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Energy storage and release of prosthetic feet Part 2: subjective ratings of 2 energy storing and 2 conventional feet, user choice of foot and deciding factor

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Abstract

This paper is the second part of a study on biomechanical and functional properties of prosthetic feet. The first part dealt with a biomechanical analysis related to user benefits. This part deals with subjective ratings and deciding factors for trans-tibia] amputees using 2 energy storing feet (ESF) and 2 conventional feet (CF).

The Otto Bock Dynamic Pro and Hanger Quantum feet were used as ESF and the Otto Bock Multi Axial and Otto Bock Lager feet were used as CF. Ten trans-tibial amputees, active walkers, without stump problems, were selected (mean age: 49 years old). The study was designed as a double-blind, randomised trial and for each foot there was a habituation period of 2 weeks.

Two questionnaires were designed. (A) concerned information about the preference of the subjects and (B) concerned the order of importance of difference aspects concerning a prosthesis.

Results indicated that no clear preference for either the ESF or the CF existed and that the individual preference is not related to age. The items 'ability to walk fast' and 'no fatigue during walking', score statistically significantly worse for the CF2. With the small contrast between the ESF and CF, in relation to energy storing capacities, the subjects cannot distinguish between the ESF and CF. The 'absence of stump pain' and 'stability while walking' are ranked as most important aspects concerning a prosthesis. The perception of stability is likely to be related to the level and kind of activities the subject performs.

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Introduction

More and more leg amputations are performed mainly due to the growing number of the elderly. In the Netherlands a steady increase is seen in the number of leg amputations (SIG, 1995). Between 1991 and 1994 the incidence increased from 0.16 to 0.17 per thousand inhabitants (2,457 amputations in 1991 and 2,618 in 1994). A further increase is expected.

Up to now in the Netherlands a prosthetist and a doctor together make the total prescription for the prosthesis. But it is realised more and more that amputees have to be involved in this decision because their demands on function, comfort and cosmesis of the prosthesis ought to weigh heavily in the choice of different parts of the prosthesis. Therefore not only are rates of satisfaction about function, comfort and cosmesis of amputees required, but also an insight into which aspects concerning the prosthesis amputees rate as important.

In the literature scant attention is given to subjective ratings of various feet, personal choice of foot and deciding factors concerning that choice.

Prosthetic Profile of the Amputee (PPA) Questionnaire is a validated questionnaire about

factors potentially and actually related to prosthetic use (Grise *et al,* 1993; Gauthier-Gagnon and Grise, 1994). It gathers information about physical condition, the prosthesis itself (comfort, weight, appearance and so on), prosthetic use, environment, leisure activities and general activities. This kind of information is important for judgment and function of the prosthesis and for screening and evaluation of treatment programmes. It is not meant to give information about the rating of importance, given by the amputee, to the different factors such as function, comfort and cosmesis.

The structured questionnaires from Alaranta *et al.* (1991 and 1994) (4-point rating scale) and the 20-point rating scale of Borg as used by Macfarlane *et al.* (1991) were developed in order to gather information about functional aspects of the prosthesis.

Different studies in the literature report the preferences of the subjects involved. These preferences are based mainly on a kind of open interview. Limited reasons are given for the preferences with no insight into the order of importance of different factors (Buchold, 1991; Burgess *et al,* 1987; Lehmann *et al,* 1993; Menard *et al,* 1992; Nielsen *et al,* 1989; Sacchetti *et al,* 1994; Wirta *et al,* 1991).

Aspects of subjects and prosthetic feet which are mentioned in the literature to determine the preference of the subject are: level of activity, age, body weight, cosmetic appearance, flexibility at loading (shock absorption), plantar flexion directly after loading, dorsiflexion during stance phase, springiness of the foot at push-off phase, balance and stability (Alaranta *et al,* 1991 and 1994; Casillas *et al,* 1995; Ehara *et al,* 1993; Goh *et al,* 1984 and 1994; Macfarlane *et al,* 1991; Nielsen *et al,* 1989; Lehmann *et al,* 1993; James and Stein, 1986).

Aim of this part of the study

- What differences do the users experience between the 4 varieties of test foot?
- What is the order of importance, as given by the users of different factors concerning the prosthesis?

Materials and methods

Prosthetic feet

The following 4 designs of prosthetic feet were chosen, Otto Bock Multi Axial (CF1), Otto Bock Lager (CPF2), Otto Bock Dynamic Pro (ESI) and Hanger Quantum (ESF2). These are described in Part 1 of this study (Postema *et al,* 1997).

All subjects were provided with the same brand of supple shoes.

Subjects

Ten trans-tibial amputees were selected as described in Part 1, Table 1 of this study (Postema *et al,* 1997).

Study design and data analysis

The study was designed as a double blind, randomised trial as described in Part 1 of this study (Postema *et al,* 1997).

Questionnaires

There was no ready-made questionnaire available to address the questions in this study. Therefore 2 questionnaires were composed. The first one (A) was used to obtain information about the preference of the subjects and the second one (B) was used to get a better understanding of the order of importance to the user of different aspects of the prosthesis.

Questionnaire A

This questionnaire consisted of 27 questions that were grouped in 4 categories. After thorough discussions with some experienced rehabilitation physicians and trans-tibial amputees it was revised.

The 4 categories were:

1. stability while standing (on the level and on a slope);
2. stability while walking (on the level and on a slope);
3. functional factors (e.g. ability to walk quickly, powerful/powerless push-off, suppleness of roll-off, no fatigue during walking);
4. special activities (e.g. stair climbing, squatting).

The questions were answered in the form of a score in an increasing scale from 0 to 10 (best possible score 10). Since it is not completely known from the literature which factors are more important, all questions received the same weighting. The mean score of all questions was supposed to be the general score for a foot, and these scores were used to put the 4 feet in a ranking order. Also the ranking order for the different categories was calculated.

Table 1. Factors concerning a prosthesis, in alphabetic order.

Factors concerning a prosthesis
ability to climb the staircase
ability to walk quickly
easy turning on the prosthetic leg
feeling of firm contact with the ground
no fatigue during walking
cosmetically good walking pattern
painless stump
possibility of squatting
powerful push-off
rolling-off in a supple way
stability in stance
stability while walking

Questionnaire B

Taking into consideration literature and after extensive discussions with trans-tibial amputees and experienced rehabilitation physicians, 12 factors which were relevant for the function of a prosthesis, were selected (Table 1). The meaning of each factor was explained to the subject. The factors were then coupled to each other resulting in 66 pairs. The subjects were asked to mark the more important factor from each pair. The marked factor from each of the pairs received a score of 1.

Statistics

The results in Questionnaire A represent subjective opinions of the amputees that are likely to be dependent on characteristics of these users. For instance one subject may always score higher or lower than another subject. Therefore mean scores and standard deviations were not used for statistical calculations, but multivariate analysis of variance with repeated measures' design with difference contrast. The only within subject factor was the type of prosthetic foot.

Table 2. Mean total scores from the questionnaire for each foot, with standard deviations between brackets.

Foot	Mean total score (s.d.)
ESF1	7.4 (1.9)
ESF2	7.3 (1.5)
CF1	7.3 (1.5)
CF2	7.0 (1.8)*

(*statistically significant).

Table 3. Mean scores with standard deviations of the 4 categories of the questionnaire with standard deviations between brackets.

Category	Foot	Mean (s.d)
1. stability in stance	ESF1	7.1 (1.8)
	ESF2	7.1 (1.4)
	CF1	7.0 (1.4)
	CF2	6.9 (1.6)
2. stability while walking	ESF1	7.2 (1.9)
	ESF2	7.1 (1.3)
	CF1	7.0 (1.3)
	CF2	6.8 (1.6)
3. functional aspects	ESF1	7.9 (2.4)
	ESF2	7.7 (2.6)
	CF1	8.1 (1.9)
	CF2	7.3 (2.1)*
4. special activities	ESF1	7.3 (1.3)
	ESF2	7.1 (1.3)
	CF1	7.2 (1.0)
	CF2	6.9 (1.7)

(*statistically significant).

Questionnaire A

The mean total scores for the 4 feet showed only little differences, as shown in Table 2. The score for the CF2 was however statistically significantly lower than the scores for the other feet ($p=0.006$).

In Table 3 the categories of Questionnaire A are listed with the mean scores and standard deviations for each variety of test foot. There were no significant differences among the 4 feet for the categories 1 ($p=0.927$), 2 ($p=0.356$) and 4 ($p=0.469$). In category 3 (functional factors) the score of CF2 was statistically significantly lower than the scores of the other feet ($p=0.008$). Two factors were responsible for this, namely 'ability to walk fast' and 'no fatigue during walking'. Scores for these factors are given separately in Table 4.

Table 4. Mean scores with standard deviations between brackets for 2 factors

	Ability to walk fast	No fatigue during walking
ESF1	7.7 (2.22)	8.2 (2.6)
ESF2	7.4 (1.8)	7.7 (3.3)
CF1	7.6 (1.4)	9.0 (2.2)
CF2	6.5 (1.8)*	7.4 (2.1)*

(*statistically significant).

Ability to walk fast

The mean score of CF2 was significantly lower than that of the other feet (p=0.048). The conventional foot CF1 however scored almost best and hence it cannot be concluded that the score of the conventional feet was clearly worse than that of the energy storing feet.

Fatigue

The score of CF2 was significantly lower than the scores of CF1 and ESF1 (p=0.046). It was striking that the CF2 scored worst for 'no fatigue during walking' as well as for 'ability to walk fast'.

Each subject could rank the feet in order of choice. First choice: seven of the 10 subjects showed a preference for an energy storing foot (4 xESFl and 3 x ESF2) and only 3 subjects preferred a conventional foot (2 x CF1 and 1 x CF20. The second foot in ranking order was seen as second choice. Table 5 shows the order of choices. The mean scores for the first, second, third and fourth choice are respectively 8.2, 7.8, 7.2 and 6.5.

Questionnaire B

With this questionnaire the different factors were ranked in order of importance. The mean ranking scores, with standard error of the mean, for each factor are shown in Table 6. The minimum is 0 (not important at all) and the maximum is 11 (most important). The subjects ranked the factors 'absence of pain' and 'stability while walking' as very important, while the possibility of squatting was almost not important at all.

Table 5. Order of foot choice of the subjects (n=10),

Subject	Order of foot choice			
	1st	2nd	3rd	4th
01	ESF2	ESF1	CF2	CF1
02	ESF1	CF1	ESF2	CF2
03	ESF1	CF2	ESF2	CF1
04	ESF2	CF1	ESF1	CF2
05	CF2	ESF1	CF1	ESF2
06	CF1	ESF2	CF2	ESF1
07	ESF1	CF1	CF2	ESF2
08	ESF1	ESF2	CF2	CF1
09	ESF2	CF2	ESF1	CF1
10	CF1	CF2	ESF2	ESF1

Table 6. Ranking of importance of aspects in perception of the subjects with standard error of the mean between brackets,

Aspects	Ranking (S.E. of the mean) (maximum ranking 11)
absence of stump pain (n=9)	8.9 (0.72)
stability while walking	8.7 (0.56)
no faigue during walking	7.4 (0.67)
possibility to walk fast	7.3 (0.93)
stability in stance	6.7 (0.86)
feeling of firm contact with the ground	5.5 (0.86)
rolling-off in a supple way	5.2 (0.51)
powerful push-off	4.1 (0.80)
easy turning on prosthetic leg	3.9 (0.81)
possiblity to climb the staircase	3.5 (0.69)
cosmetically good walking pattern (n=9)	3.3 (0.96)
possibility of squatting	1.5 (0.62)

Discussion

Questionnaire A: choice of foot

Some studies show differences in foot preference according to level of activity, related to cause of amputation (traumatic versus vascular), age and weight. Young active, good walkers seem to prefer an energy storing of a flexible foot with springy push-off, while older, less active and heavily built amputees prefer a conventional foot with less flexibility (Alaranta *et al.,* 1994; Casillas *et al.,* 1995; Menard *et al,* 1992; Nielsen *et al,* 1989; Wirta *et al,* 1991).

Two important reasons are suggested in the literature about preference and acceptance of prosthetic feet. Firstly, the realistic appearance of some feet seems to be important for acceptance for both adults as well as children (Colborne *et al,* 1992; Torburn *et al,* 1990). The second aspect mentioned in the literature is a loss of proprioceptive support control, probably, more appropriate in older subjects.

Besides visual and vestibular control proprioception is an essential feedback control mechanism for maintenance of balance (Amblard *et al,* 1990). In leg amputees balance control can be trained. This indicates that a central integration of 'new' sensory input from

the amputated limb occurs, but this 'new' sensory input cannot compensate completely for the loss of normal sensory feedback (Geurts, 1992). Peripheral neuropathy results in a decrease of proprioceptive control. In older amputees especially this often is the case. Subjects with limited proprioceptive support control prefer a stable foot with a minimum flexibility because this gives more stability, in other words, maximum safety, while subjects with good proprioceptive support control do not need maximum stabilisation, and hence seem to prefer flexibility (easy roll-off) and spring push-off (Casillas *et al.,* 1995; Goh *et al.,* 1984).

This study did not display any preference in relation to age and activity level. Three arguments may be put forward for this. Firstly, the contrast between the moderately priced energy storing feet and conventional feet used in this study was probably not as big as the contrast between the feet used in other studies. Secondly, there was a small number of subjects in the study and thirdly, all the subjects were relatively young and were good walkers. The mean scores for stability in different standing and walking situations, were almost similar for all 4 feet. However, individual differences clearly did exist.

Looking at the preference of the subjects in this study, it was found that the subjects preferred the CF2 less ($p=0.006$) than the other feet. Two factors in category 3 of the questionnaire, 'ability to walk fast' ($p=0.048$) and 'no fatigue during walking' ($p=0.046$) were responsible for this detrimental statistical difference. For both the factors the CF2 scored lowest. In contrast, the CF1 scored second best and best respectively. Therefore these results do not indicate a strong preference for either type of foot.

At individual level there were clear differences. Seven subjects did prefer an ESF. If the energy storing properties of the feet were decisive in their choices, then we should also expect an ESF as a second choice. However, only 2 of those 7 who preferred an ESF as a first choice also indicated an ESF as a second choice (Table 5).

Two reasons probably play a role:

- energy storing properties of the prosthetic foot might not be decisive for the choice of the subjects and/or the contrast between the energy storing capacities of the different feet was too small to notice;
- the sample size of the study was too small to detect the differences between the energy storing factors.

In Part 1 of this study it was shown that differences in energy expenditure of the amputees during normal walking with the 4 feet should be maximally 2.5 to 3% (Postema *et al,* 1997). It was assumed that a difference of less than 3% in the amount of energy necessary for normal walking, cannot be perceived by the subject and hence is not of clinical important. No data was found in the literature about the difference in expenditure of metabolic energy while walking with comfortable speed, that could be perceived by subjects. Thus the contrast between the energy storing capacities of the different feet is probably too small to notice. In this study the energy storing capacities did not seem to be a decisive factor in itself, but other properties, such as springy push-off, flexibility, fatigue and stability could probably be derived from the energy storing capacities.

It is known that the same characteristic of a foot can affect users totally differently. For instance some people favour the Flex foot because of its springiness (Goh *et al,* 1994; Lehmann *et al,* 1993; Macfarlane *et al,* 1991), while others dislike this foot for the same reason (Menard *et al,* 1992). The difference in preference, may be explained by different personal capacities of the subject, different circumstances under which the prosthesis is used and by different demands made on the prosthesis.

It has been reported that subjects tend to prefer their own prosthetic foot, which they are used to, to those of a study (Goh *et al,* 1984). This might be due to a very short habituation period. The data in this study showed that 4 subjects had a foot that was also part of the study (2 x ESF2 and 2 x CF2). Half of this group (1 x ESF2 and 1 x CF2) preferred this foot to the other feet. On the other hand, only 2 of the 6 subjects with a totally different own prosthetic foot than those used in the study, preferred their own prosthetic foot. It, therefore, cannot be confirmed that most subjects prefer their own prosthetic foot.

Questionnaire B: ranking order of importance of different factors of prosthetic feet

Nielsen (1991) presented a study, concerning a survey of 109 amputees (leg and arm amputations at different levels), in which orders of importance were given. Fifty-two percent of the amputees rated comfort as the most important factor of the prosthesis, 38% rated function as the most important factor, 7% cosmesis and 4% rated cost as the most important factor.

The results of the questionnaire in this study suggested that more or less 2 factors were of utmost importance in order to function well with a prosthesis. First was the 'absence of stump pain' and the second was the stability of walking. One subject ranked 'absence of stump pain' as totally unimportant. However he had never experienced stump pain, and therefore, it was supposed, he underestimated the importance of the absence of it. Absence of stump pain is of course the ultimate factor of comfort. Stability while walking is a factor of functionality and it incorporates feelings of safety. Amputees with good proprioceptive control tend to describe a flexible foot as more stable (Nielsen *et al,* 1989), because most likely the flexibility of the foot allows them to keep their balance. It gives a possibility of adaptation to an uneven surface and therefore reduces the chance of falling. These subjects seem to interpret stability not as mechanical stability, but as better balance possibilities and a smaller chance of falling, in other words, as more safety. This indicates that the perception of stability is closely related to proprioceptive capacities of the subjects and to their daily activities. Two of the subjects of the study worked very often at construction sites and both described the ESF2 (most flexible foot) as most stable. Older, less active and heavily built amputees prefer a conventional foot with less flexibility (Alaranta *et al,* 1994; Casillas *et al,* 1995; Menard *et al,* 1992; Nielsen ***et*** *al,* 1989; Wirta *et al,* 1991). Probably loss of proprioceptive capacities results in worse balance control and therefore these subjects experience a conventional foot with less flexibility as more stable. The factor 'stability while walking, as experienced by the amputee' seems to be of decisive importance in the preference of prosthetic feet.

The next 4 factors (no fatigue during walking, ability to walk fast, stability in stance and feeling of firm contact with the ground) are all in the domain of functionality and make daily functioning with the prosthesis a lot easier. These factors proved to be the reason for a statistically lower ranking of the CF2, as seen previously from the results from Questionnaire A. Two factors, both, 'stability in stance' and 'feeling of firm contact with the ground', concern stability and balance. It was therefore to be expected that they were close to each other in ranking order.

The factors 'rolling-off in a supple way' and 'powerful push-off' were in the middle of the ranking order. They were clearly less important than 'absence of pain' and 'stability' (safety). The factors 'rolling-off in a supple way' and 'powerful push-off' could be prime reasons for 'no fatigue during walking' and 'possibility to walk fast'. Hence it may be reasonable that these last 2 factors ranked higher.

The last 4 items concerned special activities and cosmesis. They were clearly of less importance. However, one subject judged the factor 'cosmetically good walking pattern', as very important. This subject is probably obsessed by the fact that others can see that he is wearing a prosthesis. For individual decision making this of course is very important but it is not representative for the total group.

It is necessary to be cautious with generalising the results of this series to all amputees, because the subjects in the trial were all good walkers and relatively young. Yet, when 'absence of stump pain' is considered as a matter of comfort and 'stability while walking' as a matter of function, the results correspond with those of Nielsen *et al.* (1991).

Conclusions

The first part of this study showed that there were no clear differences between kinematic and kinetic data, either in mechanical energy storage or release, of the 2 ESF and 2 CF feet.

It is concluded that, with such small differences in energy storage and release, subjects might not be able to distinguish a clear difference in the energy storing capacities of both kinds of feet.

In the second part of the study it was shown that no foot was specially favoured by the subjects. Despite small differences, detrimental to CF2 ('ability to walk fast' and 'no fatigue

during walking'), collectively the feet were judged as being almost the same, although individually there were clear preferences.

The preference of the subject could not be related to age. In 2 subjects the kind of daily activity, working at building sites, seemed to be the reason to prefer a flexible foot (ESF1), because this offered a better safety (stability in their experience).

From the 12 factors concerning a prosthesis the absence of stump pain was ranked as the most important by the subjects, stability while walking (as experienced by the amputee) was the second while special activity such as possibility of squatting was unimportant.

It is necessary to gather this kind of information from subjects with different levels of amputation, different levels of activities, different professions etc., because it leads to a better understanding of desires and demands of amputees on their prosthesis, and therefore it can lead to a more satisfying use of the prosthesis.

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