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Effect of endurance training program based on anaerobic threshold (AT) for lower limb amputees

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Abstract—We have already reported that the one-leg cycling test driven by the subject's sound leg as the exercise load test is effective in measuring the anaerobic threshold (AT) of unilateral lower limb amputees. The aim of this research is to investigate whether or not endurance training based on each subject's AT gained from the one-leg cycling test is useful in improving the physical fitness of lower limb amputees. The test subjects were all unilateral transfemoral amputees comprising a group of 14 undertaking endurance training and a control group of 10. The form of endurance training is driving an ergometer with the sound limb only in the same way as the load test. The training program was designed so that the subjects would exercise at a target heart rate corresponding to AT point for 30 minutes per day, 3–5 days each week for 6 weeks. After the training periods, in the training subjects the AT and maximum oxygen uptake (___O_{2max}) increased significantly. The rate of increase averaged 36.5%, 26.0%, respectively, compared to their levels before the training. On the contrary, no changes occurred in the control subjects. These results suggest that our chosen training program based on each subject's AT is effective in improving the physical fitness of lower limb amputees.

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INTRODUCTION

It is well known that for lower limb amputees the energy consumption required to walk with a prosthesis is very much higher than that required for the able-bodied (1–3). The higher the level of amputation, the greater the energy consumption demands. Therefore the burden on the cardio-respiratory system of amputees can be expected to be considerably high. Advances in prosthetics in recent years, such as weight reduction of prosthesis and the "Intelligent Prosthesis" (4), have brought about a reduction in the energy consumption required for walking with a prosthesis. If, in addition, it is possible to improve the physical fitness of the amputee, a relative reduction in energy consumption can be expected with a reduction of the burden on the cardio-respiratory system of the amputee. However, it is extremely difficult for the amputee to undergo ordinary endurance training. In addition, previous exercise load tests for evaluating physical fitness were difficult to carry out for the amputee, and training programs tailored to each individual amputee were not made. We have reported the efficacy of the one-leg cycling test driven by the subject's sound leg as the exercise load test for evaluating the physical fitness of the amputee (5). The aim of this research is to investigate whether or not endurance training based on each subject's anaerobic threshold (AT) obtained from the one-leg cycling test is useful in improving the physical fitness of lower limb amputees.

SUBJECTS

The subjects are all trans-femoral amputees who entered our hospital for prosthetic rehabilitation, and none of them had been fitted with a prosthesis in the past. The subjects were well informed of the purpose of this study and possible risk, and informed written consent was obtained. Prior to the testing, each subject underwent a complete medical examination, including ECG, blood pressure, spirometry, blood examination, and general medical check-up. None of them showed any abnormalities. The subjects were divided into two groups, one of which underwent endurance training (endurance training group) and another that was a control (control group). The endurance training group was composed of 14 amputees. The control group was composed of 10 amputees with age and weight similar to the members of the endurance training group. The cause of amputation was trauma in all cases. The physical characteristics of the subjects of the two groups are shown in **Table 1**.

METHODS

1) Research on the endurance training group comprised three elements: pretraining physical fitness evaluation, endurance training program, posttraining physical fitness evaluation.

Table 1.

	Control group (n=10)	Endutance training group (n=14)
Age (Year)	41.2±18.4	39.8±12.4
Weight (kg)	59.4±8.7	57.0±10.8
AT (ml/kg/min)	12.9±3.3	11.9±2.1
	18.8±4.7	18.6±5.8

means±SE

Pretraining physical fitness evaluation: The one-leg cycling test driven by the sound leg was performed to evaluate the physical fitness of the amputee. This method has already been reported (5). A cycle ergometer (Lode Angio WLP-300ST, Holland), which can be used from a supine position, was used. The tests were conducted with the subjects seated with their upper bodies reclining at an angle of approximately 45 degrees (**Figure 1**). An incremental exercise test was begun with 3 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 subject's self-assessed maximum load. The subject was driving the ergometer with his sound leg. During exercise the respiratory gas was monitored with a respiromonitor (Minato RM-300 system, Osaka, Japan); we then measured the AT point. At the same time the ECG and heart rate were monitored during exercise by Stress Test system (ML-5000, Fukuda Denshi, Tokyo, Japan), and cuff blood pressure was determined every minute with an autoelectrocardiometer (Colin STPB-780, Japan). The AT was determined using the following criteria: 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 ($\dot{V}_E/\dot{V}_{CO2}$).

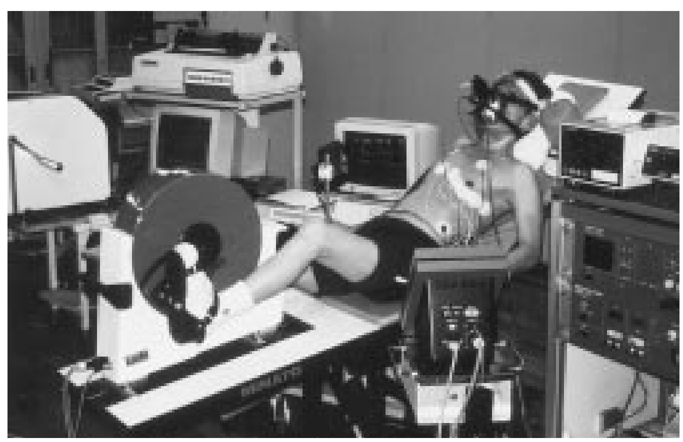

Figure 1.
One-leg cycling test. The subject is driving the ergometer with his sound leg. Under comprehensive heart monitoring, oxygen uptake and other factors are measured.

Endurance training program: In addition to ordinary prosthetic walking training, the following endurance training was implemented. The form of exercise was the same as for the load test, using the cycle ergometer (Cateye ergociser EC-3600, Osaka, Japan) driven by the sound leg (**Figure 2**). The training regimen was designed so that the subject would exercise at a target heart rate corresponding to heart rate at AT point for 30 minutes per day, 3–5 days each week for 6 weeks. During exercise the heart rate was monitored and a doctor or physiotherapist was in attendance.

Figure 2.
Endurance training in progress. The subject is driving with his sound leg only. The subject's heart rate is monitored during exercise to constantly check whether or not the target heart rate is being reached.

Posttraining physical fitness evaluation: After the completion of the endurance training program, an identical one-leg cycling test was performed to evaluate the efficacy of endurance training.

In the control group the one-leg cycling test was performed before and after a 6-week program of ordinary prosthetic walking training. The control group did not perform any regular endurance training through the training period.

Unpaired t-tests were used to evaluate the differences between the control group and the endurance training group before training. Paired t-tests were used to evaluate the differences between pre- and posttraining for both groups. Differences were considered significant at $p<0.05$. All values reported here are means±SE.

RESULTS

There were no significant differences in age, weight, or $\dot{V}O_{2max}$, AT of the subjects in both groups before the training (**Table 1**). In the control group, there were no significant changes in the parameters between pre- and posttraining values (**Figure 3**). On the other hand, in the endurance training group there were statistically significant increases after training in $\dot{V}O_{2max}$ and AT values (**Figure 4**). The rate of increase in $\dot{V}O_{2max}$ and AT values compared with the pretraining values averaged 36.5 percent, and 26 percent, respectively.

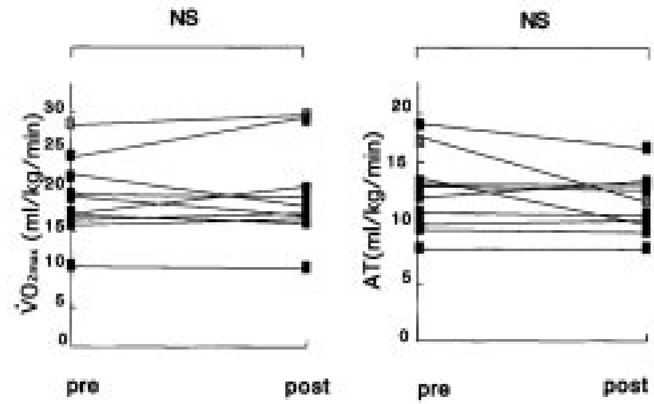

Figure 3.
Changes in VO_{2max} values and AT values before and after a 6-week program of ordinary prosthetic walking training alone are compared in control group.

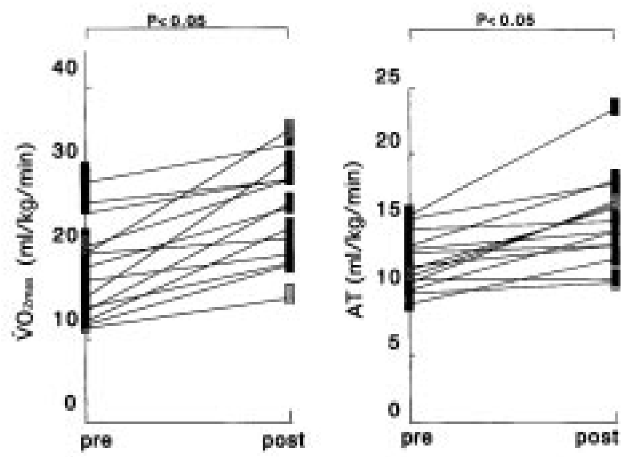

Figure 4.
Changes in VO_{2max} values and AT values before and after a 6-week program of endurance training in addition to ordinary prosthetic walking training are compared in training group.

DISCUSSION

There are many physical factors that regulate prosthetic walking capacity. One of the most important factors is physical fitness in relation to the increased energy consumption when walking with a prosthesis. Kurdibaylo noted that movement capabilities depend to a large extent on the physical fitness of the subject (6).

As is clear from the bed rest experiments of Saltin et al. (7), the decline of physical fitness brought on by a reduced amount of physical activity is extreme. The physical burden of walking with a prosthesis is rather great, with the result that lower limb amputees become less physically active, their physical fitness diminishes, and this further increases the burden of walking, involving the amputees in a vicious cycle. To prevent this phenomenon, it is important to undertake some kind of exercise training in order to improve and maintain physical fitness. However, in the past the prescriptions of exercise training for lower limb amputees have not been appropriately accomplished. Therefore, the first issue for amputees is the form of exercise to be used. According to the guidelines outlined by the American College of Sports Medicine, sustained aerobic exercise using the major muscle group is desirable (8). For lower limb amputees exercises such as cycling, swimming, and jogging are far from easy.

The next issue is where to set the level of exercise intensity. In previous exercise prescriptions maximum oxygen uptake and maximum heart rate were firmly entrenched as the standard indicators. Davidoff et al. have conducted exercise load tests on lower limb amputees using arm ergometry and have reported that exercise based on the maximum heart rate was effective in improving physical fitness (9). However, examples such as this are rare. For disabled peers, measurement of maximum heart rate and maximum oxygen uptake is difficult in practice and another indicator for exercise prescription is necessary. The exercise intensity and evaluation of fitness have been defined for able-bodied peers; the postamputation condition in a subject is not taken into account. We have already confirmed a significant correlation between AT as obtained by the one-leg cycling test and maximum oxygen uptake and have reported that the AT is an effective indicator for fitness. It is also measurable at relatively low load levels (5). Furthermore, it has been widely reported that AT is an effective indicator for setting the level of exercise intensity of endurance training (10–14). Unfortunately, no reports have been published in the past regarding the application of AT to exercise treatment of lower limb amputees.

In this research we carried out individual fitness evaluations of amputees, and by setting the exercise intensity on the basis of heart rate at each subject's AT, their maximum oxygen uptake and AT were significantly improved over their pretraining levels. These facts suggest that endurance training at AT level is effective in improving the physical fitness of amputees. It was also confirmed that driving a cycle ergometer using only the sound limb is of use as an endurance training form for amputees. On the contrary, as the control group demonstrated, it is clearly difficult to improve the fitness by ordinary prosthetic walking training alone. Therefore, prosthetic walking training should accompany some kinds of endurance training with the aim of improving fitness of amputees. The implementation of such a comprehensive program is an important task for the future.

Improvement of fitness seems to be an important factor related to functional outcome of the amputee. We have measured self-selected walking speed of amputees using "Intelligent Prosthesis" after completion of the program. Among all subjects, six of the endurance training group and five of the control group were using "Intelligent Prosthesis." Results showed that the self-selected walking speed of the endurance training group was about 70 m/min, which was almost the same as normal. On the contrary, the control group was about 50 m/min (unpublished data). These results suggest that improvement of fitness might have a clinical impact on prosthetic ambulatory capacity. In this research we did not collect the data in detail to correlate that improvement of fitness had a direct clinical impact on functional outcome. It is important to learn more about the correlation between improvement of fitness and functional outcome. Further investigation is necessary to confirm it.

CONCLUSION

The AT obtained by the one-leg cycling test is an effective indicator for setting the exercise intensity of endurance training for lower limb amputees, and driving a cycle ergometer using only the sound limb is of use as an endurance training form for amputees.

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