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Estimated maximal oxygen consumption of transfemoral amputees utilizing the Ebbeling treadmill test

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Abstract

OBJECTIVE: It is reasonable to utilize kinematic data in the evaluation of amputee functional capacity. However, physiological response to activity is another aspect that should be taken into account when evaluating patient functional K-level. The purpose of this study is to document the physiological responses of lower-limb amputees to clinical exercise testing and compare the results of using a simple submaximal protocol designed for non-amputees to an established method of measuring functional capacity in amputees.

METHODS: Three healthy unilateral transfemoral subjects had all previously been classified as functional K3-K4 ambulators using the Amputee Mobility Predictor. They were tested using the *Ebbeling Treadmill* protocol, which requires the subject maintain a heart rate between 50-70% of age-predicted maximum for four minutes. Heart rate was taken before, during, and after exercise. VO_2, CO_2 expired, and O_2 inspired were measured during exercise using the Parvo Medics TrueOne 2400 metabolic cart. Rate of perceived exertion was assessed using the Borg Scale. Utilizing the measured heart rate response; VO_{2max} was estimated using the Ebbeling equation.

RESULTS: Average exercise heart rate ranged from 109 beats per minute (fBPM}} to 135.5 BPM. Peak VO_2 ranged from 17.5 mlJkg/min to 19_mLlkg/min. Estimated VO_{2max} for the subjects ranged from 28 mLlkg/min to 42.21 mL/kg/min, which ranged from poor to fair, according to the American College of Sports Medicine guidelines.

CONCLUSION: While the low estimated VO_{2max} values are concerning at first glance, they do not seem to correlate to the Amputee Mobility Predictor stratification. In addition, the large HR response to the test that resulted in low estimated VO_{2max} values could be due to increased metabolic demands of walking, not poor cardiorespiratory capacity. Small sample size makes it impossible to draw supported conclusions. Further data collection is required.

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ESTIMATED MAXIMAL OXYGEN CONSUMPTION OF TRANSFEMORAL AMPUTEES

UTILIZING THE EBBELING TREADMILL TEST

By

Samantha Stauffer

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ABSTRACT

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INTRODUCTION

A patient's capacity to accomplish daily life activities post-amputation is called functional capacity. This is stratified into K-levels (Figure 1.1) through the use of the Amputee Mobility Predictor [AMP] assessment (Stevens, Fross, & Knapp, 2009), which is a 20-item scale that takes 15-20 minutes to perform. It includes sitting balance, gait, and negotiation of obstacles,

K-Level	Description
K0	This patient does not have the ability or potential to ambulate or transfer safely with or without assistance and a prosthesis does not enhance their quality of life or mobility.
K1	This patient has the ability or potential to use a prosthesis for transfers or ambulation on level surfaces at fixed cadence - a typical limited or unlimited household ambulator.
K2	This patient has the ability or potential for ambulation with the ability to traverse low-level environmental barriers such as curbs, stairs, or uneven surfaces - a typical community ambulator.
K3	The patient has the ability or potential for ambulation with variable cadence - a typical community ambulator with the ability to traverse most environmental barriers and may have vocational, therapeutic, or exercise activity that demands prosthetic use beyond simple locomotion.
K4	The patient has the ability or potential for prosthetic ambulation that exceeds basic ambulation skills, exhibiting high impact, stress, or energy levels - typical of the prosthetic demands of the child, active adult, or athlete.

Figure 1.1 – K-Level Stratification (Gailey *et al*, 2002)

among other activities, and is currently the only accepted method of determining functional capacity. The AMP results were compared to 6-Minute Walk scores (Balke, 1963) and the Amputee Activity Survey (Day, 1981), two previously accepted functional capacity determinants, and was found to be a valid assessment tool. This classification of K-level impacts the decision regarding the componentry and level of care a patient receives. However, it is incomplete, as it looks at only temporal-spatial and kinematic data. Factors such as comfort and confidence with regards to the prosthesis (Gailey, 2006), as well as cardiorespiratory fitness, are other areas contributing to daily functional capacity.

VO_{2max} is a commonly measured in clinical populations to test exercise capacity. This variable is the product of maximal cardiac output and arterial-venous oxygen

difference. It is a measure of the maximum amount of oxygen a body can consume and utilize per minute during work at sea level (Pescatello *et al.*, 2014). The lower an individual's VO_{2max} value, the more difficult and physically taxing it is to perform daily activities. It is treated as the most valid parameter in cardiorespiratory fitness evaluation, and there is a strong link between VO_{2max}, physical fitness, and risk factors closely associated with vascular amputations (Kurdibaylo, 1994). Approximately half of amputations performed in the US are due to vascular complications, with many linked to uncontrolled diabetes. This trend has been apparent since the 1970's (Most & Sinnock, , 1983). A sedentary lifestyle is often associated with poor diabetic management (Regensteiner *et al*, 2005) as well as a lower VO_{2max}. In one study, diabetics who participated in a 6 month training program saw a 19.7% improvement in VO_{2max} that coincided with a 22.7% increase in arterial dilation and improved fasting blood glucose (Guang-Da *et al*, 2004). In addition, amputation significantly reduces blood volume and tissue volume, and subsequently affects intra-arterial pressure, circulation, and resultant heart rate and cardiac output (Kurdibaylo, 1994). All of these factors increase metabolic demand of daily activities. As such, it is clear that VO_{2max} is closely associated with vascular amputation risk and functional status post-amputation.

VO_{2max} testing can provide insight to current cardiorespiratory functional capacity, and therefore can assist in diagnosis of functional status in day-to-day life by predicting how difficult daily life activities might be as well as possibly predict long-term mortality (Pescatello *et al.* 2014). In doing so, it can help in the assessment of a patient's current physical health status, enabling prosthetic practitioners to formulate the

best plan of action in terms of componentry and rehabilitation, thereby maximizing ambulatory capacity and improving patient quality of life.

There are several different factors to consider when prescribing an exercise test. First is modality. Treadmills have been proven to be most accurate, as this is a mode that is performed daily. Cycle ergometers are also common, and are generally used for populations with balance issues or those unable to walk without assistance. For high-risk cardiac patients, sometimes pharmacologic-induced stress tests are necessary. The next factor is intensity. For athletic subjects, a maximal test is utilized for much higher accuracy. However, this is extremely demanding and is not suitable for clinical populations. Rather, submaximal tests are used to estimate VO_{2max} in this population. The final variable is duration. A single-stage test is much less physically demanding than a multi-stage, and again is commonly used in clinical exercise testing (Pescatello et al, 2014).

The Ebbeling treadmill test is a single-stage submaximal VO_2 test that estimated VO_{2max} with an equation standardized to their testing population of healthy individuals aged 20-59. The regression analysis performed on these subjects yielded an equation that, when cross-validated, showed 90.9% of subjects estimated VO_{2max} to be within +/- 5mL/kg/min of their observed VO_{2max} (Ebbeling et al, 1991). As such, it is considered to be an accurate estimation and therefore this test is commonly used for both clinical and non-clinical populations.

The purpose of this study was to document the physiological responses of lower-limb amputees to clinical exercise testing and compare the results of using a simple

submaximal protocol to an established method of measuring functional capacity in amputees.

METHODS

A total of three subjects that had been unilateral transfemoral amputees for over 20 years were recruited for the study through connections with researchers. Subjects were instructed to hydrate sufficiently before the test, as well as to eat a light breakfast and drink no caffeine. Participants completed a health history questionnaire and a physical activity readiness questionnaire (PAR-Q) to evaluate if any medical concerns or contraindications for exercise were present as per American College of Sports Medicine (ACSM) regulations. None were detected, and so all three moved beyond the initial evaluation stage.

Each subject underwent a dual energy x-ray absorptiometry (DEXA) scan performed by a practiced technician at Eastern Michigan University's Office of Nutrition Services. This was to measure body composition, which is one of the five main components of physical fitness, and DEXA is considered the gold standard in measuring human body composition.

Following body composition analysis, the subjects were tested using the Ebbeling Treadmill test, a standard single-stage treadmill submaximal exercise test used in clinical settings. It required that the subject maintain a heart rate between 50% and 70% of the age-predicted heart rate max for four minutes, following a three-minute warmup at 2 mph and 0% grade. After the warmup, the incline was increased to 5% while the speed remained constant. After four minutes at this grade, if the heart rate had reached steady-state, the cool down stage was initiated. If steady state was not reached, the test was extended an

Rating	How Hard you are Exercising
6	No, exertion at all
7	Very, very light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Extremely hard
20	Maximal Exertion

Figure 2.1 – The Borg Scale of Perceived Exertion (ACSM, 2014)

additional two minutes. Cooldown consisted of a two-minute walk at 1.0mph and 0% grade.

Steady state was defined as a difference of no more than five beats per minute for two minutes.

Heart rate was measured before, during, and after exercise using a POLAR heart rate monitor.

Pre- and post-exercise blood pressure was measured using a manual sphygmomanometer. During

the test, ventilatory response was measured using the Parvo Medics TrueOne 2400 metabolic

cart. Rate of perceived exertion was assessed using the Borg scale (Fig. 2.1). From heart rate

data, VO_{2max} could be estimated using the following equation :

$$VO_2\,max = 15.1 + 21.8\ (\text{speed}) - 0.327\ (\text{Exercise HR}) - 0.263\ (\text{speed x age})$$
$$+\ 0.00504\ (\text{Exercise HR x age}) + 5.98\ (\text{gender; female} = 0, \quad \text{male} = 1)$$

This estimated value was then compared to normative data found in ACSM guidelines (2014).

RESULTS

All subjects answered "NO" to all questions on the PAR-Q, placing them in the low-risk

category. No subjects showed current health complications that would be a contraindication to

exercise, though one subject stated that they were in the middle of a weight loss program and

had, within the past 12 months, been diagnosed with high blood pressure and prescribed

metoprolol. Following initial weight loss, blood pressure returned to more normal levels and the

subject ceased taking blood pressure medications two months before this data was collected.

Data for the three subjects is presented below in Figure 3.1. No statistical analysis could be

performed due to small sample size.

SUBJECT	SEX	AGE (years)	WEIGHT (kgs)	AVG EX. HR (bpm)	PEAK EX. VO$_2$ (mL/kg/min)	ESTIMATED VO$_{2max}$ (mL/kg/min)
1	F	30	66.9	129	17.4	28.13
2	M	30	70.4	135.5	17.9	32.97
3	M	46	105.4	109	18.3	42.21

Figure 3.1: Exercise Data

According to ACSM guidelines (2014), subject 1 would fall into the 10th percentile of an

age and sex-matched population. Subject 2 would similarly fall between the 5th and 10th

percentile. Subject 3, however, fell at the 60th percentile for an age and sex-matched population.

Resting heart rates were normal for all three subjects. Subject 1 fell into the prehypertensive

category with a resting blood pressure of 124/86. Subject 3's resting blood pressure was at the

low end of hypertension, with a measurement of 144/92 mm Hg.

DISCUSSION

The low VO_{2max} values seen in subjects 1 and 2 are cause for concern. This indicates that either subject cardiorespiratory fitness is severely lacking, or that the amputation caused a severe increase in the metabolic demands of walking. Subjects 1 and 3 were diagnosed as a K-3 amputee according to the Amputee Mobility Predictor [AMP], whereas subject 2 was categorized as K4. By AMP standards, subjects 1 and 3 have the ability to ambulate throughout the community, while subject 2 shows ambulation ability high enough to withstand high impact stress, and activity (Gailey *et al*, 2002). This contradicts our findings in terms of ranking based on cardiorespiratory capacity. According to our results, subject 3 has a much less drastic cardiorespiratory response to exercise, indicating lower metabolic demand and greater ease of ambulation.

This study has several limitations in its application. The first is small sample size. As there is not sufficient data to statistically analyze, the possibility of our results not being applicable to the general population is high. In addition, the principle of a submaximal VO_2 test relies on the assumption that VO_2 and heart rate have a linear relationship. That is, when maximum heart rate is reached, VO_2 max is reached. For the equations, age-predicted maximum heart rate is used. This method of prediction is useful for populations, but there is often a lot of variability when applied to an individual, and therefore the equation may not be accurate. Another cause of inaccuracy could be that all three subjects found it necessary to grip the handrails of the treadmill for balance. Heart rate response could have been attenuated if weight was transferred from the feet to the handrails. Furthermore, VO_2 estimates are presented and graded relative to the body mass of an individual. Our study included the weight of the prosthesis in these calculations, even though the prosthesis is a mass that is not capable of utilizing oxygen.

The Ebbeling test's equations are standardized to an able-bodied population, so the absence of a limb might be considerably detrimental to its accuracy. An able-bodied control group might serve to illustrate if there is inaccuracy with Ebbeling's prediction, but only if the group is matched by age and activity level.

These issues illustrate a need for further testing of the physiological response to exercise of amputees. While blood pressure response was normal, heart rate response seemed high for subjects 1 and 2, even if they were sedentary individuals. This suggests that increased metabolic demand of ambulation places additional stress on the cardiorespiratory system. The increased stress could carry a higher physiological risk during ambulation. By incorporating clinical exercise testing into the initial evaluation of new amputees, the increased metabolic cost for that individual can be quantified and used to assist in determining functional capacity. However, in order to do so, further research is needed to establish both normal and at-risk values for traumatic and dysvascular amputees, as no such data currently exists.

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