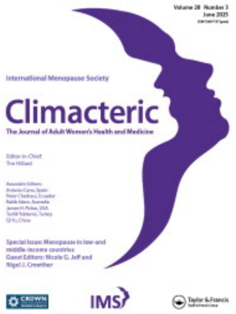

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Comparison of predicted aerobic capacity to measured aerobic capacity in menopausal women: an analysis of three methods

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ABSTRACT
Maintaining fitness throughout menopause is crucial for sustaining functional capacity and supporting healthy aging. Declines in physical activity and changes in physiology threaten cardiovascular health in menopause. Aerobic capacity is an indicator of current health status that can be measured directly, by maximal rate of oxygen uptake ($\dot{V}O_{2\ max}$), or using submaximal predictive methods that require fewer resources. This study aimed to establish the validity of these predictive methods for midlife women. Forty-four women (age 52 ± 4 years) completed three predictive cycle ergometer protocols (YMCA, Astrand-rhyming and Ekblom-Bak) and an incremental cycle ergometer $\dot{V}O_{2\ max}$ test. Predicted $\dot{V}O_{2\ max}$ scores were compared for agreement with directly measured $\dot{V}O_{2\ max}$. All methods evidenced moderate correlations with $\dot{V}O_{2\ max}$. The mean $\dot{V}O_{2\ max}$ value derived from the YMCA (35.6 ± 9.7 ml·kg–^{1}·min–^{1}) and Astrand-Rhyming (35.5 ± 8.8 ml·kg–^{1}·min–^{1}) tests was no different to measured $\dot{V}O_{2\ max}$ (34.5 ± 7.2 ml·kg–^{1}·min–^{1}), but the Ekblom-Bak test (37.5 ± 7.2 ml·kg–^{1}·min–^{1}, $p < 0.01$) overpredicted $\dot{V}O_{2\ max}$. All methods showed wide limits of agreement, suggesting variability in the accuracy of predictions. When measuring aerobic capacity or prescribing exercise using these predictive methods, the results should be interpreted with caution. Where possible, direct measurement of aerobic capacity should be utilized for prescription of exercise intensity in menopausal women.

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Introduction

Estrogen has been reported to have a cardioprotective effect and a significant role in immunity [1–5], therefore women in and after menopause are at risk for a reduced health-related quality of life and several diseases, such as cardiovascular disease and type 2 diabetes [1]. Aerobic capacity can quantify an individual's functional capacity and is a key determinant of health status and health-related quality of life [6,7]. It can be used as a predictor for risk of cardiovascular disease and mortality risk [6] and declines significantly with age [8]. Indeed, the menopausal transition has been highlighted as a point in the female lifespan when aerobic capacity is suggested to deteriorate [8,9]. This may be related to reduction of physical activity but also changes in physiological profile [10]. With the declines of estrogen, there is a decrease in resting, exercise and total energy expenditure [11] as well as decreases in fat oxidation and metabolic efficiency [1]. This results in an accumulation of visceral fat mass and declines in lean body mass, and predisposes women to an increase in percentage body fat, which can have a negative impact on health over time [1]. The relationship between estrogen and aerobic capacity is unclear. As highlighted by recent work auditing the involvement of midlife women in research [12], more research is required to explore the impact of menopause on cardiorespiratory response to exercise including the influence of hormone fluctuations.

A cardiopulmonary exercise test measuring the maximal rate of oxygen uptake ($\dot{V}O_{2\ max}$) is the gold standard for assessing aerobic capacity; accurate assessment of aerobic capacity avoids errors made from self-reported fitness and maximizes the success of exercise programs [13]. However, maximal testing may not always be possible in certain populations [14], in situations where access to a metabolic cart is not possible or with participants where motivation is limited [15]. Alternatively, predictive protocols and formulae have been produced to estimate $\dot{V}O_{2\ max}$ from the heart rate (HR) and workload relationship [16–19]. Recently, interest in the validity of predictive protocols in populations such as pregnant women, where maximal exercise testing is not always feasible or safe, has increased [13]. Whilst no specific contra-indications relating to maximal exercise performance during the menopause exist, it is well established that the physical and psychological impacts of the menopause act as barriers to exercise [20]. Recent analyses have demonstrated that women in midlife make up only 9% of participants in exercise science literature [12], with the authors suggesting that in addition to researcher bias toward male-only studies,

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menopause-related symptoms, health conditions and metabolic changes might negatively influence participation in such studies. Use of submaximal exercise testing may positively impact participation in exercise studies, as maximal exercise testing may deter sedentary participants. The validity of these methods for assessment and subsequent exercise prescription in menopausal women is unknown, and therefore establishing the validity of predictive methods in this population is essential [21].

Determining whether existing predictive protocols and formulae, such as the YMCA [17], Astrand-rhyming [18] and Ekblom-Bak [19] tests, enable accurate assessment of $VO_{2\ max}$ based on submaximal performance in midlife women is pertinent. Accurate assessment is key for both future clinical and fitness assessment and exercise prescription, to aid health-related quality of life and health outcomes in later life. For the first time, this study aimed to determine the validity of the YMCA [17], Astrand-rhyming [18] and Ekblom-Bak [19] tests in predicting $VO_{2\ max}$ of women in midlife.

Methods

Subjects

This research was approved by Bournemouth University Ethics Committee under ID number 44678 on 29 June 2022. Ethical approval and study standards conformed to the seventh revision of the declaration of Helsinki. All participants were informed of the risks of partaking and gave informed consent prior to participation.

A convenience sample of 57 healthy women from the general population was recruited by poster advertisement within the university and in the local community. Participants provided written informed consent to take part in a repeated-measures study. Following a 23% drop-out rate, 44 women completed the study (see Table 1).

Table 1. Participant characteristics.

Characteristic	*Value*
Age (years)	52.3 ± 4.3
Height (cm)	165.0 ± 5.0
Mass (kg)	67.8 ± 10.3
Physical activity (MET minutes per week)	2107 ± 1170
Menopause type	
Surgical	2
Spontaneous	42
HRT users	25
Estrogen only	1
Estrogen + progesterone	20
Estrogen + progesterone + testosterone	4

Data presented as mean ± standard deviation or *n*. HRT, hormonal replacement therapy; MET, metabolic equivalent.

Participants were defined as perimenopausal or postmenopausal based on self-reported changes in menstrual cycle [22] and symptom reporting [23], aligning with National Institute for Health and Care Excellence (NICE) guidance on the diagnosis and management of the menopause. Hormonal replacement therapies have not been evidenced to affect submaximal or maximal aerobic capacity [24], so participants were not excluded on these bases.

Participants were not taking any medication that would interfere with the safety of testing and were free from cardiovascular or orthopedic disease, as judged by a health and demographic questionnaire [25]. Participants were not pregnant and were not currently or previously using any anti-androgen therapies.

Procedures

Participants were instructed to refrain from exercise and consuming caffeine on the day of testing. Initial screening involved anthropometrics taken by a stadiometer (Seca 217; SECA, Hamburg, Germany) and body mass scales (Seca 803; SECA, Hamburg, Germany), and blood pressure screening (M3 Comfort; Omron, Kyoto, Japan).

Each participant performed one ramp maximal exercise test [26], and three submaximal exercise tests as described for the methods of the YMCA [17], Astrand-rhyming [18] and Ekblom-Bak [19] tests. The reliability of these tests has been assessed previously: the Astrand-rhyming test has been reported to have an intra-class coefficient of 0.96 [27], the Ekblom-Bak test an intra-class coefficient between 0.76 and 0.91 [28] and, finally, the YMCA test an intra-class coefficient between 0.71 and 0.85 [29].

The order of predictive tests was randomized with the maximal test performed in the final session (see Figure 1). For all exercise tests, participants wore a mask connected to a calibrated spiroergometric system throughout testing to measure expired gases (Metalyzer® 3B-R2; Cortex, Leipzig, Germany) and a chest HR monitor (Polar T31; Kempele, Finland). Fingertip blood lactate samples (Lactate Pro 2; Arkray, Kyoto, Japan) were taken before and after the maximal protocol. Ratings of perceived exertion were taken every 2 min.

Participants completed the maximal incremental exercise test on a cycle ergometer (Lode Excalibur Sport; Lode B.V.,

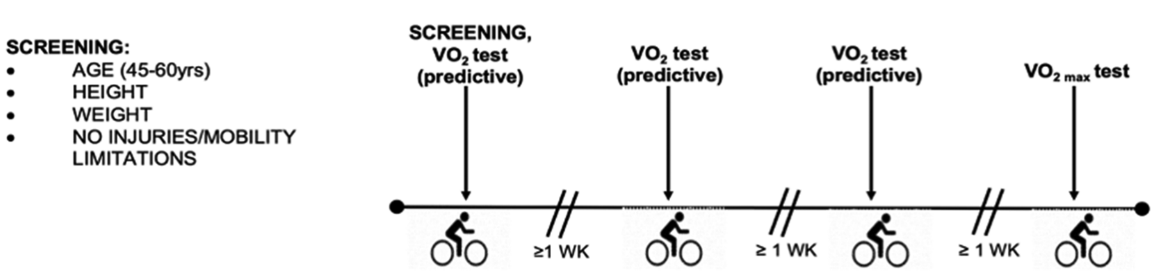

Figure 1. Study protocol. Predictive tests included the YMCA, Astrand-Rhyming and Ekblom-Bak methods completed in a randomized order. $VO_{2\ max}$, maximal rate of oxygen uptake.

Groningen, Netherlands) beginning with a 3-min warm up at 50 W, after which the power output continually increased depending on estimated fitness [26] until the test end criteria were met. Following pilot testing, this protocol was adapted to 1 W every 3 s (20 W•min^{-1}), 5 s (12 W•min^{-1}), 9 s (7 W•min^{-1}) or 12 s (5 W•min^{-1}) dependent on the self-reported activity level, which resulted in participants reaching task failure in the desired range of 10–12 min with a minimum duration of 8 min and a maximum of 17 min [30]. Participants cycled at a self-selected cadence above 70 rpm [26]. Achievement of $\dot{V}O_{2\,max}$ was determined by meeting at least two of the following criteria: blood lactate >8 mmol·l^{-1} [31], reaching the predicted (220 – age) maximum HR [31], respiratory exchange ratio (RER) >1.00 [32], rating of perceived exertion >19 and/or a plateau in $\dot{V}O_2$ indicated by an increase of <100 ml·min–^{1} in the final 20 s of the test [26].

Prior to attending the laboratory, participants gave a self-reported physical activity level that was utilized to prescribe intensity for predictive tests. Following this, participants were asked to keep a 3-week physical activity log starting from their first screening visit. Leisure time metabolic equivalent (MET) minutes per week were calculated for each participant using physical activity diaries and the MET compendium [33]. MET minutes per week were then used to quantify the activity level (see Table 1).

Statistical analysis

All expired gas data were averaged to 15-s intervals for analysis (Metasoft Studio Software version 5.16.0; Cortex). Predicted $\dot{V}O_{2\,max}$ for each of the predictive tests was calculated using previously outlined formulae for the YMCA [17], Astrand-rhyming [34] with age correction factor [35] and Ekblom-Bak [36] tests. The Shapiro–Wilk test determined that all data except the Astrand-rhyming data were normally distributed. All data are presented as the mean and standard deviation. Predicted $\dot{V}O_{2\,max}$ was compared to measured $\dot{V}O_{2\,max}$ using repeated-measures analysis of variance with Dunnett's multiple comparisons. Results from predictive tests were compared with the direct measurement of $\dot{V}O_{2\,max}$ using Pearson's correlation coefficient (r), or for Astrand-rhyming using Spearman's rank correlation coefficient (r). A value of $r \geq 0.4$ was considered moderate and $r \geq 0.7$ was considered strong. Simple linear regression between predicted $\dot{V}O_{2\,max}$ and measured $\dot{V}O_{2\,max}$ was performed to assess the strength of the relationship between the two measures and to establish whether the predicted $\dot{V}O_{2\,max}$ accurately predicts measured $\dot{V}O_{2\,max}$ (GraphPad Prism version 9.0.0 for MacOS; GraphPad, San Diego, CA, USA).

Bland–Altman plots were employed to assess the agreement of predicted $\dot{V}O_{2\,max}$ with measured $\dot{V}O_{2\,max}$. For this, the difference between the measured and estimated values (100 × [predicted $\dot{V}O_{2\,max}$ – measured $\dot{V}O_{2\,max}$] / average of predicted and measured) were compared to the average of predicted and measured values expressed as a percentage [13] and in milliliters per kilogram per minute. Subsequently, a positive bias indicated an overestimation of $\dot{V}O_{2\,max}$ by the predictive method.

Table 2. Criteria attainment in the incremental cardiopulmonary exercise test for all participants.

Blood lactate >8 mmol	*Maximum HR*	*RER >1.00*	*RPE >19*	*Plateau in VO_2*
40	26	26	34	31

Data presented as n. HR, heart rate; RER, respiratory exchange ratio; RPE, rating of perceived exertion; VO_2, rate of oxygen uptake.

Results

All participants attained $\dot{V}O_{2\,max}$ as judged by the aforementioned criteria (Table 2), with an average of four criteria being met.

The YMCA and Astrand-rhyming predicted $\dot{V}O_{2\,max}$ values were not significantly different to measured $\dot{V}O_{2\,max}$. However, $\dot{V}O_{2\,max}$ predicted by the Ekblom-Bak test was significantly greater than measured $\dot{V}O_{2\,max}$ ($p = 0.005$) and overpredicted $\dot{V}O_{2\,max}$ by 8.4% (Table 2). For all methods – the YMCA, Astrand-rhyming and Ekblom-Bak tests – there was bias toward overprediction by 1.08, 1.01 and 2.78 ml·kg^{-1}· min^{-1}, respectively. Individual predicted $\dot{V}O_{2\,max}$ scores compared to measured $\dot{V}O_{2\,max}$ scores are shown in Figure 2.

All predicted $\dot{V}O_{2\,max}$ values were significantly positively correlated with measured $\dot{V}O_{2\,max}$. Astrand-rhyming predicted scores evidenced the strongest correlation with measured $\dot{V}O_{2\,max}$ and accounted for the most variance ($r = 0.73$; R^2 = 0.53) compared to the YMCA and Ekblom-Bak tests ($r = 0.58$, R^2 = 0.33 and $r = 0.67$, R^2 = 0.45). Limits of agreement (LoA) were wider for the YMCA (–14.7 to 16.9 ml·kg^{-1}· min^{-1}) and Ekblom-Bak (–8.0 to 13.6 ml·kg^{-1}· min^{-1}) tests compared to the Astrand-rhyming test (–10.9 to 12.9 ml·kg^{-1}· min^{-1}) (Table 3).

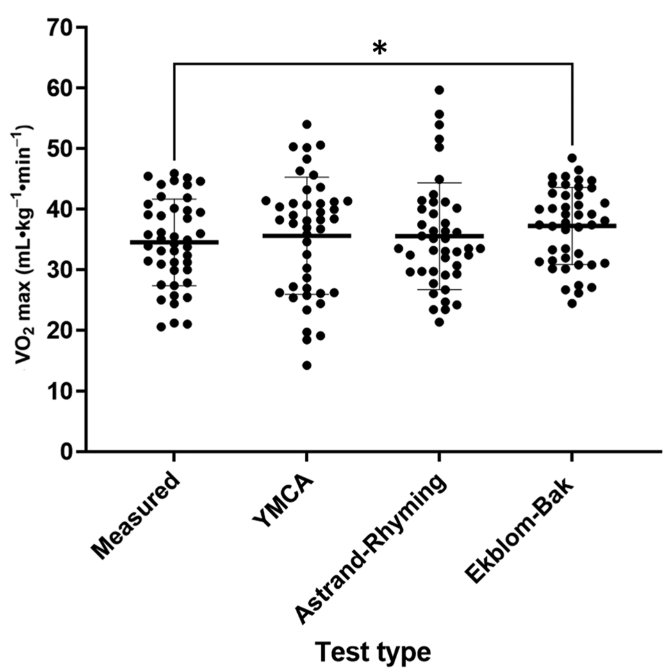

Figure 2. Mean and standard deviation individual $\dot{V}O_{2\,max}$ values from predictive and measured methods. *Significant difference between measured $\dot{V}O_{2\,max}$ and the indicated predictive test ($p \leq 0.01$). $\dot{V}O_{2\,max}$, maximal rate of oxygen uptake.

Table 3. Measured and predicted $\dot{V}O_{2\ max}$ values ($n = 44$).

Test	$\dot{V}O_{2\ max}$ ($ml{\cdot}kg^{-1}{\cdot}min^{-1}$)	Bias to $\dot{V}O_{2\ max}$ ($ml{\cdot}kg^{-1}{\cdot}min^{-1}$)	Bias to $\dot{V}O_{2\ max}$ (%)	Upper and lower 95% agreement limits ($ml{\cdot}kg^{-1}{\cdot}min^{-1}$)	Upper and lower 95% agreement limits (%)	p-Value	r	R^2
Measured	34.51 ± 7.15	–	–	–	–	–	–	–
YMCA	35.59 ± 9.68	1.08	1.18	−14.72 to 16.87	−47.65 to 50.01	0.706	0.58***	0.33***
Astrand-rhyming	35.52 ± 8.81	1.01	2.30	−10.86 to 12.88	−30.59 to 16.78	0.555	0.73***	0.53***
Ekblom-Bak	37.29 ± 6.40	2.78	8.40	−8.03 to 13.59	−23.36 to 40.16	**0.005****	0.67***	0.45***

**$p < 0.01$.
***$p < 0.001$.
Correlation coefficients and p-values presented for multiple comparisons and correlations for each predictive equation with measured maximal rate of oxygen uptake ($\dot{V}O_{2\ max}$).

Discussion

The predictive methods included in this study have been designed and validated in a range of populations, but their validity had not been assessed in menopausal women. This study was the first to demonstrate that these predictive methods may produce inaccurate estimates of $\dot{V}O_{2\ max}$ in menopausal participants, as all methods evidence wide LoA with the gold standard assessment of $\dot{V}O_{2\ max}$. These findings highlight that these predictive methods cannot be utilized with confidence to assess aerobic capacity in menopausal women for judgment of disease risk and exercise prescription.

All methods evidenced a bias toward overprediction of $\dot{V}O_{2\ max}$ scores for women in menopause, but this overprediction was only significant for the Ekblom-Bak test. As the Ekblom-Bak protocol is intended to predict $\dot{V}O_{2\ max}$ during treadmill exercise, this overprediction was expected due to use of a cycle ergometer for $\dot{V}O_{2\ max}$ assessment; but this might also suggest that measured $\dot{V}O_{2\ max}$ of menopausal women is lower than that estimated for their age and sex, despite the highly active sample used in this study. This implies that there is another influential factor, not currently considered by predictive formulae, affecting relationship between variables used within the algorithms. Whilst age alone is associated with decreases in cardiovascular health, menopause is implicated in accelerating this decrease [8]. In fact, menopause is suggested to negatively alter pulmonary [37,38] and muscle function [39] at rates unaccounted for by age alone. For example, the forced expiratory volume in 1 s (FEV1) is a determinant of $\dot{V}O_{2\ max}$ [40]; hence, declines in FEV1 [38] in menopause have implications for $\dot{V}O_{2\ max}$. This is likely to have direct implications on aerobic capacity, resulting in inaccuracies of predictive formulae. Unfortunately, the methods employed in this work are unsuitable and as protocols are best suited for the population they were established in [19]; but until a method is designed for use in menopausal women, $\dot{V}O_{2\ max}$ testing should be employed where possible.

The Ekblom-Bak test was originally designed and tested in adults with an average age of 40 years [19,36], and validated for all fitness levels between age 65 and 75 years [41]. Comparing the Ekblom-Bak predicted to cycle ergometer-derived $\dot{V}O_{2\ max}$ likely resulted in this overprediction as the Ekblom-Bak test was developed to be accurate to measured treadmill $\dot{V}O_{2\ max}$, which can be 7–18% higher than that measured by a cycle ergometer [42]. However, data have been published comparing Ekblom-Bak predicted to cycle ergometer-derived $\dot{V}O_{2\ max}$ concluding it to be valid in active populations [43]. Previously, the YMCA and Astrand-rhyming tests have been found to overestimate $\dot{V}O_{2\ max}$ measured by cycle ergometer in pre-menopausal women [18,44] and whilst this tendency toward overprediction can be seen within the present study, it was not significant. The Astrand-rhyming method has also been noted to be less accurate in adults aged between 50 and 69 years [45], indicating that an overprediction of $\dot{V}O_{2\ max}$ in mid-life women would be likely in the present study. Despite this, the $\dot{V}O_{2\ max}$ values estimated by the Astrand-rhyming test evidenced the strongest correlations with measured $\dot{V}O_{2\ max}$ compared to other predictive methods. However, the wide LoA with measured $\dot{V}O_{2\ max}$ for all predictive methods reveal inaccuracies in prediction that preclude their usage by practitioners wishing to determine aerobic capacity.

The lack of statistical difference between the group predicted $\dot{V}O_{2\ max}$ of each test and the group measured $\dot{V}O_{2\ max}$ does not necessarily confirm that the tests are optimal, as the variability of predictions is a key feature in evaluating the effectiveness of a protocol. Narrower LoA indicate a better prediction accuracy, and predictive methods have previously been validated with LoA between 10 and 20% [46]. Therefore, none of the methods presented in this work could be considered to be valid in menopausal women, with all reporting LoA at least 10 $ml{\cdot}kg^{-1}{\cdot}\ min^{-1}$ either side of the mean value. This emphasizes that the methods are not optimal for clinical or performance evaluation, as an error in assessment of this size is the difference between a low and a high classification [47].

The YMCA and Ekblom-Bak tests utilized multiple workload stages of 3–4 min and the steady-state HR to estimate $\dot{V}O_{2\ max}$, compared to the Astrand-rhyming test which uses a single-stage 6-min protocol. The Astrand-rhyming method evidenced the narrowest LoA in menopausal participants, implying that a longer steady-state protocol may be more effective when predicting $\dot{V}O_{2\ max}$ in menopause, potentially allowing physiological variables involved in the prediction to reach a steady state. The impact of fitness, sex and hormones on the relationships between HR, oxygen consumption and age is debated and findings differ dependent on the sample size and study design [48–50]. Study of these factors requires a large sample, and this work is limited by its sample size. It is also important to acknowledge that the sample was mostly highly active women and the bias this creates. Future work should seek to explore the impact of physical activity levels and hormone variation on the validity of these methods.

Conclusion

Using predictive methods for menopausal women is likely to result in overprediction of $\dot{V}O_{2\ max}$, and the wide LoA with direct measurement of $\dot{V}O_{2\ max}$ means that $\dot{V}O_{2\ max}$ derived from predictive methodologies in menopausal women should be interpreted with caution. Where possible, completion of incremental exercise testing to directly measure $\dot{V}O_{2\ max}$ in exercise studies is superior, and allows for accurate exercise intensity prescription, as well as assessment of current health and cardiovascular risk. If using $\dot{V}O_{2\ max}$ for fitness assessment of a group, the mean YMCA and Astrand-Rhyming tests may be employed; however, due to the high variability and tendency toward overestimation at an individual level, predictive $\dot{V}O_{2\ max}$ derived from these methods should not be used in assessment of health and disease risk in this population. Predictive methods do not currently provide accurate assessments of $\dot{V}O_{2\ max}$ in menopausal women, hence $\dot{V}O_{2\ max}$ testing should be employed where possible. This work evidences a shortcoming in exercise science for the provision of research for women in mid-life. In order to improve exercise research and real-world outcomes for mid-life women, as focus on individualized clinical assessment and exercise prescription increases, sex and age-specific methodologies, normative data and guidelines must be established.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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