn	Trinn tid	Hastigh. (km/t)	Helling (%)	12 avl. rapport Første	Gjenta	Median rapport Første	Gjenta	BT Første	Gjenta	Lagre Median Første	Gjenta
FØR TEST		Ramping:	av								
OPPVARM.	99:00	3.0	0.0	---	---	---	---	---	---	---	---
ARBEID		Ramping:	på								
TRINN 1	03:00	3.0	0.0	02:50	03:00	---	---	01:20	---	02:50	03:00
TRINN 2	02:00	3.6	1.0	01:50	02:00	---	---	01:20	---	01:50	02:00
TRINN 3	02:00	4.2	2.0	01:50	02:00	---	---	---	---	01:50	02:00
TRINN 4	01:00	4.8	3.0	00:50	01:00	---	---	00:20	---	00:50	01:00
TRINN 5	01:00	5.4	4.0	00:50	01:00	---	---	---	---	00:50	01:00
TRINN 6	01:00	5.4	7.0	00:50	01:00	---	---	---	---	00:50	01:00
TRINN 7	01:00	5.4	10.0	00:50	01:00	---	---	00:20	---	00:50	01:00
TRINN 8	01:00	5.4	13.0	00:50	01:00	---	---	---	---	00:50	01:00
TRINN 9	01:00	5.4	16.0	00:50	01:00	---	---	---	---	00:50	01:00
TRINN 10	01:00	5.4	19.0	00:50	01:00	---	---	00:20	---	00:50	01:00
TRINN 11	99:00	5.4	20.0	00:50	01:00	---	---	02:20	03:00	00:50	01:00
ETTER ARB.		Ramping:	av								
	99:00	3.0	0.0	00:50	01:00	---	---	00:01	03:00	00:50	01:00

14:21:16 Protokoll: MOD_FK4 Side 1

Fase/ Trinn	Trinn tid	Hastigh. (km/t)	Helling (%)	12 avl. rapport Første	Gjenta	Median rapport Første	Gjenta	BT Første	Gjenta	Lagre Median Første	Gjenta
FØR TEST		Ramping:	av								
OPPVARM.	99:00	3.5	0.0	---	---	---	---	---	---	---	---
ARBEID		Ramping:	på								
TRINN 1	03:00	3.5	0.0	02:50	03:00	---	---	01:20	---	02:50	03:00
TRINN 2	02:00	4.2	1.0	01:50	02:00	---	---	01:20	---	01:50	02:00
TRINN 3	02:00	4.8	2.0	01:50	02:00	---	---	---	---	01:50	02:00
TRINN 4	01:30	5.4	3.0	00:50	01:00	---	---	00:20	---	00:50	01:00
TRINN 5	01:00	6.0	4.0	00:50	01:00	---	---	---	---	00:50	01:00
TRINN 6	01:00	6.0	7.0	00:50	01:00	---	---	00:30	---	00:50	01:00
TRINN 7	01:00	6.0	10.0	00:50	01:00	---	---	---	---	00:50	01:00
TRINN 8	01:00	6.0	13.0	00:50	01:00	---	---	---	---	00:50	01:00
TRINN 9	01:00	6.0	16.0	00:50	01:00	---	---	00:30	---	00:50	01:00
TRINN 10	01:00	6.0	19.0	00:50	01:00	---	---	---	---	00:50	01:00
TRINN 11	99:00	6.0	20.0	00:50	01:00	---	---	01:30	03:00	00:50	01:00
ETTER ARB.		Ramping:	av								
	99:00	3.5	0.0	00:50	01:00	---	---	00:01	03:00	00:50	01:00

Appendix B: Ekblom-Bak test protocol

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The EKBLOM-BAK test

- a submaximal cycle ergometry test for estimation of VO_2max

The test is based on change in heart rate between a low standard workrate (same workrate for all subjects performing the test), followed by an individually chosen higher workrate (4 min each). The pedalling rate is 60 rpm, and average heart rate is measured during the last minute on each workrate, respectively.

1. Calibrate the ergometry cycle according to standard procedures.

2. Ensure that the individual being tested has followed conventional pre-test conditions (comment on this in the end of this manual).

3. Adjust seat and handlebar, and introduce Borg's RPE-scale.

4. Before the test, estimate a suitable higher work rate to allow the individual to reach a heart rate in the range 120-150 bpm (for individuals < 50 years) and 110-140 bpm (for individuals ≥ 50 years), respectively, aiming at a rated perceived exertion of ≈ 14 according to the Borg RPE-scale. The table below gives a rough guide to reach these pre-requisites with regard to sex and activity level.

	Woman	Man
Inactive	59 or 64 W	88 or 95 W
Low	88 or 95 W	118 or 127 W
Moderate	118 or 127 W	147 or 159 W
High	147 or 159 W	177 or 191 W

The watts depends on whether the work rate is measured by the flywheel or the pedals

5. Start standard work rate pedalling for 4 min at 60 rpm and the standard resistance. Check each minute that both pedalling speed and resistance are kept constant.

6. Measure average heart rate during the 4th min by taking notes of the heart rate at four occasions (3.15, 3.30, 3.45, and 4.00) and average these.

7. Increase resistance to the higher individual work rate (point 4 above). Check each minute that both pedalling speed and resistance are kept constant.

8. Ask for RPE during the 2nd min at the higher rate.

9. If RPE is
   < 10, increase resistance with 1 kp and redo point 8.
   10-11, increase with 0.5 kp and redo point 8.
   12 – 16, maintain rate and go to point 10.
   17 or higher, stop the test and let the subject rest for 20 min before performing a new test at a lower rate. However, it is preferable to cease testing and perform the test on another occasion.

10. Measure average heart rate during the 4th min at the higher rate by taking notes of the heart rate at four occasions (3.15, 3.30, 3.45, and 4.00) and average these.

11. After completed test, ask for RPE for the 4 min at the higher rate.

Procedure for estimating VO_2max

Electronically
An application for estimating VO_2max with the EKBLOM-BAK test is available at www.gih.se/ekblombaktest.

Manually
Input the relevant variables* into the following equation:

Men
$VO_2max = Exp((2.04900 - 0.00858*Age) – (0.90742*\Delta HR/\Delta PO) + (0.00178*\Delta PO) – (0.00290*HR \text{ at standard work rate}))$

Women
$VO_2max = Exp((1.84390 - 0.00673*Age) – (0.62578*\Delta HR/\Delta PO) + (0.00175*\Delta PO) – (0.00471*HR \text{ at standard work rate}))$

* $\Delta HF/\Delta PO$ with 2 decimals; Sex 0=Woman, 1=Man; Age in years.

Higher work rate (watts)#	Factor for higher work rate
59 or 64	32
88 or 95	64
118 or 127	95
147 or 159	127
177 or 191	159
206 or 222	191
235 or 254	222

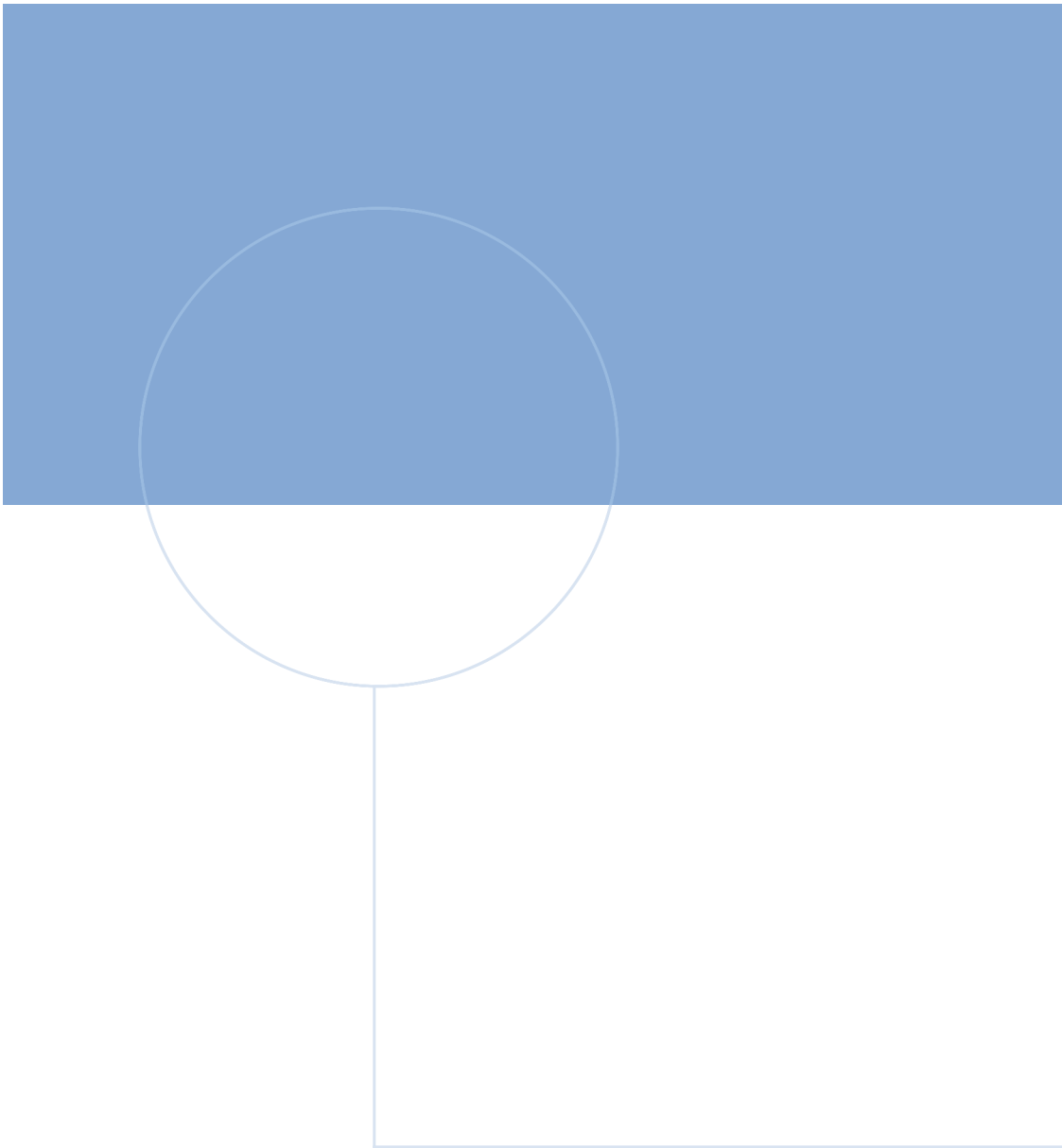
Notate Bene
The test has not been validated for electronically braked ergometers.

The test is only valid within the VO_2max range 19-62 $ml \cdot min^{-1} \cdot kg^{-1}$ for women and 24-76 $ml \cdot min^{-1} \cdot kg^{-1}$ for men, and age range 21-86 years for women and 20-84 years for men.

Conventional pre-test conditions include restrictions such as
- A heavy meal no later than 3 hours before the test.
- Smoking no later than 2 hours before the test.
- No vigorous activity on the day before and on the same day as the test.
- Avoiding running, cycling or stressing to the test.

If these pre-test conditions are not complied to, or if the individual being tested is taking medications that could influence the heart rate response, it is likely that the heart rate response and the estimation of VO_2max could be influenced.

The test was developed using a mechanically braked Monark cycle ergometer (Model 828E). It is important to consider that other types of cycle ergometers may give different work rate responses when adding the same resistance at higher work rates, and consequently a variation in the pulse response.
Available on www.gih.se/ekblombaktest is a list over equipment needed for the test and the Borg RPE scale.



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