Prediction Equations for Maximum Aerobic Capacity Using Cardiopulmonary Exercise Testing Among Thais

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Abstract

Maximum aerobic capacity $(\dot{V}O_2max)$ is the most important parameter of cardiopulmonary fitness and an independent parameter for cardiovascular and respiratory disease prognosis. Prediction equations for $\dot{V}O_2max$ varies with age, gender, body size, level of ordinary activity, type of exercise and races. Those equations have never been studied in Thais. This study aimed to provide prediction equations for $\dot{V}O_2max$ in Thai males and females and to evaluate associations between age, weight and height, and $\dot{V}O_2max$. The maximum aerobic capacity was analysed in 44 healthy Thai subjects (20 males and 24 females; aged 20 – 50 years) who underwent cardiopulmonary exercise testing (CPET) using a treadmill and an incremental protocol until symptom limitation. All subjects had normal ranges of clinical characteristics and pulmonary function except those of weight and height in males were higher than in females (p<0.001) while age in males was lower than in females (p<0.05). Predictive equations for $\dot{V}O_2max$ were obtained from multiple linear regression analysis and significant correlations demonstrated a negative correlation between $\dot{V}O_2max$ and age (p<0.05), and positive correlations between $\dot{V}O_2max$ and weight and height (p<0.001). The $\dot{V}O_2max$ prediction equation: $\dot{V}O_2max$ = 3222.9 + (792.4 * sex) + (-11.3 * age) + (21.0 * weight) + (-15.7 * height) (R^2 = 0.72, SEE=308.5 ml/min) (1 = male, 0 = female; age in years (yr); weight in kilograms (kg); height in centimeters (cm)). In addition, $\dot{V}O_2max$ in males was significantly higher than in females by 59% (p<0.001). The present study provides the prediction equation for $\dot{V}O_2max$ applicable to the Thai population. Nonetheless, it is compulsory to have more sets of normal values to be accumulated so that reference values can be established in the future. We also demonstrate that males have $\dot{V}O_2max$ higher than those of females.

Keywords : *maximal oxygen consumption, prediction equation, cardiopulmonary exercise test, Thais*

1. Introduction

Cardiopulmonary exercise testing (CPET) is regarded as crucial tool in assessing the functional reverses of the cardiovascular and respiratory systems by the American Thoracic Society (ATS) and the Association of College of Chest Physicians (ACCP) (1). It is a noninvasive technique used for assessing pulmonary, cardiovascular, and skeletal muscle system integrative responses to either a ramp (incremental) or constant-load exercise test (2). Indications of CPET include assessment of the exercise capacity and exercise limitation, and evaluation of patients with cardiovascular disease, respiratory disease, pre-operative, and pulmonary rehabilitation (1, 3).

$\dot{V}O_2$max is the maximum amount of oxygen a person can consume and the value reaches a plateau despite increased workloads over time period (4). It is expressed as liters/min as an absolute value or in milliliters/kg/min as relative $\dot{V}O_2$max (1). It is the most important parameter of cardiopulmonary fitness and an independent parameter for cardiovascular disease prognosis (5). The most accurate way to assess $\dot{V}O_2$max is during a maximal exercise test performed to volitional exhaustion on a motorized treadmill or cycle ergometer (6). Most of the studies providing reference values for $\dot{V}O_2$max used for clinical applications have been done on populations in Western countries (5, 7-12). Furthermore, prediction equations are calculated for different variables using a linear regression. $\dot{V}O_2$max in normal subjects during exercise varies with age, gender, body size, level of ordinary activity, and type of exercise (1, 5, 13). The selection of $\dot{V}O_2$max predicted

values is a challenging problem, especially because the body size and age of the usual clinical population differ from those of reference population (14). An important criterion in the selection of reference values for use in clinical physiological testing is that the reference population from which standards are derived should be as similar as possible to the patients referred for testing. There is also a lack of $\dot{V}O_2$max value for Thai population using CPET. Therefore, the objectives of the present study were to: (i) provide a prediction equation for $\dot{V}O_2$max of incremental treadmill exercise tests performed in Thai population, and (ii) evaluate associations between age, weight and height, and $\dot{V}O_2$max.

2. Materials and methods

2.1 Study design and population

The study was analytical and descriptive and approved by the Human Research Ethics Committee, Khon Kaen University (HE561453), and informed consent was obtained from each subject. This study recruited 20 males and 24 females aged between 20-50 years from healthy population with body mass index (BMI) between 18.5 to 24.9 kg/m². All subjects underwent a screening history and physical examination. Those having history of regular alcohol drinking, smoking, cardiovascular, neuromuscular, arthritic, pulmonary diseases, severe microvascular diseases, diabetes mellitus, hypertension or other debilitating diseases were not included in this study.

2.2 Cardiopulmonary exercise testing

All subjects performed an incremental exercise test on a treadmill (Stationary CPET, Cosmed, Quark CPET, Italy).

The protocol for CPET was calculated based on age, weight, height, gender and work rate (WR) (15). They were instructed before the study not to have intense physical activity during the last 4 hours before testing or eat or drink caffeinated beverages in the last 2 hours. A protocol included a 2-min rest period in a standing position on a treadmill, 3-min warm-up by beginning to walk at 0.9 km/h, followed by increases in speed rate and inclination every 1 min until exhaustion and, finally, 3-min recovery at a speed of 0.9 km/h. All tests were performed in room air (25°C) according to current guidelines for exercise testing. Continuous electrocardiography (ECG), blood pressure and oxygen saturation were monitors (1). The test could be interrupted either by the subjects, because of dyspnea, leg fatigue or disabling symptoms, or by the investigator, for safety reasons. $\dot{V}O_2$max predicted was calculated based on age, weight, height and gender according to the formula of Wasserman and co-workers (13).

The criteria for reaching maximal exercise were three or more of the followings: reaching a plateau in $\dot{V}O_2$maximum heart rate (HR) of more than 90% of the predicted value for that age (220 - age), respiratory exchange ratio (RER) of more than 1.15 (although RER values are not exactly indicative of maximum capacity), subject requested stopping because of severe fatigue or dyspnea, and reaching 18 points or more of the Borg rating of perceived exertion (RPE) scale (16).

2.3 Statistical analysis

Data were expressed as mean ± standard deviation (SD). Statistical analyses were made using STATA version 12.0 (StataCorp, College Station, Texas). Unpaired t-test was used to compare differences in characteristics between genders. Two-sample Wilcoxon rank-sum (Mann-Whitney) test was used when data deviate from normality. ANCOVA (analysis of covariance) were used to compare differences in pulmonary function and cardiopulmonary responses at maximal exercise between genders. The relationships between $\dot{V}O_2$max and variables were analyzed using multiple linear regressions. P value less than 0.05 was considered to be statistically significant.

3. Results and discussion

Clinical characteristics of 44 subjects are summarized in Table 1. Weight and height were significantly higher in males while age was lower compared to those of females; nonetheless, BMI was comparable. SBP, DBP and HR were not significantly different between genders.

Comparisons of pulmonary function in males and females are summarized in Table 2. There were no significant differences in pulmonary function among genders. All had normal pulmonary function expressed as %predicted in both males and females. Thus, none of the subjects showed obstructive and/or restrictive pulmonary disorders.

Cardiopulmonary responses at maximal exercise are summarized in Table 3. $\dot{V}O_2$max and $\dot{V}O_2$max predicted were significantly greater in males than females. HRmax, RER, SpO$_2$, RPE and time to maximal exercise were similar among genders.

Table 1. Clinical characteristics of the study population

	Males (n=20)	**Females (n=24)**
Age (years)	25 ± 4	29 ± 9**
Weight (kg)	67.1 ± 8.9	56.0 ± 4.5***
Height (cm)	172.5 ± 6.5	159.7 ± 6.1***
BMI (kg/m^2)	22.5 ± 1.9	22.0 ± 1.8
SBP (mm Hg)	122.6 ± 6.5	118.7 ± 9.1
DBP (mm Hg)	71.1 ± 8.8	71.4 ± 8.4
HR (bpm)	71.5 ± 10.6	75.8 ± 4.2

BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; HR, heart rate. Values are mean ± SD. **$p<0.01$, ***$p<0.001$ males versus females

Table 2. Pulmonary function of the study population

	Males (n=20)	**Females (n=24)**
FVC	99.6 ± 9.7	98.6 ± 11.1
FEV$_1$	101.5 ± 12.0	97.2 ± 11.3
FEV$_1$/FVC	97.6 ± 6.5	99.0 ± 4.9
PEF	93.7 ± 11.7	92.4 ± 15.2
FEF25-75%	96.1 ± 15.6	96.2 ± 21.6

FVC, forced vital capacity; FEV$_1$, forced expiratory volume in the first second; PEF, peak expiratory flow; FEF, forced expiratory flow between 25 and 75% of forced vital capacity. Values are mean ± SD expressed as % predicted value.

Table 3. Cardiopulmonary responses at maximal exercise of the study population

	Males (n=20)	**Females (n=24)**
$\dot{V}O_2$max (ml/min)	2439.1 ± 405.8	1535.2 ± 228.0***
$\dot{V}O_2$max predicted (ml/min)	3355.8 ± 286.0	2192.3 ± 126.7***
$\dot{V}O_2$max (%Predicted)	72.0 ± 15.4	70.4 ± 11.2
$\dot{V}O_2$/kg max (ml/min/kg)	36.8 ± 6.9	28.5 ± 3.8***
HRmax (bpm)	179.4 ± 10.3	178.6 ± 8.5
HRmax predicted (bpm)	195.6 ± 4.4	190.9 ± 9.1
HRmax (%predicted)	91.5 ± 4.7	93.6 ± 3.3
RER	1.2 ± 0.1	1.3 ± 0.1
SpO$_2$	98.0 ± 0.6	98.0 ± 0.5
RPE	18.5 ± 0.5	18.5 ± 0.5
Time to maximal exercise (min)	9.77 ± 1.34	10.24 ± 1.14

$\dot{V}O_2$max maximal oxygen uptake; HRmax, maximal heart rate; RER, respiratory exchange ratio; SpO$_2$, oxygen saturation; RPE, rating of perceived exertion scale. Values are mean ± SD. ***$p < 0.001$ males versus females

After calculating the mean ± SD for variables and comparison between males and females, linear regression analysis was performed for determination of normal values. Figure 1A, 1B and 1C depict the correlations between $\dot{V}O_2$max and age, weight and height (respectively) for both genders. It was found that age was inversely correlated with $\dot{V}O_2$max ($r = -0.3157$, $p < 0.05$) whereas weight and height showed positive correlations with $\dot{V}O_2$max ($r = 0.6574$, $p < 0.001$ and $r = 0.6271$, $p < 0.001$; respectively). As age, weight and height were significantly correlated to $\dot{V}O_2$max and therefore a prediction equation for $\dot{V}O_2$max was derived using multiple linear regression. In addition, Figure 2 shows the correlations between $\dot{V}O_2$max predicted and actual $\dot{V}O_2$max in both genders ($r = 0.848$, $p < 0.001$).

$\dot{V}O_2$max = 3222.9 + (792.4 * sex) + (-11.3 * age) + (21.0 * weight) + (-15.7 * height) ($R^2 = 0.72$, SEE = 308.5 ml/min), where 1 = male, 0 = female; age in years (yr); weight in kilograms (kg); height in centimeters (cm).
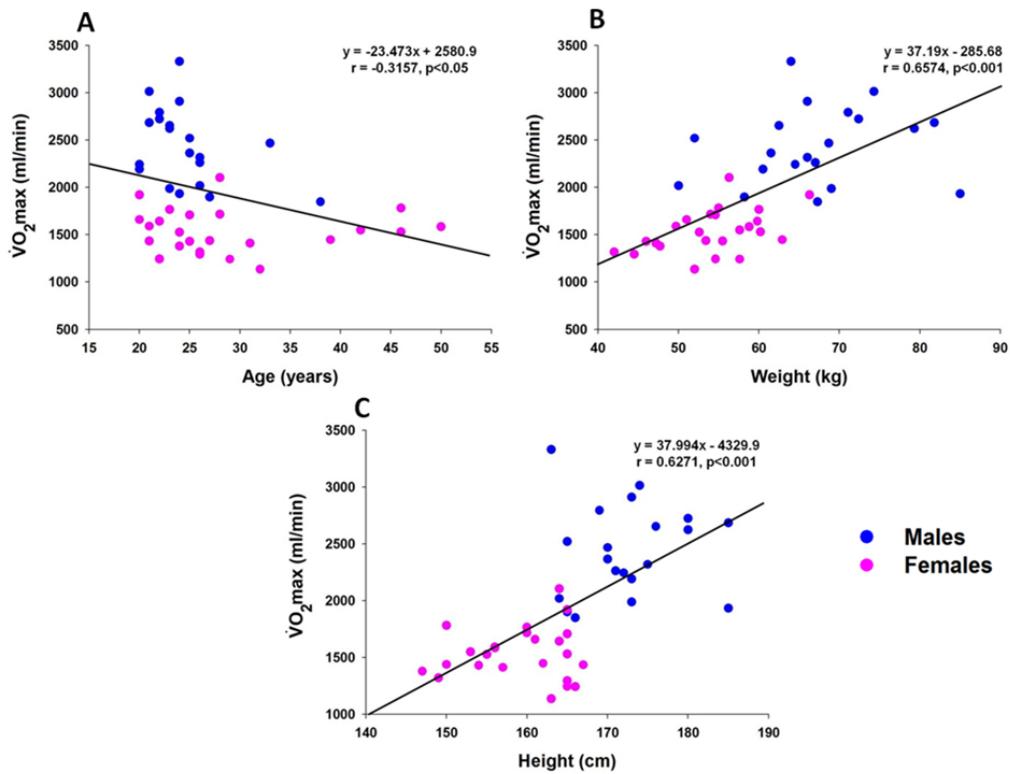
Figure 1. Correlations between $\dot{V}O_2$max and age, weight and height in both genders
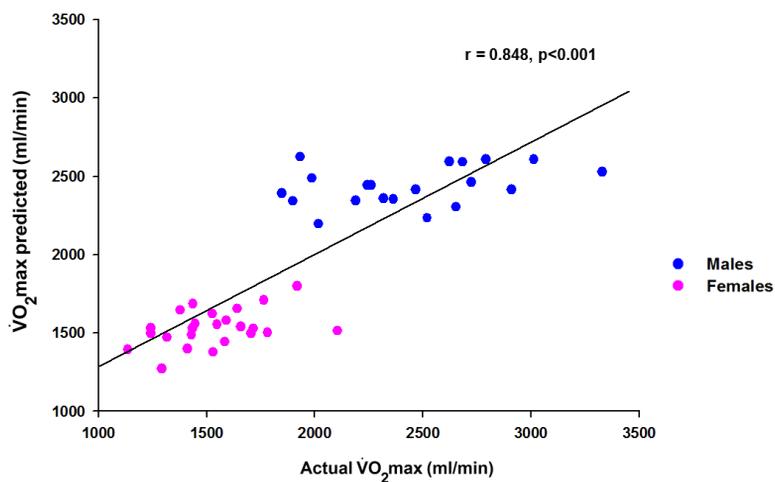
Figure 2. Correlations between $\dot{V}O_2$max predicted and actual $\dot{V}O_2$max for both genders

This was the first study examining associations between $\dot{V}O_2$max and age, weight and height, and to construct a multiple linear regression equation for predicting $\dot{V}O_2$max for an incremental treadmill exercise test aged from 20 to 50 years in both genders in healthy Thai population.

This study found that $\dot{V}O_2$max of the male subjects was higher than that of the female subjects 59% (p<0.001) being consistent with the study of Muangritdech and coworkers (17). They found that $\dot{V}O_2$max in Thai males was 71% higher compared to that of Thai females. Moreover, the higher $\dot{V}O_2$max in males is in accordance with former studies (1, 8, 18-20). Previous studies have demonstrated that males have less body fat, which consumes virtually more oxygen (21), hemoglobin concentration, an oxygen delivery protein in the blood (22). Moreover, males have larger lung and muscle mass than females (13, 23).

The negative correlation of age with $\dot{V}O_2$max in our study is in agreement with previous studies suggesting a decline in $\dot{V}O_2$max with increasing age in both genders. It has been suggested that ageing-induced changes in factors mediating the ability to utilize oxygen may explain part of the decrease in aerobic capacity (24-26). Moreover, ageing results in a loss of muscle mass, decreased fiber size and capillarization, shifts in muscle fiber profile away from that associated with aerobic performance and a decline in the enzymes and substrates associated with aerobic exercise (27). In addition, this study found positive correlations between weight and height and $\dot{V}O_2$max. Jones et al. found that $\dot{V}O_2$max was

best expressed related to gender, height, and age (28) or weight and height (8, 10, 29, 30).

The present study created a multiple linear regression equation for $\dot{V}O_2$max in healthy Thais using sex, age, weight and height as they are significantly correlated to $\dot{V}O_2$max. Most studies of $\dot{V}O_2$max performance in healthy populations have quantified age, gender and body size (7, 9, 10, 13, 14, 29-31). However, there are significant differences in the population characteristics, sample size, equipment, methodology, and reported measurements. Discrepancies may result from analytical bias, different weighting in the population of the variables or the contribution of other variables not included in the analysis and, often, the cause of these differences is not apparent.

To qualitatively compare $\dot{V}O_2$max among races, a Thai male aged 25 years old, weight 65 kg and height 165 cm. were used. The predicted $\dot{V}O_2$max is 2,507 ml/min for Thais compared to 3,388 ml/min (13) and 2,755 ml/min (10) for Caucasians, 1,884 ml/min for Indians (2), 2,331 ml/min for Chinese (32). By comparison, Thai male has $\dot{V}O_2$max of 74.0% and 91% of Caucasians, 133% of Indians and 107.5% of Chinese.

Similarly, a Thai female of the same age, weight and height as male has $\dot{V}O_2$max of 1,715 ml/min which is approximately 68.4% of that of male. Besides, they are 2,370 ml/min (13) and 2,135 ml/min (10) for Caucasians, 1,526 ml/min (2) for Indians and 1,871 ml/min (32) for Chinese. Apparently, a Thai female has $\dot{V}O_2$max of 72.4% and 80.3% of Caucasians, 112.4% of Indians and 91.7% of Chinese.

Reduced fatigue resistances, physiologic variations in skeletal muscle properties

related to whole body oxygen uptake as well as differences in chest wall anatomy, mechanical properties of the thorax, and parenchymal lung development could have contributed to the variation from other population (2).

It has been suggested that different $\dot{V}O_2max$ among races is probably due to psychic factors: (attitude, motivation); environment: (altitude, temperature, humidity); nature of work: (workload or intensity, duration, rhythm, technique); physiological characteristics of the individual which are genetically determined (inherited at birth) and posture (33). Thus, the difference in $\dot{V}O_2max$ between Thais and other races could be due to differences in those factors mentioned above. The new equation provides a more accurate reference value of $\dot{V}O_2max$ in Thai population, the extent of dysfunction assessed by a clinician will be less than when an established equation is used and reduce the risk of inappropriate referrals for various therapeutic procedures and rehabilitation programs.

Considering the small number of samples, these differences may or may not exist. In the future, a study conducted on a larger population is necessary in order that a reference value for $\dot{V}O_2max$ can be established and compared to those of other studies in different races.

4. Conclusion

The present study derives the prediction equation for $\dot{V}O_2max$ for incremental treadmill exercise testing in healthy Thai population. We also create the relationships between $\dot{V}O_2max$ and age, weight and height. Thai females had lower $\dot{V}O_2max$ than those of males.

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