Effect of the comprehensive prosthetic rehabilitation program for intelligent prosthesis users

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博　士　論　文

Effect of the comprehensive prosthetic rehabilitation program for Intelligent Prosthesis users

（インテリジェント義足使用者による包括的義足歩行訓練の効果）

に関する研究

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Abstract

The aim of this research was to divide Intelligent Prosthesis users into one group which only received conventional training in prosthetic walking (referred to below as the conventional training group) and another group which received the comprehensive training devised by our center to test the functions of Intelligent Prostheses (referred to below as the comprehensive training group), in order to compare walking ability, with reference to energy consumption, in the two groups. The comprehensive training group contained nine subjects (eight male, one female), aged 23.9 ± 6.9 and weighing 58.5 ± 6.5 kg. The conventional training group contained six subjects (all male), aged 24.2 ± 6.1 and weighing 58.2 ± 6.5 kg. The subjects walked on firm, level ground at speeds of 30, 50, 70 and 90 m/min for five minutes each. Their oxygen uptake while walking was measured on a breath by breath basis using a K4 telemetric respiratory gas analysis system, to gauge their walking energy consumption. At a walking speed of 30 m/min, energy consumption in the comprehensive training group was observed to be 15.5% lower than the conventional training group. Similar reductions in energy consumption averaging 21.1% at 50 m/min and 26.0% at 70 m/min and 16.9% at 90 m/min were also observed. With regard to energy consumption, walking ability in the conventional training group was clearly inferior to the comprehensive training group. These research results verify the effectiveness of the comprehensive training program devised by our center in reducing the energy consumption required for walking with an Intelligent Prosthesis.

Keywords: Three

Intelligent Prosthesis: Trans-femoral Amputees: Training Program

Introduction

Intelligent Prosthesis (IP) is the leading example of the remarkable technical progress that has been made in prosthetic technology in recent years. IP posses a pneumatic swing phase knee joint controlled by a microprocessor, which dynamically regulates the opening of the needle valve of a pneumatic damping cylinder in response to the walking speed [1, 2]. IP makes it theoretically possible for trans-femoral amputees to walk at any speed they like. They were expected to yield remarkable improvements in walking ability. However, actual use of Intelligent Prostheses by amputees showed that their walking ability did not improve as substantially as we had initially anticipated. Specifically, amputees were unable to vary their walking speed at will, and even if they could walk they were unable to sustain a consistent pace. The apparent main reason why amputees fitted with Intelligent Prostheses could not achieve excellent walking ability was that conventional prosthesis training had been applied without modification to intelligent prosthetic walking. Thus the limits on the mechanical performance of prostheses in conventional prosthesis training meant that there was no training in how to walk at various speeds. Furthermore, energy consumption in prosthetic walking [3-5] clearly shows that trans-femoral amputees can be expected to suffer an extreme physical burden when walking at the same speed as an able-bodied person. However, conventional prosthetic training gives little consideration to physical training that could enable amputees to bear the physical burden of walking at higher speeds.

For these reasons, our center discovered a necessity for comprehensive training, which should augment conventional prosthesis training, with training in how to walk at variable speeds, and training for physical strength, to enable IP users to achieve excellent walking ability. The aim of this research was to divide IP users into one group which only received conventional training in prosthetic walking (referred to below as the conventional training group) and another group which received the comprehensive training devised by this center to exploit the functions of Intelligent Prostheses (referred to below as the comprehensive training group), in order to compare the walking ability and energy consumption in the two groups in terms of walking energy consumption, as a means of examining the effects of our comprehensive training program on IP users.

Subjects

The trial subjects were 15 unilateral trans-femoral amputees (14 male, one female), who were hospitalized at our center. None of the subjects had received any previous prosthetic training. All were prescribed Intelligent Prostheses, and the subjects were divided into two groups. The conventional training group only received conventional prosthetic training. The comprehensive training group received the comprehensive prosthetic training program, which was devised by our center to maximize benefits gained from the functions of Intelligent Prostheses. The comprehensive training group comprised of nine unilateral trans-femoral amputees (eight male, one female). They were aged 23.8 ± 6.9, weighed 58.5 ± 6.5 kg and had stump lengths of 23.2 ± 6.2 cm. The conventional training group comprised six unilateral trans-femoral amputees (all male). They were aged 24.2 ± 6.1, weighed 58.2 ± 6.5 kg and had stump lengths of 22.6 ± 5.3 cm. The characteristics of the subjects were shown in Table 1. The cause of amputation was trauma in all cases, and none had any coexisting conditions which could impede prosthetic walking training. All subjects used an IP consisting of a quadrilateral suction socket and an energy storage foot. The fitting and alignment of the IP for all subjects was carried out by the same prosthetist. The programming of the IP for all subjects was done by the physiotherapist according to the manufacturer's instructions. The subjects were well aware of the purpose of this study and possible risks, and an informed consent was obtained from each subject.

Method

1. Conventional prosthetic training program

The main aims of prosthetic training are that the user should be able to stand unaided, bear sufficient body weight on the side supported by the prosthesis, and walk without using a cane. Training is also intended to correct various forms of abnormal gait. Specific program content is based on training for activities in daily life, concentrating on walking on flat ground, climbing stairs and slopes, walking outdoors etc. and ends when each subject is able to walk in a range of speeds that suits them. There was no whole-body endurance training.

2. The comprehensive training program

The comprehensive training program extended the conventional training to promote the aim of walking at variable speeds, with the goal of walking at 90 m/min, the speed of an able-bodied person. This training in prosthetic walking was combined with whole-body endurance training developed by Chin et al [6] to build physical fitness. The period required for the program, from the initial fitting of a prosthesis to the completion of rehabilitation, is 8 weeks. Under the prosthetic walking training program we proposed, the kind of walking training provided by the conventional programs is augmented by training aimed at increasing walking speed. In order to boost walking speed, it is necessary to increase both stride and cadence, with an appropriate balance of each. At our center we set stride and cadence guidelines for the target walking speeds. Specifically, at walking speeds of 50-70 m/min, the stride should be approximately 60 cm and the cadence should be 80-100. When the walking speed is in the 70-90 m/min range, the stride should be 70 cm and the cadence should be 100-120. Speeds in the range of 90-110 m/min require strides of approximately 80 cm with a cadence of at least 120. To make strides more even, guide marks for each speed were made on the walking path so that the amputees can always check their pace against these marks. To achieve a uniform cadence, amputees carried portable metronomes and adjusted their pace to match the steady rhythm provided by the metronomes. In this way the amputees' walking speeds were gradually raised and they continued their training until they were able to walk continuously for at least five minutes at each speed. During the course of training the IP programming was adjusted whenever the swing phase of the IP did not keep up with the walking speed.

3. Measurement of walking energy consumption

The subjects first sat for 15 minutes before testing, and then they were instructed to walk at speeds of 30, 50, 70, 90, and 110 m/min. Each test walk lasted 5 minutes with 15 minutes of rest between each test. Each subject walked around a rectangular track that had a circumference of 100m. During the test walks, measurements of the subject's respiratory gas were carried out by means of a portable telemetric system (K4 system; COSMED, Italy) (Fig 1). This system measured the following cardio respiratory parameters: oxygen uptake (VO2), carbon dioxide production, heart rate, and minute ventilation. The mean value of the last 2 minutes of each test walk was taken as the measurement value at that speed. A walking meter with a speedometer function (manufactured by Minato, Japan) was used to maintain the specified walking speeds, and the subject walked alongside a therapist who guided their walking speed.

4. Statistical analysis

Comparisons were made between the groups by using a non-paired t test. Differences were considered significant at $P < 0.05$. All values reported here are means ± SD.

Results

There was no statistically significant difference in age, height, and weight or stump length between the two groups. Table 2 shows oxygen consumption rates at each walking speed for the comprehensive training group and the conventional training group. At walking speeds of 30, 50, 70 and 90 m/min, oxygen consumption rates were significantly ($P<0.05$) lower in the comprehensive training group than in the conventional training group. The differences in energy consumption at each walking speed showed an average of 15.5% lower consumption in the comprehensive training group than in the conventional training group at 30 m/min, 21.1% lower at 50 m/min, 26.0% lower at 70 m/min and 16.9% lower at 90 m/min (Fig. 2).

Discussion

Judging only by the superior mechanical performance of the knee joint of Intelligent Prostheses [1, 2], trans-femoral amputees using them should be able to reach previously unthinkable levels of walking ability. In our practical experience, however, there has been too much concentration on the mechanical performance of Intelligent Prostheses thus many medical practitioners and amputees have formed the mistaken perception that simply fitting an IP is enough to deliver a huge improvement in the walking ability of trans-femoral amputees. About ten years have gone by since practical Intelligent Prostheses were developed, and many amputees around the world are using them, but there has been very little research [7-10] on the clinical aspects of Intelligent Prostheses and no clear guidelines have been put forward on suitable training in walking with Intelligent Prostheses, and on the effects of such training. This lack of research is the source of the misperception of Intelligent Prostheses. Our experience in training IP users to walk over the last decade indicates that conventional prosthetic walking training is not enough to give IP users an excellent level of walking ability. We took the view that a training method was required that would make the most of the functions of Intelligent Prostheses. The aim of this research was to make an objective examination, with reference to walking energy consumption, of the effects our comprehensive walking training had given.

According to Taugh et al [5], and Gonzalez et al. [11], trans-femoral amputees consume 65% more energy than able-bodied walkers, when their walking speed is approximately 50% lower. Waters et al. [4] report that trans-femoral amputees, due to hematogenous disorders, consumed 120% more walking energy than able-bodied people. They walked at approximately 40% of the comfortable walking speed for the able-bodied persons. Similarly, traumatic trans-femoral amputees used 56% more energy to walk at approximately 60% of the comfortable walking speed for the able-bodied persons. Thus trans-femoral amputees must walk at much lower speeds than able-bodied people, and they consume much more energy when using a prosthesis to do so.

The results of this research show that the comprehensive training group used 26% and 16.9% less energy than the conventional training group at speeds of 70 and 90 m/min, respectively. Other reports [3-5] put the comfortable walking speed of able-bodied people at approximately 70 80 m/min. Therefore, the energy consumption when walking at the same speeds as able-bodied people was substantially improved in the comprehensive training group. As described by Waters et al [12], the knee joint is extremely important for walking. Therefore, trans-femoral amputees, who have lost a knee joint, were thought to be at a disadvantage in walking because of their greatly increased walking energy consumption. However, as this research clearly demonstrates, energy consumption was lower in the comprehensive training group, which had received appropriate training, than in the conventional training group. This fact verifies the efficacy of comprehensive training for IP users.

On the other hand, Buckley et al [10] have reported that energy consumption for trans-femoral amputees is lower with an IP than with older pneumatic-control prosthesis, even without special training. This reduction appears to be the effect of the mechanical performance of the IP in swing phase control. However, their research showed a rate of improvement in energy consumption that was far lower than that observed in our research. This indicates that relying solely on the excellent mechanical performance of Intelligent Prostheses is not sufficient for their users to walk with high efficiency in a wide range of walking speeds and that training is important to make full use of the functions of such prostheses.

This research suggests that the comprehensive training program devised by this center is a valid method for enabling IP users to make the most of the functions of their prostheses. In future we intend to increase the number of subjects studied and develop better training programs.

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Table 1 Characteristics of subject.

	number of subject (M:F)	Age (year)	Hight (cm)	Weight (kg)	Stump length (cm)
Comprehensive training group average, standard deviation	N= 9	23.8 ± 6.9	171.8 ± 5.8	58.5 ± 6.5	23.2 ± 6.2
Range	(8:1)	18 - 37	157 - 176	49 - 66	17 - 36
Conventional Training Group average, standard deviation	N=6	24.2 ± 6.1	171.2 ± 3.4	58.2 ± 6.5	22.6 ± 5.3
Range	(6:0)	17 - 33	168 - 177	42 - 95	18 - 33

Table 2 Oxygen uptake for the comprehensive training group and conventional training group during walking.

	30 m/min	50 m/min	70 m/min	90 m/min
A: Comprehensive training group average, standard deviation	13.1±1.9	15.0±2.3	17.8±2.3	24.0±4.2
Range	10.8-16.0	12.4-18.5	15.3-21.8	19.7-30.9
B: Conventional training group average, standard deviation	15.5±2.7	19.0±2.9	24.1±3.8	28.9±5.0
Range	19.1-11.1	14.2-22.0	16.9-27.0	20.1-32.5
(B-A)/B*100	**15.5%**	**21.1%**	**26.0%**	**16.9%**
significant difference	P<0.05	P<0.01	P<0.01	P<0.05

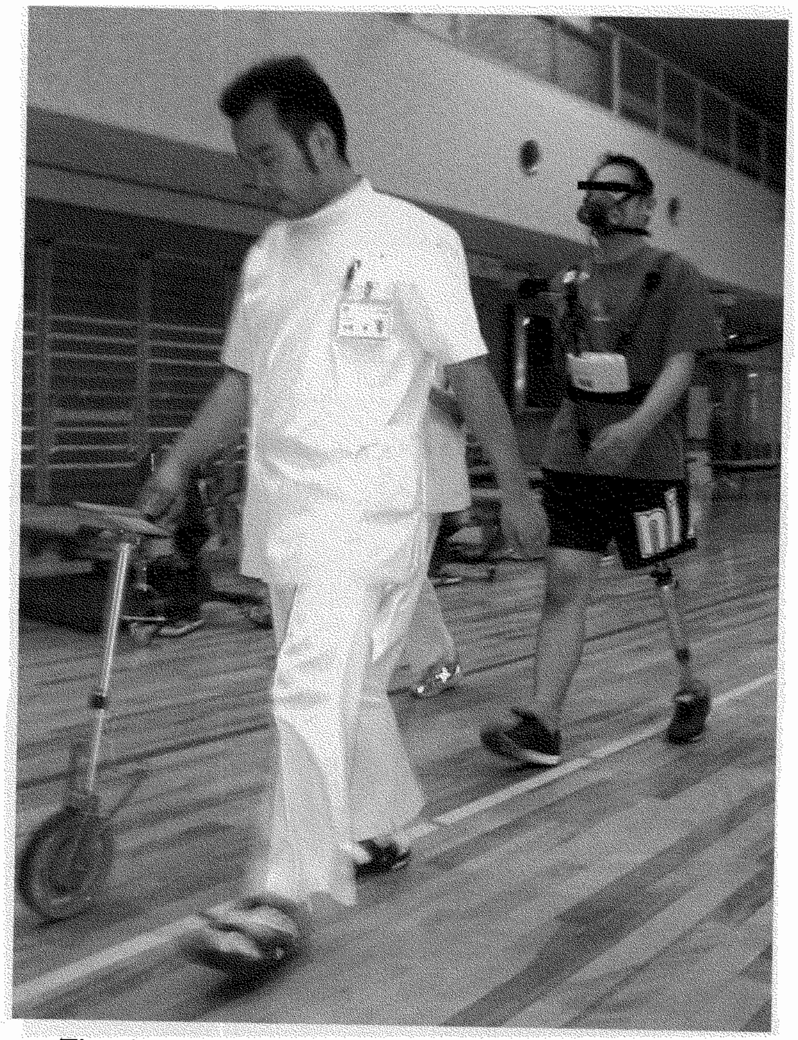

Fig. 1. Measurement of energy expenditure

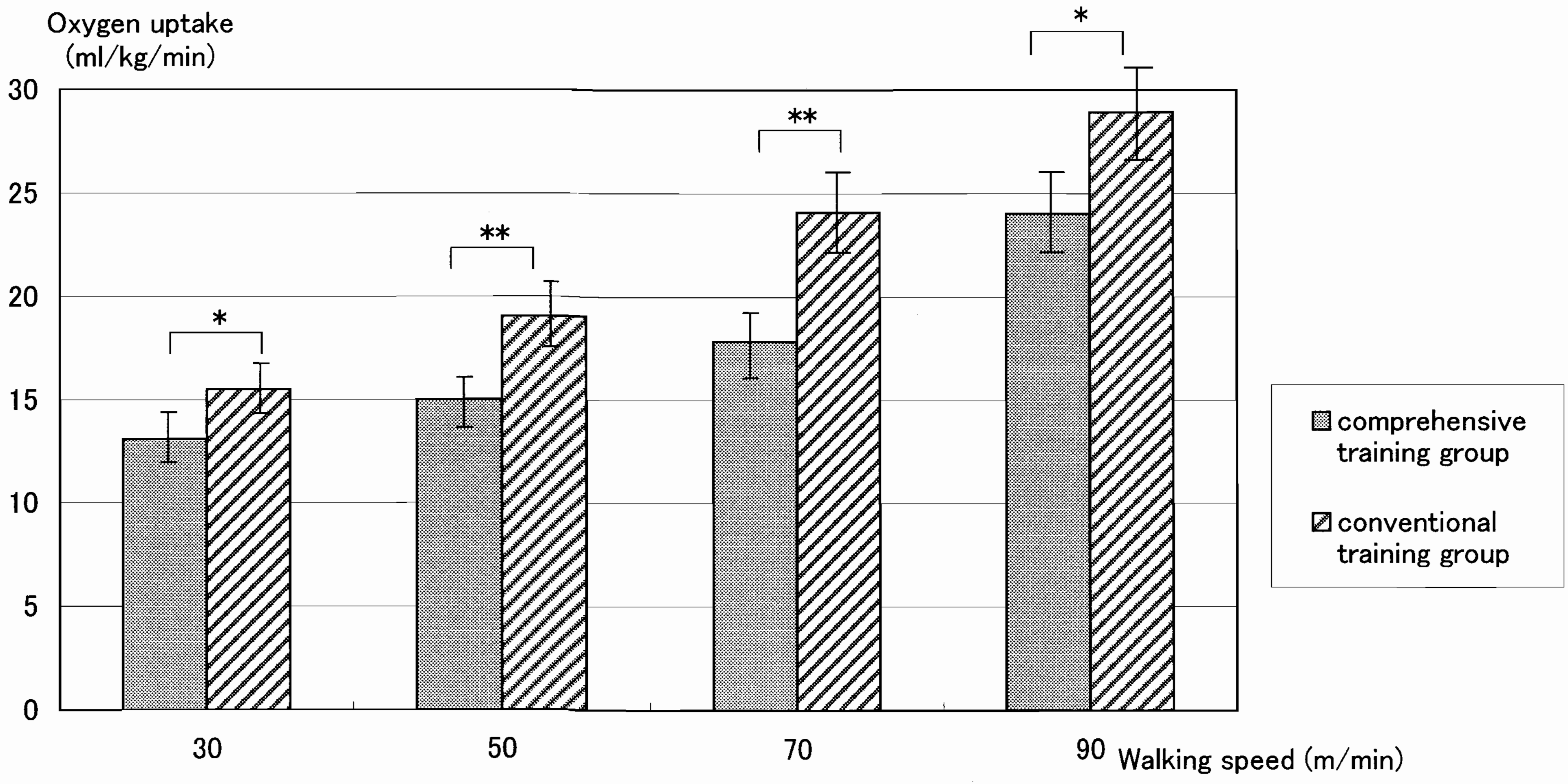

Fig. 2. Comparison of oxygen uptake between comprehensive training group and conventional training group at each walking speed.

significant difference *:p<0.05 **:p<0.01