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The efficacy of the one-leg cycling test for determining the anaerobic threshold (AT) of lower limb amputees

T. CHIN, S. SAWAMURA, H. FUJITA, S. NAKAJIMA, I. OJIMA, H. OYABU, Y. NAGAKURA and A. NAKAGAWA

Hyogo Rehabilitation Centre, Kobe, Japan

Abstract

The aim of this study was to investigate whether or not the one-leg cycling test driven by the subject's sound leg as the exercise load method is an applicable method for determining the anaerobic threshold (AT) of lower limb amputees. To evaluate physical fitness, a graded exercise test that monitored gas exchange, ventilation and heart rate (HR) was performed in 51 unilateral lower limb amputees. AT was successfully measured for 42 out of 51 subjects, an 82.3% success rate. The average AT was 12.7 ± 2.2 ml/kg/min, and the average HR at AT point was 117.7 ± 16.2 beats/min. The average peak oxygen uptake was 20.1 ± 5.6 ml/kg/min, and the average peak HR was 145.1 ± 22.4 beats/min. The peak HR exceeded the HR at AT by an average 27.4 beats/min, which indicates that a comparatively intense exercise load above the AT level is possible. The average AT was 40.9% of the predicted maximum oxygen uptake, which seems reasonable when compared to the reports of other researchers. These results suggested that the one-leg cycling test driven by the sound limb is of use as a method for determining the AT of lower limb amputees.

Introduction

Lower limb amputees walking with prostheses, particularly those with trans-femoral prostheses, must expend considerably more energy than able-bodied people (Gonzalez *et al.*, 1974; Waters *et al.*, 1976) and as a result the physical burden on them is considerable. It should be considered as whole-body exercise. Consuming more energy makes the amputee tire more quickly than his/her able-bodied peers. In turn the amputee is inclined to reduce his/her walking. Reducing his/her walking decreases the level of fitness and makes walking even more of an effort. In this connection maintenance and increase of the level of fitness is essential to the amputee, providing a preventive treatment of hypokinetic state. In this respect exercise training is considered to be of importance for the amputee. However it should be noted that in previous prescription of exercise maximum oxygen uptake was firmly entrenched as the standard indicator of the level of fitness. For disabled peers measurement of maximum oxygen uptake is practically impossible and a new indicator is required in the prescription of appropriate exercise for them. The anaerobic threshold (AT) is a concept introduced by Wasserman (Wasserman *et al.*, 1973; Wasserman, 1984). AT is an indicator for exercise performance which is particularly effective in expressing long-term performance (Yoshida *et al.*, 1982; Hurley *et al.*, 1984). AT can be used as an indicator of level of fitness for amputees. Like maximum oxygen uptake, AT can vary with fitness level. As fitness decreases, so too does the AT. Below the AT, aerobic pathways which are quite efficient, are used to supply energy. Above the AT, aerobic pathways diminish and anaerobic pathways, which are not efficient are used with greater frequency. AT is

All correspondence to be addressed to Dr. T. Chin, Hyogo Rehabilitation Centre, 1070, Akebono-Cho, Nishi-Ku, Kobe, 651-21, Japan.

a value reached by exercise load test and is measurable at relatively low load levels. However, it is of course difficult to evaluate the AT of amputees who have not yet been fitted with prostheses and the treadmill test and other incremental exercise tests which have been used in the past can be difficult for some amputees even if they are able to walk with a prosthesis. Therefore the authors used the one-leg cycling test driven by the subject's sound leg as the exercise load method to examine whether or not it is an applicable method for determining the AT of lower limb amputees. The conclusions are reported here.

Subjects

The subjects were 53 unilateral lower limb amputees, comprising 5 hip disarticulation amputees (2 male, 3 female) aged between 13 and 52 with an average age of 40.0 years, 37 trans-femoral amputees (28 male, 9 female) aged between 19 and 78 with an average age of 51.8 years and 11 trans-tibial amputees (10 male, 1 female) aged between 17 and 67 with an average age of 35.6 years. Of these, 5 were unable to walk with a prosthesis and a further 6 needed double crutches when doing so. These 11 were all trans-femoral amputees. The other 42 were able to walk without support or with one cane. The physical characteristics of the subjects are shown in Table 1.

Method

In this research a cycle ergometer was used (Lode Angio WLP-300ST, Holland) which can be used from a supine position. Informed written consent was obtained before entry into the study. The tests were conducted with the subjects seated with their upper bodies reclining at an angle of approximately 45° (Fig. 1). An incremental exercise test was begun with three minutes of unloaded pedaling with the test subjects directed to turn the pedals 60 times per minute. The exercise intensity was increased by 10 watts per minute with the increase completed at the end of each section. The exercise was at the subjects' self-assessed maximum load. The subject is driving the ergometer with his sound leg. During exercise the respiratory gas was monitored with a respiromonitor (Minato RM-300 system, Osaka, Japan) and the AT point measured. At the same time the electrocardiograph (ECG) and heart rate (HR) were monitored during exercise by Stress Test system (ML-5000, Fukuda Denshi, Tokyo, Japan) and cuff blood pressure was determined every minute with autoelectro-cardiometer (Colin STPB-780, Japan). AT was determined using the following criteria (Wasserman *et al.*, 1973) : a systematic increase in the ventilatory equivalent for O_2 ($\dot{V}_E/\dot{V}O_2$ without an increase in the ventilatory equivalent for CO_2 ($\dot{V}_E/\dot{V}CO_2$).

To confirm the reproducibility of AT values the one-leg cycling test was run twice on 10 of 42 subjects at an interval of several days, and the correlation between the two results was calculated. The predicted maximum oxygen uptake was calculated using the formula of Hassen *et al.* (1984) and the predicted maximum HR was calculated as (220 -age).

The data from the "self-assessed" maximum load was reported. The Pearson Product-Moment correlation technique was used in all correlation analysis. Differences were considered significant at $P < 0.05$. All values reported are means ± SE.

Results

AT and peak oxygen uptake values during exercise

Two test subjects showed severe arrhythmia on the ECG before the test and did not

Table 1. The physical characteristics of the subjects

Measures	Trans-femoral (n = 37)	Trans-tibial (n = 11)	Hip-disarticulation (n = 5)
Age (year)	51.8 ± 18.9	35.6 ± 17.0	40.0 ± 16.5
Height (cm)	162.7 ± 8.5	169.4 ± 5.9	158.5 ± 11.1
Weight (kg)	54.5 ± 9.7	60.9 ± 8.5	57.0 ± 9.9

Values are means ± SE.

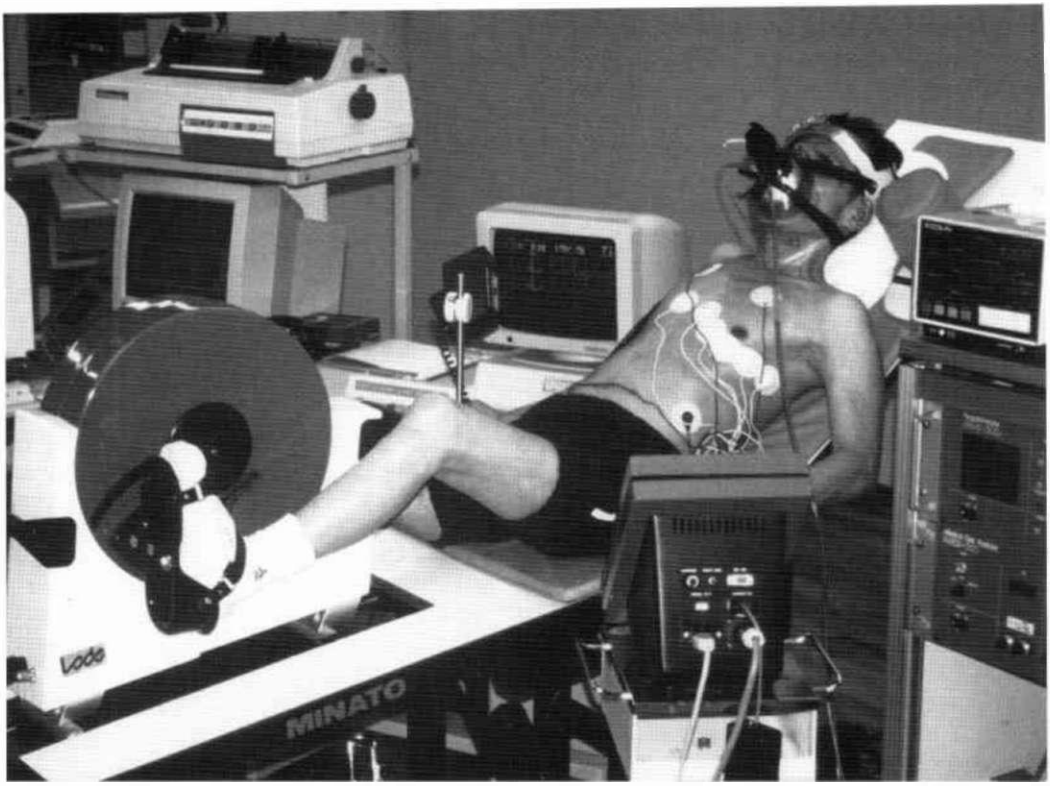

Fig. 1. One-leg cycling test. The subject is driving the ergometer with his sound leg. Under comprehensive heart monitoring, oxygen uptake and other factors are measured and their values are continuously displayed on the screen of a personal computer.

undertake the test. AT was successfully measured for 42 out of 51 subjects, an 82.3% success rate.

The remaining 9 subjects who could not be tested were all extremely weak in the muscles of their lower limbs and their tests were unavoidably suspended before completion. Among the other subjects there was no cause to suspend tests for extreme exhaustion, chest symptoms, abnormal cardiogram output or any other reason.

Among the 42 who yielded an AT value the average peak oxygen uptake was 1159.4 ± 330.2 ml/min, which corresponds to a rate per unit body weight of 20.1 ± 5.6 ml/kg/min. The average peak heart rate was 145.1 ± 22.4 beats/min. The average AT was 743.9 ± 143.7 ml/min which corresponds to a rate per unit body weight of 12.7 ± 2.2 ml/kg/min. The average heart rate on reaching AT was 117.7 ± 16.2 beats/min. The average values of predicted maximum oxygen uptake and predicted maximum heart rate were 1818.2 ± 477.7 ml/min and 177.6 ± 18.3 beats/min respectively.

The relationships between AT and the predicted maximum oxygen uptake and the peak oxygen uptake under exercise load

Among the 42 subjects who yielded an AT value the correlation coefficient for the relationship between AT and predicted maximum oxygen uptake was 0.66, indicating a significant correlation between the two ($p<0.001$) (Fig. 2). The correlation coeficient for the relationship between AT and peak oxygen uptake was 0.82, indicating a significant correlation between the two ($p<0.001$) (Fig. 3)

The reproducibility of AT found using the one-leg cycling test

The correlation coefficient between the first and second AT values found using the one-leg cycling test was 0.962, indicating a significant correlation between the two ($p<0.001$) (Fig. 4).

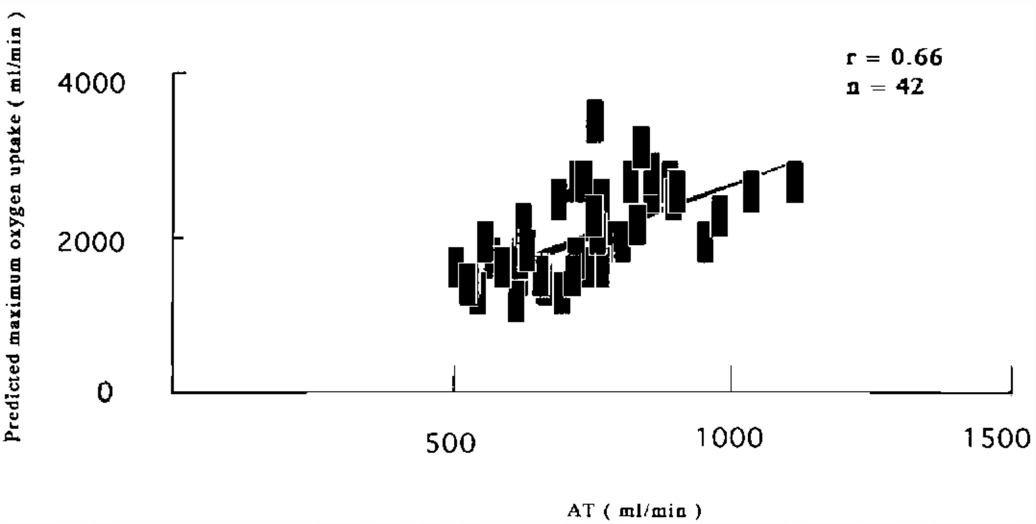

Fig. 2. The relationship between AT and the predicted maximum oxygen uptake. Among the 42 subjects for whom AT was determined a significant correlation was observed between the two factors (r = 0.66, P< 0.001).

Discussion

The purpose of the study was to demonstrate that one-leg cycling test could be used to determine AT. AT as suggested by Wasserman *et al.* yields information as to each individual's measure of fitness (Wasserman *et al.*, 1973; Wasserman, 1984) and it also has applications in exercise training as an indicator in related fields such as myocardial infarction, diabetes and obesity. It is now being adopted in clinical situations. Regrettably it has not been widely used in the field of rehabilitation of lower limb amputees suffering from numerous complications. This is because the equipment for analyzing respiratory gases is uncommon and the measurement methods are cumbersome, and also because exercise load testing of lower limb amputees by normal methods is difficult.

The authors have now taken the one-leg cycling test, using the sound limbs, as the

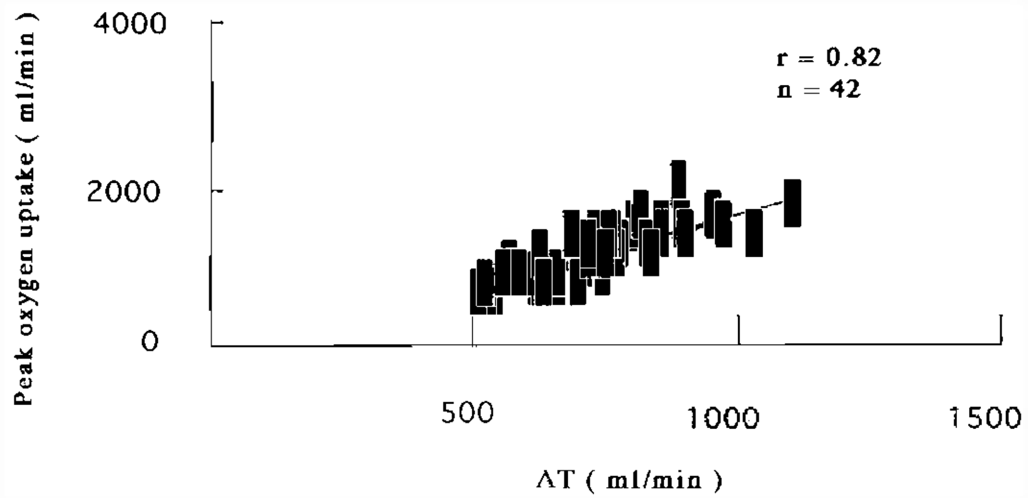

Fig. 3. The relationship between AT and peak oxygen uptake under exercise load. Among the 42 subjects for whom AT was determined a significant correlation was observed between the two factors (r = 0.82. P< 0.001).

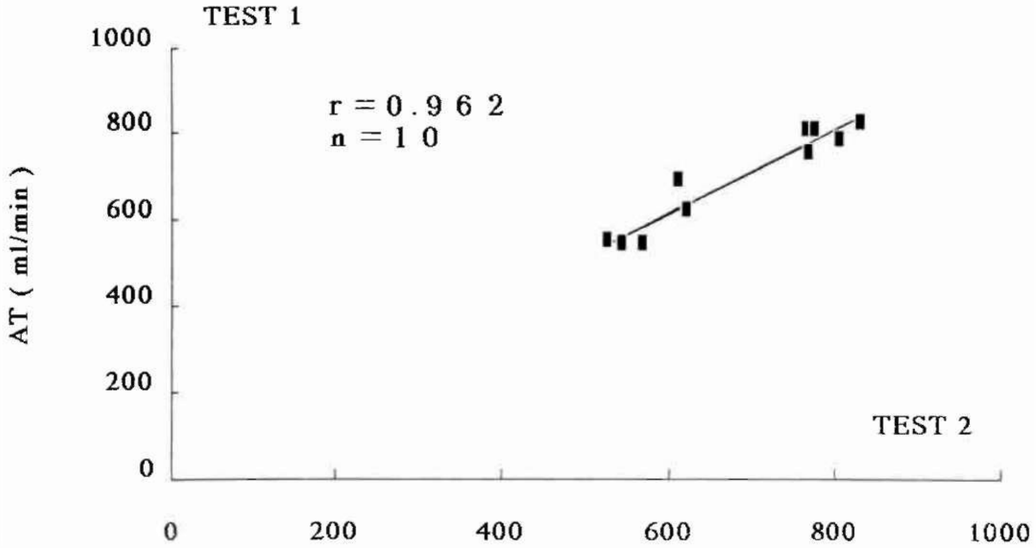

Fig. 4. Reproducibility of AT. The one-leg cycling test was repeated on ten of the amputees. A significant correlation was observed between the first and second AT levels (r = 0.962, P< 0.001).

exercise load for AT determination. On examination of its applicability it was possible to obtain the AT of 42 out of 51 patients, a high heart rate of successful detection at 82.3%. The peak heart rate was 81.6% of the predicted maximum heart rate on average. The peak heart rate also exceeded the heart rate at the AT by an average of 27.4 beats/min, which indicates that a comparatively intense exercise load above the AT level is possible. Furthermore the average AT was 40.9% of the predicted maximum oxygen uptake, which seems reasonable when compared to the reports of various other researchers (Skinner and McLellan, 1980; Davis *et al.,* 1979). Using this method the reproducibility was also good. Considering the above observations it appears that the one-leg cycling test driven by the sound limb is of use as a method for determining the AT of lower limb amputees.

Maximum oxygen uptake is closely linked to the performance of the oxygen transport system and has received wide acceptance as the indicator of level of fitness. Accordingly maximum oxygen uptake was firmly entrenched as the indicator in prescription of exercise. However, maximum load is necessary for measurement of maximum oxygen uptake which makes implementation of this test practically impossible for amputees. Prescription of exercise and evaluation of level of fitness are defined with methods and criteria suitable for able-bodied peers. The conditions in subjects with lower limb amputation are not taken into account. On the other hand this research found a significant correlation between the AT values gained from the one-leg cycling test and the predicted maximum oxygen uptake, which proved that AT is suitable as an indicator to reflect the level of fitness. In addition AT can be detected at a comparatively low exercise load which means amputees can undergo testing in safety. Thus AT can be the appropriate indicator of level of fitness for amputees. The implementation of exercise training based on appropriate indicator will improve the level of fitness of amputees, facilitating their return to life in the community as able-bodied peers.

Conclusion

The applicability of the one-leg cycling test driven by the subject's sound limb as a means of determining the AT of lower limb amputees has been proven. This study has indicated the feasibility of the clinical application of AT in exercise training for amputees.

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