Energy expenditure during walking in amputees after disarticulation of the hip

A MICROPROCESSOR-CONTROLLED SWING-PHASE CONTROL KNEE VERSUS A MECHANICAL-CONTROLLED STANCE-PHASE CONTROL KNEE

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We have compared the energy expenditure during walking in three patients, aged between 51 and 55 years, with unilateral disarticulation of the hip when using the mechanical-controlled stance-phase control knee (Otto Bock 3R15) and the microprocessor-controlled pneumatic swing-phase control knee (Intelligent Prosthesis, IP). All had an endoskeletal hip disarticulation prosthesis with an Otto Bock 7E7 hip and a single-axis foot. The energy expenditure was measured when walking at speeds of 30, 50, and 70 m/min.

Two patients showed a decreased uptake of oxygen (energy expenditure per unit time, ml/kg/min) of between 10.3% and 39.6% when using the IP compared with the Otto Bock 3R15 at the same speeds. One did not show any significant difference in the uptake of oxygen at 30 m/min, but at 50 and 70 m/min, a decrease in uptake of between 10.5% and 11.6% was found when using the IP. The use of the IP decreased the energy expenditure of walking in these patients.

The ability to walk in patients who have undergone amputation of the leg is largely determined by the level of amputation.¹⁻³ The energy expenditure is known to be significantly greater when the level of amputation is high. In the case of transtibial amputees the energy expenditure is increased only by 16% to 33% at a comfortable walking speed of approximately 50 to 70 m/min.⁴⁻⁷ However, transfemoral amputees have a large increase in energy expenditure. Gonzalez et al⁴ and Traugh, Corcoran and Reyes⁸ have shown that even at half the walking speed of an able-bodied person, transfemoral amputees require 65% more energy. Waters et al⁶ found that the energy expenditure of traumatic amputees walking at about 60% of normal speed was increased by approximately 56%.

Those who have undergone hip disarticulation have lost the function of the knee and hip. They rely on an increase and decrease in the lordosis of the lumbar spine for propulsion when walking with a prosthesis. The weight of the prosthesis is itself notable. Thus the physical load imposed by walking with a prosthesis is clearly very large. Nowroozi, Salvanelli and Gerber⁹ noted that hip disarticulation amputees walked about 40% slower and spent about 80% more energy than able-bodied persons. McAnelly et al¹⁰ showed that the increase in expenditure of energy for a 73-year-old hip disarticulation amputee walking with a pros-

thesis was more than double that observed by Nowroozi et al.⁹ The main reason for being unable to walk was fatigue. Hence, if the energy expended during walking could be decreased, mobility would be improved.

The Intelligent Prosthesis (IP) (Nabco Ltd, Kobe, Japan) has a microprocessor-controlled pneumatic swing-phase control knee which dynamically regulates the opening of the needle valve of a pneumatic damping cylinder in a way which allows adjustment to the desired walking speed.¹¹ It is theoretically possible for transfemoral amputees to walk at speeds which suit each individual. In recent years there have been some reports of transfemoral amputees using the IP to decrease the expenditure of energy when walking.¹¹⁻¹³ We therefore investigated its use in three hip disarticulation amputees.

Patients and Methods

The three patients had undergone disarticulation through the hip and were highly motivated to walk. Patient 1 was a 55-year-old woman, 157 cm tall and weighing 47 kg. She underwent amputation when aged 48 years because of an infected hip arthroplasty. Patient 2 was a 51-year-old woman, 160 cm tall and weighing 50 kg, who had undergone amputation when aged 19 years because of a malignant tumour. Patient 3 was a 52-year-old man, 172 cm tall and weighing 57 kg, who had an

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Table I. Mean values ($\pm$ sd; ml/kg/min) of oxygen uptake when using the intelligent prosthesis (IP) compared with Otto Bock 3R15 at each walking speed

Patient	30 m/min			50 m/min			70 m/min		
	IP	3R15	Difference (%)	IP	3R15	Difference (%)	IP	3R15	Difference (%)
1	10.53 $\pm$ 1.17	17.44 $\pm$ 1.09	-39.6	14.03 $\pm$ 0.67	18.98 $\pm$ 1.65	-24.6	21.45 $\pm$ 1.31	28.00 $\pm$ 0.65	-23.3
2	15.07 $\pm$ 1.58	15.86 $\pm$ 1.15	-4.9	16.97 $\pm$ 1.04	19.20 $\pm$ 1.37	-11.6	23.76 $\pm$ 1.34	26.55 $\pm$ 0.97	-10.5
3	16.41 $\pm$ 0.80	21.37 $\pm$ 1.73	-23.3	22.51 $\pm$ 1.07	25.10 $\pm$ 2.25	-10.3	25.39 $\pm$ 0.64	29.85 $\pm$ 2.09	-14.9

amputation when aged 51 years also because of a malignant tumour. All had been using endoskeletal hip disarticulation prostheses. The hip joints were all Otto Bock 7E7 (Otto Bock HealthCare GmbH, Duderstadt, Germany) and the knee joints Otto Bock 3R15 (Otto Bock) single-axis joints with stance control and constant friction. The feet were all a single-axis foot. They wore their prostheses almost all day for ordinary activities.

Initially, the energy consumed by each when walking with their usual hip disarticulation prosthesis was measured. The knees were then replaced by a microprocessor-controlled prosthesis, an IP (Nabco). The fitting and alignment in all subjects were carried out by the same certified prosthetist. The programming of the IP was done by a physiotherapist according to the manufacturer's instructions. All the patients underwent walking training using the IP. After completion of this programme, they were skilled in its use and did not need any support. The energy which each consumed when walking with the hip disarticulation prosthesis using an IP was then measured.

Before testing, each patient had a complete medical examination including an ECG, measurement of blood pressure, spirometry and routine haematological examination. None showed any abnormalities. They were aware of the purpose of the study and the possible risks, and informed written consent was obtained from each.

Measurement of energy expenditure during walking. This was undertaken after the patients had completed the rehabilitation programme.

They sat for 15 minutes before testing and were then instructed to walk at speeds of 30, 50 and 70 m/min. The test walk lasted for five minutes, with a rest for 15 minutes between each. They walked around a rectangular track which had a circumference of 100 m. During the test walks, measurements of their respiratory gases were carried out using a portable telemetric system (K4 system; COSMED, Rome, Italy). This measured the uptake of oxygen (VO_2), production of carbon dioxide, heart rate, and ventilation per minute. The mean value of the last two minutes of each test walk was taken as the measurement for that speed.

Prosthetic walking training programme using an IP. The programme took about eight weeks. Conventional training programmes for walking with a prosthesis emphasise acclimatisation to the use of the device, bearing an adequate amount of body-weight through it and correction of abnormal walking patterns. Once amputees can overcome these problems and achieve a walking speed within a range which suits them, their training is complete.

Under the prosthetic programme which we proposed, the training provided by the conventional regimes was augmented by aiming at increasing walking speed. In order to achieve this, it was necessary to increase both stride and cadence with an appropriate balance of each. Our patients were expected to achieve a stride length of 60 cm and a cadence of 80 to 100 per minute when walking at speeds of 50 to 70 m/min. When the walking speed is 70 to 90 m/min, the stride should be 70 cm and the cadence 100 to 120 per minute. To make the strides more even, guidemarks for each speed were made on the walking path so that the amputees could check their pace against them. In order to achieve a uniform cadence, amputees carried portable metronomes and adjusted their pace to match the steady rhythm provided. The walking speeds were gradually increased and the patients continued their training until they were able to walk continuously for at least five minutes at each speed. During training the IP programming was adjusted whenever its swing phase did not keep up with the walking speed.

Differences in oxygen consumption when using the IP compared with the Otto Bock 3R15 were determined by the following equation:

$$\text{Difference} = \frac{\text{oxygen rate (IP)} - \text{oxygen rate (3R15)}}{\text{oxygen rate (3R15)}} \times 100$$

Negative values indicated an energy decrease, positive values an energy increase when using IP. Any differences of less than 5% were considered statistically insignificant.

Results

The rate of uptake of oxygen for each subject when using the IP and the Otto Bock 3R15 is shown in Table I. Patients 1 and 3 showed a decreased rate of uptake, measured as the energy expenditure per unit time (ml/kg/min) of between 23.3% and 39.6% and 10.3% and 23.3% respectively, when using the IP at walking speeds of 30, 50 and 70 m/min compared with when using the Otto Bock 3R15 at the same speeds. Patient 2 showed no significant difference (4.9%) in the rate of uptake between the IP and the Otto Bock 3R15 at 30 m/min, but at 50 and 70 m/min, the rate decreased to between 10.5% and 11.6% when using the IP.

Discussion

There are several factors which hinder walking with a prosthesis in hip disarticulation amputees, particularly fatigue caused by the high levels of energy which are required.^{9,10} One method of decreasing this is to use the IP. Previous

reports have shown that the use of this prosthesis by trans-femoral amputees decreased the expenditure of energy.¹¹⁻¹³ Our study showed that all three patients with a hip disarticulation amputation also expected less energy per unit time during walking when using the IP.

A decrease in expenditure of energy may be achieved by a reduction in the weight of the prosthesis. In our study, although the weight of the IP (1097 g) was about 0.5 kg more than that of Otto Bock 3R15 (about 530 g), the consumption of energy was less when using the IP. Thus, reduction in the weight of the prosthesis seemed to have no effect on the expenditure of energy. This finding agrees with that of Czerniecki, Gitter and Weaver¹⁴ who noted that the addition of up to 1.34 kg to the prosthetic shank had no effect on the expenditure of energy. Improving the swing phase of gait may be more important in decreasing the energy expenditure than merely reducing the weight of the prosthesis.

Most patients who have to undergo disarticulation of the hip have a malignant tumour, ischaemia or severe infection,^{15,16} and have suffered a decline in their physical fitness. With vascular disease, amputation has a high rate of mortality and poor success in prosthetic fitting.¹⁵⁻¹⁹ The use of an IP can decrease energy expenditure, but these amputees require prosthetic training such as employed by us in order to be able to walk with one. It may be difficult for recent amputees to use an IP in their initial walking training. In such cases, reducing the weight of the prosthesis, and the provision of either a knee with a stance phase control or a locked knee may be a predominant consideration.

However, once time has elapsed after amputation, amputees who have become motivated to walk better and are physically fit should be considered for training in the use of an IP, in order to allow them to become more active and independent.

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