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CORRESPONDENCE

The Chester step test is a valid tool to assess cardiorespiratory fitness in adults with hypertension: reducing the gap between clinical practice and fitness assessments

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Cardiorespiratory fitness is a vital sign of cardiovascular health [1]. Despite its utmost importance due to its potential to improve risk prediction, the assessment of cardiorespiratory fitness in clinical practice is not routinely performed [1]. This is particularly relevant for highly prevalent conditions, such as hypertension, which is the major preventable cause of cardiovascular disease and all-cause mortality [2]. Moreover, a recent study following 6890 normotensive male subjects for an average period of 14.7 years highlighted the importance of routine assessments of cardiorespiratory fitness by showing that moderate to high levels of cardiorespiratory fitness are equally beneficial in preventing hypertension in subjects with and without a family history of hypertension [3].

The "gold standard" for assessing cardiorespiratory fitness is cardiopulmonary exercise testing (CPET); [4] although, several factors, such as the duration of the protocol, equipment cost, induction of high physical stress, and need for qualified professionals, make CPET impractical on a daily basis in a clinical practice [5]. Submaximal exercise tests, including step tests, could serve as practical and valid alternatives when time is limited and laboratory and specialized staff are unavailable [5]. Among these tests, the Chester step test (CST) has the advantage of requiring minimal and portable equipment and marginal space compared to tests utilizing treadmills, shuttle walks, or cycle ergometers [6].

To date, the validity of the CST to determine cardiorespiratory fitness in adults taking antihypertensive medication compared with CPET has not been examined. Hence, this study aims to (i) test the validity of the CST to estimate the maximal oxygen uptake (VO_{2max}) in adults with hypertension and (ii) assess the influence of different formulas for predicting the age-predicted maximal heart rate (HR_{max}) when estimating the VO_{2max} with the CST.

Fourteen patients (eight men) with essential hypertension [2] aged between 35 and 65 years were recruited. The exclusion criteria were as follows: diabetes or any contraindication to exercise. The power calculation was computed a priori; based on a beta error of 10% and an alpha error of 5%, a sample size of 12 patients was required to observe a 0.6 correlation between CPET and the CST VO_{2max} values. A target of 14 patients was identified to accommodate a dropout rate of 10%. The hospital ethics committee approved the study (N/Ref. 24-01-2018). The participants provided written informed consent, and all the procedures were conducted according to the Declaration of Helsinki.

For practical reasons, participants performed the CST and CPET on the same day in that order; the tests were separated by a 10-min rest or the time necessary for all physiological parameters to return to their basal values. The participants were instructed and familiarized with the rate of perceived exertion scale, the CST and CPET. The CST was performed according to test manual recommendations with

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a 15-cm step [7]. It has five stages, and each stage has a 2-min duration [8]. The step cadence was set by a tape and started at 15 steps/min and increased by 5 steps/min every 2 min. The test stopped when 80% of the age-estimated maximal heart rate was exceeded, a value above 14 on the perceived exertion scale was reached or the participant was unable to maintain the metronome-set pace. The HR_{max} was calculated with three different formulas: the Fox–Haskell (220-age) [9], Tanaka ($220 - 0.7 \times$ age) [10] and Nes ($220 - 0.64 \times$ age) formulas [11]. The examiner deriving the VO_{2max} was blinded to the study purpose. The VO_{2max} was measured on a maximal CPET performed on a cyclergometer (Cardiovit CS-200 Ergo-Spiro, Schiller, Baar, Switzerland); the test started at 50 W and increased 25 W every 2 min; the participant was instructed to keep a cadence of 60 revolutions per minute (rpm). The VO_{2max} was assessed by the following criteria: (i) a plateau in the VO_2 with increases in external work, (ii) a maximal respiratory exchange ratio (RER) > 1.10, and (iii) an HR_{max} exceeding 90% of the age-predicted maximum. The test was considered to be limited by the cardiorespiratory system when the participants could no longer maintain the targeted 60 rpm and at least the last two criteria were fulfilled. For this study, a maximal cycle test was chosen rather than a treadmill protocol because the cycle ergometer and step tests have been shown to yield similar VO_{2max} results [12]. All the tests were conducted by a cardiologist and physiotherapist. Pearson's correlation and paired *t*-tests were used to test associations and compare mean differences, respectively. To assess agreement, Bland–Altman plots were constructed using the difference between the means of VO_{2max} in the CST and VO_{2max} in CPET and the standard deviations of the calculated differences.

Table 1 summarizes the characteristics of the participants. The VO_{2max} predicted by the CST was dependent on the formula used to determine the HR_{max}, i.e., a significantly lower VO_{2max} was obtained with the Fox–Haskell formula than with the Tanaka and Nes formulas (Table 1). The VO_{2max} measured during CPET was lower than the CST VO_{2max} predicted using the Tanaka [mean diff (95% CI): −1.06 (−1.84 to −0.28) ml kg^{-1} min^{-1}, $p = 0.012$] and Nes formulas [−2.11 (−2.87 to −1.35) ml kg^{-1} min^{-1}, $p < 0.01$]; no significant difference was found when using the Fox–Haskell formula [−0.35 (−1.06 to 0.35) ml kg^{-1} min^{-1}, $p = 0.30$] (Table 1).

The VO_{2max} predicted by the CST showed a strong, positive correlation with the VO_{2max} measured during CPET, with the strongest correlation obtained with the Fox–Haskell formula ($r = 0.989$, $p < 0.001$), followed by the Nes ($r = 0.987$, $p < 0.001$) and Tanaka formulas ($r = 0.986$, $p < 0.001$). The bias (95% limits of agreement) between the VO_{2max} measured during CPET and that estimated by the CST was −0.35 (−2.74 to 2.04) ml kg^{-1} min^{-1} with the Fox–Haskell formula, −1.06 (−3.72 to 1.60) ml kg^{-1} min^{-1} with the Tanaka formula, and −2.11 (−4.70 to 0.48) ml kg^{-1} min^{-1} with the Nes formula (Fig. 1). No bias trend was observed across the range of the VO_2 values studied.

Table 1 Characteristics of the participants and main results of the exercise tests

Age (years)	51.9 ± 9.2
Weight (kg)	81.2 ± 15.0
Height (m)	1.7 ± 0.1
Body mass index (kg/m^2)	28.0 ± 4.5
Currently smoking	5 (35.7%)
Hyperlipidaemia	3 (21.4%)
Overweight/obesity	12 (85.7%)
HR at rest (bpm)	83.9 ± 10.6
SBP at rest (mmHg)	134.3 ± 13.1
DBP at rest (mmHg)	87.9 ± 3.9
Medication	
ACE inhibitors	6 (42.9%)
CCB	4 (28.6%)
ARBs	3 (21.4%)
Antiplatelet	2 (14.3%)
Diuretics	4 (28.6%)
Lipid-lowering drugs	3 (21.4%)
CPET	
HRmax (bpm)	152.3 ± 16.8
SBP at peak exercise (mmHg)	191.1 ± 20.7
DBP at peak exercise (mmHg)	91.2 ± 13.7
Duration of the test (min)	7.9 ± 3.4
Maximal workload (Watt)	117.9 ± 45.4
VO_{2max} (ml Kg^{-1} min^{-1})	25.5 ± 8.1
VO_{2max} percentage of maximal (%)	94.9 ± 18.8
RER at peak exercise	1.16 ± 0.12
Chester step test	
HR stage 1 ($n = 14$) (bpm)	97.8 ± 9.9
HR stage 2 ($n = 14$) (bpm)	113.4 ± 12.2
HR stage 3 ($n = 9$) (bpm)	123.3 ± 17.4
HR stage 4 ($n = 8$) (bpm)	134.1 ± 14.8
HR stage 5 ($n = 3$) (bpm)	140.0 ± 15.6
HR at finishing stage (bpm)	134.0 ± 15.7
Perceived exertion scale score at finishing stage	12.6 ± 2.0
Stages completed	3.4 ± 1.2 (range 2–5)
Age-predicted HRmax (bpm)	
Fox–Haskell formula	168.07 ± 9.20
Tanaka formula	171.65 ± 6.44
Nes formula	177.77 ± 5.89
Predicted VO_{2max} (ml kg^{-1} min^{-1})	
Fox–Haskell formula	25.9 ± 7.8
Tanaka formula	26.6 ± 7.8*#
Nes formula	27.7 ± 8.2*#

Values are mean ± SD or absolute frequency (%)

ACE angiotensin converting enzyme, *ARBs* angiotensin II receptor blocker, *CCB* calcium channels blockers, *HR* heart rate, *DBP* diastolic blood pressure, *RER* respiratory exchange ratio, *SBP* systolic blood pressure

*Significantly different from the VO_{2max} of the CPET, $p < 0.05$

#significantly different from Fox–Haskell formula, $p \leq 0.001$

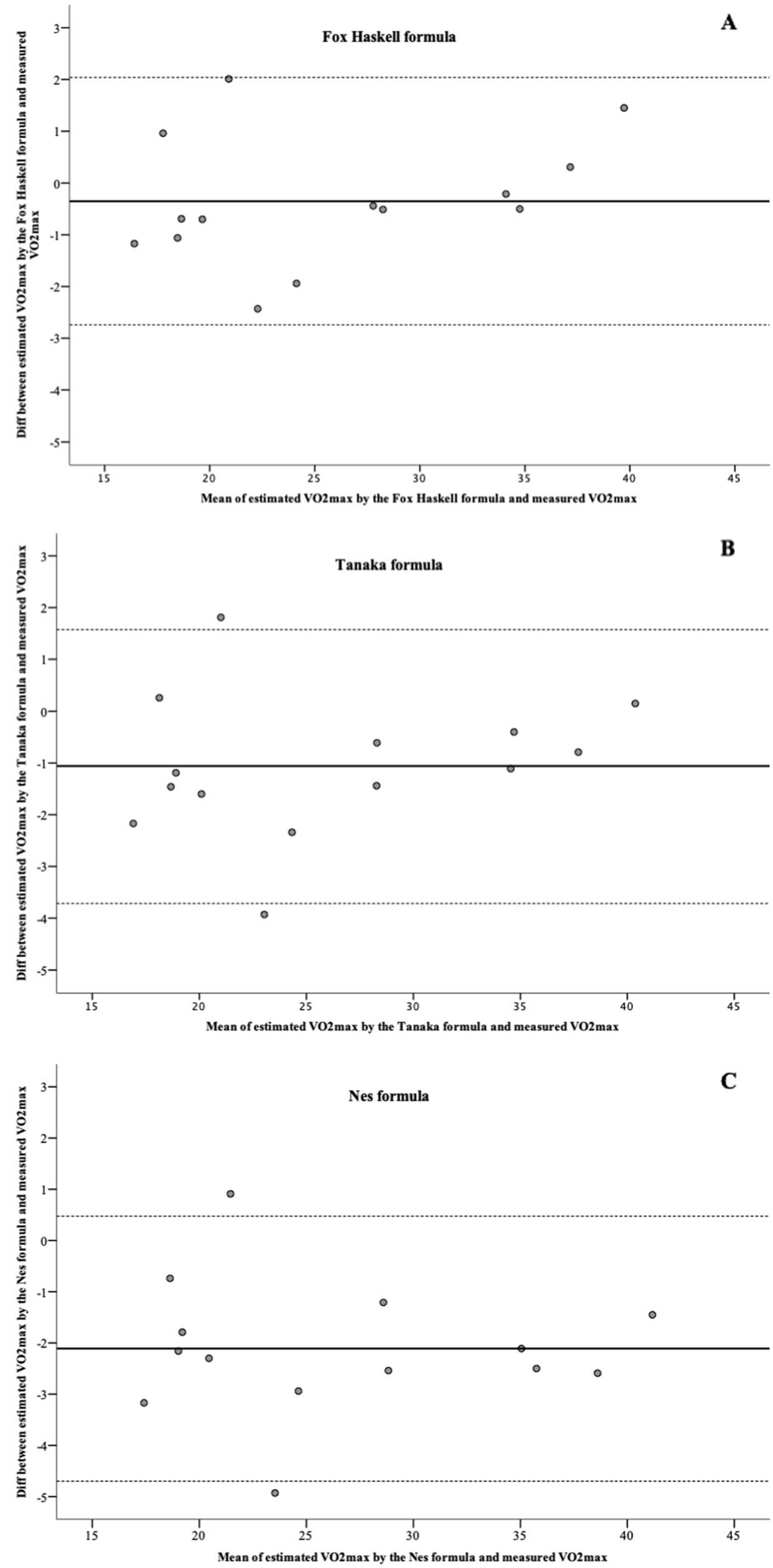

Fig. 1 Bland–Altman plots comparing the agreement between the measured VO_{2max} during CPET and estimated by the CST using the **a** Fox–Haskell formula, **b** Tanaka formula, and **c** Nes formula

One of the assumptions of the CST is that a linear relationship between HR and VO_{2max} exists, making the result of the test dependent on the accuracy of the formula used to predict the individual HR_{max}. The CST showed a strong correlation with CPET, independent of the formula used to determine the age-predicted HR_{max}. This correlation is in agreement with previous studies; a systematic review [5] on the validity and reliability of submaximal step-test protocols to estimate VO_{2max} in healthy adults found correlations between 0.469 and 0.95; the best correlations belonged to the CST and the personalized step test.

In our study, the Fox–Haskell formula seemed to be the best formula when conducting the CST in this population. The 95% limits of agreement between the VO_{2max} predicted by the CST using the Fox–Haskell formula in our study were similar to those observed in 13 young healthy subjects in two trials (-2.8 ± 6.1 ml kg^{-1} min^{-1} and -1.9 ± 7.4 ml kg^{-1} min^{-1}) [6]. In our study, the 95% limits of agreement oscillated from −2.7 to 2.0 (mean, −0.35) ml kg^{-1} min^{-1}; this bias may not be significant when prescribing exercise training, but all health professionals must be aware of these limitations when using this test. Our results should be interpreted cautiously given the sample size; however, the existing validation studies on submaximal tests had similar sample sizes. Future studies should consider the assessment of blood pressure during the CST protocol, as is done in CPET, to determine if the blood pressure response to submaximal exercise exhibits the same pattern as it does in CPET. The lack of time and availability of participants to take part in multiple day assessments was also a limitation. Hence, the final results could have been influenced by the accumulated fatigue of the participants from one test to the other, even though there was a prudential time to rest.

In conclusion, our findings highlight that (i) the CST is a valid, easy, and inexpensive solution for assessing the VO_{2max} in individuals with hypertension and (ii) the Fox–Haskell formula is good for predicting the HR_{max} when using this test to estimate cardiorespiratory fitness. The CST provides a straightforward way to evaluate cardiorespiratory fitness during routine clinical visits.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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