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Original Article

Variation of knee angle and leg length for predicting VO_{2max} in healthy male volunteers using the Queen's College step test

MANA SOPALARD[1]. JIRAKRIT LEELARUNGRAYUB[2]*, JAKKRIT KLAPHAJONE[3],
[1] Department of Sport Sciences, Graduate School, Chiang Mai University, Chiang Mai, 50200, THAILAND
[2] Department of Physical Therapy, Faculty of Associated Medical Sciences, Chiang Mai University, Chiang Mai 50200, THAILAND.
[3] Department of Rehabilitation Medicine. Faculty of Medicine. Chiang Mai University, Chiang Mai 50200, THAILAND.

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Abstract
The objective of this study was to evaluate the influence of body anthropometrics and knee joint angle (at 90 and 60 degrees) on male participants by following the Queen's College step test (QCT) and directly compare the results with VO_{2max}. The study was designed with 38 randomly selected healthy male participants with a mean age, weight, height, body mass index (BMI), and total leg length of 20.39 years, 58.07 kg, 1.68 m, 20.33 $kg.m^{-2}$, and 33.78 inches, respectively. Direct VO_{2max} of all participants was determined using the stationary bicycle exercise test and a gas analyzer. The indirect VO_{2max} protocol of QCT was determined by adjustable the height for knee joint flexion at an angle of either 90 or 60 degrees. The results showed that VO_{2max} from the indirect protocol at both 60 and 90 degrees was significantly higher and differed from the direct VO_{2max} protocol, with a significantly lower leg fatigue and heart rate recovery. Correlation results were significant between the direct and indirect VO_{2max} protocols at both 90 and 60 degrees ($p< 0.01$). The height, leg length, and BMI showed significant correlation with minute ventilation (VE) during direct VO_{2max}. Whereas, VE correlated significantly with direct VO_{2max}, when compared with both indirect QCT protocols. Finally, the leg length of all participants did not correlate with any VO_{2max}. Therefore, this result indicated that the modification of QCT, with lower leg fatigue from different angles of the knee joint at either 90 or 60 degrees, was overestimated regarding VO_{2max}, height, BMI, and leg length, which correlated with VE but not with the VO_{2max} results.
Keywords: VO_{2max}, Queen's College step test, Knee angle, Leg length

Introduction

The Queen's College step test (QCT) is easy, inexpensive, fast, popular in the field, and reflects cardiorespiratory fitness. This protocol is an indirect submaximal exercise protocol that estimates the maximum oxygen uptake (VO_{2max}), which refers to heart rate recovery after a short three-minute exercise test (Satipati, 2005). The validity of VO_{2max} from QCT is controversial when compared with direct VO_{2max} using a laboratory gas analyzer. Nevertheless, the test is still used in clinics for healthy subjects (Kumar et al., 2012; Chatterjee et al., 2005, 2004), for patients with chronic lung disease (Silva de Andrade et al., 2012), and for patients with rheumatoid arthritis (Cooney et al., 2013). However, previous results have shown that QCT overestimated the predicted VO_{2max} when compared to direct VO_{2max} via a breath-by-breath technique using a gas analyzer (Siahkouhian, 2009). The study of Chatterjee et al., (2005) showed that QCT did not predict VO_{2max} because of poor validity and absence of agreement with the direct VO_{2max} method in female subjects (Chatterjee et al., 2005). Previous evidence has shown that anthropometrics of participants [knee joint angle (Steyy et al., 2013; Laxmi et al., 2014) and height (Siahkouhian et al, 2009), as well as waist-to-hip ratio (WHR) (Vivek et al., 2013)] influence the VO_{2max} result. It was suggested that, if a step was too high, local muscular fatigue could be provoked, which affected the exact aerobic capacity (Molanouri et al., 2011). Additionally, it was proposed that a decrease in the inter participant variability of oxygen cost and heart rate during the test could produce a more valid prediction of VO_{2max}. Thus, previous results of Shamsi's report (2011) suggested that the stature or body height of a participant was significant both for direct VO_{2max} from the cycle ergometer test and for indirect VO_{2max} from QCT (Shamsi et al., 2011). Ashley et al (1997), in particular, found no significant difference between indirect VO_{2max} during QCT from a bench height based on a knee joint angle of 90 degrees and original QCT, and this modified protocol still reduced muscle fatigue during testing. (Ashley et al., 1997). However, VO_{2max} from QCT for female participants was also overestimated (Shamsi et al., 2011). In contrast, a study by Chatterjee et al. demonstrated that indirect VO_{2max} from QCT and direct VO_{2max} from the bicycle exercise test in 30 Indian men (22.6 ± 0.6 years of age) were not statistically different ($p>0.10$) (Chatterjee et al., 2003). Thus, the factors, such as gender or subject height, and the results of VO_{2max} from QCT are still controversial and need additional studies in the future. Therefore, the goal of this study was to evaluate the influence of knee joint angle

Corresponding Author: JIRAKRIT LEELARUNGRAYUB, Email: donrawee.leela@cmu.ac.th

and leg length on indirect VO_{2max} from QCT when compared with direct VO_{2max} from the exercise test, together with the breath-by-breath technique in young male participants.

Materials and Methods

Experimental design

All protocols in this study were approved by the Human Ethics Committee (Declaration of Helsinki, 2001) at the Faculty of Associated Medical Sciences, Chiang Mai University, Thailand (Ethical Registration Number AMSEC-59EX-005). A total of 39 samples (young male volunteers) were calculated statistically using the G-Power 3.0.10 program (free online under the permission license® Copyright 1992-2008), which is based on a previous protocol (Chatterjee et al., 2004), with an effective size of 0.46, power of 0.85, and α error of 0.05 in a dependent paired t-test protocol. Anthropometrics of male participants (e.g., weight, height, upper and lower leg lengths) were determined using tape measure. Then, male participants were randomly selected for the maximal oxygen consumption (VO_{2max}) test using QCT at different step heights (knee flexion angle of 90 or 60 degrees) or for direct VO_{2max} with a static bicycle ergometer and a metabolic gas analyzer using the breath-by-breath technique. The experiments were conducted in a controlled laboratory at a temperature under 25°C and a relative humidity ranging between 80 and 85% at the Department of Physical Therapy, Faculty of Associated Medical Sciences, Chiang Mai University. The experiments were performed three times in one week intervals to avoid any possible muscle pain or dyspnea.

Study subjects

This study was designed for healthy male subjects (18-29 years of age), who were neither smokers nor athletic (exercising less than 3 days per week). The health condition of individuals was obtained using physical screening, interviews, drug administration, and medical treatment from physicians. The body mass index (BMI) criterion was required to be within a normal range [18.0-24.9 kg/m^2; World Health Organization (WHO) and International obesity task force]. Any participants taking nutrient supplements or having a history of musculoskeletal injury within 6 months before entry into this protocol were excluded from it. All subjects were asked to read and approve all protocols and sign a consent form before starting the protocol. All participants were asked to abstain from eating (>4 hr), strenuous exercise (>24 hr), caffeine (>12 hr), nicotine products (>3 hr), and alcohol 24 hr before the exercise test (ACSM's guideline, 2008).

Leg-length measurement

Leg length was determined using a tape measure by following the protocol of Tan et al., (2013). The standardized length was measured using two anatomical landmarks in the anatomical standing position. Total leg length was recorded from the sum of upper and lower leg lengths. The proximal edge of the greater trochanter of the femur and the distal edge of the lateral femoral condyle were standard points of the upper leg length. Whereas, the lower leg length was measured at the lateral point or tibia knee breadth along the lateral side of the leg to the mid lateral malleolus. The total leg length unit was presented in inches (n).

Knee joint angle setting and Indirect VO_{2max} testing using QCT

The knee joint angle at either 90 or 60 degrees of flexion on a step box was measured using a universal metal goniometer with a 10-inch stationary and movable arm marked in 2-degree increments. The stationary arm was aligned in parallel to the longitudinal axis of the femur. Additionally, the stationary arm was aligned with the greater trochanter. The mobile arm was placed in parallel to the longitudinal axis of the fibular aligned to the lateral malleolus (Milanese et al., 2014).

QCT was performed on a box or stool, which could be adjusted in height for knee flexion at either 90 or 60 degrees. A step rate (cadence) of 24 steps per min was performed with a metronome for a total duration of 3 min following the standard QCT protocol (ACSM's 2008). After completion of the test, the subjects were asked to remain standing, and the radial pulse rate was counted from 5 to 20 seconds of the recovery period. The pulse count was multiplied by 4 beats per min to obtain the recovery heart rate (RHR), which followed the equation for predicting the maximal oxygen uptake (Indirect VO_{2max}) (mL/Kg/min), as in the formula: $VO_{2max} = 111.3 - (0.42 \times RHR)$. Moreover, when the 3-min exercise test was completed, leg fatigue had a scale of 10 (Zamuner et al., 2011).

Direct maximum oxygen uptake (Direct VO_{2max})

Direct VO_{2max} (mL/Kg/min) and minute ventilation (VE) (L/min) were determined using the cycling exercise test that was performed on a stationary bicycle controlled by the GE Case® Exercise Testing System (MedGraphic®, USA). Eighty-five percent of the maximal heart rate (220 minus the age) was set at the end of the test, with VO_{2max} automatically analyzed using the BreezeSuit^{TM} 6.4.1. Software program (MGC Diagnostics cooperation, USA) with the breath-by-breath technique. The criteria, precautions, and reasons for stopping the exercise followed the guideline of the American College of Sports Medicine (ACSM) (ACSM. 2008). MGC Diagnostics Corporation.

Statistical analysis

All data were presented as the mean ± standard deviation (SD). VO_{2max} from the direct measurement (direct VO_{2max}) and from the QCT protocol at the knee joint angle of either 90 or 60 degrees was compared statistically using independent ANOVA measurement and the *post hoc* Bonferroni test. The correlation between

BMI, leg length, and all VO_{2max} outcomes was analyzed statistically using the Pearson Correlation test. The SPSS program (version 16) was used, and the significance level was set at 0.05.

Results

In 39 total subjects in this experiment study, 38 healthy male volunteers completed this study because one subject lost contact. All subjects volunteered from different departments of the Chiang Mai University, and their BMIs were within acceptable range [18.0-24.9 kg/m^2].

Indirect VO_{2max} from QCT for a knee joint angle of 60 degrees was significantly higher than that for a 90 degree angle (p = 0.000). Furthermore, the value was higher than direct VO_{2max} from the stationary bicycle exercise test (p= 0.000). When the knee joint angle was 90 degrees, indirect VO_{2max} was still significantly higher than direct VO_{2max} (p = 0.000). These VO_{2max} results were consistent with a lower heart rate recovery from QCT at a 60 degree knee joint angle, when compared with a 90 degree angle in the direct QCT protocol (p = 0.000) (Table 1). Furthermore, the results showed that the scale of leg fatigue from the direct VO_{2max} protocol was significantly higher than that from the indirect VO_{2max} protocol for QCT at either 90 (p = 0.004) or 60 (p = 0.000) degree angles.

Table 1. Characteristics, VE, VO_{2max}, recovery heart rate and leg fatigue of all 38 healthy male participants

	Mean ± SD (Min-Max)
Age (years)	20.39 ± 1.56 (18 – 24)
Weight (Kilogram)	58.07 ± 8.30 (40 – 75)
Height (meter)	1.68 ± 0.05 (1.54 – 1.78)
BMI (Kg.m^{-2})	20.33 ± 2.12 (18.58 – 24.86)
Leg length (inch)	33.78 ± 1.39 (31.50 – 36.50)
Minute ventilation (VE) (L/min)	74.74 ± 13.20 (54.68 - 101.24)
VO_{2max} (mL/min/Kg)	
Direct VO_{2max}	39.01 ± 4.96 (32.20 – 47.50)
90 degree knee flexion (QCT)	43.67 ± 2.68 * (40.77 – 49.17)
60 degree knee flexion (QCT)	54.72 ± 4.37 *, # (50.85 – 69.33)
Recover heart rate (beats per min)	
Direct VO_{2max}	172.7 ± 5.4 (152 – 182)
90 degree knee flexion (QCT)	161.0 ± 6.3* (148 – 168)
60 degree knee flexion (QCT)	134.8 ± 10.5 (100 – 144)
Leg fatigue	
Direct VO_{2max}	4.4 ± 0.5 (4 – 5)
90 degree knee flexion (QCT)	3.9 ± 0.6* (3 – 5)
60 degree knee flexion (QCT)	3.0 ± 0.4 *, # (2 – 4)

Data presents the mean ± SD (minimal - maximal raw data). P< 0.01 when compared to Direct VO_{2max}, # p < 0.01 when compared to indirect VO_{2max} by QCT (90 degrees)

Table 2 shows a significant correlation between direct VO_{2max} from the gas analysis protocol and indirect VO_{2max} from QCT, when the knee joint angle was 90 and 60 degrees (p< 0.01) (Figure 1.A). Furthermore, both indirect VO_{2max} protocols, at either 90 or 60 degrees, were significantly correlated (Figure 1.B) (r = 0.81, p< 0.01). When analyzing the correlation between all anthropometric parameters, the results showed significant VE and height (r = 0.719, p < 0.01) (Figure 2.A), leg length (r = 0.64, p < 0.01) (Figure 2.B), and BMI (r = 0.44, p < 0.01) (Figure 2.C). Whereas, the VE only showed a significant correlation with direct VO_{2max} (r = 0.52, p < 0.01), when compared with the indirect QCT protocol at either 90 (r = 0.26, p> 0.05) or 60 degree (r = 0.19, p > 0.05) angle of the knee joint (Figure 2.D). Finally, the leg length of participants did not correlate with VO_{2max} (p> 0.05) (Table 2).

Table 2. The correlation and significant level between anthropometrics, VE, and VO_{2max} data

N =38	VE	Direct VO_{2max}	Indirect VO_{2max} (90°)	Indirect VO_{2max} (60°)
BMI	0.44 (0.006)*	0.34 (0.037)#	0.29 (0.078)	0.248 (0.134)
Height	0.719 (0.000)*	0.39 (0.014)*	0.42 (0.008)*	0.251 (0.128)
Leg length	0.64 (0.000)*	0.21 (0.205)	0.29 (0.080)	0.19 (0.233)
Direct VO_{2max}	0.52 (0.001)*	1.0	0.86 (0.000) *	0.75 (0.000)*
Indirect VO_{2max} (90°)	0.26 (0.115)	0.86 (0.000)*	1.0	0.81 (0.000)*
Indirect VO_{2max} (60°)	0.19 (0.236)	0.75 (0.000)*	0.81 (0.000)*	1.0

Data show the person correlation result (r). (Statistically significant level, * $p < 0.01$, # $p < 0.05$), VE = minute ventilation

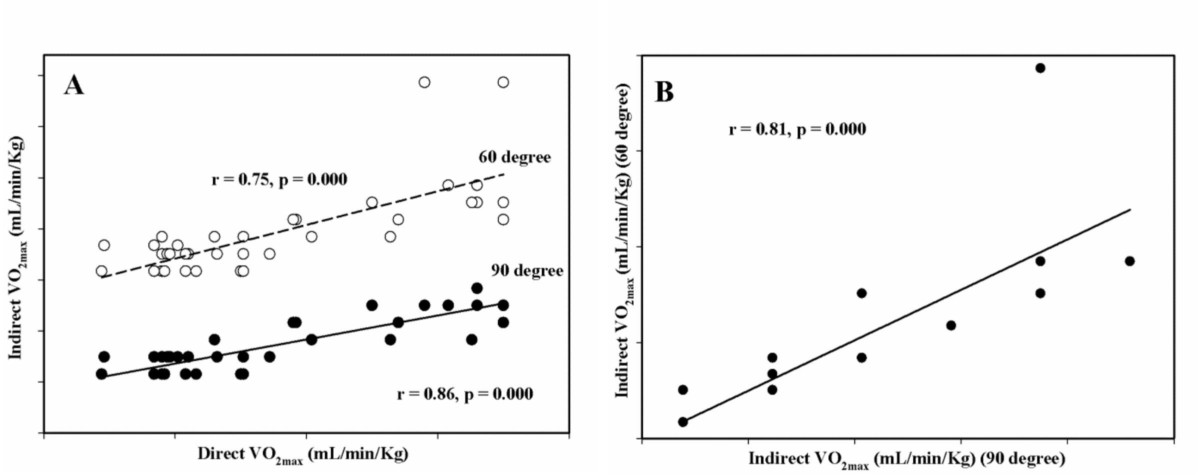

Figure 1. Correlation between direct VO_{2max} and both indirect VO_{2max} (90 and 60 degree angle of the knee joint) (A), and between indirect VO_{2max} at a 90 and 60 degree angle of the knee joint (B). Pearson correlation was analyzed statistically.

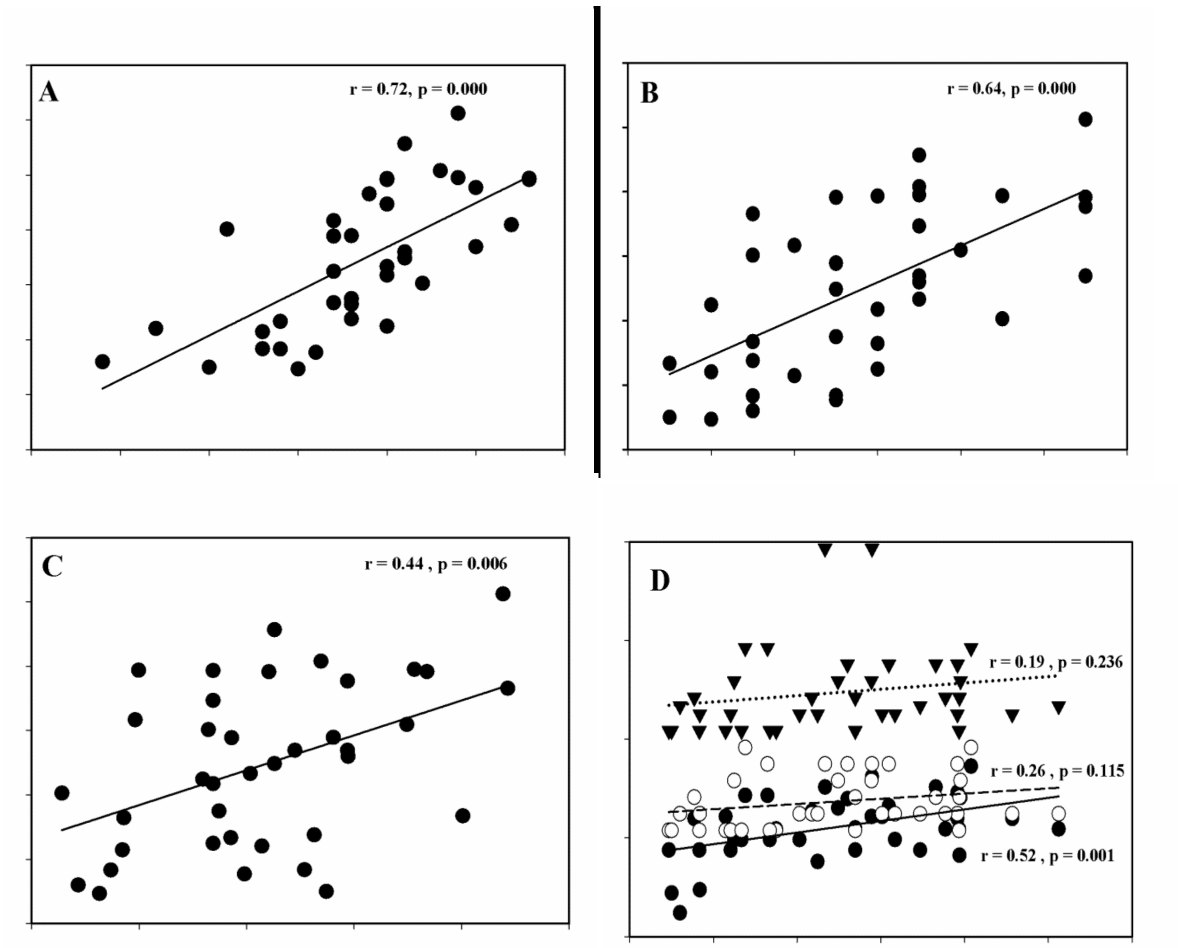

Figure 2. Correlation between the VE (X-axial) and anthropometric data (Y-axial) as height (A), leg length (B), and BMI (C), and correlation between VE and all VO_{2max} ($r = 0.52$ is direct VO_{2max}, $r = 0.26$ is indirect VO_{2max} at 90°, and $r = 0.19$ is indirect VO_{2max} at 60°) (D). All data were analyzed statistically by the Pearson correlation test.

Discussion

This study was performed on 38 healthy young male subjects, whose BMI was within the normal reference range that followed the WHO criteria [18.0-24.9 kg/m^2]. The results showed a statistical difference of VO_{2max} between the direct and indirect protocol, which was similar to a previous study on female subjects (Siahkouhian, 2009). The predicted VO_{2max} from the QCT protocol presented a higher yield than that from direct VO_{2max} using the breath-by-breath technique using a gas analyzer tool (Siahkouhian, 2009).

This study was designed to compare knee joints at different angles (60 and 90 degrees of flexion), and significantly higher yield of direct VO_{2max} was found (Table 1) ($p< 0.01$). Previous evidence showed that during squats, muscle force at the knee joint was greater at a 60 degree angle than at 90 degrees (Admad et al., 1998), which possibly relates to lower heart work. This hypothesis is possibly explained by the recovery heart rate (RHR) and leg fatigue results (Table 1). Significantly lower RHR and leg fatigue were shown for knee joint exercises at 90 degrees and for direct VO_{2max}, respectively. In addition, this study found a statistical difference of VO_{2max} between the indirect VO_{2max} protocol for knee joint at a 90 degree angle and direct VO_{2max} ($p < 0.01$). This was in contrast to a previous study by Ashley and coworkers (1997). They found no difference between the knee joint bench height at a 90 degree angle and original QCT (Ashley et al., 1997). This was possibly explained by the difference in structural and physical performance of the participants. Therefore, previous study suggested that the elevation of indirect VO_{2max} using QCT under limited muscle fatigue was not available or suitable for estimating VO_{2max} (Ashley et al., 1997).

Moreover, this study compared VO_{2max} between direct and indirect protocol for the knee joint at an angle of either 90 or 60 degrees. The study found a significant correlation between indirect VO_{2max} at both knee joint angles and direct VO_{2max} (Figure 1 A and B). The step height at either 90 or 60 degree angle of the knee joint showed a correlation value of 0.86 and 0.75 (Table 2), which was higher and similar, respectively, to a previous study that showed 0.71 in a group of men with a mean age of 22.6 years (Abdossaleh and Amin, 2013). This confirmed that indirect VO_{2max} using QCT was still applicable for estimating the VO_{2max} uptake for predicting cardiorespiratory fitness. However, the anthropometric variation of subjects could have affected the VO_{2max} results. A previous study showed a significant correlation between the height and VO_{2max} (Siahkouhian, 2009) in active young men. It was suggested that the reasons for this were high lung capacity and shorter subjects. This study evaluated minute ventilation (VE) during the exercise test (Table 1). A significant correlation was observed only with the standard direct VO_{2max} (Figure 2.C), and not with either indirect VO_{2max} protocols. In addition, the height of participants significantly correlated with VE (Figure 2.A), leg length (Figure 2.B), and BMI (Figure 2.C). In contrast, the results of BMI and VO_{2max} evaluation in the study of Laxmi and coworkers (2014) found a negative correlation between BMI (Laxmi et al., 2014) and obesity (Setty et al., 2013) using the original QCT (Laxmi et al., 2014). This was attributed to participants having larger BMIs or weighing more than 30 Kg/m^2. Whereas, this study was designed within the normal BMI range (18.0-24.9 kg/m^2), which possibly caused contrasting results. Therefore, our results suggest that height, leg length, and BMI are related to minute ventilation (VE). However, no QCT protocol can be suggested. Furthermore, this study was performed on healthy male subjects (18-24 years old) and did not extend to general population. Therefore, more experiments are needed with a larger sample size of different ages as well as a female group. Indirect VO_{2max} using QCT requires additional studies for estimating VO_{2max} consistently with direct VO_{2max} in a laboratory test. This is especially true regarding the formula for predicting the accuracy of VO_{2max} related to anthropometry in different nationalities worldwide.

Competing interests

The authors declare no competing interests.

Author contributions

JL and MS were responsible for designing the study. JL established all protocols, performed laboratory testing, and collected data for analysis under the academic laboratory supervision from JK. All authors have read and approved the final version.

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