

## การศึกษานำร่องของความสามารถในการออกกำลังกายสูงสุด และจุดเริ่มล้าในประชากรไทย

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## A Pilot Study of Maximum Aerobic Capacity and Anaerobic Threshold among Thais

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**หลักการและวัตถุประสงค์:** การทดสอบการทำงานของหัวใจ หลอดเลือด และปอด ขณะออกกำลังกาย หรือ cardiopulmonary exercise test (CPET) เป็นการประเมินภาพรวมการตอบสนองแบบบูรณาการของการทำงานระบบหัวใจ หลอดเลือด และระบบหายใจต่อการออกกำลังกาย ถูกใช้อย่างกว้างขวาง โดยความสามารถในการออกกำลังกายสูงสุดขึ้นกับความสามารถในการใช้ออกซิเจนสูงสุด (maximal aerobic capacity;  $\dot{V}O_2$  max) และจุดเริ่มล้า (anaerobic threshold; AT) ที่ตอบสนองต่องาน (work rate; WR) ประเทศไทยยังไม่มีค่าปกติดังกล่าว ดังนั้นในการศึกษานี้มีวัตถุประสงค์เพื่อวัดค่า  $\dot{V}O_2$  max และ AT ต่อการปรับความหนักเพิ่มมากขึ้น ขณะทดสอบการออกกำลังกายในประชากรไทย

**วิธีการศึกษา:** อาสาสมัครสุขภาพดี 30 ราย (ชาย 15 ราย อายุเฉลี่ย  $27 \pm 5$  ปี และหญิง 15 ราย อายุเฉลี่ย  $27 \pm 3$  ปี) ได้รับการทดสอบการทำงานของหัวใจ หลอดเลือด และปอด ขณะออกกำลังกาย โดยมีการปรับเพิ่มความหนักของการออกกำลังกาย จนกระทั่งอาสาสมัครไม่สามารถทำการทดสอบต่อไปได้

**ผลการศึกษา:** น้ำหนัก และส่วนสูง แต่ไม่ใช่ดัชนีมวลกายในเพศชายสูงกว่าหญิง ( $p < 0.001$ ) แต่อยู่ในช่วงปกติ ความสามารถในการใช้ออกซิเจนสูงสุด ( $\dot{V}O_2$  max) ความสามารถในการใช้ออกซิเจนสูงสุดต่อกิโลกรัม ( $\dot{V}O_2$  max/kg) การใช้พลังงาน และงานขณะออกกำลังกายสูงสุดในเพศชายสูงกว่าหญิง ร้อยละ 71, 42, 41 และ 85 ( $p < 0.001$ ) การใช้ออกซิเจนที่จุดเริ่มล้า ในเพศชายมากกว่าหญิง ( $p < 0.001$ ) ส่งผลให้การระบายอากาศต่อการใช้ออกซิเจน 1 ลิตร ในเพศหญิงน้อยกว่า

**Background and objective:** An integrative cardiopulmonary exercise test (CPET) has been widely used to simultaneously evaluate the performance of the cardiovascular and respiratory systems. The achievement of this function is revealed by the maximum oxygen uptake ( $\dot{V}O_2$  max) and anaerobic threshold (AT) in response to a specific work rate (WR) stimulus. There is a lack of data on the normal CPET values for Thais. Therefore, this study aimed to measure  $\dot{V}O_2$  max and AT during rapidly incremental treadmill testing.

**Methods:** The maximal cardiopulmonary responses were performed in 30 healthy Thai subjects (15 males; aged  $27 \pm 5$  years and 15 females; aged  $27 \pm 3$  years) who underwent the CPET using an incremental progressive treadmill test until reaching symptom limitation.

**Results:** Weight and height, but not a body mass index, were higher ( $p < 0.001$ ) in males than in females. Greater  $\dot{V}O_2$  max,  $\dot{V}O_2$  max/kg, maximum metabolic equivalent (METmax) and maximal WR in males than females by 71%, 42%, 41% and 85% ( $p < 0.001$ ) were found. The  $\dot{V}O_2$  at AT was higher in males ( $p < 0.001$ ) than females. Consequently, the ventilatory equivalent for  $O_2$  uptake ( $\dot{V}E/\dot{V}O_2$ ) was lower ( $p < 0.05$ ). Besides,  $\dot{V}O_2$  has positive correlation with WR (males,  $r = 0.9215$ ,  $p < 0.001$ ; females,  $r = 0.8768$ ,  $p < 0.001$ ).

ชาย ( $p < 0.05$ ) นอกจากนี้ยังพบว่าการใช้ออกซิเจนมีความสัมพันธ์เชิงบวกกับงาน (ชาย  $r = 0.9215$ ,  $p < 0.001$ ; หญิง  $r = 0.8768$ ,  $p < 0.001$ )

**สรุป:** การศึกษานี้ทำให้ทราบถึง ความสามารถในการใช้ออกซิเจนสูงสุด และการใช้ออกซิเจนที่จุดเริ่มล้ม โดยใช้การทดสอบการทำงานของหัวใจ หลอดเลือด และปอดขณะออกกำลังกายในคนไทยสุขภาพดี นอกจากนี้ยังแสดงให้เห็นว่าความสามารถในการใช้ออกซิเจนสูงสุด และการใช้ออกซิเจนที่จุดเริ่มล้ม ในผู้ชายสูงกว่าผู้หญิง

**คำสำคัญ:** ความสามารถในการออกกำลังกายสูงสุด จุดเริ่มล้ม การทดสอบสมรรถภาพหัวใจ หลอดเลือดและปอดขณะออกกำลังกาย

**Conclusions:** The present study provides primarily data on maximal aerobic capacity and anaerobic threshold to maximal exercise using the CPET in healthy Thais. We also demonstrate that males have maximal aerobic capacity and oxygen uptake at anaerobic threshold higher than those of females.

**Key words:** Maximum aerobic capacity, anaerobic threshold, cardiopulmonary exercise test

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## Introduction

Cardiopulmonary exercise test (CPET) provides a means for revealing abnormal physiologic function which may not be present at rest<sup>1</sup>. It is dynamic assessment of cardiac and pulmonary performance during exercise in a variety of surgical setting<sup>2, 3</sup>. Additionally, CPET can identify potential deficiencies within these systems by measuring dynamic gas exchange during graded exercise. It has also been used to evaluate the exercise capacity and reasons why exercise is not tolerated<sup>4, 5</sup>, unexplained dyspnea<sup>6</sup>, evaluation of patients with respiratory disease<sup>7</sup>, cardiovascular disease<sup>8</sup> and pulmonary rehabilitation<sup>9</sup>.

The choice of work protocol for incremental exercise testing to exhaustion is guided by the recommendation of exercise duration of 10 minutes<sup>10</sup>. The response normalcy to rapidly incremental CPET is more commonly judged by comparing the observed values at discrete time points (e.g. at the estimated AT and  $\dot{V}O_2$  at peak or maximum exercise) with those previously obtained in apparently healthy subjects<sup>11-14</sup>.

The  $\dot{V}O_2$  max and the AT are parameters used in the assessment of the maximum cardiopulmonary function and functional reserve<sup>15</sup>. The AT is an estimate of the onset of anaerobic metabolism induced lactic acidosis due to an oxygen supply<sup>16, 17</sup>.  $\dot{V}O_2$  max is an

important determinant in CPET as it indicates the maximum possible oxygen uptake of the person to absorb, carry and consume  $O_2$ <sup>16, 18</sup>.

AT and  $\dot{V}O_2$  max are also dependent on modes of exercise, age, gender, body weight, height and training<sup>10, 16</sup>. Many studies report that males have higher AT and  $\dot{V}O_2$  max than females<sup>19, 20</sup>. In addition, considering the ethnic, geographical and behavioral differences between Asians and people of other nationalities, a new definition for normal values of CPET in Asians seems necessary<sup>21</sup>. There is also a lack of data on the normal CPET values for Thais. Therefore, this preliminary study aimed to measure the  $\dot{V}O_2$  max and AT for Thais using rapidly incremental treadmill testing and to compare differences in those responses between genders.

## Methods

### Study Design and Population

In this study, the design was analytical and descriptive. The subjects in the present study were recruited from healthy population in Khon Kaen province of Thailand. A total of 30 subjects (15 males and 15 females) in the age range of 20 to 40 years were participated. Number of subjects was calculated according to a previous study done by Fairbairn et al.<sup>22</sup>.

Those having a positive history with their physical examination and health-screening questionnaires or showing any signs of cardiovascular, pulmonary, neuromuscular, arthritic, severe microvascular diseases, diabetes mellitus, hypertension or other debilitating diseases and history of regular alcohol drinking or smoking were not include in this study. They were healthy with BMI between 18.5 to 24.9 kg/m<sup>2</sup>. Additionally, a written informed consent was obtained from all subjects after a full explanation of the procedures and risks. This study was approved by the Human Research Ethics Committee, Khon Kaen University (HE561453).

#### Clinical and Anthropometric Characteristics

Physical examination and anthropometry measurements according to the World Health Organization (WHO) guidelines 2008 were taken<sup>23</sup>. Participants were light clothing without shoes. Weight was determined using a digital scale to the nearest tenth. Height was measured standing with feet together and arms relaxed at the sides. The BMI was calculated as weight (kg) divided by height (m<sup>2</sup>).

#### Cardiopulmonary Exercise Testing

CPET was performed on a motorized treadmill with an incremental exercise test method of Porszasz et al., 2003<sup>24</sup>. This included 2 minutes of resting, 3 minutes of warm-up, incremental phase until exhaustion or symptom limited maximal exercise tolerable WR, and 3 minutes of recovery phase using Stationary CPET (Quark CPET, Cosmed, Italy). The exercise work rate was increased in speed rate and inclination every 1 minute until exhaustion. The intensity of exercise chosen depends on a physical activity of each individual. Therefore, each test took about 8 to 12 minutes to accomplish.

The criteria for reaching maximum capacity were three or more of the followings: reaching a plateau in  $\dot{V}O_2$ , maximum heart rate was more than 90% of the predicted value for that age (age - 220), RER was more than 1.15 (although RER values are not exactly indicative of maximum capacity), subject requested stopping because of severe fatigue or dyspnea and the participants reached 18 points or more in the RPE scales (Borg's scales)<sup>25</sup>.

The amount of variables including  $\dot{V}O_2$ ,  $\dot{V}O_2$ /kg, ventilatory equivalent for O<sub>2</sub> ( $\dot{V}E/\dot{V}O_2$ ), the ventilatory equivalent for CO<sub>2</sub> ( $\dot{V}E/\dot{V}CO_2$ ),  $\dot{V}E/\dot{V}CO_2$  slope, AT, MET,  $\dot{V}CO_2$ ,  $\Delta\dot{V}O_2/\Delta WR$  WRmax and RER were calculated.

#### Statistical analysis

Data were expressed as mean(SD). The Stata 10 Statistical software was used to perform the statistical analysis. Unpaired t-test was used to compare differences in characteristics, pulmonary function and all parameters between genders. A two-sample Wilcoxon rank-sum (Mann-Whitney) test was used when data deviate from normality. A value of p<0.05 was taken to be the threshold of statistical significance.

## Results

Males and females had similar mean ages; 27±5 and 27±3 years old. Weight and height were significantly higher in males compared to those of females (64.6±8 vs. 53.0±5.5 kg. and 174.0±10.0 vs. 159.2±6.6 cm.) (p<0.001). Nonetheless, BMI were not significantly different (21.3±2.0 vs. 20.9±2.0 kg·m<sup>-2</sup>). SBP, DBP, MAP and HR in males and females were within normal ranges (data not shown).

Moreover, there were no statistical differences between genders in regard to %predicted of FVC, FEV<sub>1</sub>, FEV<sub>1</sub>/FVC, PEF and FEF<sub>25-75%</sub> while FVC (L) and FEV<sub>1</sub> (L) were significantly higher in males than females (p<0.001). Thus, none of the subjects showed obstructive or restrictive pulmonary disorders.

CPET parameters are given in Table 1. All participants performed incremental CPET without complications and were able to complete the protocol to volitional exhaustion. No electrocardiography abnormalities were noted during exercise testing.

Highly positive correlations between  $\dot{V}O_2$  and WR (males, r = 0.9215, p<0.001; females, r = 0.8768, p<0.001) (Figure 1). In males, WRmax and  $\dot{V}O_2$  max were 91.5% and 92.4% predicted. Besides, they were 84.7% and 89.8% predicted in females.  $\Delta\dot{V}O_2/\Delta WR$  and slopes at the AT were 11.7 ± 1.9 ml·min<sup>-1</sup>·watt<sup>-1</sup> and 25.7 ± 2.3 in males which were relatively similar to those of females

**Table 1** Cardiopulmonary exercise test results

Measurements	Males (n=15)	Females (n=15)
WRmax predicted, watts	224	131***
WRmax, watts	205(39)	111(18)***
WRmax, % predicted	91.5	84.7
$\dot{V}O_2$ max predicted, ml·min <sup>-1</sup>	2981(386)	1794(253)***
$\dot{V}O_2$ , ml·min <sup>-1</sup> (rest, AT, max ex)	357(59), 1941(246), 2754(392)	295(95)*, 1211(226)***, 1611(259)***
$\dot{V}O_2$ max, %predicted	92.4	89.8
$\dot{V}O_2$ /kg, ml·min <sup>-1</sup> ·kg <sup>-1</sup> (rest, AT, max ex)	5.6(1.0), 30.4(5.0), 43.2(7.8)	5.6(2.0), 22.8(3.5)***, 30.5(28.0)***
$\dot{V}CO_2$ , ml·min <sup>-1</sup> (rest, AT, max ex)	294(56), 1686(231), 3106(426)	231(82)*, 1001(215)***, 1744(253)***
$\dot{V}E/\dot{V}O_2$ (rest, AT, max ex)	32(8), 23(2), 35(5)	31(4), 25(3)*, 34(7)
$\dot{V}E/\dot{V}CO_2$ (rest, AT, max ex)	39(7), 26(2), 31(3)	40(3), 30(3)***, 31(3)
$\Delta\dot{V}O_2/\Delta WR$ , ml·min <sup>-1</sup> ·watt <sup>-1</sup>	11.7(1.9)	12.0(1.8)
$\dot{V}E/\dot{V}CO_2$ slope	25.7(2.3)	27.4(3.5)
MET (rest, AT, max ex)	1.6(0.3), 8.7(1.4), 12.3(2.2)	1.6(0.5), 6.5(1.0)***, 8.7(1.3)***
RER (rest, AT, max ex)	0.82(0.08), 0.87(0.05), 1.13(0.09)	0.78(0.07), 0.83(0.08), 1.09(0.12)

$\dot{V}E/\dot{V}CO_2$  maximal oxygen uptake;  $\dot{V}O_2$ , O<sub>2</sub> uptake;  $\dot{V}CO_2$ , CO<sub>2</sub> output;  $\dot{V}E/\dot{V}O_2$ , ventilatory equivalent for O<sub>2</sub>;  $\dot{V}E/\dot{V}CO_2$ , ventilatory equivalent for CO<sub>2</sub> output; the slope of linear part of the curve describing absolute O<sub>2</sub> uptake (ml·min<sup>-1</sup>) per unit of WR (watt);  $\dot{V}E/\dot{V}CO_2$  slope, slope of ventilatory equivalent for CO<sub>2</sub> output; MET, metabolic equivalent; RER, respiratory exchange ratio; AT, anaerobic threshold. Values are mean(SD). \*p<0.05 and \*\*\*p<0.001: significance between genders.

(Table 1). Compared to females, males showed higher WRmax,  $\dot{V}O_2$ /kg and MET. In addition, the AT expressed as  $\dot{V}O_2$ , and  $\dot{V}O_2$ /kg was higher in males than females (p<0.001) (Fig. 2, 3 and 4). It was also observed that at the AT,  $\dot{V}E/\dot{V}CO_2$  was significantly higher in females than males (p<0.05). Nevertheless,  $\Delta\dot{V}O_2/\Delta WR$  and RER were not significantly different between genders.

### Discussion

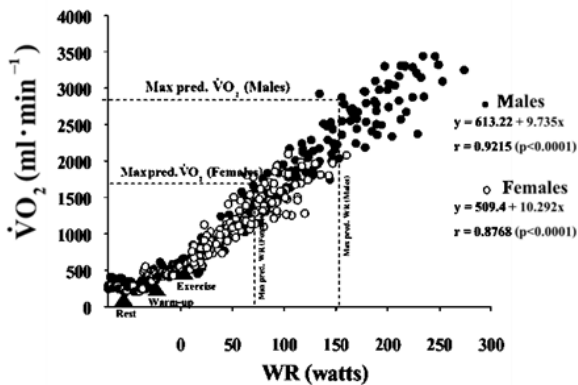
This study presents a systematic evaluation of rapidly incremental CPET by running on a motorized treadmill in randomly selected samples of healthy males and females aged between 20 to 40 years old. It provides sex-specific indices of metabolic response;  $\Delta\dot{V}O_2/\Delta WR$ , exercise at the AT;  $\dot{V}E/\dot{V}CO_2$  slope,  $\dot{V}O_2$ ,  $\dot{V}O_2$ /kg and maximum aerobic capacity;  $\dot{V}O_2$  max,  $\dot{V}O_2$ /kg, METmax and WRmax, a frame of normal values for maximum responses during incremental CPET.

The main findings of this study are such that the  $\dot{V}O_2$  &  $\dot{V}O_2$ /kg at rest, AT, METmax and WRmax at maximal exercise were higher in males in comparison with

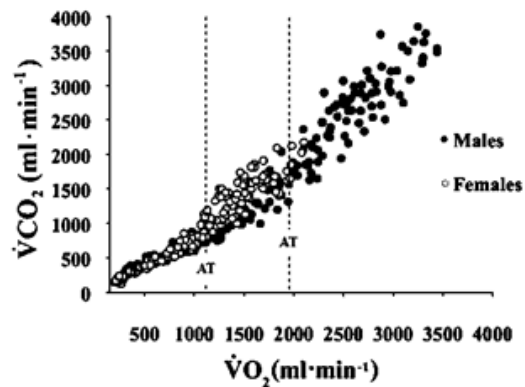
females whereas  $\Delta\dot{V}O_2/\Delta WR$ ,  $\dot{V}E/\dot{V}CO_2$  slope and RER did not differ significantly. We measured  $\dot{V}O_2$  max but not  $\dot{V}O_2$  peak, as the best available index for the assessment of aerobic capacity.

It has been suggested that max  $\dot{V}O_2$  values vary with age, genders, weight, physical activities levels and types of exercise<sup>10, 16</sup>. The higher  $\dot{V}O_2$  max in males is in accordance with former studies<sup>26, 27</sup>. Moreover, the  $\dot{V}O_2$  max were comparable to those reported in American<sup>27, 28</sup>, Japanese<sup>29</sup>, and Brazilian<sup>19</sup> studies but lower than that of another study reported in American<sup>24</sup>. The larger  $\dot{V}O_2$  max in males found in this study could be due to less body fat, which consumes virtually more oxygen<sup>30</sup>, more hemoglobin concentration, an oxygen delivery protein in the blood<sup>31</sup>; and slightly larger heart relative to body size than the female heart<sup>32, 33</sup>. In addition, males have larger lung, lower body volume, more muscle mass than females<sup>16</sup>.

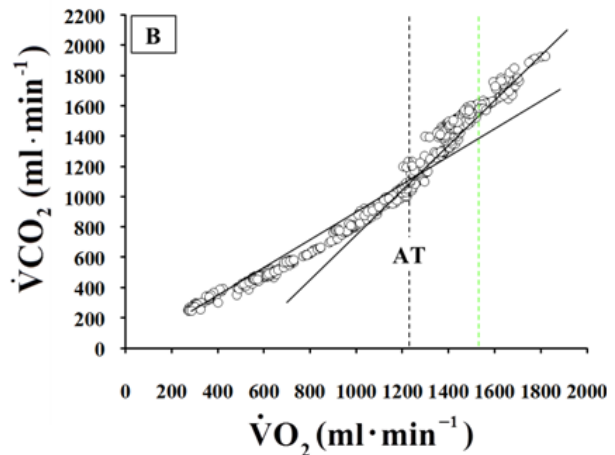
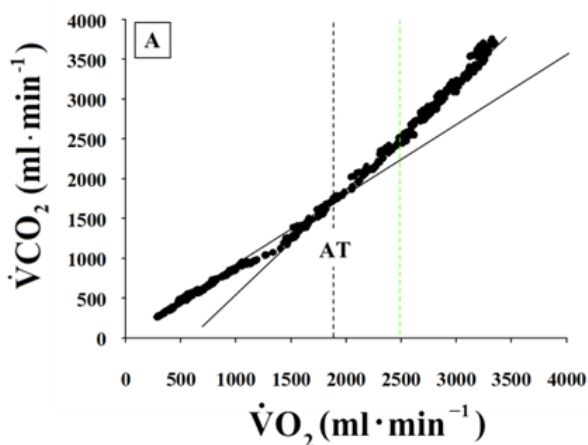
The AT is also an index used to estimate an aerobic capacity. The observation that  $\dot{V}O_2$  at the AT was higher in males than females has been reported previously<sup>19</sup>. According to the available literature, it appears that there are sex differences in some areas of



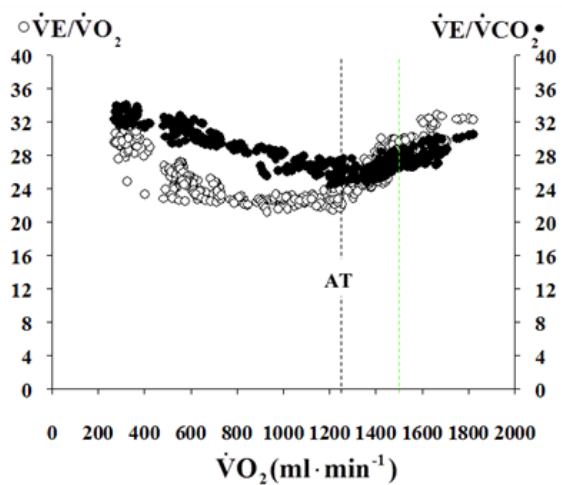
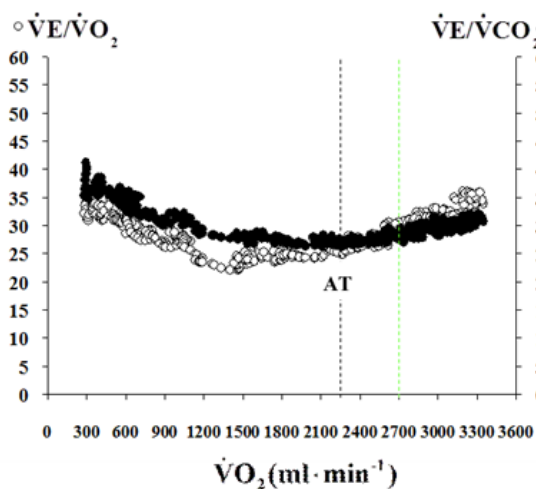
**Figure 1** Relationships between oxygen uptake ( $\dot{V}O_2$ ) and work rate (WR) during a rapidly incremental CPET in healthy Thai adults.



**Figure 2** Overview of a V-slope method, plotting  $\dot{V}CO_2$  as a function of  $\dot{V}O_2$  uptake in  $ml \cdot min^{-1}$ .  $\dot{V}O_2$ , oxygen uptake,  $\dot{V}CO_2$ ,  $CO_2$  output in  $ml \cdot min^{-1}$ ; AT, anaerobic threshold.



**Figure 3** Anaerobic threshold (AT) in both genders (A; males, B; females)



**Figure 4** An anaerobic threshold (AT) determined from  $\dot{V}E/\dot{V}O_2$  &  $\dot{V}E/\dot{V}CO_2$  in both genders (A, male; B, female).  $\dot{V}E/\dot{V}O_2$ , ventilatory equivalent for  $O_2$  uptake;  $\dot{V}E/\dot{V}CO_2$ , ventilatory equivalent for  $CO_2$  output.

respiratory exercise physiology, detailed sex comparisons, however, are difficult because the number of subjects studied has been small.

Moreover, the finding that genders did not affect the slopes of  $\Delta\dot{V}O_2 / \Delta WR$   $\dot{V}E / \dot{V}CO_2$  curve and RER is consistent with the studies reported previously<sup>34, 35</sup>.  $\Delta\dot{V}O_2 / \Delta WR$  and  $\dot{V}E / \dot{V}CO_2$  were comparable compared to their normal values<sup>10</sup>. A shallow  $\Delta\dot{V}O_2 / \Delta WR$  over the entire range of values and/or a shift from a linearly increasing profile to a shallower rate of change has been shown to be indicative of circulatory dysfunction<sup>36</sup> and severe impairment in mitochondria function<sup>37</sup>. This is not the case in our study.

The  $\dot{V}E / \dot{V}CO_2$  slope at the AT has been shown to be an only predictor of death in patients with cardiac heart disease<sup>38</sup> and, more recently, in pulmonary artery hypertension<sup>39</sup>. An increase in  $\dot{V}E / \dot{V}CO_2$  slope could be indicative of maldistribution of pulmonary blood flow with increased physiological dead space ventilation<sup>40</sup>.

Regarding the observed differences in WRmax and  $\dot{V}O_2$  expressed as %predicted between our values and those of Porszasz et. al., this could be due to the narrow range of age in our study and ethnic differences.

### Conclusions

The present study derives maximal aerobic capacity and anaerobic threshold using the CPET in healthy Thai population. Thai females had lower maximum aerobic capacity and anaerobic threshold than those of males. Furthermore, Thais had comparable AT to Caucasians regardless of genders. Besides, Thai males had similar to and/or lower maximum aerobic capacity compared to those of Caucasians while it was greater in female Caucasians than in Thais. A further study performed in a larger sample size is required to obtain normal values for different variables with greater confidence.

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