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Subjective benefits of energy storing prostheses

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Abstract

The energy storing (ES) prosthesis has been used in the Prosthetic Foundation's workshop since 1987. Subjective responses from 168 amputees (141 trans-tibial and 27 trans-femoral) fitted with the ES prosthesis were analysed. Ratings were generally favourable in comparison with those for conventional prostheses. The most pronounced advantages of the new prosthesis as shown by the ratings were in walking uphill or swift walking. The younger amputees had more benefit than the older ones. High body weight decreased the benefit of the ES prosthesis. The ES prosthesis does not seem to provide any major advantage for the less active amputee whose movements are mainly indoors.

Introduction

Lower limb amputees spend significant time and effort attempting to regain their lost walking ability. Most lower limb amputees can still achieve an efficient gait within the limits of their disability. For optimum gait efficiency, it is imperative that prosthetic devices keep energy expenditure to a minimum. The gait of amputees has been studied by means of motion and force analysis and also energy cost assessment techniques. Results from these studies show that an amputee walker with a limb prosthesis consumes more energy than a non-amputee at comparable walking velocities (James, 1973; Gonzalez *et al.*, 1974; Pagliarulo *et al.*, 1979). Within the last ten years, new foot components, the so called energy storing (ES) feet, have become commercially available. It has been reported that for trans-tibial amputees ambulation with ES prostheses conserves energy at higher walking velocities: This procedure leads to lower levels of exercise intensity at a given speed and enhanced gait efficiency (Michael, 1987). The biomechanical analysis of Wagner *et al.* (1987) revealed improved ankle range of motion and gait symmetry using the ES foot compared to the SACH (solid-ankle-cushion-heel) foot. Incorporation of a flexible plastic leaf spring in the forefoot is common. This not only permits a more normal range of motion during the stance phase, but also gives the amputee a sense of active push-off. Data are beginning to emerge suggesting that under some circumstances ambulation with these sophisticated prosthetic feet requires less oxygen consumption than with a more common SACH type of prosthetic foot (Nielsen *et al.*, 1988). Previously the authors have found that the energy storing prosthesis provides beneficial effects in walking for most trans-tibial amputees (Alaranta *et al.*, 1991).

The purpose of this study was to investigate subjective differences, benefits and disadvantages of the ES prosthesis and the conventional prosthesis. This might help to develop guidelines in the prescription of the ES prosthesis.

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Table 1. Characteristics of the final study group

Characteristics	Males		Females		All	
Trans-tibial amputees (N)	130	(6*)	11	(4*)	141	(10*)
Trans-femoral amputees (N)	26	(1*)	1		27	(1*)
Total number of amputees (N)	156	(7*)	12	(4*)	168	(11*)
Age at amputation (Yrs; mean, SD)	24.0	11.3	21.3	14.9	23.8	11.6
Duration of wearing the old type of prosthesis (Yrs; mean, SD)	32.8	16.8	21.5	15.9	32.0	17.0
Duration of wearing the ES prosthesis (Yrs; mean, SD)	2.5	1.5	2.3	1.3	2.5	1.7
Age during the follow-up (Yrs: mean, SD) (youngest – oldest)	59.5 (18 – 82)	16.8 (19 – 68)	44.7 (18 – 82)	11.7	58.4	16.7
Height (cm; mean, SD)	174	15	165	6	173	15
Body mass (kg; mean, SD)	77.1	10.4	59.3	15.9	75.8	11.8

* = bilateral amputees

Methods

Since 1987, the workshop of the Prosthetic Foundation has fitted ES prostheses. The selection criteria for the ES prosthesis have been that the patient should have at least moderate physical activity using a conventional prosthesis (CP).

The conventional prosthesis

In this study, most of the trans-tibial prostheses (about 75%) were of the normal patellar-tendon-bearing (PTB) type with soft socket, suspension strap and laminated socket. About 15% of the wearers had a thigh cuff on their PTB prosthesis. About 10% of the amputees had a Kondylar-Bettung-Münster (KBM) type prosthesis. Both modular and wooden components and also the SACH and the Greissinger foot were used.

The socket design for the trans-femoral prosthesis was quadrilateral in all cases. The material of the socket was laminated (65%), thermoplastic (30%) or wood (5%). A pelvic suspension belt was used by 60% of the amputees. Wooden components (60%) were used more than modular (40%). The SACH foot and the Greissinger foot were used.

The energy storing prosthesis

The socket design for the trans-tibial amputee was nearly the same as for the conventional prosthesis. Also, as many thigh cuffs were used for both types of prostheses. KBM modification was a little more common (15%). Carbon fibre components used were Flex-Foot, Flex-Walk or other Flex-Foot type components.

The trans-femoral socket design was the same for the conventional prosthesis. The number of laminated and thermoplastic sockets was equal. Also, wooden components were used as often as modular ones. In 90% of cases Flex-Walk was used.

Follow-up

Follow-up was performed by mailing a structured questionnaire in January 1993. In this study the inclusion criteria were as follows: the fitting of the ES prosthesis was after January 1990, the walking period with the ES prosthesis was at least six months, the age of the amputee was at least 16 years. In the final study group there were 208 patients fulfiling these criteria. A total of 168 (81.8%) patients responded by adequately completing the questionnaire. The characteristics of the final study group are shown in Tables 1 and 2.

In the questionnaire, the subjects were asked, "What was the usefulness of the prosthesis in the following situations:

- walking indoors
- walking upstairs
- walking downstairs

Table 2. Diagnosis of the amputation

Diagnosis	Males	Females	All
Trauma	87.8	66.7	86.3
Vascular dysfunction	4.5	8.3	5.0
Other	7.7	25.0	8.7
	100%	100%	100%

- walking on an even street or ground
- walking on uneven ground (grass, sand, snow)
- walking in forest
- walking on an uphill street
- walking on a downhill street
- swift walking
- running."

The scale for walking disability was as follows:

0 – like normal walking, no significant problems
1 – only mild disability
2 – significant disability
3 – unable to walk

Similar questions were asked for both the earlier conventional prosthesis and the current ES prosthesis. The assessment included 10 different items concerning the amputees' disability with the current ES and their previous prosthesis, the presence of stump pain and dermal symptoms. The contents of the items are shown in Tables 3 and 4. There were open questions to characterise the benefits and disadvantages of the old and new prosthesis.

Statistics

The paired t-test (two-tailed test) was applied for the evaluation of statistical significance between the means of the disability index. The Pearsson's correlation test was used to examine the subjective benefit gained from the ES prosthesis. For the correlation analysis, the differential index (called the Benefit) was formed as follows: first, the sum index of subjective disability in ten different items according to the questionnaire described earlier was calculated for both types of prosthesis, and then the disability scoring for the ES prosthesis was subtracted from that of the conventional prosthesis. This difference was called the Benefit in the correlation analysis.

Results

According to Tables 3 and 4 and Figures 1 and 2 the trans-tibial amputees considered the benefit of the ES prosthesis more pronounced than the trans-femoral amputees. However, the different results were partly because there were fewer trans-femoral than trans-tibial amputees.

Table 3: Subjective ratings of the movement disability index (0 = like normal walking, 3 = severe disability) for the energy storing (ES) and the conventional prosthesis (CP) in 10 different situations among 141 trans-tibial amputees, mean values of the disability index and statistical difference between the means.

Item of movement	Prosthesis	Rating of disability 0	1	2	3	Mean value	SD	t-value and statistical significance
Indoors	CP	70	56	9	0	0.55	0.62	4.31***
	ES	92	36	5	0	0.35	0.55	
Upstairs	CP	39	70	27	0	0.91	0.69	4.09***
	ES	59	61	13	1	0.67	0.68	
Downstairs	CP	25	70	41	0	1.12	0.69	2.84**
	ES	34	73	23	2	0.95	0.70	
Even street	CP	62	63	11	0	0.63	0.63	4.92***
	ES	87	37	9	0	0.41	0.62	
Uneven ground (sand, snow)	CP	29	68	36	1	1.07	0.72	4.88***
	ES	51	60	16	1	0.74	0.70	
Forest	CP	13	55	61	9	1.48	0.76	4.86***
	ES	27	60	35	6	1.16	0.81	
Street uphill	CP	19	71	46	0	1.20	0.66	5.55***
	ES	47	57	25	1	0.85	0.75	
Street downhill	CP	17	65	53	1	1.28	0.69	4.78***
	ES	38	63	28	2	0.95	0.75	
Swift walking	CP	17	40	49	25	1.63	0.94	8.90***
	ES	52	38	20	18	1.03	1.06	
Running	CP	8	17	42	64	2.24	0.90	6.10***
	ES	14	39	33	42	1.80	1.02	

**p<0.01; ***p<0.001
SD = Standard deviation

Table 4: Subjective ratings of the movement disability index (0 = like normal walking, 3 = severe disability) for the energy storing (ES) and the conventional prosthesis (CP) in 10 different situations among 27 trans-femoral amputees, mean values of the disability index and statistical difference between the means.

Item of movement	Prosthesis	Rating of disability 0	1	2	3	Mean value	SD	t-value and statistical significance
Indoors	CP	10	13	4	0	0.78	0.70	1.73
	ES	15	7	4	0	0.58	0.76	
Upstairs	CP	6	18	12	1	1.30	0.87	3.12**
	ES	11	6	8	1	0.96	0.96	
Downstairs	CP	5	7	14	1	1.41	0.84	1.28
	ES	6	8	11	1	1.27	0.87	
Even street	CP	10	10	7	0	0.89	0.80	2.28*
	ES	15	5	6	0	0.65	0.85	
Uneven ground (sand, snow)	CP	5	13	9	0	1.15	0.72	1.80
	ES	8	12	6	0	0.92	0.74	
Forest	CP	3	8	14	0	1.56	0.80	1.65
	ES	4	11	9	2	1.35	0.85	
Street uphill	CP	3	14	10	0	1.26	0.66	3.41**
	ES	9	11	6	0	0.89	0.77	
Street downhill	CP	3	7	15	1	1.54	0.76	2.05
	ES	5	9	11	1	1.31	0.84	
Swift walking	CP	3	3	11	10	2.04	0.98	3.17**
	ES	6	9	3	8	1.50	1.17	
Running	CP	1	3	3	19	2.54	0.86	2.79**
	ES	2	6	1	16	2.24	1.10	

*p<0.05; **p<0.01
SD = Standard deviation

The items of swift walking, running, and uphill walking were the most beneficial in favour of the ES prosthesis in the trans-tibial group and swift walking and uphill walking in the trans-femoral group.

The beneficial trend for the ES prosthesis was weakly correlated with the age at the phase of the interview ($r = -0.30$, $p < 0.01$). The younger amputees gained more benefit than the older ones. In closer analysis, the beneficial effect of the ES prosthesis was more significant among the amputees under 65 years in several items. However, the positive effect of the ES prosthesis for swift walking was found also among amputees older than 65 years. However, the age at the time of amputation had not any significant correlation to the subjective benefit ($r = -0.08$). Thus, the number of years of wearing of the conventional prosthesis rather than age itself was the key variable in this context. That was in a strong correlation with the age at the time of the interview, ($r = 0.77$).

The amputees with the ES prosthesis reported a statistically significant ($p < 0.01$) smaller number of skin problems like abrasions compared to the CP, but in the frequency of stump pain no significant differences were observed.

The lighter weight amputees seemed to gain more benefit from the ES prosthesis compared to heavier ones. The benefit of the ES prosthesis was inversely correlated with the body-weight ($r = 0.29$, $p < 0.01$), but not the body-mass index (weight divided by the square of the height of the amputees (kg/m^2)).

The trans-tibial amputees considered the CP well-fitting and technically reliable in use. However, more than half of those considered the CP heavy and stiff and walking was angulated and jerky. The majority evaluated the ES prosthesis as light and flexible. The gait was more natural and easy. Technically limited adjustability and difficulties in adjusting the spring stiffness were considered as disadvantages for the ES prostheses.

The trans-femoral amputees also thought that the reliable technology was the main benefit of the CP. More than half of the trans-femoral amputees felt that the CP was heavy, stiff and clumsy. Most of the trans-femoral amputees

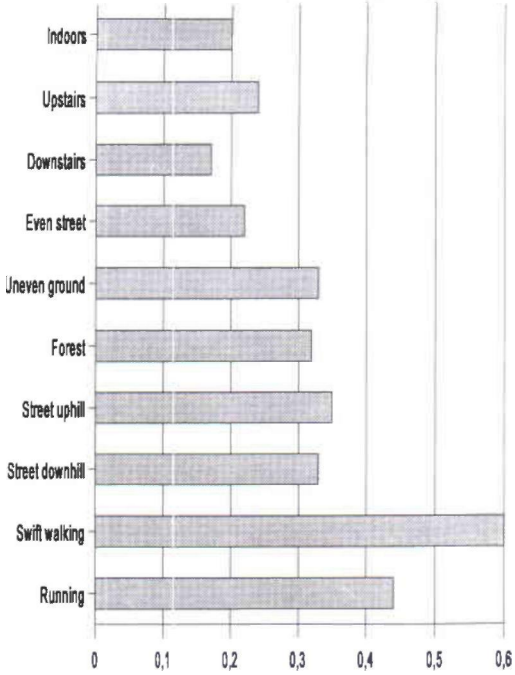

Fig 1. The means of the differences in scores of subjective walking disability (scale: 0-3) between ES and CP among trans-tibial amputees illustrating the benefit of the ES prosthesis in different situations.

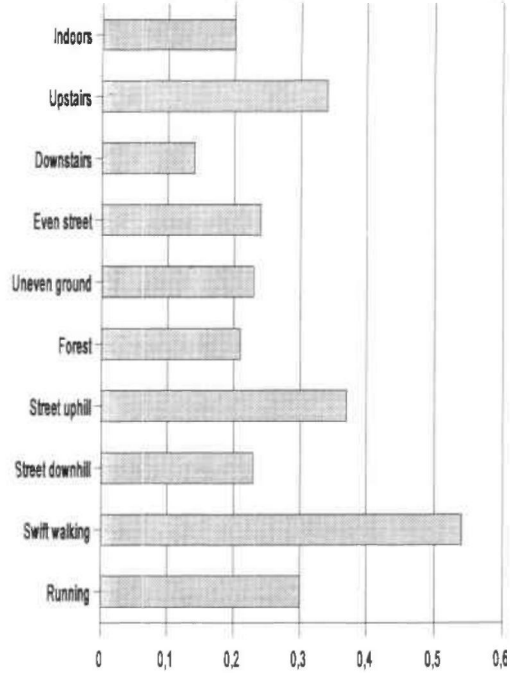

Fig 2. The means of the differences in scores of subjective walking disability (scale: 0-3) between ES and CP among trans-femoral amputees illustrating the benefit of the ES prosthesis in different situations.

evaluated the ES as natural, light to use and flexible in walking. It was demanding and time-consuming to learn the new walking pattern with the ES prosthesis. Problems of the knee joints and technical adjustments were identified as difficulties.

Discussion

Since there was no control group in the series and a "placebo effect" remains possible, the results should be interpreted with caution. Because most of the subjects had a traumatic cause of amputation, it is not possible to draw general conclusions related to amputees with dyvascular history.

According to practical experience, many lower limb amputees benefit from an ES prosthetic foot system (Michael *et al.*, 1990). The findings are parallel to the conclusions by Wirta *et al.* (1991). According to their objective findings, the amputees preferred devices that transmitted less shock and had greater damping properties. However, for the amputee who is less active and walks mainly indoors in spaces with no stairs, the ES prosthesis is less likely to provide as much advantage as it does the lower limb amputee who is more active and also moves outside.

Although the ES prosthesis may individually provide a significant benefit both for trans-femoral and trans-tibial amputees, it should be used chiefly for trans-tibial amputees.

The best possible prosthesis cannot replace the function of the natural knee joint. It is becoming increasingly obvious that preservation of the knee in amputation surgery is of vital importance (Jain, 1992).

For amputees under 65 years the subjective benefit of the ES prosthesis was in several respects more than for amputees over 65 years. For older amputees (over 65 years) who were active and walked quickly, the ES prosthesis is a reasonable alternative. Although wearing the ES does not seem to decrease stump pain, its flexibility and elasticity can decrease skin problems.

ES prostheses were considered technically somewhat primitive. A better knee brake mechanism is now available for the ES prosthesis. The more active the ES user is, the more accurately the prosthetic spring stiffness has to be chosen. To find the right stiffness and

adapt the new walking pattern takes time (Schuch, 1988). For very heavy amputees the ES prosthesis may not provide major benefit. The conventional SACH ankle foot device may be the choice for amputees who are markedly overweight (Wirta *et al.*, 1991).

According to the above findings and guidelines lower limb amputees have to be instructed and observed very carefully when ES prosthetic devices are prescribed. The cost of the ES prosthesis may be double that of the conventional prosthesis (Wing and Hittenberger, 1989). Despite the positive subjective benefits the cost of the ES prosthesis still limits its general use.

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