

The Validity of the YMCA 3-Minute Step Test for Estimating Maximal Oxygen Uptake in Healthy Korean and Vietnamese Adults

Nguyen Thi Van Kieu^{1,6,7}, Su-Jin Jung^{1,2}, Sang-Wook Shin³, Han-Wool Jung², Eun-Soo Jung¹, Yu Hui Won⁴, Young-Gon Kim^{1,2,5,*}, Soo-Wan Chae^{1,2,6,*}

¹Clinical Trial Center for Functional Foods, Chonbuk National University Hospital, ²Biomedical Research Institute of Chonbuk National University Hospital, ³Department of Medical Nutrition Therapy, Jeonbuk National University, Departments of ⁴Physical Medicine and Rehabilitation, ⁵Urology, ⁶Pharmacology, Jeonbuk National University Medical School, Jeonju, Korea, ⁷Department of Rehabilitation, Hue University of Medicine and Pharmacy, Hue, Vietnam

Background: Cardiorespiratory fitness (CRF) is a fundamental component of physical fitness. While maximal oxygen uptake (VO₂max) is the gold standard for quantifying CRF, standard maximal exercise tests using direct measurements VO₂max are dependent on the availability of laboratory equipment, and thereby expensive and time consuming. Recently, an equation was formulated to indirectly estimate VO₂max using the YMCA 3-minute step test.

Methods: The study included 15 Korean (KR) and 15 Vietnamese (VN) healthy adults aged 19-35 years. All subjects completed a YMCA 3-minute step test (YMCA 3MST) and a maximal exercise treadmill test to predict VO₂max and VO₂max measures, respectively.

Results: There was a significant relationship between VO₂max predicted from the YMCA 3MST and actual VO₂max measurements from the treadmill test ($r = 0.80$, $p < 0.0001$; KR group: $r = 0.81$, $p < 0.0001$; VN group: $r = 0.93$, $p < 0.0001$). Bland-Altman analysis revealed statistical agreement between tests, although there was a systematic over-estimation of 3.36 mL/kg/min for the KR group.

Conclusion: The equation for predicting VO₂max from the YMCA 3MST was validated among the study subjects. However, future research should explore the validity and reliability of the YMCA 3MST equation for estimating VO₂max in other populations.

Key Words: Step test, Cardiorespiratory fitness, Exercise testing, Maximum oxygen uptake, VO₂max

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*Corresponding author: Soo-Wan Chae

Department of Pharmacology, Jeonbuk National University Medical School, 567 Baekje-daero, Deokjin-gu, Jeonju 54896, Republic of Korea

Tel: 82-63-259-3040, Fax: 82-63-250-1564

E-mail: soowan@jbnu.ac.kr

*Corresponding author: Young-Gon Kim

Department of Urology, Jeonbuk National University Medical School, 567 Baekje-daero, Deokjin-gu, Jeonju 54896, Korea

Tel: 82-63-250-1567, Fax: 82-63-250-1564

E-mail: ygkim@jbnu.ac.kr

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INTRODUCTION

Cardiorespiratory fitness is an element of physical fitness requiring a combination of the circulatory, respiratory, and muscular systems to supply oxygen to the working tissues during physical activity [1]. There is a considerable body of evidence suggesting that poor CRF is associated with increased risks of morbidity and mortality in men and women through cardiovascular and metabolic risk factors [2]. VO₂max is the main indicator used for assessing cardio-pulmonary capacity and determining respiratory circulation

functions such as exercise intensity [3]. The magnitude of VO_2max is dependent on the transport of oxygen by the cardiorespiratory system from the atmosphere to exercising muscles, followed by the utilization of oxygen by metabolically active tissue [4]. To accurately determine VO_2max , a subject is required to perform a maximal test to exhaustion and oxygen consumption is measured by indirect calorimetry. Such tests are normally carried out in laboratories while subjects exercise on a treadmill or cycle ergometer. Maximal tests have practical limitations. For example, the measurement of VO_2max is expensive, requires a high level of technical experience and supervision, and is time-consuming and impractical outside of the laboratory and in the field. Furthermore, powerful motivation is required for a subject to achieve exhaustion under high-intensity load that is not appropriate for individuals who do not have an exercise habit, the elderly, or those with diseases [5]. As a result, investigators have attempted to accurately predict VO_2max using a variety of more convenient modalities [6-14]. This has resulted in a proliferation of submaximal tests to predict CRF, which overcome many limitations of direct tests. Consequently, sub-maximal exercise testing is frequently used to estimate VO_2max when time is limited, laboratory equipment is unavailable, or high-intensity exercises are deemed unsafe [15-17]. Submaximal exercise refers to non-exhaustive exercise that disturbs homeostasis by increasing the metabolic rate. An exercise intensity below 85 percent of age-predicted maximum heart rate is considered to be submaximal [18]. Submaximal tests in the laboratory usually involve one of three modes of exercise: running, cycling, or stepping on a treadmill or cycle ergometer, or they may involve stepping up and down off of a bench. The tests are either single stage or multistage protocols.

Step tests were among the earliest submaximal tests designed to predict VO_2max [6], and have advantages over other submaximal tests. There are wide ranges of step-test protocols that differ in stepping frequency, test duration, and number of test stages [19], but the main purpose of all step tests is to assess CRF. One popular step test is the YMCA 3MST [20], but it is only intended to assess cardiorespiratory fitness, and not to estimate VO_2max .

In 2014, the Korean Institute of Sport Science (KISS) conducted a study with a large sample ($N = 661$) and devel-

oped an equation for estimating VO_2max using the YMCA 3MST (male: $r^2 = 0.429$, $\text{SEE} = 5.236 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$; female $r^2 = 0.439$, $\text{SEE} = 4.35 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) intended for use in Koreans from 19 to 64 years old [21]. But no studies have generalized this equation to other settings. In Vietnam, where the highly trained personnel and experimental equipment required to directly measure VO_2max are scarce, simple tests like this are necessary. Thus, in this study we aimed to verify the validity of the equation estimating VO_2max using the YMCA 3MST equation, and to determine whether the equation designed for Koreans was suitable for Vietnamese subjects.

MATERIALS AND METHODS

1. Subjects

The study subjects were recruited and selected among participants in the Clinical Trials Center for Functional Foods (CTCF2) at Chonbuk National University Hospital from September to October 2019. All subjects provided written informed consent before entering the study. The Helsinki Declaration guidelines were applied in this study, and the Chonbuk National University (CBNU) Institutional Review Board (IRB) approved all protocols (approval No.: 2019-07-004-005); the approval was subsequently transferred to the CBNU IRB. This clinical trial protocol was registered at the Clinical Research Information Service of Republic of Korea (<https://cris.nih.go.kr/cris/en/>; board approval number: KCT0004656).

The criteria for selection and exclusion of participants in this study are described below.

Inclusion criteria:

- 1) Healthy Korean and Vietnamese adults between 19 and 35 years of age at the time of screening.
- 2) Subjects who did not answer “Yes” to any questions on the Physical Activity Readiness Questionnaire (PAR-Q).
- 3) Subjects who fully understood the test and decided to participate of their own free will and agreed with the written consent document.

Exclusion criteria:

- 1) Subjects with cardiovascular and pulmonary disease, hypertension, orthopedic disabilities, pregnancy, or who were taking beta blocker or beta agonist asthma medi-

cations.

2) Subjects who did not abstain from caffeine or alcohol for 24 hours, food for 2 hours, and strenuous exercise for the 10 hours prior to the test.

3) Subjects who required antipsychotic medication within 2 months before the screening test.

2. Study protocol

All subjects underwent screening tests within 4 weeks before the first visit. On the first day the subjects were reviewed and enrolled in the study and the YMCA 3-minute step test was conducted. The next day, subjects underwent the treadmill test according to the Bruce protocol (Fig. 1). Tests were performed between 9:30 a.m. and 5:30 p.m. The age, height, and weight of each subject was recorded. Body mass index (BMI) was calculated as kg/m^2 . Before testing, each subject's heart rate and blood pressure were measured automatically by machine (OMRON HBP-9020, Omron Healthcare Co., Ltd., Kyoto, Japan) to ensure measurement of their baseline state.

3. Outcome measurements

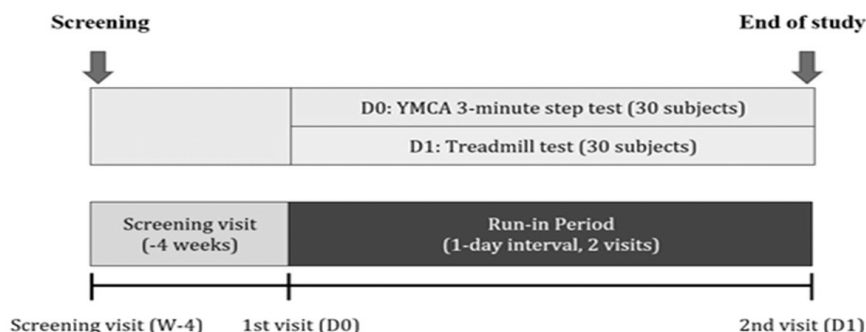
1) YMCA 3-minute step test

Each test starts with a 2-minute resting phase while subjects are seated on a chair in a quiet temperature- and humidity-controlled room. Subjects are required to step up and down on a 30 cm box 72 times in 3 minutes (step up-up-down-down). Stepping frequency is indicated by a metronome set at 96 beats per minute (4 clicks = one step cycle) for a stepping rate of 24 steps per minute. The subject immediately stops upon completion of the test and then sits down and remains still. After 5 seconds, the subjects heart rate is monitored for one minute. Finally, subjects remain seated during a 5-minute recovery phase. VO_2max was calculated using an equation formulated by the Korean Institute of Sport Science as follows:

$$\text{Males: } \text{VO}_2\text{max} = 70.597 - 0.246 \times (\text{Age}) + 0.077 \times (\text{Height}) - 0.222 \times (\text{Weight}) - 0.147 \times (\text{HR})$$

$$\text{Females: } \text{VO}_2\text{max} = 70.597 - 0.185 \times (\text{Age}) + 0.097 \times (\text{Height}) - 0.246 \times (\text{Weight}) - 0.122 \times (\text{HR})$$

Equation 1



D0: Stepping apparatus for predictive VO_2max in YMCA 3-minute step test



D1: Machine for measuring VO_2max in Treadmill test

Fig. 1. Flow diagram of the participants in this study.

2) Treadmill exercise stress test

Each subject warmed up for one minute by walking on the treadmill at their own pace at a 0% gradient. Speed and incline were increased according to the Bruce protocol [22] until the subject was unable to continue with the test grade. VO_2max was measured using the same breath-by-breath analysis system during the test (VMAX29, SensorMedics, CA, USA).

Oxygen uptake was considered maximal if any two of the following criteria were met: plateau in oxygen consumption with increasing work, respiratory exchange ratio ≥ 1.1 , heart rate at or near age-predicted maximum ($220 - \text{age} \pm 10$ beats/min).

3) Safety analysis

Safety outcomes were assessed by documenting adverse events during the overall clinical study period. Blood was collected after subjects had fasted for more than 12 h overnight. The blood was centrifuged at 3,000 rpm (Hanil Science Industrial Co., Ltd., Seoul, Korea) for 20 min and

kept frozen at -80°C until analysis. Laboratory tests (blood and urinalysis) were conducted and liver enzyme indexes of GGT, ALT, AST and total bilirubin, were analyzed with an ADVIA 2400 chemistry system (SIEMENS, Munich, Germany). ECG, vital signs, and anthropometric parameters (data not shown) were also evaluated.

4) Statistical analyses

All statistical analyses were performed using SAS[®] version 9.4 (SAS Institute, Cary, NC, USA). Values were expressed as mean \pm SD (standard deviation). Paired *t*-tests were used to compare VO_2max measured during the treadmill test and VO_2max predicted by the YMCA 3-minute step test equation. To assess validity, normally distributed data were analyzed with the Pearson test to determine the correlation coefficient between measured VO_2max and predicted by YMCA 3-minute step test. Data that were not normally distributed were analyzed with the Spearman test. Bland and Altman analysis was performed to assess agreement between measured and predicted VO_2max . Statistical

Table 1. Baseline demographic and clinical characteristics of subjects

	KR Group (n = 15)	VN Group (n = 15)	Total (N = 30)	p-value*
Age (years)	25.0 \pm 1.6	26.4 \pm 2.0	25.7 \pm 1.9	0.039 [†]
Sex (M/F)	7/8	7/8	14/16	> 0.999 [†]
Weight (kg)	65.3 \pm 15.6	57.7 \pm 10.0	61.5 \pm 13.4	0.124
Height (cm)	169.5 \pm 11.5	163.4 \pm 7.8	166.5 \pm 10.1	0.097
BMI (Kg/m ²)	22.4 \pm 3.3	21.5 \pm 2.9	22.0 \pm 3.1	0.436
SBP (mmHg)	119.7 \pm 15.6	119.1 \pm 13.4	119.4 \pm 14.3	0.911
DBP (mmHg)	71.9 \pm 9.0	73.6 \pm 9.0	72.8 \pm 8.9	0.617
Heart rate (BPM)	76.0 \pm 7.3	79.6 \pm 11.8	77.8 \pm 9.8	0.325
Alcohol (Y/N)	8/7	7/8	15/15	> 0.999 [†]
Alcohol (unit) [‡]	8.5 \pm 9.3	1.6 \pm 0.8	5.3 \pm 7.5	0.076
Smoking (Y/N)	3/12	0/15	3/27	0.068 [†]
Smoking (unit)	8.7 \pm 1.2		8.7 \pm 1.2	
Treadmill test				
VO_2max	35.72 \pm 4.83	38.16 \pm 5.94	36.94 \pm 5.46	0.227
RER	1.25 \pm 0.08	1.25 \pm 0.07	1.25 \pm 0.08	0.891
HR max	189.93 \pm 8.84	192.40 \pm 6.38	191.17 \pm 7.67	0.388
RPE	17.67 \pm 0.98	16.80 \pm 0.77	17.23 \pm 0.97	0.015
YMCA test				
VO_2max	39.08 \pm 4.66	39.32 \pm 4.98	39.20 \pm 4.74	0.888

Values are presented as mean \pm SD or number.

*Analyzed by independent *t*-test.

[†]Analyzed by chi-square test.

[‡]Alcohol 1 unit = Alcohol 10 g = Alcohol 12.5 mL.

KR: Koreans, VN: Vietnamese, BMI: Body mass index, SBP: Systolic blood pressure, DBP: Diastolic blood pressure, RER: Respiratory exchange ratio, HR: Heart rate, RPE: Rating of perceived exertion.

significance was determined at the level of $p < 0.05$.

RESULTS

1. Demographic characteristics

The general characteristics of the subjects included in this study are presented in Table 1. The average age was 25.7 ± 1.9 years, but the VN group was older than the KR group ($p = 0.039$). Weight, BMI, blood pressure, pulse, blood glucose and lipid profiles, drinking history, and smoking history did not differ significantly between the two groups.

Thirty subjects voluntarily provided written consent and were screened for this study, and all 30 were selected following evaluations of suitability for the study. No one was allowed to drop out or violate the research plan during the

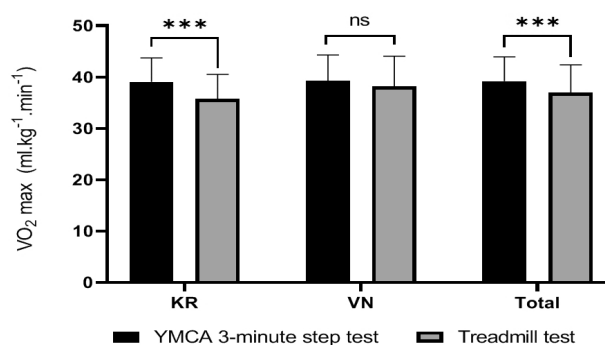


Fig. 2. Differences between VO₂max measured during the treadmill test and VO₂max predicted using the equation from the YMCA 3-minute step test.

Value: means \pm SD, ns: no significant difference, *** Significant difference with $p < 0.001$.

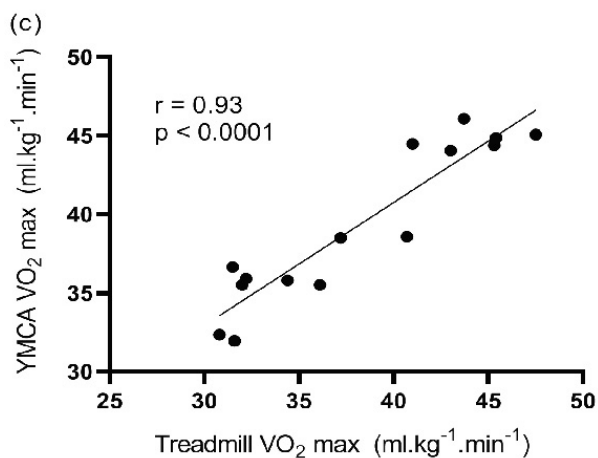
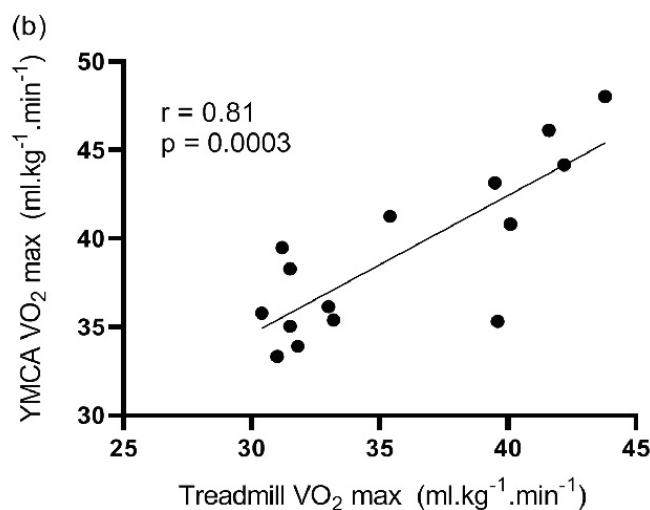
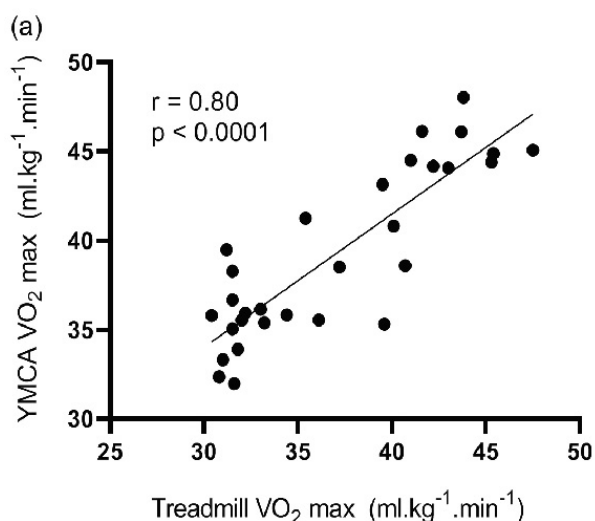


Fig. 3. The relationship between measured VO₂max from treadmill test and predicted VO₂max using equation from the YMCA 3-minute step test. (a) total, (b) Korean group, (c) Vietnamese group.

study, and all 30 registered subjects completed all of the study procedures (Fig. 1).

2. Exercise tests

The groups did not differ in the remaining variables. In the KR group, the mean predicted VO₂max using the YMCA 3MST was significantly greater than the TM VO₂max. However, VO₂max was similar between tests in the VN group (Fig. 2). The pooled (KR and VN) mean VO₂max predicted using the YMCA 3MST was 39.20 ± 4.74 mL.kg⁻¹.min⁻¹, which was significantly greater than the TM VO₂max (36.94 ± 5.46 mL.kg⁻¹.min⁻¹, p = 0.001). In the KR group, the mean VO₂max predicted using the YMCA 3MST was 39.08 ± 4.66 mL.kg⁻¹.min⁻¹, which was significantly greater than the TM VO₂max (35.72 ± 4.83 mL.kg⁻¹.min⁻¹, p = 0.0006). In the VN group, the mean predicted VO₂max using the YMCA 3MST was 39.32 ± 4.98

mL.kg⁻¹.min⁻¹, which was similar to the TM VO₂max (38.16 ± 5.94 mL.kg⁻¹.min⁻¹, p = 0.063).

3. Correlations between VO₂max measured during the treadmill test and VO₂max predicted using the YMCA 3MST equation

There was a strong correlation between VO₂max predicted using the YMCA 3MST equation and direct measurements of VO₂max made during the maximal treadmill test study (r = 0.80, p < 0.0001, Fig. 3a). This relationship remained strong in each group (KR, r = 0.81, p < 0.001; VN, r = 0.93, p < 0.0001, Fig. 3b, 3c).

4. Differences between VO₂max values vs. their means

The Bland-Altman plot is presented in Fig. 4, and it further demonstrates acceptable agreement between tests in

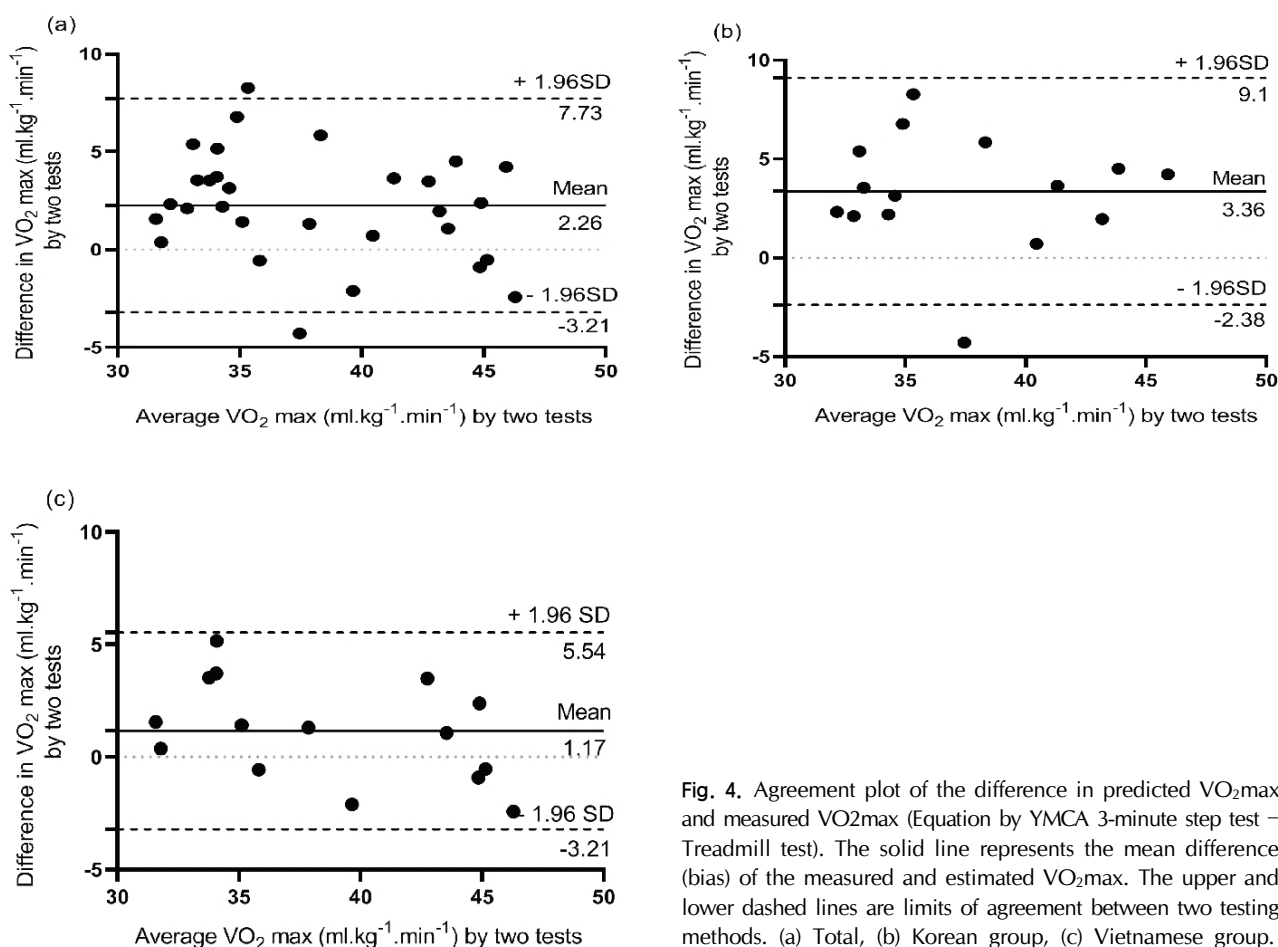


Fig. 4. Agreement plot of the difference in predicted VO₂max and measured VO₂max (Equation by YMCA 3-minute step test – Treadmill test). The solid line represents the mean difference (bias) of the measured and estimated VO₂max. The upper and lower dashed lines are limits of agreement between two testing methods. (a) Total, (b) Korean group, (c) Vietnamese group.

Table 2. Laboratory profiles of subjects

Laboratory profiles (standard range)	KR Group (n = 15)	VN Group (n = 15)	Total (N = 30)	p-value*
Hematology				
WBC (4.8-10.8 × 10 ³ /μL)	6.04 ± 0.95	6.34 ± 1.08	6.19 ± 1.01	0.423
RBC (4.7-6.1 × 100 ³ /μL)	4.70 ± 0.49	4.94 ± 0.57	4.82 ± 0.54	0.220
Hemoglobin (13-18 g/dL)	14.34 ± 1.46	14.49 ± 1.62	14.42 ± 1.52	0.787
Hematocrit (42-52 %)	42.31 ± 3.73	42.69 ± 4.17	42.50 ± 3.89	0.798
Platelet (130-450 × 10 ³ /μL)	234.67 ± 32.09	253.20 ± 53.52	243.93 ± 44.37	0.260
Biochemistry				
GGT (12-73 IU/L)	21.53 ± 12.84	20.53 ± 8.70	21.03 ± 10.79	0.805
AST (12-33 IU/L)	25.13 ± 9.64	21.67 ± 5.92	23.40 ± 8.06	0.245
ALT (5-35 IU/L)	26.40 ± 21.24	21.27 ± 8.53	23.83 ± 16.12	0.392
Total bilirubin (0.2-1.2 mg/dL)	0.88 ± 0.33	0.72 ± 0.20	0.80 ± 0.28	0.121
Total protein (6.7-8.3 g/dL)	7.18 ± 0.19	7.19 ± 0.30	7.19 ± 0.25	0.886
Albumin (3.5-5.3 g/dL)	4.73 ± 0.24	4.67 ± 0.21	4.70 ± 0.23	0.475
BUN (8-23 mg/dL)	12.73 ± 2.58	13.20 ± 3.30	12.97 ± 2.92	0.669
Creatinine (0.7-1.7 mg/dL)	0.74 ± 0.14	0.76 ± 0.16	0.75 ± 0.15	0.704
Total cholesterol (~200 mg/dL)	174.07 ± 33.15	179.47 ± 30.25	176.77 ± 31.30	0.645
Triglyceride (~200 mg/dL)	103.00 ± 48.62	89.47 ± 54.90	96.23 ± 51.41	0.481
HDL-cholesterol (41.5-67.3 mg/dL)	57.13 ± 10.41	52.33 ± 13.84	54.73 ± 12.28	0.292
LDL-cholesterol (0-140 mg/dL)	106.27 ± 31.68	121.33 ± 32.04	113.80 ± 32.23	0.206
Glucose (74-106 mg/dL)	81.27 ± 8.54	79.67 ± 5.15	80.47 ± 6.98	0.539
Creatine Kinase 46-171 IU/L)	130.20 ± 137.40	140.60 ± 81.96	135.40 ± 111.29	0.803
Urinalysis				
SG (1.005-1.030)	1.02 ± 0.00	1.02 ± 0.01	1.02 ± 0.01	0.038
pH (4.5-9.0)	5.67 ± 0.52	6.43 ± 0.94	6.05 ± 0.84	0.010

Values are presented as mean ± SD.

*Analyzed by independent t-test.

KR: Koreans, VN: Vietnamese, WBC: White Blood Cell, RBC: Red Blood Cell, ALP: Alkaline Phosphatase, GGT: Gamma Glutamyl Transferase, AST: Aspartate Transaminase, ALT: Alanine Transaminase, BUN: Blood Urea Nitrogen.

both groups. The mean difference between measured and predicted VO₂max is 1.17 mL/kg/min with a 95% confidence interval (CI) of -0.07 to 2.40 mL/kg/min in the VN group. Systematic bias was observed between VO₂max tests, indicating higher values in the predictive vs. maximal test in the KR group (mean difference = 3.36 mL/kg/min).

5. Safety analysis

Safety outcomes were assessed by assessing adverse events during the clinical study period as indicated by laboratory tests (blood and urinalysis), ECG, vital signs, and anthropometric parameters (data not shown). No serious adverse events were reported during the study period. The parameters of the safety assessments were within the normal range, and no subjects withdrew because of adverse events (Table 2).

DISCUSSION

The current study confirmed the validity of the VO₂max prediction equation developed by the YMCA 3MST for use in adults Korean and Vietnamese healthy. Our objective was to enable the use of predictive equations for fitness assessment in lieu of the maximum exercise test, which may allow clinicians to more frequently prescribe exercise for improving health.

Beutner previously reported a strong correlation between VO₂max values predicted from a linear regression model including age, sex, and 1-minute heart beat count (HBC) from the YMCA 3MST, and actual measurements of VO₂max during the treadmill test (r = 0.86) [23]. In the present study, the VO₂max predicted using the YMCA 3MST equation had a correlation of r = 0.80 with a VO₂max measured using the treadmill test, therefore agreeing with

the previous reported study [23]. This directly indicates a strong linear relationship between the prediction and measurement of VO_2max and confirm the applicability of the YMCA 3MST equation to the study sample. The Bland and Altman plot [24,25], was used to determine the limits of agreement between measured and predicted VO_2max , and showed that 95% of the differences between measured and predicted VO_2max lie within the limits of agreement, which were $-3.21 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ and $7.73 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$. The limits of agreement are narrow enough that the YMCA 3MST equation can be used confidently for the prediction of VO_2max in the study population in lieu of the complicated and exhaustive procedure for direct measurement of VO_2max . In the KR group, a significant mean difference indicates that the YMCA 3MST slightly over predicts TM VO_2max ($3.36 \text{ mL}/\text{kg}/\text{min}$), while in VN group there was no difference between the YMCA 3MST-predicted VO_2max and TM VO_2max (mean difference = $1.17 \text{ mL}/\text{kg}/\text{min}$, $p > 0.05$). Additionally, although a moderately high correlation coefficient was observed in the KR group ($r = 0.81$), it was lower than that observed in VN group ($r = 0.93$). We have no clear explanation for why VO_2max was slightly better predicted in the VN group than in the KR group based on a mean difference that was not different from zero, and a higher correlation coefficient. There are some limitations to this study. Although the findings of the present study indicate that the YMCA 3MST equation is suitable for the prediction of aerobic capacity among healthy Korean and Vietnamese adults, it remains questionable whether the YMCA 3MST is also applicable to other groups of different age, health status, or other factors. The YMCA 3MST may not be suitable for use in all subjects. The YMCA 3MST equation for VO_2max prediction is based on post-test heart rate. Therefore, for subjects in whom heart rate does not respond typically to physical exertion, including those using heart rate-regulating medications (e.g., beta blockers) or atrial fibrillation, the equation would not obtain a valid VO_2max prediction. Besides this, completion of the stepping test requires moderate physical exertion. It may therefore not be appropriate for populations in which exercise is not advisable or with orthopedic problems (such as knee or hip arthritis) that limit the ability to climb stairs. More research is warranted to examine the validity of the YMCA 3MST

prediction equation in various clinical populations (e.g., obese individuals and individuals with diabetes).

CONCLUSION

The YMCA 3MST equation is a valid sub-maximal test for the prediction of maximum aerobic capacity in Koreans, and can be adapted to predicting VO_2max in healthy Vietnamese adults. With its useful features (convenience, low cost, safety, and ease of use), the YMCA 3MST equation is suitable to be used in clinical or community settings, allowing a wide range of health professionals in various facilities to prescribe exercise for health benefits.

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