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Original Research

Comparison of VO_{2max} Prediction of Submaximal Exercise Testing for Six Minute Arm Ergometer Test with Six Minute Walking Test in Untrained Healthy Young Adult Males

Taufan Hartawan[1*], Nurul Kusuma Wardani[1], Andriati[1]
[1]*Department of Physical Medicine and Rehabilitation, Faculty of Medicine, Universitas Airlangga, Dr. Soetomo Academic General Hospital, Surabaya, East Java, Indonesia*

*Corresponding Author:
Taufan Hartawan, Department of Physical Medicine and Rehabilitation, Faculty of Medicine, Universitas Airlangga, Dr. Soetomo Academic General Hospital, Surabaya, Indonesia, Jl. Mayjen Prof. Dr. Moestopo No. 6-8, Surabaya, East Java, Indonesia
Email: taufanhartawan@gmail.com

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ABSTRACT

Background: Six-minute walking test (6-MWT) is one of the submaximal exercise testing that is commonly used. The 6-MWT has limited use in the condition of individuals with limited limbs. Therefore, a six-minute arm ergometer test (6-MAT) submaximal exercise testing was developed. The presence of 6-MAT for assessing VO2max prediction is still relatively small.
Aim: To compare the predicted VO_{2max} of 6-MWT and 6-MAT, and to see if there are differences in each predicted VO_{2max} value.
Material and Methods: This was a cross-sectional study with a consecutive sampling, involving 31 untrained healthy young adult males, aged 26-40 years old. Each subject underwent two exercise testing 6-MWT and 6-MAT, which were carried out on different days with a minimum washout period of 24 hours. VO2max prediction value was evaluated for each exercise testing on each subject.
Results: There are significant differences between the predicted VO2max values of 6-MWT and 6- MAT (p = 0.00). The mean VO_{2max} prediction values of 6-MAT is higher than 6-MWT with 2288.43 mL.min^{-1} and 1573.72 mL.min^{-1}, respectively.
Conclusion: The 6-MAT could be used for assessing VO2max prediction of individuals, although, there is a difference value between the predicted VO_{2max} of the 6-MWT and 6-MAT submaximal exercise testing, with the VO_{2max} value of the 6-MAT higher than the 6-MWT submaximal exercise testing.

Keywords: *six-minute walk test, six-minute arm ergometer test, submaximal, VO_{2max}*.

Introduction

Determination of maximum oxygen consumption (VO_{2max}) has an important role for prescribing an aerobic exercise program. VO_{2max} is useful for determining the optimum intensity of exercise that is safe for an individual in order to achieve improvement in the patient's aerobic capacity.[1] VO_{2max} can be measured directly through maximal graded exercise testing or predicted from submaximal exercise testing.[1,2] In many situations, prediction of VO_{2max} is preferred because this type of test is easy to do, does not require expensive equipment and is relatively safe.[1,2]

Submaximal exercise testing to assess individual aerobic capacity (VO_{2max}) has long been developed by multiple ways, such as the cycle ergometer test, treadmill test, step test, walk test and the most commonly used is the six-minute walking test (6-MWT).[1] The 6-MWT training test is often used because it is easy and does not require expensive equipment, but certain conditions for individuals with disorders of the lower limbs will experience obstacles such as in patients with Spinal Cord Injury (SCI) and lower limb amputations.[1]

According to world health organization (WHO) and the international spinal cord society (ISCOS), 40-80 new cases occurred per one million world populations per year in 2013, 250,000-500,000 people suffer from SCI per year.[3] In 2014, Fatmawati Hospital Jakarta Indonesia recorded 104 cases of SCI.[4] The incidence of lower limb amputations in the United States is around 30,000-40,000 per year, in 2005 there were 1.6 million people with leg amputations and it is estimated that this number will increase to 3.6 million by 2050.[5]

Submaximal arm exercise testing is an alternative option for assessing VO_{2max} for patients with lower limb disorders.[6] Submaximal arm exercise testing can be used to determine exercise intensity prescription based on the predicted VO_{2max} results obtained.[6] Franklin stated that the arm exercise testing is more appropriate to asses VO_{2max} or aerobic capacity in individuals with dominant occupations or activities using upper limbs.[6] Bulthuis et al. stated that the arm exercise testing is considered to be of little use as a tool for exercise testing, because there is still no standard protocol for its application.[7]

Abadie and Schuler conducted a study comparing VO_{2max} predicted value obtained using a formula from a submaximal 5-6 minutes arm crank ergometer exercise testing, with a directly measured VO_{2max} value from maximum graded testing.[2] The study involved 60 healthy young men and resulted a conclusion of no significant difference between the two examination tools.

Hol et al. conducted a study that a 6-MAT had significant reliability and validity values for the evaluation of cardiovascular fitness in patients with SCI.[8] Bulthuis et al. conducted a study by comparing VO_{2max} submaximal exercise testing for six minutes using two different arm crank ergometers and comparing them with bicycle ergometers in 30 healthy subjects.[7] A good reliability value (ICC = 0.63) was obtained between two arm crank ergometers, so 6-MAT can be used as an evaluation tool for improving one's physical fitness.[7] Good validity value (ICC = 0.64) was also obtained between the arm crank ergometer with bicycle ergometer, so the 6-MAT can be used as a training test to measure physical fitness.[7]

The aim of this study is to determine whether 6-MAT could be an alternative to measure VO2max prediction for people that has limitation of the lower extremity. At present, to the best of our knowledge, there were no studies comparing the predicted VO_{2max} value between 6-MAT and 6-MWT. Based on the foregoing, this study was conducted to compare the predicted VO_{2max} between 6-MAT and 6-MWT submaximal exercise testing with the hypothesis of this study was the predicted VO_{2max} value of the 6-MAT exercise training is higher than the 6-MWT.

Material and Methods

This study was a crossover observational analysis with paired sample design and the sampling method was consecutive sampling until the minimum amount of sample reached. The subjects of this study were 31 untrained healthy young adult males selected among students and employees of Dr. Soetomo Academic General Hospital Rehabilitation Medicine Outpatient Clinic and each subject underwent basic medical examination and electrocardiogram (ECG) examination before. The inclusion criteria were untrained healthy young adult males, 18 – 40 years old, not consuming heart rate affecting medications (HR), could understand and follow the instruction of exercise testing and volunteered for participation in this study.

Exclusion criteria are having cognitive, cardiac, pulmonary, metabolic, upper and lower musculoskeletal disturbance or disease. Drop out criteria of the subject were discontinuing the program once, unwilling to continue the program and occurrence of any disturbance or disease on cardiovascular, pulmonary and musculoskeletal during the study period. Each subject underwent two exercise testing, the first was 6-MWT and the second was 6-MAT, which were carried out on different days with a minimum washout period of 24 hours. Each subject was instructed to refrain from consuming heavy meal, caffeinated beverages, and smoking for 2-3 hours prior to the scheduled exercise testing.[2,9] Subjects were also asked to refrain from strenuous activity for at least 24 hours before testing.[2] Before and after each exercise testing, the vital sign was measured.[2,9]

Each subject underwent the 6-MWT exercise testing according to protocol from American Thoracic Society.[9] The 6-MAT exercise testing, in this study used arm ergometer MOTO med® viva 2 from RECK-Technic GmbH & Co.KG.[10] Each subject was seated, the axis of the arm ergometer was positioned level with the xiphoid process, positioned at a distance from the arm ergometer which allowed for a full arm extension during the crank rotation.[2,7] Before exercise testing, subjects warmed up for 3 minutes at a work rate of 30 $kg.m.min^{-1}$ (5 W) and then followed by 6 minutes of submaximal exercise at a work rate that elicited a steady state HR between 110 and 150 bpm or 60 % - 85% from predicted maximum HR.[2] The work rate selected for the initial test was based on the HR responses during the 3 minutes warm up.[2] If the HR response was low during warm up session, the selected resistance ranged between 305-650 $kg.m.min^{-1}$ (50- 107 W) during the 6-minute submaximal exercise test.[2] If the HR response during the 3 minutes warm up session was high, a lower resistance ranged between 60-600 $kg.m.min^{-1}$ (10-98 W).[2]

During exercise test, the HR was measured every minute of test. After the first and second minute of test, if the HR was lower than 110 bpm, the work rate could be increased 5-10 W and if the HR was higher than 150 bpm, the work rate could be decreased 5-10 W.[7] The propulsion of the pedaling arm crank was set to 55-65 rpm. The steady state HR notation was made at fifth and sixth minute when the fluctuation of HR was not more than 5 bpm.[2] After the test was complete, subject could do cooling down with pedaling for 3-5 minutes with minimal load of arm crank.[2,7] The outcome that was evaluated was VO_{2max} prediction for each exercise testing on each subject. In this study, to get the VO_{2max} prediction, Nury Formula was used for 6-MWT [11]:

$$VO_{2max} = 0{,}053\,(\text{distance}) + 0{,}022\,(\text{age}) + 0{,}032 \times (BH) - 0{,}164 \times (BW) - 2{,}228\,(\text{sex}^*) - 2{,}287$$

explanation:
* 0 = Male 1 = Female
Walking distance in meter
Age in year old
BH = Body Height in centimeter
BW= Body Weight in kilogram

Abadie and Schuler formula was used for 6-MAT [2]:

$$VO_{2max} = -1461{,}22 + 1{,}45\,(WR) + 10{,}65\,(BW) + 8{,}59\,(SHR) + 47{,}28\,(age)$$

explanation:
WR = Work Rate ($kg.m.min^{-1}$)
BW = Body Weight (kg)
SHR = Steady state HR (bpm)
Age in year old

Statistical analysis was performed using the statistical package SPSS (version 23.0 SPSS for Windows). The statistical normality distribution test for each subject characteristics and VO_{2max} were tested using Shapiro-Wilk test and to evaluate the difference of VO_{2max} predictions from both exercise testing, we use paired sample t test, because the data had normal distribution. The differences were considered statistically significant at $p < 0.05$. All study subjects had signed the informed consent form and this study had ethical clearance (No. 1981/KEPK/IV/2020) from the ethical committee of Dr. Soetomo Academic General Hospital.

Results

All 31 subjects completed the sessions and study protocol, with no drop out throughout the study. None of the subjects reported any adverse effects during or after the exercises testing. Subjects' age, body weight, body height, distance in 6-MWT, and work rate in 6-MAT were normally distributed ($p > 0.05$), except for SHR ($p < 0.05$) (Table 1). Each VO_{2max} prediction from both exercise testing was also normally distributed ($p > 0.05$) (Table 2). Comparison of mean VO_{2max} prediction from 6-MWT and 6-MAT revealed that there were significant differences ($p < 0.05$) (Table 3) and the value of VO_{2max} prediction of 6-MAT were higher than 6-MWT (Figure 1).

Table 1. Subjects characteristics

Characteristics	N	Min.	Max.	Mean ± SD	*p* Value
Age (years)	31	26	40	33.32 ± 3.84	0.373*
Body Weight (cm)	31	47	95	72.80 ± 12.22	0.609*
Body Height (cm)	31	156	183	168.35 ± 7.26	0.349*
6-MWT					
Distance (m)	31	472.50	671.70	564.44 ± 53.64	0.672*
6-MAT					
Work rate ($kg.m.min^{-1}$)	31	134.64	397.80	264.57 ± 56.94	0.659*
SHR (bpm)	31	112.00	135.50	119.03 ± 5.53	0.035

Explanation: SHR: *steady state heart rate*. Shapiro-Wilk test, *normal distribution if $p > 0{,}05$

Table 2. VO_{2max} prediction of 6-MWT and 6-MAT

Variable	N	Min.	Max.	Mean ± SD	*p* Value
6-MWT	31	1168.85	2362.82	1573.72 ± 268,86	0.113*
6-MAT	31	1864.25	2735.88	2288.43 ± 238.70	0.322*

Explanation: Shapiro-Wilk test, * normal distribution if $p > 0.05$

Table 3. Comparison of VO_{2max} prediction

Variable	6-MWT (Mean ± SD)	6-MAT (Mean± SD)	*p* Value
VO_{2max} ($mL.min^{-1}$)	1573.72 ± 268.86	2288,43 ± 238.70	0.00*

Explanation: *Paired t-test*, *significant if $p < 0.05$

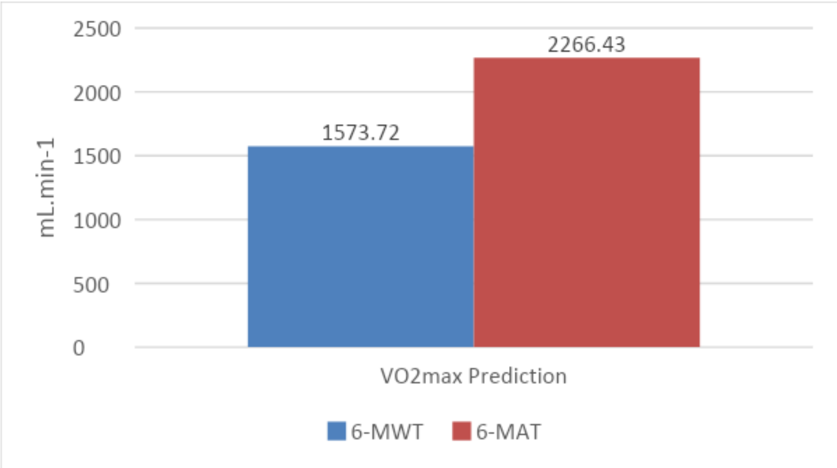

Figure 1. Comparison of VO_{2max} prediction

Discussion

The calculation for VO_{2max} prediction of 6-MWT in this study used Nury formula.[11] Nury formula is the appropriate predictor of maximum oxygen uptake for healthy Indonesian adult as it was designed using Indonesian subjects (Mongoloid).[11] This is appropriate with the recommendation of the American Thoracic Society (ATS) guideline and other references that each department and/or country should have its own reference values.[9,11-13]

The calculation for VO_{2max} prediction of 6-MWT in this study used Abadie and Schuller formula because this formula was the appropriate predictor of maximum oxygen uptake for the subjects of this study which were untrained healthy young adult males.[2]

This study showed the difference of predicted VO_{2max} between 6-MWT and 6-MAT. This is consistent with some previous research from Franklin and Bulthuis et al. which stated that important things to note in the submaximal training test using the upper limb and lower limb are each who has different physiological responses.[6,7]

Franklin and Fardy et al. stated that in training with submaximal workloads, it turns out that the physiological response of exercises using the upper limbs is greater than those using the lower limbs, whereas in exercises with maximum effort, the physiological responses are higher in exercises using the lower limb compared to those using the upper limb.[6,14] This difference in physiological response is due to the difference of muscle mass that the upper limbs are smaller compared to the lower limbs.[7,15,16] This smaller muscle mass causes differences in mechanical efficiency with greater muscle mass.[14,17]

This study showed that the mean VO_{2max} prediction value of 6-MAT (2288.43 $mL.min^{-1}$) was higher than 6-MWT (1573.72 $mL.min^{-1}$). It is due to the difference in mechanical efficiency of smaller muscle mass of the arms, so VO_{2max} from exercise with upper limbs were twice as big as lower limbs.[14] In another study by Vokac et al., it was found that oxygen consumption with submaximal load on arm cranking (training test using upper limbs) was significantly higher than pedaling (training test using lower limb).[17] This mechanical efficiency will also affect the endurance of the arm muscles that at maximum work load, the arm muscles tend to decrease more easily which then results in decreased VO_{2max} before finally becoming fatigue.[17] Therefore, the VO_{2max} at maximum exercise testing that uses upper limbs obtained smaller number than the exercise testing that uses the lower limb.[17]

Kofsky et al. stated that the use of muscle mass of the upper limbs on the arm crank ergometer is only able to reach 60% of the maximum load that can be achieved by the muscle mass of the lower limbs.[18] Therefore, the use of workloads during submaximal arm crank ergometers must be adjusted to each individual and be started from a minimum workload.[7]

Another physiological response when the muscles of the upper limbs perform a submaximal exercise is a rapid increase of sympathetic tone reflexes in the heart so that the heart rate increases sharply, whereas in the muscles of the lower limbs, increase of sympathetic tone reflexes in the heart occurs when exercise reaches maximum load.[6,17] This is consistent with Fick's theory that VO_{2max} is the result of two main components of the equation, namely maximal cardiac output and arterial-venous oxygen difference [VO_{2max} = Cardiac Output x (a-vO_2 diff)].[1] Cardiac output itself is affected by stroke volume and heart rate, so if there is an increase in heart rate, the VO_{2max} value will increase. Therefore, VO_{2max} submaximal training test on the upper limbs is higher than the lower limbs.

This study has several limitations. First, the subjects were only young adult males, so it could not be generalized to female gender and in the older people. Second, this study was not designed to find a new VO_{2max} value algorithm conversion for 6-MWT and 6-MAT. For further research, it needs to be done with other healthy populations such as women and a wider sample age range and it needs more complex research to find a new algorithm for converting the value of VO_{2max} prediction of 6-MAT to be 6-MWT and vice versa.

Conclusion

The VO_{2max} prediction value of the 6-MWT and 6-MAT submaximal exercise testing was different with the VO_{2max} prediction value of the 6-MAT that is higher than the 6-MWT submaximal exercise testing.

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