The Use of Clinical Exercise Testing in Prosthetic Evaluation, Prescription and Rehabilitation

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Literature Review, 2015/2016
The physiological impact of limb loss and the resultant medical risks associated with ambulation in lower limb amputees has not been adequately explored\(^8,10\). Prosthetic fitting and rehabilitation following amputation can be complicated by numerous physiological risk factors. Limb amputation, reduction of body mass and vascular channel, hypomobility, and disturbances in the static-dynamic function of the musculoskeletal system drastically influence homeostasis in the body, create disturbances in blood circulation and metabolism, reduce physical working capacity, and reduce tolerance for work or the amount of energy required to perform a task\(^3,10\).

This is true to some extent with any amputation level or cause whether it be upper limb, lower limb, or bilateral due to trauma or disease\(^10\). Various authors have reported that if a lower limb amputee is to be able to learn to walk with a prosthesis at a practical level of activity, it is very important that he or she be able to meet the high energy expenditure demands\(^9,10,21\). These authors; however, did not go so far as to comment on specifically what degree of physical fitness is required\(^9\). The standard method for estimating energy cost is the direct measurement of oxygen consumption (VO\(_2\)) in relation to temporal spatial parameters such as walking velocity, step with, and vertical displacement of the body\(^2,3,7,9\). Abnormal kinematics and associated compensations tend to be overemphasized as the cause of the high metabolic demand in individuals with lower-limb amputations, exemplified by the initial evaluation and outcomes measures used most frequently in both research clinical practice\(^19\). Additionally, oxygen consumption is not the only physiological information needed to determine the movement capabilities in adults with amputation\(^10\). Other post-amputation physiological parameters in addition to respiratory function that need to be evaluated include contractile function of the heart, the dynamic responses of the blood circulation system including heart
rate and blood pressure, motor capabilities, associated co-morbidities, age, baseline fitness, and the amount of time spent sedentary. Each of these parameters must be assessed and then analyzed as a whole in order to appropriately and safely prescribe prosthetic componentry, rehabilitation, and eventual independent ambulation.\(^3,4,9,10\)

It is widely accepted that individuals with a lower limb amputation, especially those related to disease, have greater metabolic demands during walking than nondisabled non-amputees.\(^2,3,4,5,7\) These increased metabolic costs can and should be quantified in clinical practice. In current prosthetic research, it appears that maximal oxygen uptake (VO\(_{2\text{max}}\)) is the standard in determining energy consumption.\(^16\) This is certainly valid in that maximum oxygen intake (VO\(_{2\text{max}}\)) is accepted as the criterion measure of cardiorespiratory fitness.\(^2,7,22\)

Cardiorespiratory fitness is related to the ability to perform large muscle, dynamic, moderate to high intensity physical activity for prolonged periods of time. This type of activity depends on the functional state of the respiratory, cardiovascular, and skeletal muscle systems all of which are significantly impacted by limb loss.\(^10,22\) Cardiorespiratory fitness essentially determines the level at which a person can safely, independently and actively participate in daily living. Additionally, low levels of cardiorespiratory fitness are associated with a significantly increased risk of premature death from all causes and specifically from cardiovascular disease, which is often associated with dyvascular amputations.\(^22\) Gailey et al. considered multiple factors of energy expenditure following lower limb amputation and found that the baseline rate of oxygen consumption (VO\(_2\)) contributed to 40% of the increased energy cost of prosthetic ambulation.\(^4,13,20\) The other 60% of the increased metabolic cost can be attributed to patient age, co-morbidities, amount of time spent sedentary, prosthetic experience and prosthetic
componentry. These additional factors, specifically co-morbidities and sedentary lifestyle, can greatly impact other physiological factors that seemingly go unnoticed and unevaluated in a prosthetic clinic. Rate of oxygen consumption, heart rate, blood pressure, cardiac output, and blood circulation are just a few of the physiological functions that can be impacted by both limb loss itself and associated co-morbidities such as diabetes, peripheral vascular disease, and arteriosclerosis. Most people with a lower-limb amputation are also less active. Ten thousand steps per day is the recommended activity level for adults, whereas a sedentary lifestyle is generally defined as fewer than 5000 steps per day. Daily step counts in individuals with lower-limb amputation range from 2500 to 8500 steps depending on age, cause of amputation (vascular vs. traumatic), level of amputation, co-morbidity, and type of prosthetic componentry. Before this adopted sedentary lifestyle, patients are often recovering from a traumatic incident or surgical amputation for several weeks. While sedentary lifestyle itself is not a disease, it leads to numerous and serious physiological risks to ambulation that should be considered and assessed prior to prosthetic prescription and rehabilitation. Additionally many amputees suffer from diseases that impact the cardiorespiratory system and as a result impact a patient’s ability to safely and functionally ambulate. Maximal oxygen uptake (VO2max) testing is a scientifically tested and reliable means of assessing an amputee’s current physical health and to create a plan that will be safe and effective for future prosthetic componentry, rehabilitation, and eventual ambulation.

There are two primary categories of measurements to collect the data needed to assess the functional status of a lower limb amputee: quantitative gait analysis which consists of temporal-spatial and kinematic data, and physiological analysis describing the energy cost and
medical risks associated with ambulation\textsuperscript{15}. In much of the current literature, studies use gait analysis to assess both the biomechanical and physiological aspects of gait. While gait analysis in prosthetics offers quantitative information on different adaptive mechanisms and asymmetries of the body associated with walking with a prosthesis, physiological testing is required to understand what those adaptive measures mean for energy cost and health risks to the patient. At similar walking speeds, metabolic demand for individuals with a lower limb amputation is significantly greater than nondisabled individuals and can influence rehabilitation, prosthetic prescription, and safe participation in daily physical activities\textsuperscript{3, 4, 7}. Patients with traumatic amputations generally incur lower metabolic cost per unit distance walked than dyvascular amputees because their amputations were not due to medical conditions or behaviors that typically affect metabolic rate (e.g. diabetes, peripheral vascular disease, smoking)\textsuperscript{3, 4, 9}. The literature demonstrates that movement capabilities and efficiency of prosthetic rehabilitation in adults with amputation depends not only on the level of amputation, residual limb condition, and prosthetic componentry, but to a great extent on the dynamic capabilities of the cardiac, respiratory and muscular systems’ ability to adjust to the limb loss whether is be traumatic or dyvascular in nature\textsuperscript{10}. The addition of vascular co-morbidities often associated with lower limb amputation further compromise the cardiorespiratory system’s ability to functionally adapt to ambulation with a prosthesis. The literature on the functional capacity of lower limb amputees reveals a lack of research on the physiological effects of limb loss and associated risks of regular exercise training and rehabilitation of lower limb amputees\textsuperscript{10}. In a recent systematic review of literature on the biomechanical and physiologic parameters studied in lower-limb amputee gait, researchers
found that out of 89 articles analyzed there were only seven physiological parameters measured in comparison to over fifty temporal-spatial or kinetic parameters\textsuperscript{18}. The need for research supporting the addition of VO$_{2\text{max}}$ testing to the currently accepted evaluations and outcomes used in prosthetic care is becoming increasingly clear as the field continues to advance and more medically sound evidence is required for insurance coverage of prosthetic care. Outcomes measures that collect data on both physiological and temporal-spatial parameters can not only offer evidence of patient progress, but also can become a preventative tool to future health problems and allow for more accurate and individualized prosthetic prescription and rehabilitation.

In current prosthetic clinical care and research, gait analysis is often used to assess both the biomechanical and physiological aspects of prosthetic ambulation\textsuperscript{18}. If the goal is to quantify both body movements and energy expenditure, temporal-spatial and kinetic data alone is not sufficient. Interruption of the normal gait cycle and energy conserving characteristics of trunk and limb motion results in increased energy expenditure\textsuperscript{3}. While temporal-spatial gait analysis is crucial to determining the extent of asymmetry and the progress of prosthetic ambulation, it alone cannot explain the physiological energy expenditure of gait and any resultant medical risks. Both categories of information are necessary to appropriately develop a holistic plan of care for a prosthetic patient. Medicare defines “functional level” as the capacity and potential for a patient to accomplish his or her expected post-rehabilitation daily activities. The index of recognized evaluations and outcomes; however, is not based on formal scientific research and yet it determines the level of prosthetic care a patient will receive\textsuperscript{13}. Currently, the Amputee Mobility Predictor (AMP) is the only functional
assessment instrument that is recognized by Medicare as able to determine or predict the functional K-Level of an amputee\textsuperscript{6, 13}. The AMP is a 20-item scale designed to be used by prosthetists, physical therapists, and physicians to measure patient capabilities either with or without a prosthesis and typically takes about 15-20 minutes to administer. The items assessed in the AMP are organized with increasing levels of difficulty and include assessments of sitting balance, transfers, standing balance, gait, and obstacle negotiation\textsuperscript{6}. Other commonly used outcome measures that have been found to be both valid and reliable in prosthetic assessment include the six-minute walk test, the timed up-and-go test (TUG), and the L-Test of functional mobility\textsuperscript{6, 13}. Self-report such as the Activity-specific Confidence Scale (ABC) and the Socket Comfort Score (SCS) also exist and are considered valid assessment tools\textsuperscript{6}. The inclusion of VO\textsubscript{2max} testing in clinical practice to quantify the energy expenditure and cardiorespiratory fitness associated with amputee ambulation is necessary in order to assess all parameters of patients’ functional capacity and create an optimized and safe plan of care.

Maximal oxygen uptake (VO\textsubscript{2max}) is the product of the maximal cardiac output and arterial-venous oxygen difference and represents the highest oxygen uptake an individual can attain during work while breathing air at sea level\textsuperscript{3, 22}. It is considered the criterion method to evaluate cardio-respiratory fitness and there are well-established data related to VO\textsubscript{2max}, physical fitness and many of the physiological risk factors associated with limb loss\textsuperscript{2, 22}. Significant variation in VO\textsubscript{2max} across populations and fitness levels results primarily from differences in maximal cardiac output. Post-amputation changes in a patient with lower-limb loss significantly impacts blood volume, intra-arterial pressure, blood circulation, and resultant heart rate and cardiac output which establishes a clear relationship between limb loss and
cardiorespiratory function\textsuperscript{10, 22}. In this way, VO\textsubscript{2}max is closely related to the functional capacity of the heart in the amputee population and should be tested and used in clinical evaluations to create the safest, most functional plan of care for patients\textsuperscript{9, 22}.

VO\textsubscript{2}max is often used in addition to temporal-spatial measures in prosthetic research to describe functional capacity of patients with various amputations and prosthetic components. Rarely, however, are the procedure, results, and clinical meaning of the data reported in the literature. Understanding the testing procedure and the information gathered from clinical exercise testing and implementing it into the educational curriculum and clinical practice of prosthetics would be an invaluable addition to the field and would cultivate a more reliable and medically driven foundation to clinical decision making. A VO\textsubscript{2}max test is a standard graded exercise test used in clinical applications to assess a patient’s ability to tolerate higher intensity exercise while symptomatic responses such as heart rate, blood pressure and ventilatory response are monitored\textsuperscript{9, 16,22}. VO\textsubscript{2}max tests can be used clinically for diagnostic, prognostic, and therapeutic applications. In prosthetic care VO\textsubscript{2}max testing could be used in patient evaluation to aid in more precise and safe patient assessment, prescription and rehabilitation as it is widely accepted that walking with a prosthesis results in a significantly higher energy expenditure than a normal healthy individual would experience. Exercise testing can be useful in assessing disease severity and when combined with other clinical data related to risk factors, symptoms, functional ambulatory capacity, exercise hemodynamics, and ECG findings both at rest and in response to exercise can reliably describe a patient’s functional capacity and predict long-term mortality\textsuperscript{22}. 
The treadmill and cycle ergometer are the most commonly used modalities for clinical exercise testing with arm ergometry being a third alternative. The treadmill provides a more common form of physiological stress such as walking, but cycle and arm ergometers would likely be a necessary secondary option in a prosthetic clinic, as many patients will unable to walk on a treadmill in the initial stages of prosthetic care. The protocol chosen for a graded exercise test; in this case a VO$_{2\text{max}}$ test, should consider the purpose of the evaluation, the outcomes desired and the individual characteristics of the patient being tested. Some of the most common protocols in VO$_{2\text{max}}$ testing include The Bruce treadmill test, The Bruce Ramp, The Naughton and the Balke-Ware. Each protocol is designed for a different population and outcome. For example, the Bruce is better suited for younger and more active individuals with larger and more challenging increments while the Naughton is designed with smaller increments for older patients or those with chronic disease. In the amputee population, individualized ramp tests where the work rate increases in a constant and continuous manner could be a way to standardize physiological testing while keeping the unique needs and fitness level of the patient’s incorporated. Ramp testing can be used on either a treadmill or cycle ergometer and individualizes the rate of increasing intensity based on the subject. In this way, large increases in workload can be avoided, there is a uniform and linear increase in physiologic responses, estimation of exercise capacity and ventilatory threshold are more accurate, and test protocol and duration are individualized based on the patient’s health status. Ideally, the protocol designed should increase the workload a rate such that total test time ranges between 8 and 12 minutes with the end point being volitional fatigue determined by the patient. Common variables assessed during clinical exercise testing include heart rate, blood pressure,
ECG changes, subjective ratings (e.g. RPE), and visual signs and symptoms. Ventilatory responses are also often measured in patients with cardiopulmonary disease. According to the American College of Sports Medicine’s Guidelines for Exercise Testing and Prescription, there are standardized procedures and norms that should be adopted for each laboratory, in this case for prosthetic patient testing, so that baseline measures can be assessed more accurately when repeat testing is performed\textsuperscript{22}. While the response to physical activity in patients with cardiorespiratory and other common diseases are well understood, it has been suggested in the literature that limb loss also results in altered heart rate and blood pressure responses to physical activity\textsuperscript{2, 10, 16, 22}. More research is necessary to establish why and what these altered responses look like in VO\textsubscript{2max} test data from both traumatic and dyvascular amputees and to establish procedures and normal and at risk values for the amputee population.

The valuable information obtained in a relatively short amount of time makes VO\textsubscript{2max} testing is a reasonable addition to the temporal-spatial tests currently performed by prosthetists to evaluate a patient’s functional status prior to and throughout prosthetic prescription and rehabilitation. Using this information, it can be determined if it is safe for a patient to begin ambulating using a prosthesis with the knowledge that the energy expenditure will be significantly higher than that of a healthy non-amputee or if the patient should receive physical therapy to improve his or her cardiorespiratory fitness prior to receiving prosthetic care in order to optimize rehabilitation and prosthetic success. It can also be used as an outcome measure to assess patient progress once they receive a prosthesis. More research is necessary to determine at what percentage of VO\textsubscript{2max} in this population would be considered healthy enough to safely ambulate and how and why these values may differ from those of
healthy individuals. Knowledge and evidence of the physiological changes and high metabolic costs of ambulation that amputees experience due to limb loss and related co-morbidities is becoming increasingly important as the field continues to expand and proof of medically necessary treatment is becoming a standard for patient care. The addition of clinical exercise testing in prosthetic research, education and clinical care could be a major benefit and aid in the advancement of the prosthetic field allowing more safe and specific patient care.
The Use of Clinical Exercise Testing in Prosthetic Evaluation,
Prescription and Rehabilitation

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Introduction

The physiological impact of limb loss and the physiological condition of lower limb amputees effects prosthetic candidacy. Limb amputation, reduction of body mass and vascular channel, hypomobility, and disturbances in the static-dynamic function of the musculoskeletal system drastically influence homeostasis in the body, create disturbances in blood circulation and metabolism, reduce physical working capacity, and reduce tolerance for work or the amount of energy required to perform a task. Successful ambulation with a prosthesis requires that the amputee be able to meet these high energy expenditure demands and more research is necessary to determine what degree of physical fitness is required.

Knowledge and evidence of the physiological changes amputees experience due to limb loss and related co-morbidities is becoming increasingly important as medically justified treatment is becoming a standard for patient care. In much of the current literature, studies use gait analysis to assess both the biomechanical and physiological aspects of gait. Potential for positive prosthetic outcome is traditionally determined by use of the AmpNoPro, a multi-step test involving physical activities. This test has become a litmus test, of a sort, by virtue of Medicare’s adoption of this as a standard to determine K Level, and, thus, eligibility for insurance coverage for prosthetic treatment under Medicare and many other insurers. However, given the impact of amputation on patient physiology, would testing physical fitness of lower limb amputees via oxygen consumption provide valuable information regarding potential outcomes of prosthetic use? While gait analysis in prosthetics offers quantitative information on different adaptive mechanisms and asymmetries of the body associated with
walking with a prosthesis, physiological testing is required to understand what those adaptive measures mean for energy cost and health risks to the patient. Both categories of information are necessary to appropriately develop a holistic plan of care for a prosthetic patient.

Current literature demonstrates that movement capabilities and efficiency of prosthetic rehabilitation in adults with amputation depends not only on the level of amputation, residual limb condition, and prosthetic componentry, but to a great extent on the dynamic capabilities of the cardiac, respiratory and muscular systems’ ability to adjust to the limb loss. The addition of vascular co-morbidities often associated with lower limb amputation further compromise the cardiorespiratory system’s ability to functionally adapt to ambulation with a prosthesis. Cardiorespiratory fitness is related to the ability to perform large muscle, dynamic, moderate to high intensity physical activity for prolonged periods of time. This type of activity depends on the functional state of the respiratory, cardiovascular, and skeletal muscle systems all of which are significantly impacted by limb loss. Essentially, it determines the level at which a person can safely, independently and actively participate in activities daily living. Additionally, low levels of cardiorespiratory fitness are associated with a significantly increased risk of premature death from all causes and specifically from cardiovascular disease, which is often associated with dysvascular amputations.

Maximal oxygen uptake (VO$_{2\text{max}}$) is the criterion method used to describe and stratify levels of cardiorespiratory fitness and associated physiological risk factors. Significant variation in VO$_{2\text{max}}$ across populations and fitness levels results primarily from differences in cardiac output; therefore, VO$_{2\text{max}}$ is closely related to the functional capacity of the heart. Lower-limb amputation greatly impacts blood volume, intra-arterial pressure, and circulation, subsequently
affecting cardiac output. As VO$_2$ accounts for approximately 40% of the increased energy cost of prosthetic ambulation, a low VO$_{2\text{max}}$ value is cause for concern among amputee populations.

The physiological impacts of lower limb loss and the resultant medical risks associated with ambulation have not been adequately explored. Knowledge and evidence of the physiological changes amputees experience due to limb loss and related co-morbidities is becoming increasingly important as medically justified treatment is becoming a standard for patient care. Collecting temporal-spatial and kinematic data alone is not sufficient to determine these risks, and the inclusion of clinical exercise testing in patient evaluation and the use of the results to justify clinical decision-making could be an invaluable addition to the care of the prosthetic patient.

**Purpose**

The purpose of this study is to document the physiological responses of healthy lower-limb amputees to clinical exercise testing and compare the results of a submaximal protocol to an established method of measuring functional capacity in amputees.

**Methods**

Currently, this study outlines a recommended protocol for VO$_{2\text{max}}$ testing on lower-limb amputees. To date, there is only a small amount of research that explores the physiological impact of lower limb loss. Additionally, there is no literature on the clinical application of physiological testing to describe the functional capacity of amputees. The quantitative data obtained using a VO$_{2\text{max}}$ test would further justify the need for physiological evaluation of
functional capacity in clinical practice. Additional functional tests would enable more accurate
determination of the ambulatory needs of the patient.

VO\(_{2\text{max}}\) testing can either be maximal or submaximal. Modes of testing in the amputee
population are generally either a bicycle or arm ergometer with some sort of resistance or a
treadmill. Results are most accurate using tests that more closely mimic daily activities;
therefore, a treadmill test is preferred when possible. Submaximal tests are generally less
demanding of the subject, so they carry fewer risks for clinical populations and make them the
most appropriate for this pilot study. They also require less expensive equipment and the
duration of the test is generally shorter than a maximal test. Although submaximal tests are
fairly accurate and reliable in estimating VO\(_{2\text{max}}\), maximal tests provide a far more accurate
representation of the subject’s physiological functional capacity and should be considered
whenever possible.

The test chosen for this study closely emulates daily locomotion for the general
amputee population and should not be particularly strenuous. The Ebbeling Treadmill protocol
is a single stage walk test where heart rate data is extrapolated to estimate true VO\(_{2\text{max}}\).
Although they are not used in the Ebbeling equation to determine VO\(_{2\text{max}}\), ECG, blood
pressure, and ventilatory responses will also be monitored to observe any abnormal responses
to exercise that could be due to physiological changes such as blood volume, intra-arterial
pressure, cardiac output, and circulation that likely occur as a result of limb loss. VO\(_{2\text{max}}\) will be
estimated using the Ebbeling equation developed using data from healthy non-athletic young
adults. This study will be measuring the physiological responses of healthy, young amputees
with no comorbidities. With minimal confounding variables, any abnormal results of this study can be assumed to be a result of the physiological adaptations to limb loss.

**Subjects**

One healthy female transfemoral amputee (height 1.6 m, mass 65.8 kg) and one healthy male transfemoral amputee (height 1.8 m, mass 72.6 kg) will be used in this study.

**Medical History**

Subjects will complete a medical history form as well as the Physical Activity Readiness Questionnaire [PAR-Q] per ACSM regulations. Any contraindications to exercise according to these assessments will result in exclusion from the study.

**Ebbeling Protocol**

The Ebbeling Protocol is a single stage submaximal treadmill-walking aerobic fitness test that estimates VO$_{2\text{max}}$. It is suitable for low risk, apparently healthy, non-athletic adults 20-59 years of age, appropriate for this population.

Age predicted heart rate max is calculated using the equation 220-age=HRmax. Each subject’s resting heart rate and blood pressure is taken prior to the beginning of the test. Height and weight are also recorded. Traditionally, subjects are fit with a POLAR heart rate monitor. In order to monitor obtain more in-depth data on cardiovascular function, this study will utilize an ECG machine to record heart rate and monitor the electrical activity of the heart during
exercise. The subject being tested will be fitted with the headgear and mouthpiece used with the Parvo metabolic cart to monitor the subject’s ventilatory response to exercise. The subject will warm up on the treadmill at a comfortable, yet brisk pace in the range of 2.0-4.5mph with 0% elevation. After 2-3 minutes of warm-up, if the heart rate is between 50% and 70% of age predicted HRmax, the elevation of the treadmill is increased to 5%. If not, then the speed of the treadmill is increased and the warm-up stage is repeated. The subject walks for 4 to 5 minutes with the 5% grade. Heart rate and blood pressure is recorded every minute. When the last two minutes of heart rate measures do not vary by more than 5bpm, the cool down stage is initiated. The speed of the treadmill is reduced to 2.0mph with 0% elevation. The subject walks until the heart rate is below 120bpm and heart rate and blood pressure continue to be recorded every minute. Seated recovery HR and BP were taken following cool down.

**Data Analysis:**

Subject’s self-selected walking speed, treadmill grade, heart rate, and rate of perceived exertion will be recorded. VO\(_{2\text{max}}\) will be estimated using the Ebbeling protocol equation.

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\text{Estimated } \text{VO}_{2\text{max}} (\text{ml\,kg}^{-1}\text{\,min}^{-1}) = \]

\[
15.1 + 21.8 \text{ (speed in mph)} - 0.327 \text{ (SS HR in bpm)} - 0.263 \text{ (speed x age in years)} + 0.00504 \text{ (SS HR x age in years)} + 5.98 \text{ (gender; female = 0, male = 1)}
\]

\[
15.1 + 21.8 \text{ ( )} - 0.327 \text{ ( )} - 0.263 \text{ ( } \times \text{ )} + 0.00504 \text{ ( } \times \text{ )} + 5.98 \text{ ( )} = \underline{\text{______________}} \text{ (ml\,kg}^{-1}\text{\,min}^{-1})
\]
Results

This project will report on two transfemoral amputees’ physiological responses to submaximal exercise and the results will be compared to the statistical norms for able-bodied populations.

Discussion/Clinical Application

Gailey et al. considered multiple factors of energy expenditure following lower limb amputation and found that the baseline rate of oxygen consumption (VO\textsubscript{2}) contributed to 40% of the increased energy cost of prosthetic ambulation\textsuperscript{4,13,20}. The other 60% of the increased metabolic cost can be attributed to patient age, co-morbidities, amount of time spent sedentary, prosthetic experience and prosthetic componentry\textsuperscript{4,13}. These additional factors, specifically co-morbidities and sedentary lifestyle, can greatly impact other physiological factors that seemingly go unnoticed and unevaluated in a prosthetic clinic. Rate of oxygen consumption, heart rate, blood pressure, cardiac output, and blood circulation are just a few of the physiological functions that can be impacted by both limb loss itself and associated co-morbidities such as diabetes, peripheral vascular disease, and arteriosclerosis. While sedentary lifestyle itself is not a disease, it leads to numerous and serious physiological risks to ambulation that should be also considered and assessed prior to prosthetic prescription and rehabilitation to determine safety and potential for prosthetic success.

Maximal oxygen uptake (VO\textsubscript{2max}) is considered the criterion method used to describe and stratify levels of cardiorespiratory fitness and associated physiological risk factors. It is the
product of the maximal cardiac output (L blood · min⁻¹) and arterial-venous oxygen difference (mL O₂ per L blood). Significant variation in VO₂max across populations and fitness levels results primarily from differences in cardiac output; therefore, VO₂max is closely related to the functional capacity of the heart. Post-amputation changes in a patient with lower-limb loss significantly impact muscle mass, blood volume, intra-arterial pressure, blood circulation, and resultant heart rate and cardiac output, establishing a clear relationship between limb loss and cardiorespiratory fitness. As VO₂ accounts for 40% of the increased energy cost of prosthetic ambulation, a low VO₂max value is cause for concern among amputee populations¹³, ²⁰.

Cardiorespiratory fitness is a measure of the functional capacity of the cardiovascular and respiratory systems related to the ability to perform large muscle, dynamic, moderate to high intensity physical activity for prolonged periods of time. This type of activity depends on the functional state of the respiratory, cardiovascular, and skeletal muscle systems all of which are significantly impacted by limb loss¹⁰, ²². Cardiorespiratory fitness essentially determines the level at which a person can safely, independently and actively participate in daily living. For example, the energy cost of walking to the mailbox or cleaning the kitchen may have a significantly higher energy cost for amputees if limb loss leads alters the cardiorespiratory system. Additionally, low levels of cardiorespiratory fitness are associated with a significantly increased risk of premature death from all causes and specifically from cardiovascular disease, which is often associated with dyvascular amputation²².

Current evaluation of an amputee’s functional level utilizes the Amputee Mobility Predictor (AMP). The AMP is a 20-item instrument designed to measure ambulatory potential of lower-limb amputees with (AMPPRO) and without (AMPnoPRO) the use of a prosthesis. Patients’ are
scored based on their ability to perform a series of tasks involving sitting balance, transfers, standing balance, gait, and obstacle negotiation. Cumulative scores are used to define the patient as a K1, K2, K3, or K4 ambulator. K1 describes a limited household ambulator, K2 a limited community ambulatory, K3 an active unlimited community ambulatory, and K4 is reserved for highly active amputees such as athletes and children. These K Levels determine what prosthetic componentry a patient is approved by Medicare to receive. Because this test is indicative of a patient’s ability to function safely in daily life and is directly responsible for determining the quality of his or her prosthesis, it must be modified or used in conjunction with a test that will also evaluate the physiological health of the patient. It is widely accepted that individuals with a lower limb amputation, specifically related to disease, have greater metabolic demands during walking than nondisabled non-amputees. These increased metabolic costs can and should be quantified in clinical practice. The addition of clinical exercise testing in prosthetic research, education and clinical care could help clinicians better understand the physiological impacts and ambulatory risks associated with limb loss and assist in the evaluation of a patient’s functional capacity and potential ability to ambulate with a prosthesis.

**Conclusion**

Clinical exercise testing can be a useful screening tool to assess lower limb amputee’s functional capacity; i.e. their readiness and/or potential for safe and successful prosthetic ambulation.

**Future Research**
While the response to physical activity in patients with cardiorespiratory and other common diseases are well understood, it has been suggested in the literature that limb loss also results in altered heart rate and blood pressure responses to physical activity\textsuperscript{2, 10, 16, 22}. More research is necessary to establish why and what these altered responses look like in VO\textsubscript{2max} test data from both traumatic and dysvascular amputees and to establish normal values and at risk values are for the amputee population.
Resources:


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