
The Journal of the International Society for Prosthetics and Orthotics

# Prosthetics and Orthotics International

August 1994, Vol 18, No. 2

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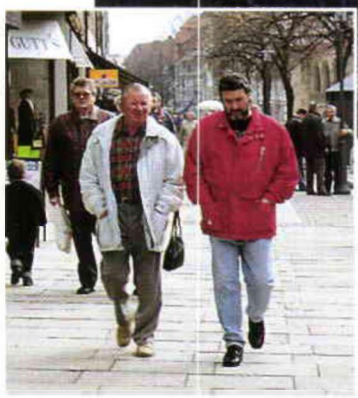

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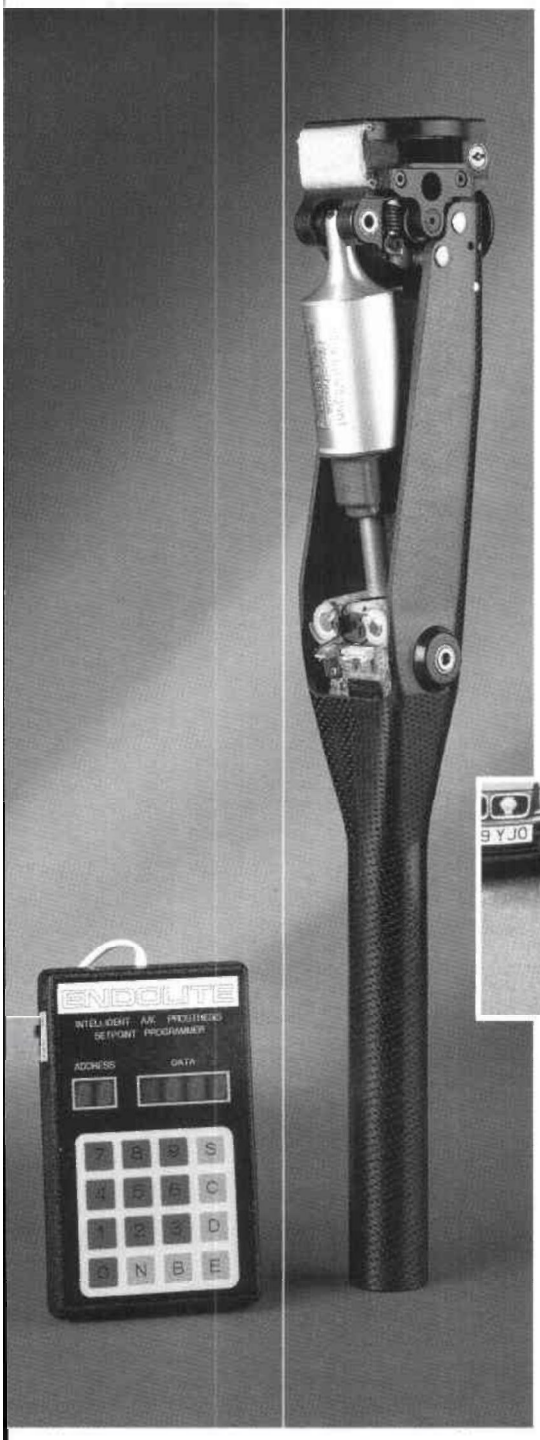


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# The Journal of the International Society for Prosthetics and Orthotics

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*Prosthetics and Orthotics International, 1994, 18, 63-64*

# Editorial

There is less than one year left in this triennium. I am amazed how quickly time has passed. The Society has been very busy with several projects that directly influence both orthotic and prosthetic patient care.

The Amputation Surgery and Related Prosthetics instructional course has been successfully run in the Netherlands, Tanzania and Thailand and is also scheduled for Slovenia on 26-30 September, 1994 and Panama on 14-18 November, 1994.

These instructional courses have provided the participants with the most recent thinking and latest technology related to amputation surgery and prosthetic care. They have been developed specifically for the regions in which they are given. Amputees in the developing world have little opportunity to undergo revision surgery, so it is extremely important that the operating surgeon understands the surgical techniques as well as the prosthetic principles necessary to create a functional weight bearing limb.

Another area of interest and differing opinions is that of lower limb orthotic management of cerebral palsy. ISPO has organized a consensus conference on the subject, and it will be held at Duke University in Raleigh-Durham, North Carolina, USA, on November 10-12, 1994. David Condie and his Committee have identified the areas of controversy and the professionals considered to be experts in the orthotic management of cerebral palsy. The list of participants is international and well-balanced. In keeping with ISPO's philosophy of utilizing the team approach, those disciplines involved in clinical practice and research have been invited. A full report of this consensus conference will be made available, and it is hoped that it will spawn a series of instructional courses that will be given over the next triennium.

One final consensus conference, on appropriate prosthetic technology in the developing world, has been planned for the near future. For the first time, ISPO has submitted a grant proposal to a government agency to fund this consensus conference.

There is considerable controversy today about what is appropriate prosthetic technology. There are many private volunteer organizations (PVOs) and non-governmental organizations (NGOs) working in prosthetics in the developing world. The technology they advocate varies tremendously. It includes primitive technology, for example, no more than a padded bucket attached to a stick. Out of necessity primitive material may be used but when applied with the knowledge of prosthetic principles a good result may be achieved. In another area a villager is taught to make his own leg using plastic polystyrene bottles dissolved in acetone in order to make a socket. That villager is then encouraged to teach others how to make their own limbs using the same technology. In some areas the necessary materials and equipment are available, but the prostheses provided do not fit properly nor were they ever dynamically aligned. Thus, full functional potential is not achieved because of poor fit. Some agencies are using all-plastic technology, and all of the necessary components are locally produced. Another group is using imported, prefabricated sockets and components in order to provide a prosthetic service. Computer aided design and computer aided manufacture is also used in the developing world. Regardless of the technology used, however, a functional prosthesis is not always produced. The overwhelming number of patients needing prosthetic services has led to the belief that quantity is more important than quality, in many instances.

Another real concern is the training received by those providing prosthetic services. Some agencies use only graduates of recognized university prosthetic/orthotic training programmes, while others provide their own training to professionals not previously trained as prosthetists/orthotists. These training programmes may be a few days long or a week or two in length. Some agencies provide training by having an expatriate on staff providing ongoing clinical instructions so that one day the project can be turned over to the local government for management. Other agencies have no projected completion date, and training is not a part of their project.

To sort all this out and to reach a consensus on what is appropriate prosthetic technology, a listing of NGOs and agencies providing technology, technology users, national aid organizations, component manufacturers and professionals experienced in the complexities of providing prosthetic services in the developing world has been developed. It is the intention not only to reach a consensus as to what is

appropriate prosthetic technology, but also to provide guidelines to be followed in providing prosthetic services in developing countries in the future.

ISPO has been active in its relationship with other agencies and organizations. The Society is contacted on a frequent basis for information or advice. Many times it is a simple phone call with a request for the name of an individual who may be able to give technical assistance. Other times it may be a request to review a project, inspect a school, or conduct a site visit. ISPO's role is well-recognized, and will continue its efforts with the limited resources there is available.

ISPO has been very busy. In a short time the plans for the 1995 Melbourne Congress will be completed after which Seishi Sawamura and the newly elected Executive Board will have three short years to further ISPO's mission. ISPO's true strength still lies with its membership. There are wonderful opportunities today to get involved in order to continually advance the services we provide.

Melvin L. Stills
*President*

**ISPOCOL**

The Society is pleased to announce the formation of a new National Member Society in Colombia.

Following is a list of its Board of Directors:

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# Proposed Amendments to the Constitution

The following amendment to ISPO's Constitution have been formulated by the Executive Board and will be discussed and voted on by the International Committee at its meeting which will be held in association with the World Congress in Melbourne, 2nd-7th April, 1995.

The amendment to the proposed Clause 2.5.1 rewords it in a more acceptable manner.

| Original Clause | Proposed Clause | Amended Proposed Clause |
|---|---|---|
| **2.5.1** An individual may resign at any time. Members who fail to pay the specified fees will be automatically severed. | **2.5.1** An individual may resign at any time. Members or Fellows who fail to pay the specified fees will be automatically severed. | **2.5.1** An individual may resign at any time. Members or Fellows who fail to pay the specified fees will lose membership status. |

The following additions to the Constitution are proposed in order to make the Education Committee a Standing Committee of the Society:

| Original Clause | Proposed Clause |
|---|---|
| **4.5.1** There shall be a Standing Finance Committee and a Standing Protocol and Nominations Committee. | **4.5.1** There shall be a Standing Finance Committee, a Standing Protocol and Nominations Committee and a Standing Education Committee. |
| | **4.5.9** The Education Committee shall comprise a Chairman, two members, the President, the President-Elect, the Honorary Secretary (ex officio). Further members may be co-opted to carry out specific tasks. |
| | **4.5.10** The Chairman and the two members shall be appointed by the Executive Board for a three year term and may be re-appointed. |
| | **4.5.11** The Education Committee shall:<br>**4.5.11.1** have a continuing responsibility to review the educational policy of the Society and make recommendations to the Executive Board.<br>**4.5.11.2** oversee the educational activities of the Society as directed by the Executive Board. |

Before the International Committee discusses these proposals, the Constitution requires they be published to the International Committee and Members and Fellows for comment. Any such comments should be received by the Honorary Secretary before **1st February 1995.**

*Prosthetics and Orthotics International, 1994, 18, 66-67*

# Obituary

## Howard R. Thranhardt
## 1911-1994

When Howard Thranhardt died unexpectedly on 28th April owing to complications following by-pass surgery, ISPO lost a member who perhaps more than anyone else in the United States has contributed to the transition of prosthetics and orthotics from a craft to a profession. His contributions did not come in the form of new mechanical developments or the promotion of revolutionary methods although he participated in these programmes, but by silently providing, through his own conduct, standards of integrity, honesty, service, and steadfastness of purpose.

Without the support and example of Howard Thranhardt, it is doubtful that the formal education programme for prosthetists and orthotists begun in the US in 1952-3 and emulated in other parts of the world would have been successful. At this time in history it is difficult to believe that when the committee on Prosthetics Research and Development of the National Academy of Sciences in 1953 initiated formal courses for prosthetists the majority of practitioners were not in favour of the movement. But Howard Thranhardt understood the value of formal education, and supported the education movement wholeheartedly by sending one or more prosthetists from each of the facilities in the Hanger Company that he represented. His actions encouraged others to participate, and in a relatively few years the programme was accepted so well that it was difficult to find anyone who would admit that he or she ever opposed the idea.

Howard also recognized the need for standards of practice and played a significant role in the creation of the American Board for Certification in Prosthetics and Orthotics (ABC). His Certification Number was CP 12, and he served as President of ABC for three years in the 1960s. He was elected President of the American Orthotic and Prosthetic Association for the 1976-77 year having served previously in other official capacities. Howard became a member of ISPO immediately after its founding in 1972, and served as Treasurer and as a member of the Board of the US National Member Society for a number of years in the 1970s.

It was Howard Thranhardt who, during the First World Congress in Montreaux in 1974, invited ISPO to hold the next World Congress in the United States in 1977. ISPO accepted, and Howard was requested to serve as Secretary General, which he did with distinction, setting standards for future Congresses. Soon after his retirement from the Hanger firm, Howard was elected an Honorary Fellow of ISPO.

From the 1950s until his retirement Howard was the senior liaison between the research activities of the Committee on Prosthetics Research and Development of the National Academy of Sciences and the clinical practice of prosthetics in the US. His activities in this capacity

resulted in an acceleration of the transition of many ideas from the laboratory to the clinic and were extremely valuable in the introduction of new devices and methods through the years. Howard was requested by the Veterans Administration and National Institute on Disability Research and Rehabilitation on many occasions to represent the United States Government at meetings and training courses held abroad, including trips to Argentina, Poland, and India. From the 1950s until well after his retirement, government officials responsible for making policy that affected prosthetists, orthotists and their patients rarely, if ever, made a policy before consulting Howard Thranhardt.

In the forty-five years that I knew, worked with and travelled with Howard Thranhardt, I never heard him say anything untoward about another person, and I do not recall anyone saying anything critical about him. His speech was direct and free of crude language and innuendo. He was a gentleman in every sense of the word.

A. Bennett Wilson, jr

**ISPO – PANAMA**

The Society is pleased to announce the formation of a new National Member Society in Panama.

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*Prosthetics and Orthotics International, 1994, 18, 68-77*

# Gait in male trans-tibial amputees: a comparative study with healthy subjects in relation to walking speed

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**Department of Orthopaedics, Helsingborg Hospital, Helsingborg, Sweden*
***Department of Physical Therapy, Lund University, Lund, Sweden*

**Abstract**

Walking speed, stance duration and ground reaction forces were studied with the use of a stable force platform (Kistler) in 24 male trans-tibial amputees and 12 healthy subjects matched for sex and age. The aim of the study was to compare the gait performance of two groups with unilateral trans-tibial amputations for either vascular disease or trauma and also to compare the results of the two groups with the results of a group of healthy subjects. Multiple linear regression analysis was used to compare the stance duration and the ground reaction forces in relation to walking speed. The vascular and traumatic amputees had significantly reduced walking speeds compared with the healthy subjects, 0.85±0.2 m/s and 0.99±0.2 m/s. respectively, as compared to 1.42±0.2 m/s. By comparing the vascular and traumatic amputees with the healthy subjects in relation to walking speed, it was shown that the gait performance of the vascular amputee differed from that of the traumatic amputee, a difference that was not caused by the reduced walking speed. The active forces during push off on both the healthy ($p = 0.02$) and the prosthetic leg ($p = 0.003$) in the trauma group were not found in the vascular group. This disparity could be an effect of the systemic disease. It may be argued that the results of this study contribute to the understanding of the reduced walking ability of the vascular amputee and should be borne in mind when planning rehabilitation.

All correspondence to be addressed to Y. Hermodsson, Department of Orthopaedics, Helsingborg Hospital, S-251 87 Helsingborg, Sweden.

## Introduction

After an amputation of a leg, the muscular strength and the somatosensory information are reduced. The postural function is now also dependent on the stump, the prosthesis and how well the stump fits the socket (Murdoch, 1969; Sanders *et al.*, 1992; Zahedi *et al.*, 1987). The person must regain the capacity to stand and walk with an artificial leg in order to feel confident in the activities of daily living (Moncur, 1969; Winter and Sienko, 1988).

In healthy subjects normal walking speed decreases with age (Nigg and Skleryk, 1988; Öberg *et al.*, 1993) and in general women have been found to walk at a slower speed than men (Öberg *et al.*, 1993). Walking speed is reduced in leg amputees compared with healthy subjects (Levine, 1984; Robinson *et al.*, 1977; Saleh and Murdoch, 1985), and is significantly decreased at higher amputation levels (Skinner and Effeney, 1985; Waters *et al.*, 1976). Variations in walking speed as well as abnormalities affect the walking pattern (Andriacchi *et al.*, 1977). Compared to the side with the normal leg in trans-tibial amputees, stance duration, vertical ground reaction force (Suzuki, 1972) and the horizontal ground reaction forces in the fore and aft directions (Seliktar and Mizrahi, 1986) are decreased on the side with the prosthetic leg. This creates an asymmetric gait where the sound leg has to compensate for the prosthetic leg (Hurley *et al.*, 1990).

The aim of the present study was to compare the gait performance of two groups with unilateral trans-tibial amputations for either vascular disease or trauma in males and to compare the results of the two groups with the

results of a group of healthy subjects matched for sex and age. Stance duration and the ground reaction forces of the vascular and traumatic amputees were compared with the healthy subjects in relation to walking speed. Another aim was to relate the person's own perception of postural function when moving in different situations to the mean walking speed of each group respectively.

## Subjects and methods

### *Subjects*

The criteria for inclusion in this study were: men with unilateral trans-tibial amputation for either vascular disease or trauma, no major sight problems (with glasses if needed), ability to talk and write in Swedish, and to be able to walk stretches of 8 metres, repeatedly, with a prosthesis without using a walking aid. A total of 24 male amputees fitted with a prosthesis at the orthopaedic workshop at Helsingborg Hospital, Sweden, were asked to participate in the study. All the selected amputees agreed to participate. Twelve male vascular amputees were matched for age with 12 male traumatic amputees.

*Vascular amputee group:* Twelve men with trans-tibial amputation for vascular disease were included in the study. One third of the men had diabetes. Concomitant diseases among the men were gastric ulcer in 1 and varicose ulcer of the other leg in another. In addition, 2 men had a big toe amputation on the healthy leg. Concerning pharmacological treatment, half of the men were on antihypertensive and/or analgesics; 1 was on antihypertensives, analgesics and sedatives; 1 was on antacids and 4 not on drugs at all. Three men considered their hearing to be bad, but this was not evident at the clinical investigation. To feel secure 5

Table 1. Characteristics of the groups studied (n = 12 in each group).

| | Vascular | | | Trauma | | | Healthy | | |
|---|---|---|---|---|---|---|---|---|---|
| Characteristics | M | SD | range | M | SD | range | M | SD | range |
| Age (years) | 67 | 10.6 | 48-82 | 67 | 9.9 | 48-82 | 68 | 10.5 | 48-82 |
| Height (cm) | 173 | 7.3 | 161-187 | 175 | 3.9 | 168-180 | 176 | 6.7 | 165-191 |
| Body mass (kg) | 74 | 17.8 | 51-111 | 75 | 7.4 | 63-90 | 74 | 6.0 | 60-83 |
| Years since the amputation | 7 | 5.7 | 0-18 | 39 | 19.5 | 5-62 | – | – | – |
| Age of the last prosthesis (years) | 2 | 2.8 | 0.7 | 3 | 3.0 | 0.11 | – | – | – |
| Stump length (cm) | 15 | 3.1 | 11-21 | 15 | 7.4 | 8.34 | – | – | – |
| Characteristics | | | | Number | | | | | |
| Sight (normal/slight impairment) | | | | 7/5 | | | 9/3 | | 7/5 |
| Hearing (normal/slight impairment/bad) | | | | 7/2/3 | | | 7/4/1 | | 4/8/0 |
| Smoking habits (smokers/ex-smokers/ non-smokers) | | | | 5/4/3 | | | 2/7/3 | | 1/4/7 |
| Concomitant diseases (yes/no) | | | | 2/10 | | | 6/6 | | – |
| Medication (yes/no) | | | | 9/3 | | | 8/4 | | – |
| Walking aid outdoors (yes/no) | | | | 5/7 | | | 5/7 | | – |
| Side of amputation (right/left) | | | | 5/7 | | | 7/5 | | – |
| Stump pain (yes/no) | | | | 4/8 | | | 3/9 | | – |
| Phantom sensation (yes/no) | | | | 11/1 | | | 4/8 | | – |
| Phantom pain (yes/no) | | | | 10/2 | | | 6/6 | | – |
| Satisfaction with last prosthesis (yes/no) | | | | 8/4 | | | 6/6 | | – |
| Suspension (PTB/Supracondylar/ PTB with a thigh corset/other | | | | 0/12/0/0 | | | 1/7/4/0 | | – |
| Liner (foam/leather/silicone/other) | | | | 11/0/1/0 | | | 10/1/1/0 | | – |
| Make (Boa/Bock/Swepro/TPJ/ Flex-Foot/other) | | | | 3/6/1/1/1/0 | | | 1/11/0/0/0/0 | | – |
| Foot (SACH/Single-axis/Multi-axis/ Energy storing/other) | | | | 6/3/2/1/0 | | | 4/4/4/0/0 | | – |

men walked with a walking-stick outdoors. The characteristics of the vascular group are shown in Table 1.

*Trauma amputee group:* The vascular amputee group was matched for age with a group of 12 traumatic amputees. Regarding concomitant diseases among the men, 2 had asthma and 1 had both cardiac insufficiency and chronic bronchitis. Two men had had myocardial infarction and another had had a minor stroke more than one year previously but they were all back in their normal status again without any sequelae. Concerning pharmacological treatment, half of the men were on antihypertensives and/or analgesics; 1 was on antihypertensives, analgesics and sedatives; 1 was on anti-asthmatic inhalation medication and 4 were not on drugs at all. One man considered his hearing to be bad, but this was not evident at the clinical investigation. To feel secure 5 men walked with a walking-stick outdoors. The characteristics of the trauma group are shown in Table 1.

*Healthy reference group:* The vascular and traumatic amputee groups were matched for age with a group of 12 healthy men. The criteria for inclusion in this group were feeling healthy, taking no medicine and having experienced no problems with standing balance. All the subjects selected according to these criteria agreed to participate. The characteristics of the healthy group are shown in Table 1.

### *Methods*

*Force platform:* The Vifor system was used for data collection of the gait performance. The main components of the Vifor system are a stable force platform (Kistler) measuring the forces between the foot and the surface, two video cameras and a video cassette recorder for recording the pattern of movement, a personal computer (IBM AT-3 compatible) for processing the force data, plotting ground reaction forces in video format and controlling the video cassette recorder, and a video mixer for superimposing information from the video cameras onto the computer images. In addition, the system includes two photocells for recording the walking speed and a video copier to furnish hard copies of selected video images (Lanshammar, 1991). In this study only the walking speed and the force platform data were

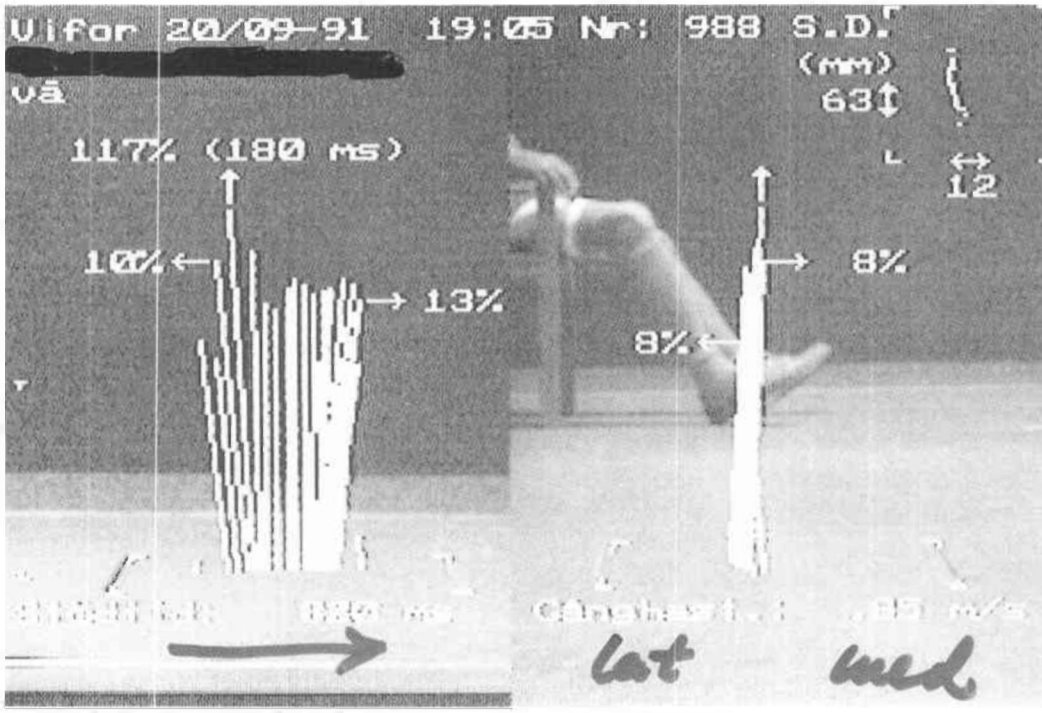


Fig 1. Parameters on the summary picture in the Vifor system for the gait performance of the sound leg of one of the male vascular trans-tibial amputees. Walking speed = 0.85 m/s; stance duration = 820 ms; max acc GRF (%BW) = 13; max ret GFR (%BW) = 10; med GRF (%BW) = 8; max lat GRF (%BW) = 8.

used for the gait analysis.

In the middle of the 8 m walkway, the force platform was incorporated into the floor and on a level with it. The force platform and the walkway were covered with the same material to prevent the subject from modifying the gait pattern in order to hit the platform properly. When the second photocell had been passed by the subject, a summary of the measurements was displayed on the screen. This summary contained a graphic illustration of the ground reaction forces during the step in the sagittal and frontal planes measured with 50 samples per second (Lanshammar, 1991).

Parameters shown on the summary picture in the Vifor system for the gait performance: walking speed = mean velocity (m/s) along the walkway; stance duration = total support time on the force platform (ms); max GRF (%BW) = the largest measured vertical ground reaction force in per cent of body weight; max acc GRF (%BW), max ret GRF (%BW) = the largest measured horizontal ground reaction forces in per cent of body weight in the fore and aft directions respectively in the walking direction; max med GRF (%BW), max lat GRF (%BW) = the largest measured horizontal ground reaction forces in per cent of body weight in the medial and lateral directions respectively perpendicular to the walking direction (Lanshammar, 1991).

*Gait performance:* As the ground reaction force (GRF) is measured in per cent of body weight (%BW) all subjects were weighed on the force platform. The subjects wore their ordinary walking shoes. Before recording with Vifor each subject walked repeatedly on the walkway. When walking the subject was instructed to look straight ahead and to walk at what they considered their normal walking speed when walking along a pavement without obstructions. In order to get the stance phase of each foot on the force platform, starting marks were placed at the beginning of the walkway. These were adjusted according to the gait performance of each subject. Three stance phases of each leg were recorded. One recording for each leg which was closest in time according to walking speed was chosen for the analysis, as changes in walking speed produce changes in the overall pattern of movement (Andriacchi *et al.*, 1977). The gait performance of the sound leg in 2 men is illustrated in Figures 1 and 2, 1 vascular

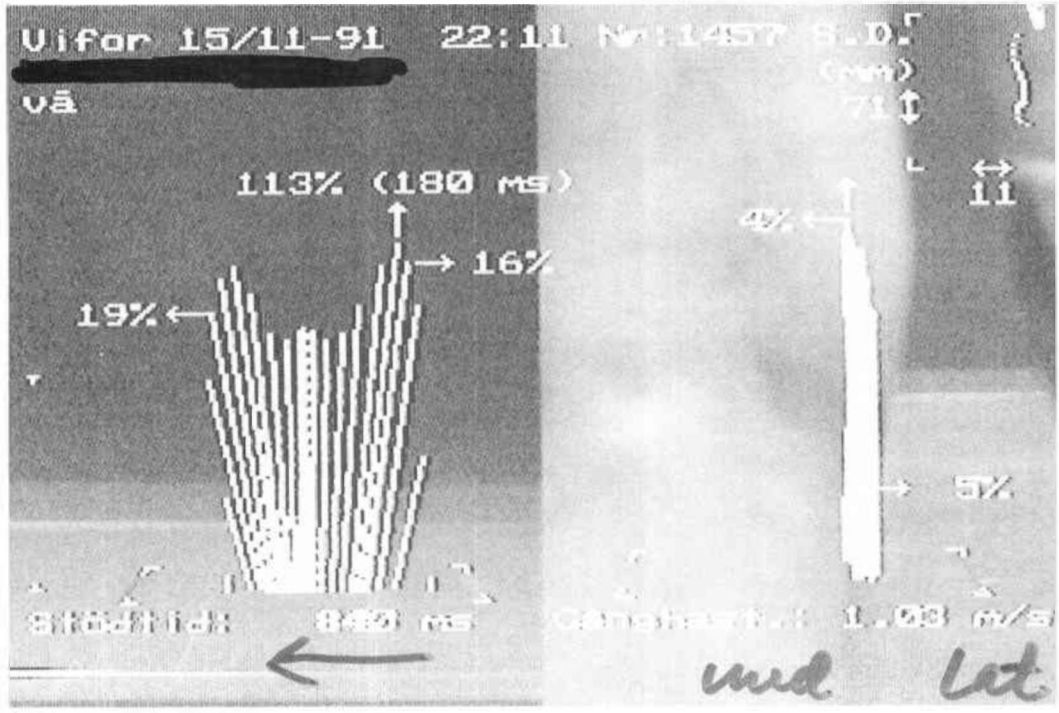


Fig. 2. Parameters on the summary picture in the Vifor system for the gait performance of the sound leg of one of the male trauma trans-tibial amputees. Walking speed = 1.03 m/s; stance duration = 840 ms; max acc GRF (%BW) = 19; max ret GFR (%BW) = 16; med GRF (%BW) = 4; max lat GRF (%BW) = 5.

amputee (Fig. 1) and 1 trauma amputee (Fig. 2).

*Questionnaires:* Before the tests of postural function, the subjects were asked to fill in a questionnaire about height, body mass, sight (normal/slight impairment), hearing (normal/slight impairment/bad), smoking habits (yes/ex-smokers/non-smokers), concomitant diseases (yes/no) and medication (yes/no).

For the leg-amputees additional questions were asked about years since the amputation, age of last prosthesis, stump length, walking aids outdoors (yes/no), side of amputation (right/left), stump pain (yes/no), phantom sensation (yes/no), phantom pain (yes/no) and satisfaction with the last prosthetic (yes/no). Together with the prosthetist suspension (PTB/Supracondylar/PTB with thigh corset/other), liner (foam/leather/silicone/other), make (Boa/Bock/Swepro/TPJ/Flex-Foot/other) and foot of the prosthesis (SACH/Single-axis/Multi-axis/Energy storing/other) were recorded. Abbreviations for prosthesis, make and foot: PTB = Patellar Tendon Bearing. PTS = Patellar Tendon Suspension. TPJ = Torsten Pettersson Jigg. SACH = Solid Ankle Cushion Heel.

In the other questionnaire all subjects were asked about their own perception of their postural function (good/fair/bad/cannot) when walking across the street, walking up the stairs, walking down the stairs, rising from a chair and sitting down on a chair. They were also asked how they would describe a perceived good postural function (There are times when the balance might not be as good as at other times. How do you perceive your balance when it is good? Please, write in your own words in the empty space below).

*Statistics:* Multiple linear regression was used in the analysis of the walking test battery where the walking speed was the dependent variable along with the interesting prognostic factors. All categorical data were analysed using the Chi-square test. All pairwise comparisons between the groups were analysed using the Student's t-test. To declare a test statistically significant, a level of 5% was used. The statistical software used in the analysis was SAS Version 6.08.

## Results

There were no significant differences between the three groups concerning the characteristics in common (Table 1). A longer period of time since the amputation ($p = 0.0003$) among the amputees was the only characteristic showing significant difference between the vascular and traumatic groups, but this was not, however, found to affect walking speed.

### *Gait performance*

Means and standard deviations for the vascular, traumatic and healthy groups during the gait performance are shown in Table 2. Compared to the healthy leg, the prosthetic leg had a reduced max acc GRF (%BW) and max

Table 2. Means and standard deviations for the groups studied (n = 12 in each group) during the gait performance according to the summary picture on the Vifor system.

| | Vascular group | | | | Trauma group | | | | Healthy group | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Healthy leg | | Prosthetic leg | | Healthy leg | | Prosthetic leg | | Right leg | | Left leg | |
| Gait variables | M | SD | M | SD | M | SD | M | SD | M | SD | M | SD |
| Walking speed (m/s) | 0.85 | 0.2 | 0.85 | 0.2 | 0.99 | 0.2 | 0.99 | 0.2 | 1.42 | 0.2 | 1.42 | 0.2 |
| Stance duration (s) | 0.85 | 0.1 | 0.83 | 0.1 | 0.87 | 0.1 | 0.80 | 0.1 | 0.67 | 0.0 | 0.67 | 0.1 |
| Max GRF (%BW) | 113.1 | 8.8 | 106.3 | 8.7 | 114.9 | 9.3 | 107.3 | 10.6 | 123.3 | 9.8 | 122.8 | 10.3 |
| Max acc GRF (%BW) | 13.1 | 4.9 | 10.3 | 4.2 | 17.4 | 5.2 | 10.8 | 2.7 | 21.3 | 3.9 | 21.0 | 4.2 |
| Max ret GRF (%BW) | 12.2 | 4.1 | 9.3 | 3.6 | 17.0 | 4.3 | 11.2 | 5.2 | 20.0 | 6.3 | 20.8 | 5.0 |
| Max med GRF (%BW) | 6.9 | 2.1 | 6.8 | 2.0 | 6.4 | 1.2 | 6.6 | 2.1 | 6.5 | 2.1 | 5.6 | 2.0 |
| Max lat GRF (%BW) | 3.2 | 1.5 | 1.6 | 1.3 | 4.1 | 2.6 | 2.1 | 0.8 | 5.5 | 3.0 | 5.6 | 2.7 |

Abbreviations: max GRF (%BW) = the largest measured vertical ground reaction force in per cent of body weight; max acc GRF (%BW), max ret GRF (%BW) = the largest measured horizontal ground reaction forces in per cent of body weight in the fore and aft directions, respectively, in the walking direction; max med GRF (%BW), max lat GRF (%BW) = the largest measured horizontal ground reaction forces in per cent of body weight in the medial and lateral directions, respectively, perpendicular to the walking direction.

Table 3. Multiple linear regression analysis for the stance duration and the ground reaction forces in the gait performance using walking speed as a dependent variable for the matched men in the vascular and trauma groups compared to the healthy group (n = 12 in each group).

| | Trauma & vascular/healthy groups | | | | Vascular/healthy groups | | | | Trauma/healthy groups | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Healthy leg | | Prosthetic leg | | Healthy leg | | Prosthetic leg | | Healthy leg | | Prosthetic leg | |
| Gait variables | Difference[a)] | p | Difference[a)] | p | Difference[a)] | p | Difference[a)] | p | Difference[a)] | p | Difference[a)] | p |
| Stance duration (s) | 0.01 | 0.66 | -0.02 | 0.44 | 0.00 | 0.99 | 0.00 | 0.95 | 0.04 | 0.17 | -0.01 | 0.60 |
| Max GRF (%BW) | 5.39 | 0.14 | -6.62 | 0.18 | 4.39 | 0.09 | -1.50 | 0.64 | 5.27 | 0.21 | -4.77 | 0.40 |
| Mac acc GRF (%BW) | 3.80 | 0.01 | -3.97 | 0.007 | 1.40 | 0.11 | 0.24 | 0.74 | 3.86 | 0.02 | -5.30 | 0.003 |
| Max ret GRF (%BW) | 3.36 | 0.10 | -2.78 | 0.14 | 1.11 | 0.47 | -1.32 | 0.29 | 4.56 | 0.06 | -1.91 | 0.38 |
| Max med GRF (%BW) | -0.16 | 0.87 | 0.55 | 0.61 | 0.31 | 0.70 | 0.60 | 0.44 | -0.20 | 0.85 | 1.64 | 0.20 |
| Max lat GRF (%BW) | 0.25 | 0.84 | -3.36 | 0.001 | -0.11 | 0.90 | -1.98 | 0.03 | 0.50 | 0.76 | -2.72 | 0.03 |

[a)] Difference in seconds for the stance duration and in %BW for the ground reaction forces (GRF).
Abbreviations: max GRF (%BW) = the largest vertical ground reaction force in per cent of body weight; max acc GRF (%BW), max ret GRF (%BW) = the largest measured horizontal ground reaction forces in per cent of body weight in the fore and aft directions, respectively, in the walking direction; max med GRF (%BW), max lat GRF (%BW) = the largest measured horizontal ground reaction forces in per cent of body weight in the medial and lateral directions, respectively, perpendicular to the walking direction.

lat GRF (%BW) in the vascular group (p = 0.01 and p = 0.03, respectively) and a reduced max acc GRF (%BW), max ret GRF (%BW) and max lat GRF (%BW) in the trauma group (p-values = 0.0003, 0.001 and 0.03, respectively). The remaining gait variables in this comparison between the healthy and prosthetic leg did not reach statistical significance in the vascular or traumatic groups.

### *Stance duration and ground reaction forces in relation to walking speed*

The vascular and trauma groups, calculated together or separately, had significantly reduced walking speeds compared with the healthy group (p = 0.0001 in all three cases). Multiple linear regression analysis was used to compare the stance duration and the ground reaction forces of the vascular and traumatic amputees with the healthy subjects in relation to walking speed (Table 3). The vascular and traumatic amputees as one group, differed significantly in their max acc GRF (%BW) on both the healthy (p = 0.01) and prosthetic leg (p = 0.007) and the max lat GRF (%BW) (p = 0.001) on the prosthetic leg only, compared to the healthy group. When comparing the vascular group separately with the healthy group only max lat GRF (%BW) differed significantly (p = 0.03) on the prosthetic leg. The trauma group differed significantly (p = 0.02) in their max acc GRF (%BW) on the healthy leg while the max ret GRF (%BW) on this leg showed a tendency towards a significant difference (p = 0.06). The max acc and max lat GRF (%BW) on the prosthetic leg differed significantly (p = 0.003 and p = 0.03, respectively) in the trauma group compared to the healthy group.

### *Perceived postural function*

Perceived postural function is reported in Table 4. No significant differences were found between the three groups in the self-report of perceived postural function when walking across the street and sitting down on a chair. Self report of perceived postural function when

Table 4. Perceived postural function when moving (good/fair/bad/cannot). Frequencies in the vascular, trauma and healthy groups.

| Activity | Vascular (n = 12) | Trauma (n = 12) | Healthy (n = 12) |
|---|---|---|---|
| Walk across the street | 8/4/0/0 | 8/3/1/0 | 11/1/0/0 |
| Walk up the stairs | 5/7/0/0 | 6/5/1/0 | 11/1/0/0 |
| Walk down the stairs | 6/6/0/0 | 5/5/2/0 | 12/0/0/0 |
| Rise from a chair | 9/3/0/0 | 7/5/0/0 | 12/0/0/0 |
| Sit down on a chair | 10/2/0/0 | 8/4/0/0 | 12/0/0/0 |

walking up and down the stairs and getting up from a chair were found to differ significantly between the three groups (p-values = 0.058, 0.01 and 0.05, respectively). The healthy group thought their balance to be significantly ($p = 0.01$) better than the trauma group and close to significantly ($p = 0.06$) better than the vascular group when getting up from a chair. In addition the healthy group considered their balance to be significantly better than the amputee groups when walking down the stairs ($p = 0.01$ in both cases). When walking up the stairs, however, only the vascular group reported a significantly ($p = 0.01$) decreased perceived postural function compared to the healthy group. Non of the three situations mentioned above was found to differ significantly between the vascular and trauma groups.

All the healthy subjects thought they had no problem with balance. To have good balance when using a prosthesis could be expressed as, "Then it feels as if I have two legs," or, "It's like having a real leg, only a little more stiff." One of the men in the trauma group thought that, "It can never be exactly the same as when you have two legs. The balance is in my healthy leg and the prosthetic leg I only use as a support," and one of the men in the vascular group wrote, "The days when the prosthesis fits well the balance is quite good. Then I enjoy life." Activities difficult to perform were walking up and downhill, walking fast, walking when the ground was slippery, sloping or bumpy and walking in the wind.

***Perceived postural function compared to the mean walking speed.***

Those who thought their postural function was "good" when walking across the street, walking up and down the street, sitting down and getting up from a chair were separated from those who felt that their postural function was "fair/bad/cannot" in one or more than one of the five situations. Of the 6 men who walked faster than 0.85 m/s in the vascular group, only 1 though his postural function was good. Among the 6 men who walked more slowly, half thought their postural function was good. In the trauma group 8 walked faster than 0.99 m/s and half of them thought their postural function was good. Four walked more slowly and 1 of them thought his postural function was good. In the healthy group 6 walked faster than 1.42 m/s and 5 of them thought their postural function was good, and among the 6 men who walked more slowly 5 said their postural function was good.

## Discussion

The results of this study show that the gait performance of the male vascular amputee differs from that of the male traumatic amputee. Due to the availability of too few female amputees, a corresponding comparison between female vascular trans-tibial amputees and female traumatic trans-tibial amputees could not be carried out. The small number of female traumatic amputees is explained by the high frequency of accidents among men in contrast to women (Hansson, 1964). Female vascular amputees having a higher failure rate than males in using the prosthesis (McKenzie, 1953) explains the small number of female vascular amputees, but the reason for this remains unclear and merits further study. Amputees having significantly reduced walking speed compared to healthy subjects, as reported earlier in the literature (Levine, 1984; Robinson *et al.*, 1977; Saleh and Murdoch, 1985), is confirmed in this study. In the pairwise comparison, significantly reduced horizontal ground reaction forces were found in the fore direction in the vascular group and in the fore and aft directions in the trauma group on the prosthetic leg, compared to the healthy leg. This asymmetry is partly in agreement with earlier studies (Hurley *et al.*, 1990; Seliktar and Mizrahi, 1986; Suzuki, 1972).

Subjects with diseased joints in the lower limbs have been found to have a decreased walking speed as compared to normal walking speed. According to Andriacchi *et al.* (1977) one should distinguish which variations from normal walking patterns are due to differences in walking speed and which are due to gait abnormalities. As the aim of this study was to investigate whether the gait of vascular trans-tibial amputees differed from that of traumatic trans-tibial amputees, and whether any differences could contribute to the understanding of the reduced walking ability of the vascular amputee in daily life, self-selected walking speed was chosen as a clinically relevant walking speed for the gait analysis. No attempt was made to study the effect of walking speed on the gait variables. Stance duration was

found by Andriacchi *et al.* to be inversely proportional to walking speed and the ground reaction forces to vary linearly with walking speed. Thus, the subjects in this study were asked to walk at their normal speed and the gait variables of the amputees were analysed in relation to the normal walking speed of the healthy subjects.

Two patients, one in each group and both on sedatives, walked more slowly than the mean walking speed of the amputee groups. As the two men were older (73 and 79 years) than the mean age of the groups, we are inclined to say that medication has not been proven to influence the walking speed. This is in agreement with Brocklehurst *et al.* (1982) who found no relationship to falls or sway in a group of healthy elderly people on sedatives compared with controls without sedatives. The authors agree, however, with Brocklehurst *et al.* that high dosage of sedatives could make a difference. Two men in the vascular group had a big toe amputation, but despite this they did not need any walking aids outdoors, and they both walked faster than the mean walking speed of the vascular group.

The mean normal walking speed of 1.42 m/s of the healthy men is comparable to the 1.45 m/s in men walking at unrestrained speed measured by Water *et al.* (1976). The lower walking speed of 1.32-1.41 m/s reported by Nigg and Skleryk (1988) could be due to the subjects being older, 60-82 years, and of both sexes. In order to analyse pathological gait data, attempts have been made to establish normal reference data. The reference tables of Öberg *et al.* (1993) show normal mean walking speed of healthy men 10-79 years to be 1.18-1.34 m/s, which is slower than the result of the present study. When comparing their tables to those of other authors, Öberg *et al.* found the results to be partly contradictory. Apart from being dependent on age and sex, they suggest that walking speed could be dependent on the length of the walkway and if the measurements have been performed under outdoor or indoor conditions. Accordingly, they recommend gait data only to be analysed with reference data made in the same test situation under the same test conditions.

In the study mentioned previously, Waters *et al.* (1976) found that a group of vascular trans-tibial amputees with a mean age of 63 years, sex not accounted for, walked with a velocity of 0.75 m/s at unrestrained speed, which is slower than the men in this study who had a mean age of 67 years and walked with a velocity of 0.85 m/s. As walking speed decreases with age, the group of traumatic trans-tibial amputees with a mean age of 29 years in Waters *et al.* series are not comparable to the traumatic amputees in this study. Lemaire *et al.,* (1993) studied eight elderly traumatic male trans-tibial amputees who had an average walking speed of 1.20 m/s when walking at a natural cadence, which is faster than the men in the trauma group in the present study who walked with a velocity of 0.99 m/s.

As a general rule, those variables which do not change when adjusted for normal walking speed, indicate an abnormality (Andriacchi *et al.*, 1977). Stance duration and the max GRF (%BW) showed no change on the healthy or the prosthetic leg for the two amputee groups together or for the vascular and traumatic groups separately, compared with the healthy group. This might indicate that amputees of different etiology have the same reduced weight bearing ability during the stance duration on the supporting leg in the walking direction, on both the healthy and the prosthetic leg compared to healthy subjects.

The horizontal ground reaction forces show how much force the subject uses in the fore direction during push off and in the aft direction during heel strike and reflects how active the leg is (Seliktar and Mizrahi, 1986). The two amputee groups compared together showed an active push off on the healthy and the prosthetic leg. The trauma group was equally active in the push off on both legs in contrast to the vascular group, who turned out to lack this powerful push off on both legs. Besides, the trauma group showed a tendency towards an active heel strike, which might have been significant if the trauma group had been larger.

The ground reaction forces in the medial and lateral directions reflect the alternating motion sideways when moving the body over the supporting leg and taking a step forward. The medial ground reaction force showed no change in the amputee groups when analysed in relation to the walking speed of the healthy group. The lateral ground reaction force, however, changed on the prosthetic leg in both amputee groups. Andriacchi *et al.* (1977) came to the same

conclusion when assessing patients with knee disabilities. They did not consider themselves to have sufficient data to explain why the medial force was the same in the knee patients as in the normal subjects. But they thought the finding was worth considering as the mediolateral forces cause bending moments in the knee which could cause loosening of prosthetic components. Like Andriacchi *et al.* the authors do not have sufficient data to explain the reason why the medial force does not change, but presume that these bending moments might occur between the stump and the prosthesis.

The amputee groups thought their postural function to be just as good as the healthy group when walking across the street. This is somewhat surprising as the traffic signals in Sweden are set according to a walking speed of 1.4 m/s (Dahlstedt, 1977). When rising from a chair the amputee groups considered their balance to be reduced. This is an agreement with Yoshida *et al.* (1983) who found hemiparetics to need more time to stand up and regain postural control than healthy elderly persons when rising from a chair. But the amputees did not perceive their balance to be reduced when sitting down on a chair as measured in the hemiparetics in the study by Yoshida *et al.* Walking up and down the stairs caused some difficulty in the amputee groups. To the authors' knowledge, studies on postural function when walking on stairs has not been reported in the literature.

The subject's own perception of his postural function when moving in the different situations did not correspond well to the mean walking speed of the different groups, which explains the somewhat contradictory findings mentioned above. This is in agreement with Ekdahl *et al.* (1989) who found low correlations between experienced and tested standing balance in patients with rheumatoid arthritis and osteoarthrosis. The fact that the healthy group showed more confidence in their postural function, independent of walking speed, confirms that they were selected according to the inclusion criteria. As they walked faster than the vascular and traumatic group, it could also indicate that when a person, as a normal walking speed, choses to walk at a speed approaching 1.4 m/s they also have a better postural function. This is similar to the results of Mathias *et al.* (1986) who found that in a group of elderly patients with some degree of balance disturbance, all subjects with a walking speed faster than 1 m/s had a sway path in standing balance below 20 mm/s. This they thought confirmed the dependence of rapid walking on good balance.

When trying to describe perceived good postural function, all groups had difficulties in putting words to this phenomenon regardless of what degree of postural function they had. In general, good balance is something that is natural, taken for granted or never given any special thought. When not good, as in the amputee groups, balance is classified in what activities one cannot do. As noted by others (Murdoch 1969; Sanders *et al.*, 1992; Zahedi *et al.*, 1987), the importance of a well-fitting prosthesis to good balance cannot be overlooked and it contributes to a greater satisfaction with life.

To conclude, by comparing the vascular and traumatic amputees with the healthy subjects in relation to walking speed, the authors have shown that the gait performance of the vascular amputee differs from that of the traumatic amputee, a difference that is not caused by the reduced walking speed. The active forces during push off on both the healthy and the prosthetic leg in the trauma group were not found in the vascular group. This disparity could be an effect of the systemic disease. It may be argued that the results of this study contribute to the understanding of the reduced walking ability of the vascular amputee and should be borne in mind when planning rehabilitation.

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# Experiences with respect to the ICEROSS system for trans-tibial prostheses

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**Abstract**

This article describes the authors' initial experiences and those of their patients with respect to the ICEROSS system for trans-tibial prostheses. Up to October 1992, 54 patients attending the "Hoensbroeck" Rehabilitation Centre received such a prosthesis.

With the aid of patients' records an all-round evaluation has been made. In addition, a survey was undertaken and an examination made amongst the 43 patients who responded to a written request. For 26 patients who were provided with the ICEROSS as a second appliance after having used an older kind of prosthesis a comparison was made with the old system. In general these patients considered the new prosthesis as providing a clear improvement.

## Introduction

For the past 3 years the authors' experiences with the ICEROSS (Icelandic Roll-on Silicone Socket) system have proven largely positive. This article provides a description and an analysis of those experiences and those of their patients with respect to the ICEROSS.

Any prosthesis necessitates a good suspension in the swing-phase and adequate pressure distribution in the stance-phase. It has been claimed that the use of a silicone roll-on socket with trans-tibial prostheses provides benefits with regard to both of these aspects (Kapp and Cummings, 1992; Madigan and Fillauer, 1991; Roberts, 1986; Sanders *et al.*, 1992; Wetz *et al.*, 1992). Since 1990 the authors have built up experience with respect to the pre-fabricated ICEROSS sockets.

The Icelandic Roll-on Silicone Socket was developed in 1985 by Össur Kristinsson (Kristinsson, 1993). It is an elastic socket which is rolled over the stump and provides good overall contact with the skin. The secure fitting on the skin provides a good suspension and the visco-elastic features of the socket are said to facilitate good pressure distribution.

As a consequence, a reduction in problems to the skin can be expected as well as a reduction in problems which may otherwise result from poor suspension of the prosthesis (Sanders *et al.*, 1992).

## Materials, patients and methods

The ICEROSS roll-on sockets are made from silicone rubber and are available in a number of standard sizes. The silicone layer is thicker at the distal end of the socket into which a screwthread has been moulded and into which the means of fixture can be screwed. The socket is unfurled over the stump. The close fitting and the secure attachment to the skin essentially aims for no movement at all between skin and socket. As regards the outer socket the authors generally use a PTB fitting (without knee-strap). The inner and outer sockets are attached to each other by means of a suspension device in the outer socket: sometimes a string attached

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Table 1. Data collected from all patients

| *From the patient record* | *Survey and examination* |
|---|---|
| Age | Problems with ICEROSS prosthesis |
| Sex | Length of stump |
| Double-sided amputation | Skin condition |
| Length of time since amputation | |
| Cause of amputation | |
| Complications<br>vision<br>sensibility<br>fine motory<br>other | |

to the outer wall of the outer socket, is used, sometimes a "shuttle lock" is used.

With regard to hygiene it can be said that the silicone material does not absorb any moisture and can easily be cleaned with water.

Either an ID10 or a Quantum foot was used as a prosthetic foot.

The sample population comprised all patients with a trans-tibial amputation who had been provided with a new prosthesis with an ICEROSS inner socket at the "Hoensbroeck" Rehabilitation Centre before October 1992 (n = 54). For some patients it was their first appliance, whilst the rest received such a prosthesis after first having used another type for some time.

Table 2. Additional data in respect of patients with a second appliance

| *Survey and Examination* | |
|---|---|
| Duration of use of old prosthesis | |
| Problems with old prosthesis | |
| Patients' assessment of:<br>donning and doffing<br>ease of maintenance<br>feeling of hygiene<br>suspension<br>standing<br>getting up<br>walking, general<br>walking indoors<br>necessity of walking aid<br>walking speed<br>walking distances<br>walking outdoors on the pavement or street<br>walking on uneven surfaces<br>climbing<br>cycling<br>getting in and out of the car | |
| Final verdict of patient: | do you wish to keep this prosthesis or get the old one back? |

Some 43 of the 54 patients who were written to, took part in the survey. Those who dropped out were either not able to attend (n = 1), could not be traced (n = 2) or did not reply to the second request (n = 8). The response was therefore 78 per cent.

Data on patients were acquired from a status report and by means of an interview with the aid of a standard questionnaire and survey at the out-patients' department. The survey was carried out by a doctor who was not treating these patients. Data were collected with respect to: the cause of amputation, the length of time since amputation, characteristics of the previous prosthesis, the medical reasons for the ICEROSS, skin compalints and a functional assessment of the prosthetic appliance (Table 1).

The registration of objective measurements such as changes in walking speed were rejected on the basis that they were unreliable and difficult to measure consistently. It was believed that, the subjective assessment of the prosthesis user is of overriding importance in determining the success or failure of the appliance provided.

The population was then divided into two sub-groups, one comprising those who were given the ICEROSS as a first prosthesis (Group 1) and the other consisting of those who received it as a subsequent appliance (Group 2). Data collected on the second group are displayed in Table 2. The second group are a subject of particular interest, since they could be considered able to make a comparison between this system and the previous suspension system.

Differences between the two groups can be found primarily in the length of time since amputation – which is longer in the case of Group 2 – and in the cause of amputation (Figs 1, 2 and 3).

Group 1 contains relatively more diabetic patients with accompanying vision and sensitivity complications, whilst Group 2 contained more patients having a traumatic amputation with relatively few associated complications.

This latter group is further divided into two sub-groups. One group had KBM prostheses

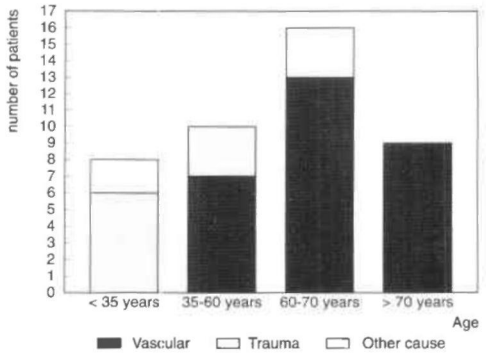


Fig. 1. Cause of amputation: all 43 assessed patients, relation with age.

with a soft inner socket (Group 2a), whilst the other had an older prosthesis type before the ICEROSS, such as a PTB with a leather inner socket, or a conventional prosthesis (Group 2b).

A comparison of the make up of these groups can be found in Table 3.

The group of users with modern prostheses (Group 2a) and the group of users with old-fashioned prostheses (Group 2b) are very similar to each other. They differ mainly with regard to the length of time since amputation, which averages respectively 5.2 years and 16.9 years.

## Results

*Assessment of ICEROSS general features*

In the first few months following the provision of the prosthesis, the groups had all experienced similar problems, namely skin irritation in the form of itching or perspiration. It is interesting to note that after some weeks or months the intensity of these problems diminished markedly, either in combination with anti-perspiration lotion or not.

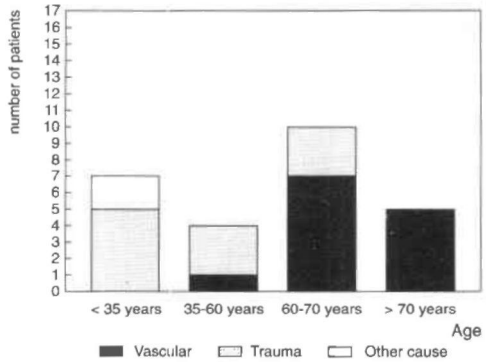


Fig. 2. Cause of amputation: patients with ICEROSS as second appliance, relation with age.

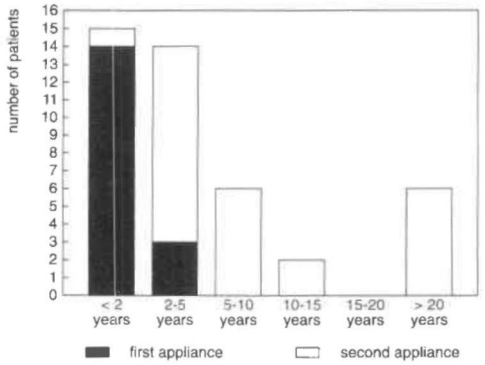


Fig. 3. Length of time since amputation: all 43 assessed patients.

However, compared with the previous prostheses, distinct problems remained.

Table 4 shows how pre-existing skin complaints responded to the ICEROSS for Group 2. Figures 4 and 5 reveal that users of the ICEROSS reacted favourably towards its ease of maintenance and the feeling of hygiene which it gave.

Both groups noted that the donning and doffing processes were simple to carry out. The fact that a number of patients considered it to be worse than their previous prosthesis could be put down to night-time use; the majority of older types of prosthesis could be fitted quickly for going to the toilet, whereas this is not so easy with the ICEROSS.

Table 3. Description of respondents

| | Group 1 | Group 2a | Group 2b |
|---|---|---|---|
| Total | 17 | 13 | 13 |
| Men | 11 | 9 | 11 |
| Women | 6 | 4 | 2 |
| Double amputation | 5 | 0 | 5 |
| Average stump length (cm) | 14 | 14 | 13 |
| Complications | | | |
| vision | 9 | 4 | 2 |
| sensitivity | 7 | 1 | 3 |
| fine motory | 4 | 3 | 3 |
| other | 3 | 2 | 2 |
| Length of time since amputation | | 5.2 | 16.9 years |

Group 1: Patients with an ICEROSS prosthesis as a first appliance.

Group2a: Patients with an ICEROSS prosthesis as a second appliance. The previous appliance was a KBM

Group 2b: Patients with an ICEROSS prosthesis as a second appliance. The previous appliance was not a KBM.

Table 4. Responses of Group 2 with regard pre-existing skin complaints

| | Perspiration | Itching | Soreness | Local pressure | Creasing* |
|---|---|---|---|---|---|
| Decrease | 1 | 0 | 2 | 16 | 0 |
| Increase | 11 | 12 | 8 | 1 | 10 |

*Creasing at the back of knee during knee flexion

As regards cosmesis, many viewed the cord, used to fix the ICEROSS to the socket and visible on the outside of the prosthesis, as annoying.

Criticism of quality primarily focused on the over-stockings which have to be slit at the bottom to facilitate fixture and therefore laddered easily. In two cases the ICEROSS itself appeared to split fairly quickly, particularly at the point where the reinforced lower tip meets the rest of the sock.

*Assessment of the suspension*

Both Groups 1 and 2 reacted positively to the suspension of the ICEROSS on the skin. (Figs. 4 and 5).

Several users appeared to consider the cord, used to connect the ICEROSS to the prosthesis, as insufficiently secure. In some cases it did actually break as a result of insufficient attention having been paid to the wear and tear to which the cord is liable.

This occurred mainly during donning, i.e. in a sitting position, but in two cases it resulted in falls, one of which resulted in a fracture.

*Assessment of pressure distribution*

In 20 of the 26 cases in Group 2, it was pressure problems which caused patients to be changed to the ICEROSS appliance. For 14 persons these problems disappeared with the ICEROSS, for 5 persons there was no change and for 1 person a deterioration was observed.

*Assessment of the functional characteristics*

Groups 1 and 2 for the most part reacted favourably towards the functional effects of the prosthetic appliance.

Figures 6 and 7 show the most significant functional items. When Group 2 were asked for a subjective comparison with their previous appliance, a number of items were emphasised. Walking was said to be improved, when measured in terms of distance, speed and difficulty of conditions (such as an uneven surface), as did stair-climbing.

For the other items there were no clear differences found between the old and the new prostheses. Assessment by previous users of modern (Group 2a) and old-fashioned (Group 2b) prostheses was similar.

## Discussion

For the patients who had changed from an older type of trans-tibial prosthesis to a trans-tibial prosthesis with a roll-on socket, there were initial skin complaints, for example, more perspiration, itching and soreness.

The back of the knee in particular was somewhat adversely affected by the ICEROSS' creasing. For this group pressure sores occurred considerably less frequently with the new prosthesis than the old.

The formation of blisters, localised on the

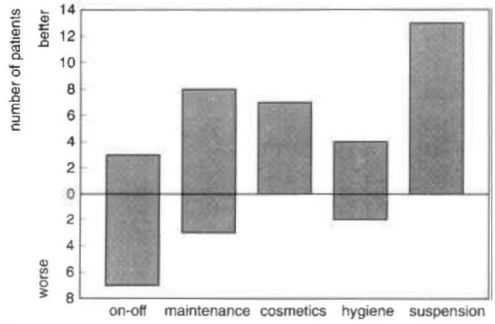


Fig. 4. Assessment of patients: general characteristics. Group 2b: Patients who had not a KBM as previous appliance.

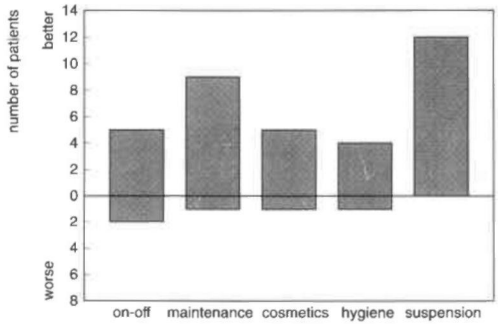


Fig. 5. Assessment of patients: general characteristics. Group 2a: Patients who had a KBM as previous appliance.

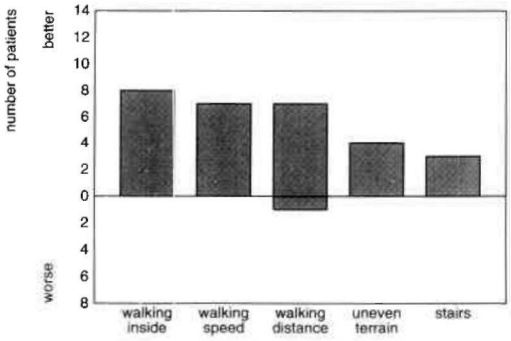


Fig. 6. Assessment of patients: functional characteristics. Group 2b: Patients who had not a KBM as previous appliance.

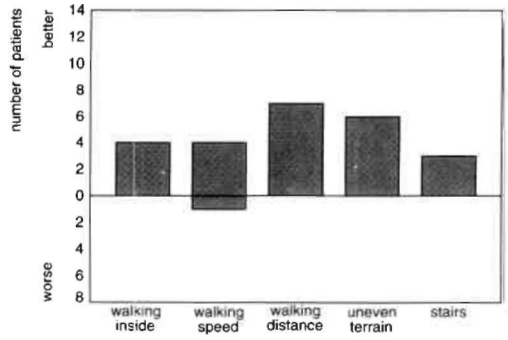


Fig. 7. Assessment of patients: functional characteristics. Group 2a: Patients who had a KBM as previous appliance.

upper lip of the roll-on socket, appeared in general to be a passing phenomenon.

Technical problems appeared to consist primarily of defects to the fixture of the cord between the roll-on socket and the outer socket. This problem has since been satisfactorily overcome by the design of a more durable construction, where the cord is led through the socket in such a manner that rubbing along the sharp edges is prevented, counteracting the effects of wear and tear. Nowadays the "shuttle-lock" closure is more frequently used. Laddering to the over-stockings is currently averted by the prior application of glue at the point where the opening occurs.

*Donning and doffing*

Although more operations are required when donning and doffing the roll-on socket prosthesis, most users did not consider this a problem. For a number of users however it did provide problems when they wanted to do it quickly for going to the toilet at night. A "shuttle-lock" proved to be more appropriate when the vision was impaired.

*Cosmesis*

In comparison with the old prosthesis this aspect was in general favourably received. The cord for the fixture, partly visible on the outside of the prosthesis, was found to be annoying, particularly by women who liked to wear a skirt. This complaint is overcome however, with the used of the "shuttle-lock".

*Suspension*

The improved suspension was clearly the most significant advantage of the roll-on socket. All patients felt positive about this.

*Function*

The findings above illustrated that most patients experienced the change to the roll-on socket as beneficial with respect to function. This applies equally to patients who had used a KBM prosthesis for their previous appliance and those who had previously had a prosthesis with a different suspension.

From the 26 patients who were provided with the roll-on prosthesis as a second appliance, 22 said that they did not wish to go back to the old system, 2 had doubts and only 2 were unsatisfied with the roll-on system.

*Comparisons with existing literature*

In the consulted literature no reference was found to large samples of patients who have worn a roll-on prosthesis. The small numbers of existing samples are generally positive towards the effects attained.

The authors' experiences are, in general, able to support the cited findings in the literature, i.e. the improvement of suspension (Madigan and Fillauer, 1991; Wetz *et al.*, 1992; Roberts, 1986; Kapp and Cummings, 1992) and pressure distribution (Fillauer *et al.*, 1989).

The high level of user satisfaction expressed has led to the situation today where the authors have come to consider the prosthesis with the roll-on socket as the standard appliance for a trans-tibial amputee.

If sufficient care is given to skin complaints which may temporarily arise, and to patient training, it is believed there will be few adverse symptoms. High standards are to be expected

with respect to the knowledge and expertise of the prosthetist and the rehabilitation team must be willing to acquaint themselves with the system.

As regards supply, the extra cost of the roll-on socket in relation to the KBM prosthesis and the extra time demanded of health-care workers may prove problematic.

## Conclusion

The ICEROSS roll-on socket was perceived to be of benefit in a subjective assessment by a group of patients. Previously difficult suspension and pressure problems have been considerably remedied. The numerous skin complaints experienced at the trial stage do not prevent patients from being ultimately satisfied with improvements in respect of suspension and increased function.

As such it is important for rehabilitation teams to be fully aware of these improvements.

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# Energy expenditure of trans-tibial amputees during ambulation at self-selected pace

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**Abstract**

The purpose of this investigation was two-fold: 1) to compare the metabolic cost ($VO_2$), heart rate (HR), and self-selected speed of ambulation of trans-tibial amputees (TTAs) with those of non-amputee subjects; and 2) to determine whether a correlation exists between either stump length or prosthesis mass and the energy cost of ambulation at the self-selected ambulation pace of TTAs. Subjects were thirty-nine healthy male non-vascular TTAs between the ages of 22 and 75 years (mean ± sd = 47 ± 16). All had regularly used their prosthesis for longer than six months and were independent of assistive ambulation devices. Twenty-one healthy non-amputee males aged 27-47 years (31 ± 6) served as controls. Subjects ambulated at a self-selected pace over an indoor course, with steady-state $VO_2$, HR, and ambulation speed averaged across minutes seven, eight and nine of walking. Results showed that HR and $VO_2$ for TTAs were 16% greater, and the ambulation pace 11% slower than the non-amputee controls. Significant correlations were not observed between stump length or prosthesis mass and the energy cost of ambulation. However, when the TTA subject pool was stratified on the basis of long and short stump length, the former sustained significantly lower steady-state $VO_2$ and HR than the latter while walking at comparable pace. These data indicate that stump length may influence the metabolic cost of ambulation in TTAs.

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**Introduction**

The surgical, rehabilitative, and prosthetic management of individuals sustaining amputation from all causes represents a significant challenge for contemporary health care professionals. In the United States alone, the National Centre for Health Statistics estimates that 105,000 to 115,000 amputations are performed annually, of which 25,000 to 30,000 involve loss of limb below the knee. Moreover, the National Health Interview Survey (1983-1985) reported that 268,000 survivors of amputation presently live in the United States. Based upon population growth, the total amputee population would now number nearly 311,000, of whom 77,750 will have undergone trans-tibial amputation (TTA).

The energy cost of ambulation following amputation has long been a topic of concern among physicians, prosthetists, and physical therapists. Related to this concern is the question of an optimal stump length following amputation, an aspect of surgical management which is highly influential in determining the success of post-amputation ambulation. Historically, opinions concerning the effect of stump on efficient prosthetic use date to Yale Medical Institute Professor Nathan Smith, whose lecture notes of 1825 contained the admonition that "as a general rule, you should save all the stump you can" (Sanders, 1986). More recently, investigations have directed their attention toward identifying a stump length for TTA which will optimize prosthetic fit, biomechanical conditions, and limb circulation (Levy, 1983) (Fig. 1).

The majority of studies examining metabolic

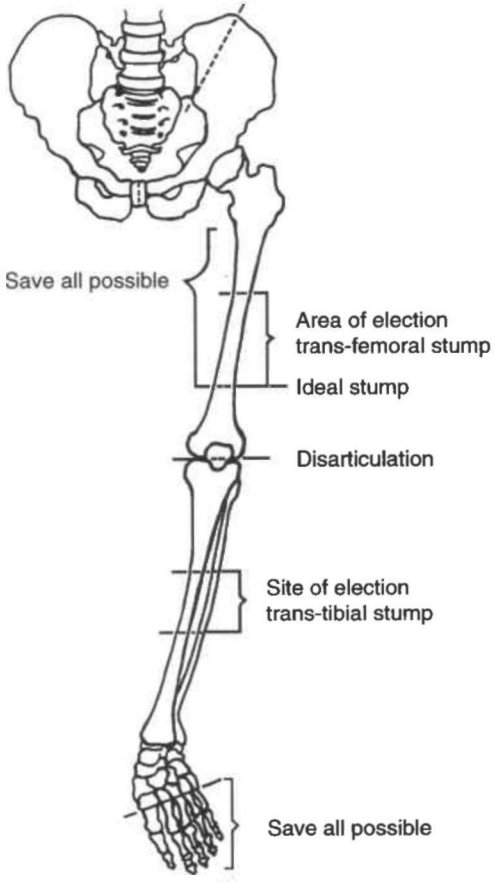


Fig. 1. Commonly accepted levels of amputation. (Adapted, with permission, from Levy, SW: Skin problems of the amputee. St. Louis, Warren H. Green Inc.).

cost of ambulation in TTAs have been cross-sectional in design, comparing subjects of varying stump length during ambulation at various speeds. In studies where correlation between metabolic cost and stump length has been analyzed, the interpretation has been hampered by small sample groups or by subject populations mixed with amputee subjects of traumatic and vascular etiologies. Gonzalez *et al.* (1974) studied 9 subjects with amputation resulting from peripheral vascular disease (n=4), trauma (n=4), and congenital malformation (n=1). The investigation found that a significant inverse relationship existed between stump length and energy expenditure measured during ambulation ($r=0.74$, $p<0.05$). When compared to non-amputee control subjects, amputees having a long stump used 10% more energy, while energy output of those with a short stump was 40% greater. By expressing limb length as a percentage of body height, the investigators then stratified the subjects into groups with short (n=3) and long stump length (n=6). While both groups ambulated at 2.4 mph (64.3m/min) – 22% slower than control subjects – correlational analysis showed no effect of stump length on comfortable walking pace.

Ganguli *et al.* (1974) reported that 20 TTA subjects found 50 m/min (1.86 mph) to be the average comfortable walking speed over a distance of 1 km. Their energy cost was higher when forced to walk at a pace which was slower than comfortable walking speed, and they expended the least amount of energy during walking at a self-selected pace. While ambulating at 50 m/min, non-amputees consumed 0.045 kcal/min/kg, while TTA subjects used 33% more energy (0.060 kcal/min/kg).

To date, Molen (1973) has studied the largest number of amputees from trauma alone. Fifty-four TTA subjects walked on a treadmill at a variety of imposed speeds ranging from 50-90 m/min. Comparison of energy costs of amputee and non-amputee control subjects at matched treadmill speeds showed the former to use 20% more energy. Water *et al.* (1976) studied 70 amputees who varied in level of amputation, cause of amputation, and age. When comparing 13 vascular and 14 traumatic trans-tibial amputees during walking on a 60.5 m track at either self-selected or fastest possible pace, vascular amputees walked 37% more slowly while utilizing 25% more energy than their traumatic TTA counterparts. A control group of 87 men and women was also tested, recording an average walking speed of 82 m/min (3.02 mph).

Collectively, these studies demonstrate general agreement that amputee subjects walk more slowly than non-amputee controls while using more energy. Unfortunately some have investigated small subject populations which challenges study validity as well as the ability to draw statistically significant conclusions; studies of amputee subject populations of mixed etiology may result in an overestimate of energy expenditure of ambulation in traumatic TTAs, as vascular amputees walk more slowly and use

more energy than these individuals; the use of imposed ambulation pace may also overestimate energy expenditure, as walking at self-selected pace for TTAs has been shown to be most energy efficient. Moreover, few studies have attempted to establish a relationship between the metabolic cost of ambulation and specific variables that may directly influence energy expenditure, including stump length, baseline energy expenditure, age, and prosthesis mass. Thus, the purposes of this investigation were to: 1) compare the metabolic cost ($VO_2$), heart rate (HR), and self-selected speed of ambulation of trans-tibial amputees (TTAs) with those of non-amputee controls; and 2) determine whether a correlation exists between either stump length or prosthesis mass and the energy cost of ambulation at the self-selected ambulation pace of TTAs. It was hypothesized that pace of ambulation would be slower in the TTA subjects than non-amputee controls, that their energy expenditure would be greater during ambulation, and that a significant relationship would be observed between energy cost of ambulation, stump length, and mass of prosthesis.

## Methods

*Subjects*

Subjects studied were thirty-nine healthy male non-vascular trans-tibial amputees between the ages of 22-75 years (47 ± 16). All subjects had used their prosthesis for more than six months and were independent of any assistive ambulation devices. Their stumps were free from skin irritation, swelling, or restrictive pain. Additionally, socket design and prosthetist for each subject varied, although all subjects were well-fitted regardless of socket design or components. Twenty-one healthy male non-disabled ambulators aged 24 to 47 years (31 ± 6) served as control subjects. All subjects consented to treatment in accordance with the guidelines of the Medical Sciences Subcommittee for the Protection of Human Subjects of the University of Miami School of Medicine.

*Testing Procedures*

Subjects were instructed to ambulate at their most comfortable pace around an open 36m L-shaped track covered with industrial carpeting. All turns were gently rounded and prompted no changes in the subjects' walking pace. Heart rates were monitored using a Vantage Performance Monitor[1]. Oxygen uptake ($VO_2$) was quantified by open-circuit spirometry using a calibrated Horizon System II Metabolic Measurements Analyzer[2] and a Hans-Rudolph non-rebreathing valve suspended from a stabilizing headset. Baseline $VO_2$ and HR measurements were obtained during one-minute of quiet standing before ambulation. Subjects then walked for nine minutes with data collected at minutes six and nine. Measurements were also taken while standing one minute after cessation of ambulation. Speed of ambulation was determined by dividing the distance travelled during the trial by the total time of ambulation (Fig. 2).

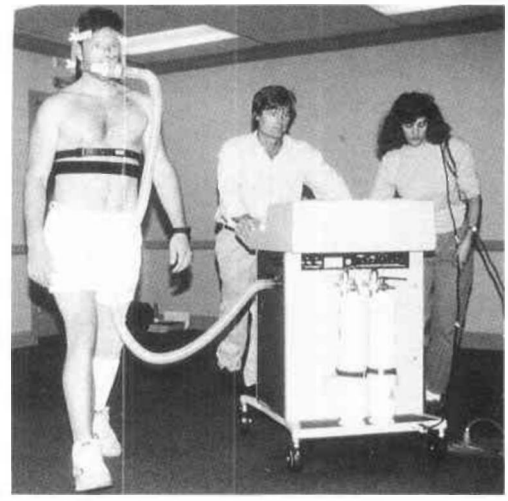

Fig. 2. Subject ambulating while being tested with MMC Horizon Metabolic Cart and Vantage Heart Rate Monitor.

*Prosthesis mass and stump length*

The prosthesis and shoe were weighed (kg) to determine the total mass suspended from the stump. The length of the stump (cm) was measured from the medial tibial plateau to the distal end of the tibia. The stump percentage length was expressed as the ratio of the amputated tibial length to the distance from the medial tibial plateau to the medial malleolus of the intact limb.

[1]Polar Electro Inc., P.O. Box 920, 300 Cottonwood Avenue, Hartland, WI 53029, USA.
[2]SensorMedics Corporation, 1630 South State College Boulevard, Anaheim, CA 92806, USA.

*Data analysis*

Descriptive characteristics were defined operationally as age, speed of ambulation, baseline HR and $VO_2$, prosthesis mass, and length and stump percentage length. Amputee and control subjects were compared for their descriptive characteristics (excluding prosthesis mass and stump length) using independent Student's t-tests. Pearson product moment correlation was used to explore association between descriptive characteristics and post-ambulation HR and $VO_2$. Differences in physiological responses of control and amputee subjects to ambulation were analyzed using a repeated measures ANOVA. Additionally, analysis of co-variance (ANCOV) was performed to control for the effects of observed differences of age and baseline $VO_2$ on ambulation $VO_2$. Multiple linear regression was performed to model the relationship between various descriptive characteristics and ambulation $VO_2$ in amputees.

## Results

Amputee subjects were significantly older than the controls, and while there was no significant difference between the two groups in baseline $VO_2$, the amputee group had a significantly higher baseline heart rate (HR) than the control group (Table 1).

There was no significant difference between amputees and controls in the self-selected speed of ambulation during the trial (Table 2). However, there was a significant difference in both final HR and final $VO_2$. A two-group repeated measure ANOVA was calculated and the time-group interaction was statistically significant ($p<0.005$) indicating that the amputee and control groups differed in the change in mean $VO_2$ following ambulation (Table 3).

In order to understand factors which may contribute to the difference between amputees and controls in their $VO_2$, response to ambulation, correlation coefficients were calculated between the ambulation HR and ambulation $VO_2$ and various amputee and control characteristics. In both the amputee and control groups baseline $VO_2$ and baseline HR were significantly positively correlated with ambulation $VO_2$, and ambulation HR, respectively (Tables 4 and 5). In the amputee group, speed of ambulation was moderately negatively correlated with ambulation HR and moderately positively correlated with ambulation $VO_2$ (Table 4). Stump length was moderately negatively correlated with ambulation $VO_2$ but not with ambulation HR.

A regression analysis was conducted to examine the contribution of various factors to the ambulation $VO_2$ in amputees. Baseline $VO_2$ alone explained 40% of the variance in ambulation $VO_2$. Age, speed of ambulation, and stump length each individually explained between 10 and 18% of the variance. Age was

Table 1. Comparison of amputee and control group baseline characteristics

| Characteristic | Amputee mean | Control mean | p-value[a] |
|---|---|---|---|
| Age (years) | 47.05 | 31.19 | 0.0001 |
| Baseline $VO_2$ (ml/kg.min) | 4.9 | 4.5 | 0.2093 |
| Baseline HR (bpm) | 82.9 | 72.6 | 0.0008 |
| Prosthetic mass (kg) | 2.45 (5.37lb) | | |
| Stump length (cm) | 16.41 (6.46in) | | |

[a] Student's t-test
Amputee group N=39
Control group N=21

Table 2. Comparison of amputee and control group ambulation characteristics

| Characteristic | Amputee mean | Control mean | p-value[a] |
|---|---|---|---|
| Walking speed (m/min) | 69.7 (2.6mph) | 75.0 (2.8mph) | 0.1674 |
| Final $VO_2$ (ml/kg.min) | 12.9 | 10.9 | 0.0051 |
| Final HR (bpm) | 102.5 | 86.5 | <0.0001 |

[a] Student's t-test
Amputee group N=39
Control group N=21

Table 3. Change in $VO_2$ during ambulation by group

| Group | Baseline $VO_2$ | Final $VO_2$ |
|---|---|---|
| Amputee (ml/kg.min) | 4.92 | 12.87 |
| Control (ml/kg.min) | 4.47 | 10.88 |
| **Source of variance** | **F[a]** | **p-value** |
| Group effect | 6.50 | 0.0100 |
| Time effect | 886.98 | 0.0001 |
| Time* Group effect | 8.66 | 0.0047 |

[a] Two group repeated measures ANOVA

Table 4. Association between descriptive characteristics and ambulation outcomes in amputee group

| | Ambulation heart rate | Ambulation $VO_2$ |
|---|---|---|
| Baseline heart rate | 0.7138[a] | 0.0978 |
| | 0.0001[b] | 0.5535 |
| Baseline $VO_2$ | 0.1711 | 0.6351 |
| | 0.2978 | 0.0001 |
| Age | -0.0367 | -0.3575 |
| | 0.8243 | 0.0255 |
| Speed | -0.4750 | 0.4354 |
| | 0.0022 | 0.0056 |
| Prosthesis mass | -0.1285 | 0.0978 |
| | 0.4355 | 0.5538 |
| Stump length | -0.0548 | -0.3223 |
| | 0.7404 | 0.0454 |

[a] Pearson product moment correlation
[b] p-value

not a significant factor when added to a model containing baseline $VO_2$ and speed of ambulation. The final model which contained baseline $VO_2$, speed of ambulation and stump length, explained 63% of the variance in ambulation $VO_2$ (Table 6).

The effect of prosthetic mass on ambulation $VO_2$ was examined by dividing the amputee group into those who have had heavy prostheses – operationally defined as of mass greater than 2.27kg (5 pounds) (N=23) and those who had light prostheses, defined as of mass 2.27kg (5 pounds) or less (N=16). Significant effects testing the stratified heavy and light prosthetic groups were limited to the mean prosthetic mass. Differences in mean stump length

Table 5. Association between descriptive characteristics and ambulation outcomes in control group

| | Ambulation heart rate | Ambulation $VO_2$ |
|---|---|---|
| Baseline heart rate | 0.7693[a] | 0.1231 |
| | 0.0001[b] | 0.5949 |
| Baseline $VO_2$ | 0.0829 | 0.7144 |
| | 0.7210 | 0.0003 |
| Age | 0.0800 | 0.1909 |
| | 0.7302 | 0.4070 |
| Speed | 0.0815 | 0.3941 |
| | 0.7254 | 0.0771 |

[a] Pearson product moment correlation
[b] p-value

Table 6. Factors predicting ambulation $VO_2$ in amputees

| Model | R-square | F | p-value |
|---|---|---|---|
| 1. Baseline $VO_2$ | 0.4034 | 25.017 | 0.0001 |
| 2. Age | 0.1278 | 5.421 | 0.0255 |
| 3. Speed | 0.1895 | 8.654 | 0.0056 |
| 4. Stump length | 0.1038 | 4.288 | 0.0454 |
| 5. Baseline $VO_2$ Speed | 0.5465 | 21.691 | 0.0001 |
| 6. Baseline $VO_2$ Speed Age | 0.5671 | 15.284 | 0.0001 |
| 7. Baseline $VO_2$ Speed Stump length | 0.6277 | 19.667 | 0.0001 |

approached statistical significance (Table 7). An analysis of co-variance was performed to test for the difference between the heavy and light prostheses groups in ambulation $VO_2$ adjusting for possible confounding factors. Even after controlling for stump length, age, speed of ambulation and baseline $VO_2$, there was no significant difference in ambulation $VO_2$ between the heavy and light prosthetic groups (Table 8).

## Discussion

The stump lengths of subjects presently under study were representative of common practice for persons undergoing TTA, and similar to those observed in TTA subjects previously studied. The subjects in this study had an

Table 7. A comparison of heavy versus light prostheses

| Factor | Light[a] prosthesis | Heavy[b] prosthesis | p-value |
|---|---|---|---|
| Prosthesis mass (kg) | 2.0 (4.5lb) | 2.7 (5.9lb) | 0.0001 |
| Stump length (cm) | 15.2 (5.98in) | 17.3 (6.80in) | 0.0884 |
| Age (yrs) | 50.6 | 44.6 | 0.2660 |
| Baseline HR (bpm) | 85.9 | 80.8 | 0.1220 |
| Ambulation HR (bpm) | 103.8 | 101.6 | 0.5061 |
| Baseline $VO_2$ (ml/kg.min) | 4.8 | 5.0 | 0.6997 |
| Ambulation $VO_2$ | 12.4 | 13.1 | 0.3411 |
| Speed (m/min) | 67.0 (2.5mph) | 72.4 (2.7mph) | 0.2561 |

[a] Light defined as prosthesis weighing 2.27kg (5lb) or less. N=16.
[b] Heavy defined as prosthesis weighing more than 2.27kg (5lb). N=23

Table 8. Comparison of ambulation $VO_2$ between heavy and light prostheses controlling for possible confounding

| Model | Adjusted $VO_2$ (light) | Adjusted $VO_2$ (heavy) | R-square | p-value for means equal |
|---|---|---|---|---|
| 1. Mass group | 12.44 | 13.15 | 0.0245 | 0.3411 |
| 2. Mass group stump length | 12.15 | 13.36 | 0.1692 | 0.1010 |
| 3. Mass group Stump length age | 12.32 | 13.20 | 0.2769 | 0.1894 |
| 4. Mass group Stump length Age Speed | 12.44 | 13.15 | 0.3497 | 0.3010 |
| 5. Mass group Stump length Age Speed Baseline $VO_2$ | 12.51 | 13.11 | 0.6695 | 0.2279 |

average stump length equal to 40% of their unaffected limb, with a mean stump length of 16.41cm (6.46 in). This is within the range commonly recommended by surgeons when the amputation site is not dictated by trauma, tumour or vascular considerations. For example, Levy (1983) has advised that a site 12.7 to 17.8cm (5 to 7in) below the knee joint is ideal for TTA, as it represents a length that allows for the muscular padding of the gastrocnemius and soleus muscles used in the posterior flap technique. While this length might be optimal for surgical construction of the amputation stump, the question as to whether a longer stump might result in improved gait, increased ambulation speed, or might minimize energy cost of ambulation for persons with traumatic amputation has received limited attention.

The subject-selected comfortable walking speed (CWS) and energy expenditure of TTA in this study were similar to those reported in two other studies. Gonzalez *et al.* (1974) described an ambulation speed of 64 m/min at an oxygen consumption of 13.06 ml/kg.min in a mixed population including TTAs of peripheral vascular etiology. Pagliarulo *et al.* (1979) reported that 15 traumatic TTAs walked at 71 m/min with an energy expenditure of 15.5 ml/kg.min. The 39 non-vascular TTAs in the present study walked at an average pace of 67.1 m/min and an energy cost of 12.9 ml/kg.min, 5% slower using 2% less energy than subjects studied by Gonzalez *et al.*, and 5% slower with 17% lower metabolic expenditure than those reported by Pagliarulo *et al.*

The length of the stump following amputation has long been considered an important factor in determining the energy cost and speed of walking. This difference has best been demonstrated when comparing energy cost of ambulation between trans-femoral and trans-tibial amputees, in which the metabolic cost of walking in the former is higher, and the speed of ambulation slower. To date, however, Gonzalez *et al.* (1974) have performed the only study specifically addressing the relationship between stump length and ambulation energy cost in TTAs, in which a significant negative correlation was observed between stump length and energy cost. These findings differ from those reported herein when subjects were not segregated by long and short stump length. This observation suggests that small differences in stump length might have minimal impact on metabolic consequences of ambulation in these subjects. In contrast, stratification of subjects on the basis of long and short stump length suggests that sparing as much limb as possible may desirably influence both walking pace and energy utilized during walking.

In order to understand factors contributing to differences in metabolic response between amputees and non-amputee controls, correlation coefficients were calculated between the ambulation HR and ambulation $VO_2$ as well as various amputee and control characteristics. In both the amputee and control groups, baseline $VO_2$ and baseline HR were significantly positvely correlated with ambulation $VO_2$ and ambulation HR, respectively (Tables 4 and 5). Interestingly, in the amputee speed of ambulation was moderately negatively correlated with ambulation HR and moderately positively correlated with ambulation $VO_2$ (Table 4). Stump length was moderately negatively correlated with ambulation $VO_2$ but not with ambulation HR. Thus, a paradox exists in which HR and $VO_2$, which normally respond in parallel fashion during submaximal work, do not respond this way in trans-tibial amputee subjects. The basis for this paradox is not immediately clear, but may represent a loss of the feedback from joint, tendon and muscle

movement sensors, as well as muscle chemical receptors, which normally regulates the heart response to work in the intact lower limb. While HR and $VO_2$ responses to work throughout the submaximal exertional range are normally positively correlated in persons without amputation, the HR response is also influenced by peripheral neurogenic input which may be lost or diminished in a limb without a distal leg, ankle joint, and foot.

A regression analysis was conducted to examine the contribution of various factors to the ambulation $VO_2$ in amputees. Interestingly, baseline $VO_2$ alone explained 40% of the variance in ambulation $VO_2$, a finding which implicates level of fitness as a major factor influencing the metabolic cost of ambulation. Otherwise, subject age, speed of ambulation, and stump length each individually explained between 10% and 18% of the variance. Age did not significantly influence ambulation. $VO_2$ when added to a model containing baseline $VO_2$ and speed of ambulation. The final model which contained baseline $VO_2$, speed of ambulation and stump length, explained 63% of the variance in ambulation $VO_2$ (Table 6).

Prosthetic manufacturers and prosthetists have long been concerned with minimizing the mass of the amputee's prosthesis. During the past two decades, use of lightweight materials including titanium and carbon graphite composites have decreased overall prosthesis mass, in some cases, by half. Prosthetic limb mass in this study (which included the shoe) ranged from 1.59 to 3.4 kg (3.5 to 7.5 lb) (mean $\pm$ sd = 2.45 $\pm$ 0.4 kg). It was interesting to observe however, that prosthesis mass did not explain a significant percentage of the variance observed in ambulation $VO_2$. Moreover, when controlling for stump length, age, speed of ambulation, and baseline $VO_2$, there was no significant difference in ambulation $VO_2$ between groups that were segregated on the basis of heavy and light prostheses. One might normally expect that additional mass of the prosthetic limb would penalize the heavy prosthesis user through higher energy cost. While significant effects of mass on energy cost might be unmasked by testing during longer ambulation periods, heavier prosthetic limbs might also stimulate musculoskeletal and cardiopulmonary adaptations favouring greater tolerance of the additional mass. This finding is important, especially as considerable emphasis is placed during prosthesis design and fabrication on minimizing its mass, emphasis possibly at the exclusion of componentry or materials which might favour improved function and decreased energy expenditure. Moreover, the small advantage provided by a lightweight prosthesis might eventually be buffered by user characteristics including age, gait mechanics, level of fitness, or training effects imposed by the mass of the prosthesis itself. However, as not all trans-tibial prosthesis users are young and fit, these results may not be generally applicable to those with deteriorating vascular conditions, sensory loss in the amputated limb, muscle dysfunction, or cardiac impairment. Nonetheless, and within the boundaries of successful amputation procedure and proper prosthetic fitting, an optimal "window of mass" might exist in which a device provides optimal function without excluding the use of selected componentry on the basis of excessive mass. For example, if a rotation device or locking mechanism, once thought to be contraindicated due to mass considerations, could be incorporated into the prosthesis, function might be improved without increasing the energy cost of walking.

Moreover, physicians and prosthetists have generally credited longer stump lengths with specific advantages, including: 1. longer lever arm; 2. greater muscle capacity; and 3. greater load bearing capability.

## Conclusion

It was concluded that:

1. Non-vascular TTAs in the present study walked at an average pace of 67.1 m/min and an energy cost of 12.9 ml/kg.min which is comparable to that reported by other investigators.
2. A significant effect of stump length on metabolic cost and speed of ambulation was observed when TTA subjects were stratified by long and short stump length. This indicates that while small differences in amputation level might have minimal impact on metabolic consequences of ambulation in these subjects, sparing as much limb as possible may desirably influence both walking pace and energy utilized during walking.

3. Resting $VO_2$ explained 40% of the variance observed in ambulation $VO_2$, a finding which implicates level of fitness as a major factor influencing the metabolic cost of ambulation. To a lesser extent, age, speed of ambulation, and stump length each represent meaningful factors in predicating energy cost of walking.
4. Prosthesis mass did not significantly alter ambulation $VO_2$, and when controlling for stump length, age, speed of ambulation, and baseline $VO_2$, no significant difference in ambulation $VO_2$ was observed between groups that were segregated by heavy and light prostheses.
5. Absence of a significant effect of prosthesis mass on $VO_2$ may be explained by musculoskeletal adaptation to heavier prostheses. As the mass of the prosthesis does not apparently affect the amount of energy expended during walking this might suggest greater use of accessories such as rotators and multi-axial feet and other componentry that might improve ambulation gait and efficiency.

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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

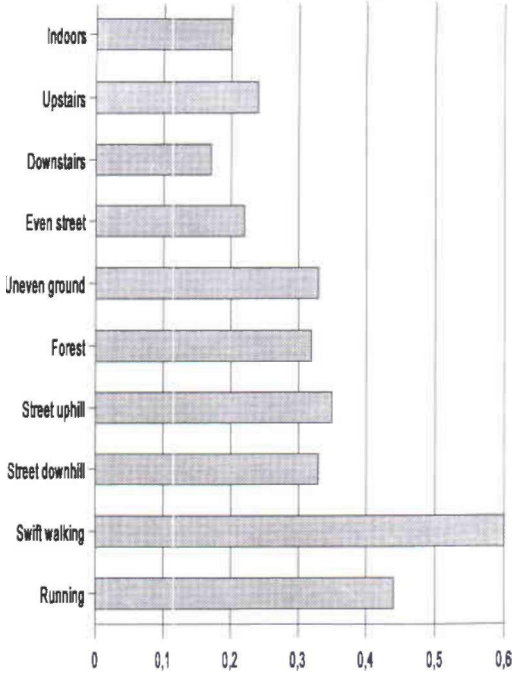


Fig 1. The means of the differences in scores of subjective walking disability (scale: 0-3) between ES and CP among trans-tibial amputees illustrating the benefit of the ES prosthesis in different situations.

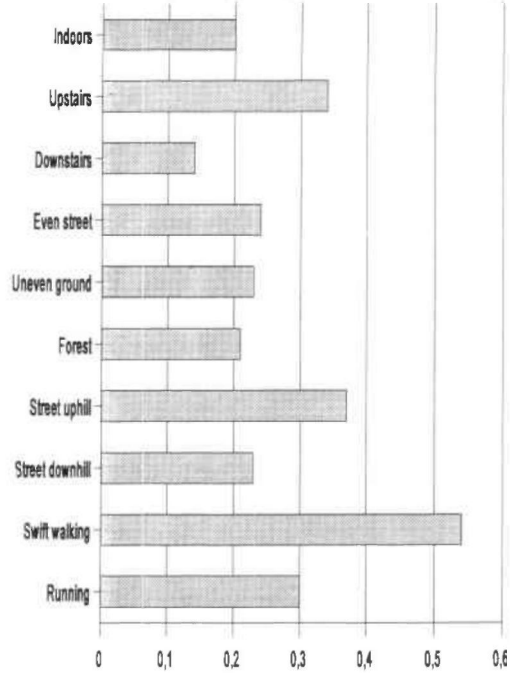


Fig 2. The means of the differences in scores of subjective walking disability (scale: 0-3) between ES and CP among trans-femoral amputees illustrating the benefit of the ES prosthesis in different situations.

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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# A new modular six-bar linkage trans-femoral prosthesis for walking and squatting

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**Abstract**

Four-bar linkage mechanisms produced by many designers of knee joints for trans-femoral prostheses can provide knee rotation to permit walking only. In Afro-Asian countries people are accustomed to a squatting posture in their daily activities. A six-bar linkage knee-ankle mechanism trans-femoral prosthesis is described which was developed and fitted to an amputee. The motion patterns of the ankle, knee and thigh during walking and squatting (obtained using a flickering light emitting diode system) for the above prosthesis is compared with motion patterns obtained for normal subjects. The closeness between both the patterns establishes the suitability of the new modular trans-femoral prosthesis for producing near normal patterns of motion during walking and squatting. The additional facility of cross-legged sitting provided in the prosthesis makes it functionally suitable for Afro-Asian amputees.

## Introduction

People in Afro-Asian countries are in the habit of sitting in a squatting posture for many activities starting from the use of the toilet to farming operation and in cross-legged sitting posture for relaxation and during their daily prayers. Amputees wearing usual trans-femoral prostheses are not in a position to perform the above functions. Most of the models for trans-femoral prostheses are of single knee axis with solid ankle except a few which have the provision for ankle dorsiflexion (Radcliffe and Lamoreux, 1972; Seliktar and Kenedi, 1976) and polycentric action at the knee joint (Radcliffe and Lamoreux, 1972; Cortesi, 1975; Cappozzo *et al.*, 1980). The required amount of ankle dorsiflexion with knee flexion during squatting is not possible with any of the existing models except for one (Chaudhry *et al.*, 1972) designed so far. But this model is an exoskeletal single axis prosthesis which makes it difficult to provide a proper cosmetic cover. This being a fixed, single axis knee, requires more effort at the start of flexion during stance phase than the polycentric knee prosthesis. This is because of the smaller effective lever arm of the single axis prosthesis as compared to the polycentric knee axis prosthesis.

In normal walking two major muscle groups of the lower limb control the swing phase of walking. The prosthetic leg without any swing phase control arrangement at the knee joint behaves like a pendulum and without any control produces an unnatural gait. In earlier designs this problem was solved by mechanical means or by providing frictional resistance at the knee joint (Murphy, 1964). Later different hydraulic control systems (Lewis, 1965) were introduced. The disadvantage of a mechanical frictional resistance system lies in the fact that this system cannot produce natural gait. Moreover, these devices get damaged due to wear. The hydraulic control unit can provide a better control of swing but generally due to the

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weight of the unit the prosthesis becomes heavy and also due to leakage of oil the prosthesis becomes dirty. On the other hand, when a pneumatic control is provided at the knee joint both the above disadvantages can be removed and a better walking pattern can be achieved. The pneumatic swing phase control unit was first developed in the Biomechanics Laboratory at the University of California (Radcliffe and Lamoreux, 1968; Zarrugh and Radcliffe, 1976). But this prosthesis is not able to provide the knee ankle coordinated motion necessary for squatting. Therefore, it was felt necessary to develop a new prosthesis which (i) can provide the basic requirement of a stance phase stability with proper polycentric action (such that the hip ankle reference line during stance phase passes in front of the variable knee axis), (ii) should be of modular design and will provide ease of walking and sitting in and rising from the squatting posture, (iii) should be able to provide swing phase control.

In this paper, details of a new modular six-bar linkage trans-femoral prosthesis, with facilities for (i) swing phase control, (ii) coordinated motion between knee and ankle (provided by a six-bar linkage), (iii) squatting and (iv) cross-legged sitting, are described. The prosthesis is fitted to an amputee and his motion patterns (obtained experimentally) are compared with normal patterns.

## Methodology

The prosthesis designed and developed for different functional improvement is shown schematically in Figure 1. Different functional capabilities of the prosthesis are described below.

### *Polycentric action at knee*

The trans-femoral prosthesis has a six-bar linkage arrangement at the knee (Fig. 2) by which the motion from the thigh can be transmitted to the foot during squatting action and during the swing phase of walking. The four bars 'a', 'b', 'c' and 'd' form a four-bar linkage mechanism with a short posterior link 'c', designed after several trials, so as to create an instantaneous centre in full extension located well above a corresponding single axis knee centre and posterior to the hip ankle line. This results in stability of the prosthesis during stance phase. With little effort of the hip

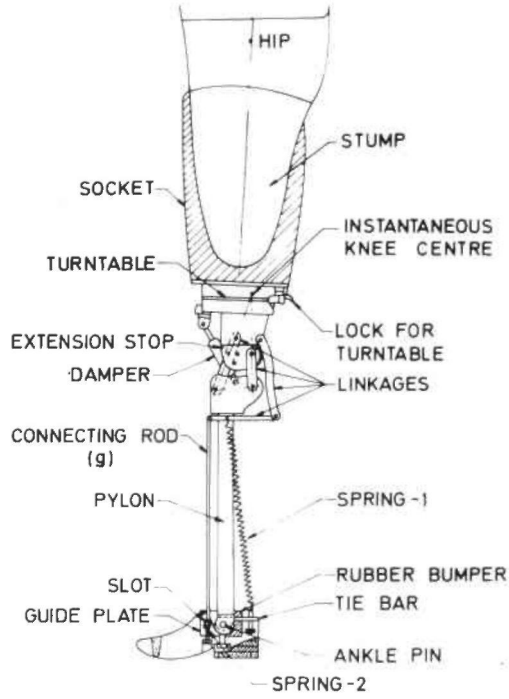



Fig. 1. Schematic diagram of the new modular six-bar linkage trans-femoral prosthesis.

muscles, flexion can be initiated and the instantaneous centre moves rapidly down to the natural position of the anatomical knee joint. Up to 10° of knee flexion, the centre of rotation is well above the location of a single axis knee joint, thus the amputee will be able to control both extension and flexion voluntarily over this critical range of motion. With this linkage arrangement a flexion angle of 150° can be achieved for squatting action.

### *Coordination of knee-ankle motion during squatting*

To achieve the coordinated knee-ankle motion during sitting in the squatting posture two links 'e' and 'f' (Fig. 2) are arranged in such a fashion that the links 'e' and 'f' with the four bar linkages 'a', 'b', 'c' and 'd' form a six-bar linkage mechanism consisting of two loops CABDC and GFEBDG. An analysis of relative rotations between the linkages was carried out by solving two vector loop equations obtained from the dimensions and orientations of the linkages. With thigh motion, the relative rotation obtained between the link 'b' and link 'f' is transferred to the ankle by connecting a

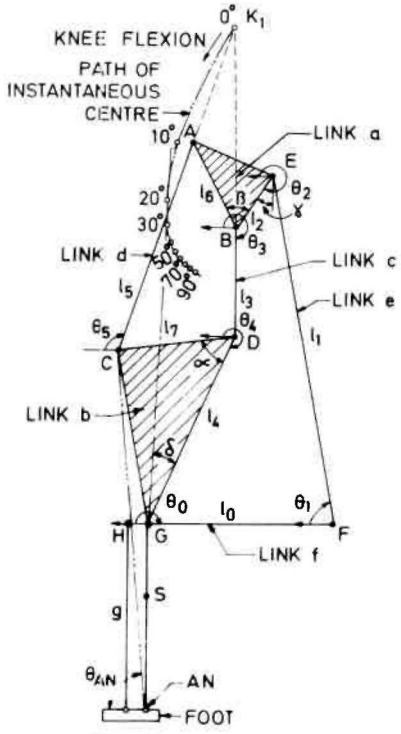



Fig. 2. Six-bar linkage knee-ankle mechanism used in the new prosthesis.

rod 'g' in parallel with the pylon connecting the anterior end of the link 'f' to the foot unit. The position of the pivotal point E and dimensions and orientations of links 'e' and 'f' were selected after several trial solutions of the above mentioned loop equations so as to have a variation of knee and ankle angles with the thigh angles similar to those of normal persons.

The position of links in the mechanism and the locus of instantaneous knee centre for rotation of the thigh unit relative to the shank is shown in Figure 3. During squatting the upward movement of the lower end of the connecting rod 'g' is restrained by the upper end of a slot provided at the foot and the shank rotates forward with knee flexion to provide the co-ordinated flexion of the ankle joint.

*Ankle dorsiflexion and plantarflexion during walking*

During normal walking after heel strike the ankle undergoes plantarflexion of about 8° until the foot flat position, after which the shank rotates forward with foot flat on the ground to provide a dorsiflexion of about 13°, before heel off. With knee flexion after heel off, the ankle angle starts increasing by rotation of the foot pivoting at the toe. Dorsiflexion at the ankle joint after midstance facilitates a smooth pattern of walking. In the case of a SACH or conventional foot flexion at the ankle joint is very limited and the amputee has to follow an unnatural gait by raising the hip with much physical effort. In the present design to provide facilities of dorsiflexion after midstance and plantarflexion after heel off, the lower end of the connecting rod 'g' is allowed to move in a slot (Figs. 1 and 6) provided in the foot unit. Normally when the prosthesis is straight i.e. when knee flexion is zero the pin connected at the lower end of the rod 'g' touches the upper surface of the slot thus restricting the relative movement between the shank and the foot and thus behaves almost as a single foot-shank unit during the early phase of stance. The initial plantarflexion at heel strike is obtained by the compression of a rubber bumper provided behind the ankle joint. A spring (marked 2 in Figure 1 and marked 12 in Figure 6 inside the slot) and the rubber bumper facilitate a

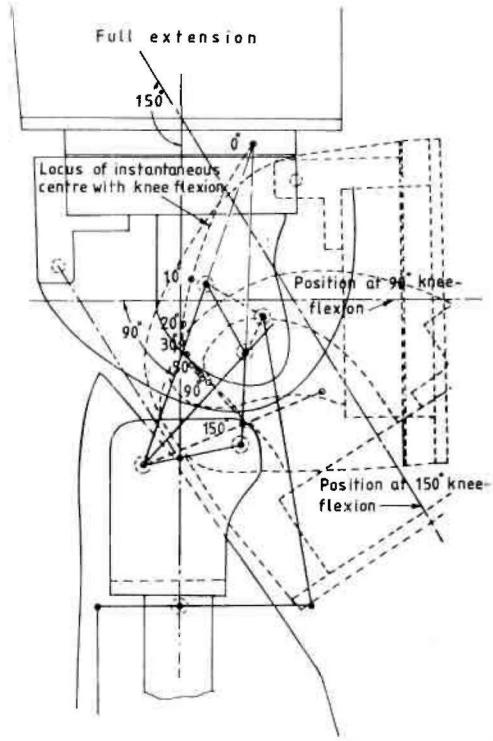


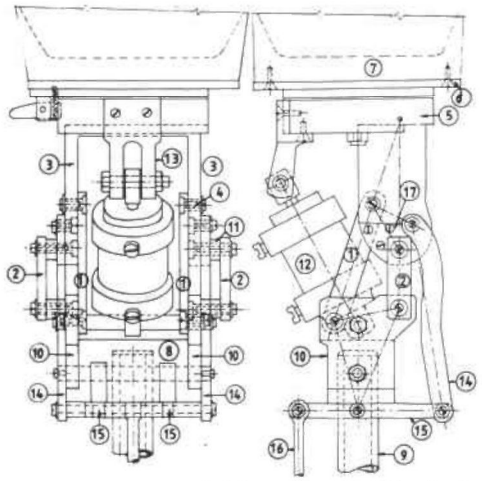

Fig. 3. Locus of instantaneous knee centre for rotation of thigh relative to shank up to 150° of flexion.

restraining action at ankle during plantarflexion. A relatively strong tension spring (marked 1 in Figure 1) connected to the pylon at a point posterior to the ankle joint facilitates rising from the squatting position and is also useful in minimising the inherent knee instability during flexion by resisting ankle dorsiflexion.

Although a total of eight links are used for transferring motion from thigh to foot, the prediction of motion of the prosthesis and estimation of forces in the pneumatic damper have been obtained from the kinematic analysis of the two loop equations for a six-bar linkage knee mechanism consisting of the linkages 'a', 'b', 'c', 'd', 'e' and 'f'.

*Swing phase control*

During the normal swing phase of walking the motion of the foot and shank is controlled by quadriceps muscles during flexion and by hamstring muscles during extension of knee. Quadriceps action restricts excessive heel rise after push off and provides acceleration in the initial part of swing phase followed by deceleration by hamstrings so as to have smooth entry (heel strike) into the next stance phase. In the trans-femoral prosthesis to achieve similar control during swing phase, a pneumatic damper may be provided between thigh and shank at the knee joint. This damper is basically a double acting cylinder with a piston moving inside. With knee flexion and extension, the air inside the cylinder is compressed and provides resistance to pendulum motion of the shank. On the top and bottom end of the cylinder, provisions are made for air leakage to achieve resistance characteristics similar to resisting moments developed in natural knee joint during swing phase.



1. Anterior links
2. Posterior links
3. L. Brackets
4. Internal threaded pins
5. Turn table
6. Top plate
7. Socket
8. Lower block
9. Pylon
10. Plates
11. Spacers
12. Pneumatic damper
13. Damper holder
14. Links
15. Links
16. Connecting rod
17. Extension stop

Fig. 4. Details of knee unit.

*Cross-legged sitting*

Sitting on the ground in cross-legged posture is a regular habit in Afro-Asian countries. A provision is made in the present design for cross-legged sitting with the help of a turntable located above the knee joint (in the thigh portion) of the prosthesis. A lock is provided to prevent motion of the turntable during walking. Before sitting in cross-legged posture the lock is operated manually to allow the rotation of the shank about the thigh axis.

*Modular and endoskeletal design*

The prosthesis is made of high strength aluminium and the different parts fabricated separately, are assembled together to provide an endoskeletal structure. The modular design by its fabrication facilitates mass production and replacement of parts of the prosthesis. The dimensions of different linkages are selected such that the endoskeletal structure can be provided with a soft cosmetic cover.

## Details of the mechanical design of the prosthesis

The mechanical design description of different parts of the prosthesis are given below.

*Knee unit*

The knee unit (Fig. 4) consists of two sets of aluminium linkages (part numbers 1 and 2) connecting the upper and lower portions of the joint. The anterior links (1) are longer than the posterior links (2). The upper ends of the linkages are connected to two L-brackets (3) by specially designed internally threaded pins and screws (4), so that the joints can provide mobility during motion. The L-brackets are fitted to the back of the turntable (5). A thin plate is fitted to the top of the turntable to connect the whole unit with the socket (7). The socket is made of moulded resin cast from the positive mould of the amputee's stump.

The lower portion of the knee unit is fitted to the shank and it consists of an aluminium block (8) to which the pylon (9) is fitted. Two specially shaped aluminium plates (10) are fitted on both sides of the lower block. The lower ends of the linkages for knee rotation are connected to these plates. The planes of rotation of the shorter links and longer links are separated by spacers (11), so that the upper part of the knee joint can move freely relative to the lower part of the knee mechanism up to 150° of knee flexion without any interference from link motion. Space is provided in between the two L-brackets for fitting the swing phase control unit (12) which is connected to the upper portion of the knee unit at the desired position by a bracket (13). The lower portion of the swing phase control unit is connected to the block (8) of the lower portion of the knee unit.

To transmit the knee motion to the ankle, another set of links (14) and (15) are connected between the upper portion and the lower portion of the knee unit. The links (14) are connected at suitable selected points on the L-brackets and links (15) are pivoted at intermediate points of the pylon vertical axis. The two sets of links are connected together at their ends. The projected ends of the link (15) are connected to the foot and ankle unit by a connecting rod (16). An extension stop (17) is provided to stop hyperextension of the prosthesis during stance phase.

*Turntable*

The turntable consists of two aluminium circular discs; the upper one fitted inside the groove of the lower one to provide sufficient bearing surface (Fig. 5). Steel balls provided between the two discs act as ball-bearings and minimize friction and facilitate smooth relative rotation between them. A tension spring is fitted inside along a circular groove, connecting the top and bottom discs. When the bottom disc rotates counter clockwise relative to the top disc during cross-legged sitting, the spring is extended and helps, when it is released, the lower portion of the prosthesis to come back to its initial position. The turntable can rotate 110° of axial rotation for ease of sitting in the cross-legged position. In order to avoid any accidental rotation of the prosthesis about the long axis during walking a locking arrangement is provided. In the normal position of the prosthesis this lock will hold the two discs together. At the time of cross-legged sitting the lock has to be manually operated for unlocking. The upper disc and the lower disc are connected by a central bolt.

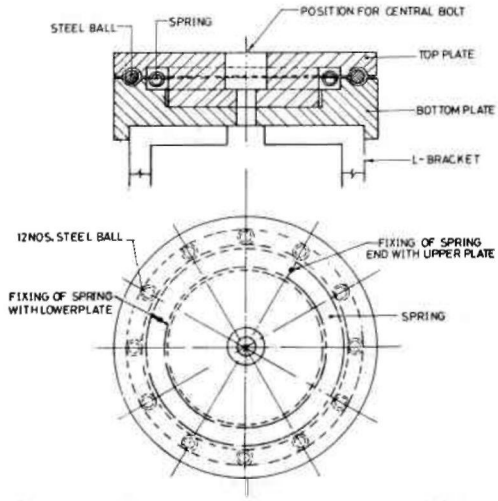



Fig. 5. Details of turntable used for cross-legged sitting.

*Pneumatic damper*

The pneumatic damper consists of an aluminium cylinder inside which a brass piston moves. The cylinder is closed by two aluminium caps on each end. The caps are each provided with a one way check valve to allow the air to enter into the chambers when the piston is moving away from the ends. When the piston moves towards the cap after compressing the air for a specified distance, a spring-loaded pin is pressed to leak the air through a throttling valve. The lower connecting point of the damper is adjusted so that the piston can be fully extended up to 60° of knee flexion after which the extension of piston will cease for further flexion of the knee during squatting. The force developed inside the cylinder can be adjusted by the flexion throttling screw or the extension throttling screw (as the case may be), thus providing the necessary resistance for control of swing. The fully extended length of the damper is 140 mm.

*Foot and ankle unit*

The conventional foot used in the trans-femoral prosthesis has generally a wooden solid ankle with the provision of heel cushioning and toe flexion by rubber blocks. In the present design

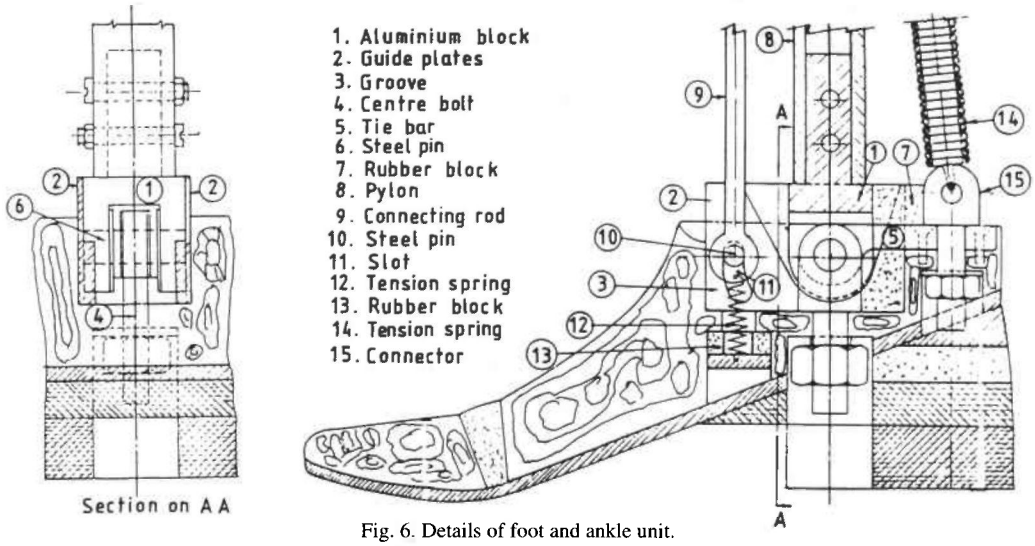



Fig. 6. Details of foot and ankle unit.

the foot has been modified to provide ankle flexion during walking and squatting (Fig. 6). An ankle unit fabricated separately, is fitted in a groove made in the wooden ankle block of the foot unit.

An U-shaped aluminium upper block (1) rests on two guide plates (2) which are embedded in a rectangular groove (3) on the foot unit at the ankle position. This upper block is connected with the foot unit by a central bolt (4) and a tie-bar (5). A steel pin (6) connecting the upper block, central bolt and a tie-bar is supported on both sides by the walls of the guide plates. The central bolt is fitted with the foot from the bottom side by a nut. The tie-bar is screwed to the wooden portion of the foot on the posterior side. This arrangement helps in resisting the horizontal force transmitted to the ankle joint during motion. A hard rubber block (7) is placed at the posterior side of the upper unit to resist the ankle plantarflexion. The pylon (8) is connected to the upper U-block. The lower end of the connecting rod (9) from the knee unit is connected to the ankle unit by a steel pin (10) which is allowed to move along a slot (11) made on both guide plates to allow ankle dorsiflexion and plantarflexion during walking. To provide additional resistance to ankle plantarflexion at heel strike, the free end of the rod (9) is loosely connected to the foot by a tension spring (12) and a plate (which is cushioned by a rubber block (13)). A tension spring (14) is connected from the pylon rod to the back side of the ankle unit by a nut and bolt arrangement (15) to provide the necessary resisting force to ankle dorsiflexion during squatting and to help the foot to rise after heel off during walking. The total mass of the prosthesis is 4 kg which is much less than the mass of the lost limb of the amputee.

## Results

Figure 7 shows computed variations of knee and ankle rotations with thigh rotation as independent variable during squatting posture for the selected dimensions of the links of the prosthesis. The analytical graphs for the prosthesis mechanism for knee and ankle rotations are obtained by giving the thigh rotations obtained experimentally from normal walking as input to the loop equations. Corresponding normal patterns are superimposed on Figure 7 and it is observed that the pattern, given by the prosthetic mechanism closely follows the normal pattern of squatting.

The walking pattern of the amputee, wearing the trans-femoral prosthesis was recorded using a modified method of flickering light emitting diode system originally proposed by Soderberg and Gabel (1978) and as detailed below. Flickering light emitted diodes (LEDs) are fitted at hip, above and below the knee joint, ankle joint, toe and heel. In addition four LEDs (of different colour) are fitted at the pivoting points

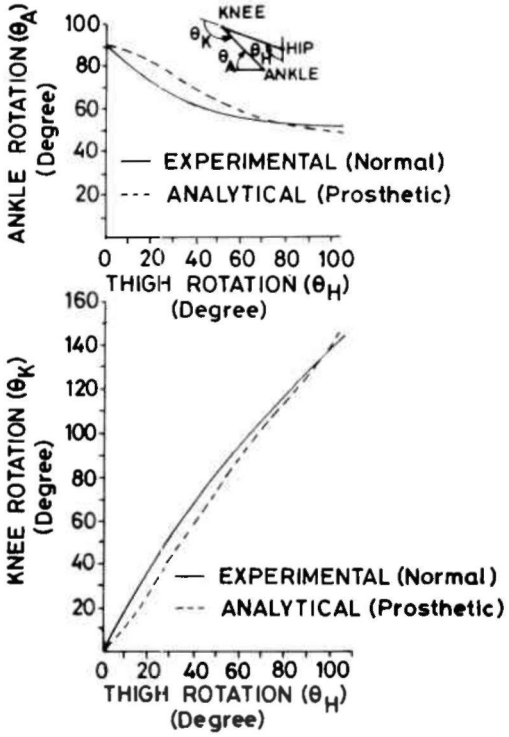



Fig. 7. Knee and ankle angle variations during squatting.

of the four-bar linkages (a b c d) to record the motion of the relative centre of rotation of the shank and thigh, required for the dynamic analysis of the prosthetic motion. The LEDs connected with the toe and heel switches are attached to thigh and shank portions of the prosthesis to record the temporal factors of walking. When the amputee is walking, motions of flickering LEDs are recorded on a single frame of a colour film using a still camera whose shutter is kept open in a dark room during one complete cycle of walking. The displacement pattern of hip, knee, ankle joints and toe of the prosthesis, recorded on the film, are projected on a screen and a stick diagram is drawn.

The direction of the line passing through the hip and centre of contact of the foot with the ground (obtained from the force platform, recorded simultaneously with the walking pattern) and the position of instantaneous knee centres for the rotations of the thigh relative to the shank of the prosthesis, are drawn for different phases of amputee walking (Fig. 8). The positions of instantaneous knee centres with reference to lines joining the centre of contact of the foot with the ground and hip joint for different phases, indicate that the design is suitable for providing stability during stance phase with little voluntary control of hip musculature and is also suitable for easy flexion during push off phase.

From the analysis of the six-bar linkage knee mechanism during prosthetic walking the motion of the different points of interest on the prosthesis can be predicted when the co-ordinates of the hip displacement and angular rotation of the thigh (obtained from LEDs

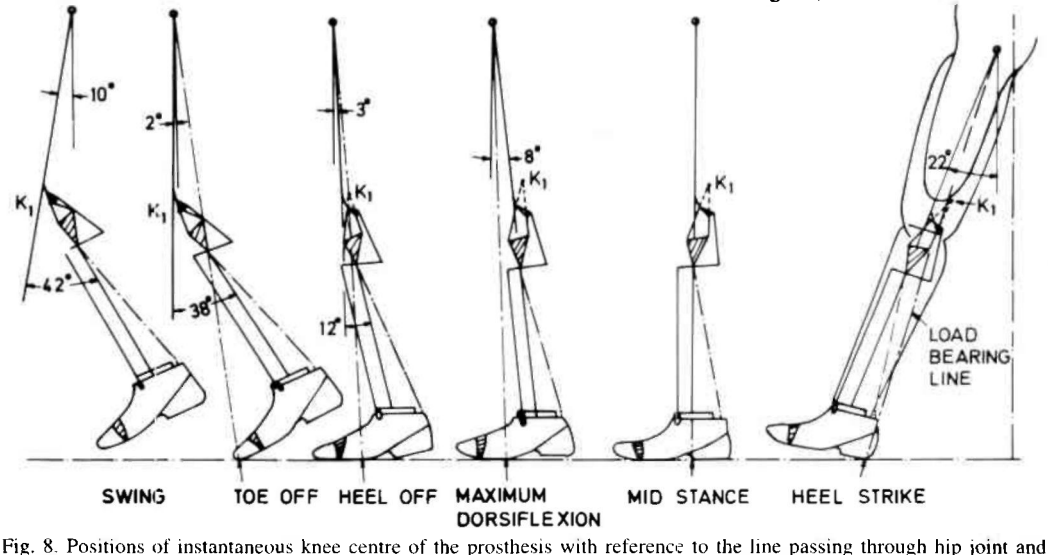



Fig. 8. Positions of instantaneous knee centre of the prosthesis with reference to the line passing through hip joint and centre of contact of foot with ground at different phases of walking

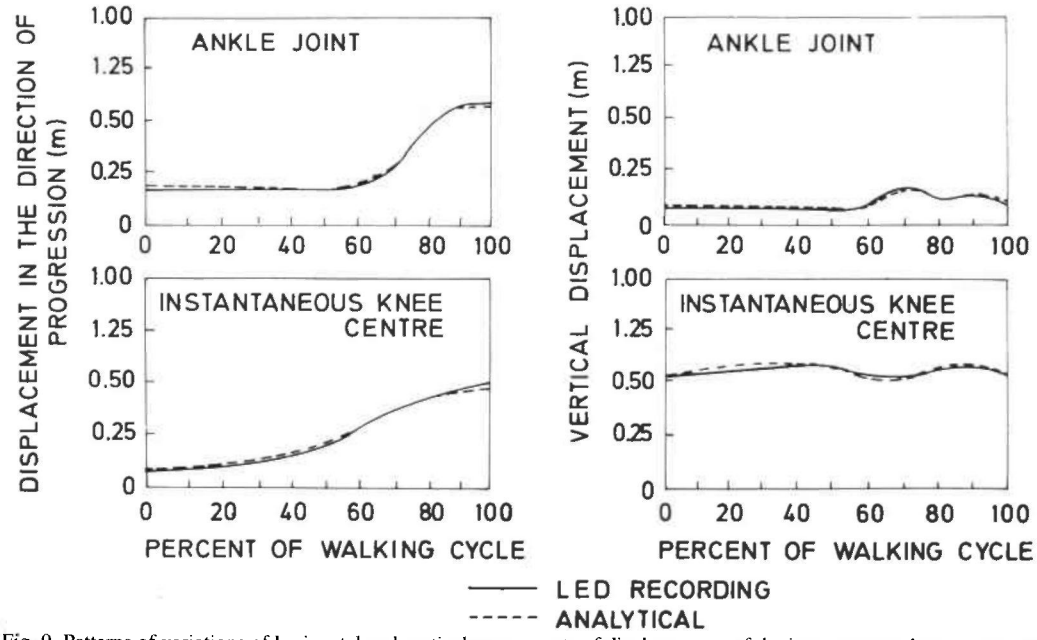



Fig. 9. Patterns of variations of horizontal and vertical components of displacements of the instantaneous knee centre and the ankle joint.

study) are given as input. Figure 9 shows typical variations of horizontal and vertical components of displacements of the instantaneous knee centre and the ankle joint. The corresponding patterns obtained by LED recording of amputee walking pattern are superimposed for comparison. The results show close agreement between the analytical and experimental values.

A comparative study, of normal walking, prosthetic walking using the newly designed prosthesis with pneumatic damper and the old conventional single axis prosthesis, was carried out (Fig. 10). It is observed that the motion patterns are closer to that of the normal than the corresponding patterns for the amputee wearing the conventional prosthesis.

The pressure developed inside the two chambers of the pneumatic damper during knee flexion was recorded by properly mounted pressure sensitive transducers mounted on the flexion and extension chambers of the damper. The transducer is a piezo-resistive type and its resistance changes in accordance with the pressure acting on it above the atmospheric pressure. The output pressures are recorded simultaneously with the ground reaction forces obtained from the force platform during amputee walking. The pressures in the flexion chamber and extension chamber are in the order of 580 kPa and 210 kPa, respectively. A hardly audible noise (due to exhaustion of the air from the pneumatic chambers into the atmosphere) is heard during amputee walking and this does not cause any discomfort either to the amputee or the surroundings.

To examine the effect of the pneumatic damper on the walking pattern, the amputee walking patterns wearing the new prosthesis are recorded both for prosthesis fitted with and without pneumatic damper. Figure 11 shows the variations of (i) relative rotations, (ii) relative angular velocities and (iii) relative angular accelerations at knee during amputee walking fitted with the new prosthesis with and without pneumatic damper. It is seen that the new prosthesis with pneumatic damper has a relative knee angle pattern similar to the normal pattern (Fig. 10). But the prosthesis without pneumatic damper gives rise to higher relative angular accelerations of the knee (at the end of stance and beginning of swing phase) as compared to the corresponding values for the new prosthesis provided with pneumatic damper. Comparing the angular variations at knee for the new prosthesis with and without pneumatic damper, it is found that the prosthesis fitted with pneumatic damper has a pattern more closely

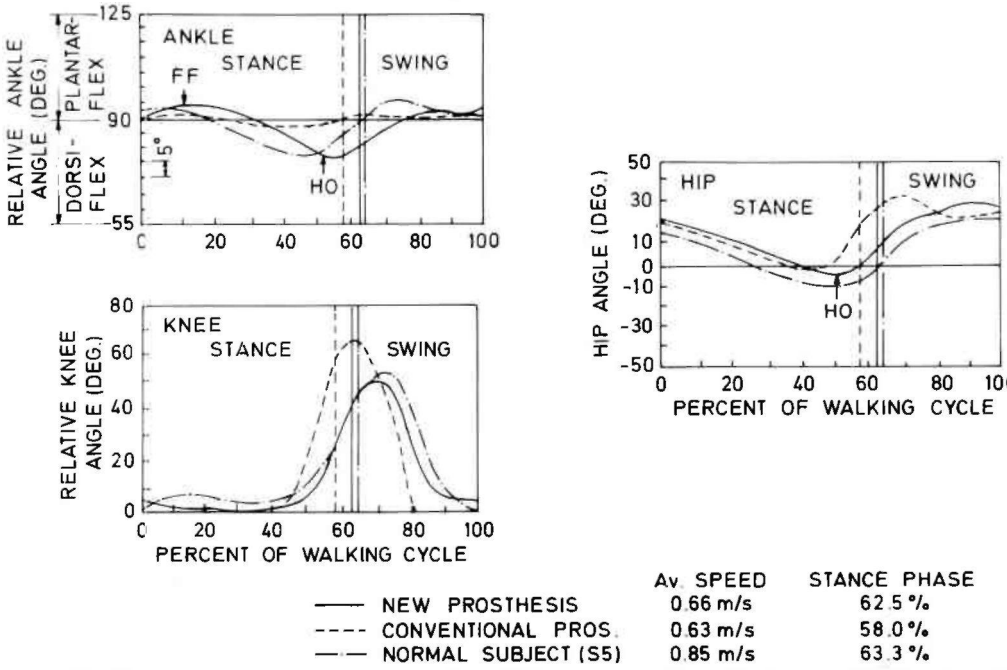



Fig. 10. Relative angular rotations of ankle, knee and hip during amputee walking with (i) new prosthesis and (ii) single knee axis conventional prosthesis and their comparison with the corresponding patterns for normal subjects.

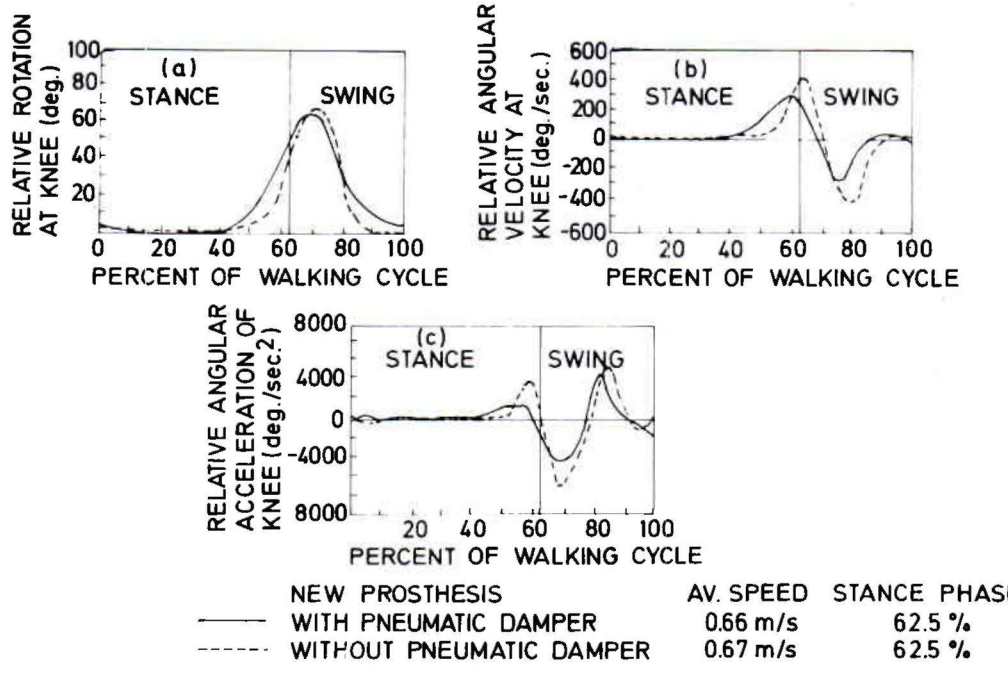



Fig. 11. Variations of (a) relative rotations, (b) relative angular velocities and (c) relative angular accelerations at knee during amputee walking with new prosthesis with and without pneumatic damper.

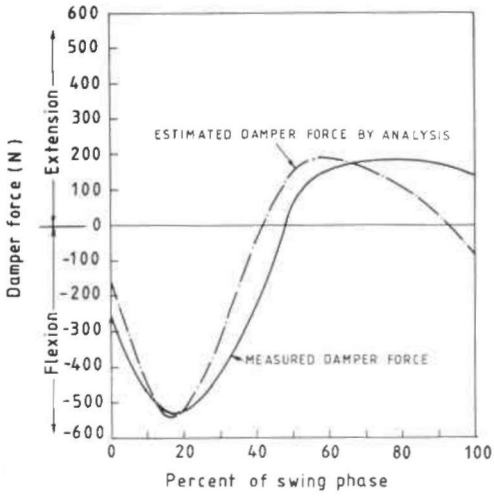



Fig. 12. Variations of forces in pneumatic damper during swing phase of walking obtained from dynamic analysis of prosthesis and experimental measurements.

following the pattern for the normal subject.

The damper force (obtained by multiplying the recorded pressure by the cross-sectional area of the respective chamber), is plotted as a percentage of swing phase (Fig. 12). Damper forces obtained from the dynamic analysis of swing phase of amputee walking is superimposed on the experimental measured pattern. The result shows a close agreement between estimated damper forces and the measured values.

Figure 13 shows the amputee wearing the new prosthesis in walking, squatting and cross-legged sitting postures. It is observed that the new prosthesis is able to provide considerable improvement in reproducing normal motion patterns of ankle, knee and hip angles as compared to a conventional trans-femoral prosthesis.

## Conclusions

Positions of the instantaneous knee centre of the prosthesis with reference to the hip ankle reference line drawn at different phases of walking showed stability of the prosthesis during stance phase and ease of flexion for the initiation of swing. The motion patterns, of ankle, knee and hip during walking and squatting, obtained experimentally for the six-bar linkage mechanism trans-femoral prosthesis, were compared with the corresponding patterns obtained for normal subjects. The closeness in the two patterns establishes the suitability of the new prosthesis for producing near normal patterns of motion during walking and squatting.

The cross-legged sitting feature makes it functionally suitable for Afro-Asian amputees. The modular nature of the prosthesis enables variation of the size of the pylon very easily to suit different heights of amputees and makes the mass production of parts possible, thereby potentially reducing the cost of production. The endoskeletal nature of the prosthesis facilitates

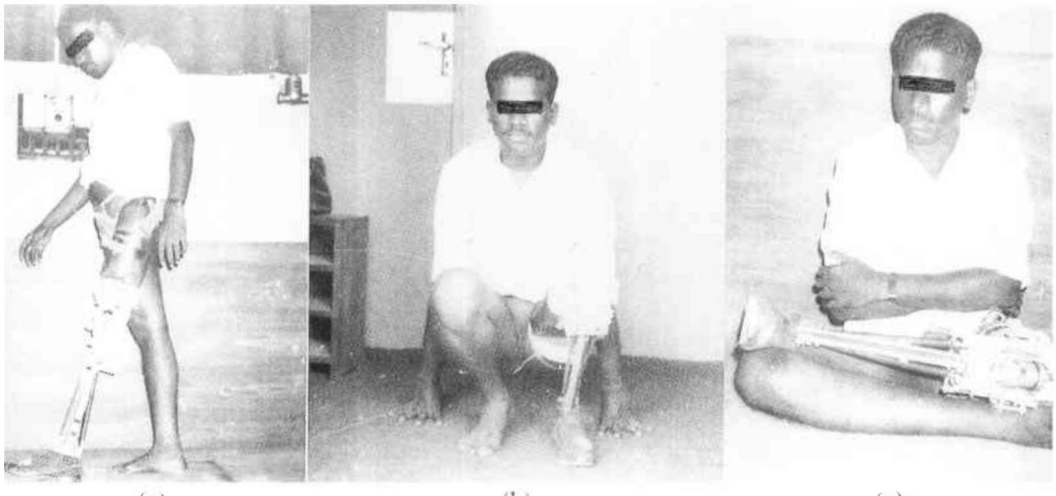



Fig. 13. The amputee (a) walking, (b) squatting and (c) sitting with the new prosthesis.

the provision of a suitable cosmetic cover in the future development of the prosthesis.

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## Clinical note

# Amputation and reflex sympathetic dystrophy

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**Abstract**

Reflex sympathetic dystrophy is a chronic pain syndrome characterized by chronic burning pain, restricted range of motion, oedema and vasolability. Patients are difficult to treat and the prognosis is very often poor. This report emphasizes that an amputation in case of a reflex sympathetic dystrophy is mostly due to a too late recognition of this syndrome. In the international literature little is written about an amputation as a therapy for reflex sympathetic dystrophy. It is only mentioned as a therapy in the end stages of this syndrome. Sometimes a rejected amputation, as in this case report, can have a relatively good result. An early recognition of this pain syndrome produces the best possible outcome.

**Introduction**

Reflex sympathetic dystrophy (RSD) is a pain syndrome in which the pain is accompanied by loss of function and evidence of autonomic dysfunction (Amadio *et al.*, 1991). There are many definitions in the literature and many names are used, such as Sudeck atrophy, neurovascular atrophy, painful osteoporosis and algodystrophy (Ascherl and Blumel, 1981). Mostly pain (burning) in an extremity, oedema, restrained range of motion, hyperaemia, hyperaesthesia, alterations in sweating and skin alterations are mentioned in the definition (Amadio *et al.*, 1991; Geertzen *et al.*, 1994; Poplawski *et al.*, 1983). The etiopathogenesis remains uncertain. The initial cause may be a traumatic or surgical injury of the peripheral nerves but can also be a fracture or another trauma in the peripheral tissues. Sometimes vascular or cardiac disorders or diseases of the central nervous system can be the provoking cause.

All kinds of therapy are used with different results. Physical therapy, occupational therapy, regional intravenous blocks with guanethidine or brethyllium (Hannington-Kiff, 1974), stellate ganglion blocks, oxygen free radical scavengers (Goris *et al.*, 1987; Veldman *et al.*, 1993), corticosteroids and psychotherapy (Lynch, 1992). Sometimes in an end-stage reflex sympathetic dystrophy amputation is suggested. Few papers concerning this problem have been published (Erdmann and Wynn-Jones, 1992; Eyres *et al.*, 1990; Rohrich *et al.*, 1987; Szeinberg-Arazi *et al.*, 1993). Most articles concern case reports and are of a descriptive nature. Erdmann and Wynn-Jones (1992) describe two patients who were amputated (both trans-humeral amputations) two and three years after recognition of the RSD and one was successfully fitted with a prosthesis. Eyres *et al.* (1990) describe only one patient whose leg (trans-fermoral) was amputated after a RSD. The preoperative pain was abolished; nothing is said about the functional outcome. In the Rohrich *et al.* (1987) study one patient is mentioned who underwent a distal trans-radial amputation 21 years after the RSD syndrome. Nothing is said about the functional outcome. Szeinberg-Arazi *et al.* (1993) reported on 12 patients with RSD of which 10 underwent an amputation of the affected limb (7 lower limb amputations). None of the patients who had undergone upper-limb amputations used their prostheses. Of the 7 lower limb amputation patients 6 used their prostheses frequently. All patients required a prolonged support structure to aid them in coping.

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There are doubts about an amputation as a treatment in the end-stage of the RSD syndrome especially in the light of new publications concerning the influence of psychosocial aspects in this syndrome (Geertzen, *et al.*, 1994; Van Houdenhove *et al.*, 1992). A very unusual case of reflex sympathetic dystrophy is presented following a lateral epicondylitis.

## Case report

A 28-year-old man presenting in the department of surgery had pain from his left elbow during several months. The patient was right-handed. The medical history revealed 13 different operations, an additional 5 admissions to a general hospital for different complaints and one admission into a psychiatric hospital. A psychologist recently advised not to operate on this patient (only when life was at stake) because of the high risk for recurrences. A lateral epicondylitis (a "tennis" elbow) was diagnosed on the basis of the history of pain and the acute tenderness at the origin of the extensor muscles of the forearm. The patient had to carry heavy weights every day for his occupation (garbage collector). Therapy was advised and the patient received at first two injections with steroid followed by a few weeks of rest. After this rest period without result his arm was immobilized in plaster of Paris. This treatment also was without result. Then he was operated by a general surgeon; the extensor origin was stripped from its attachment on the lateral epicondyle (Homan procedure). The pain disappeared but the elbow became unstable. After consulting several specialists, he was again operated (6 months later). A reconstruction of his lateral ligaments was performed followed by 6 weeks of immobilisation in plaster of Paris. Hereafter persistent pain followed. The diagnosis of RSD was proposed and confirmed. The following symptoms were seen: atrophy of the muscles and skin, discolouration of the skin, hyperhidrosis, restricted range of motion, dysaesthesia and osteoporotic changes on the X-rays. Rehabilitation followed and the patient received a combination of physiotherapy, occupational therapy, orthotic management and medication (analgetics). He refused guanethidine blocks. A psychiatrist was consulted and asked to see the patient. The conclusion was that there were signs of conversion and neuroticism. No treatment was proposed. In the meantime the arm became afunctional (Fig. 1). An electromyographic study confirmed that there was neurogenic lesion. Five years after the Homan procedure the patient asked for an amputation through his upper arm because of the pain. The orthopaedic surgeon agreed because of the existence of multiple small wounds on the afunctional left hand and arm. In the meantime he was fitted with an orthosis for protection (Fig. 2). The psychiatrist and rehabilitation specialist opposed amputation because of his psychiatric history and for fear of the so-called "salami-technique".

Six months later the amputation was performed through his left upper arm. His post-operative recovery was uneventful. Now, two years after his amputation, the patient is very satisfied and only occasionally has pain in his stump. There is no phantom pain; fitting a prosthesis was not successful mainly because the patient refused to wear it.

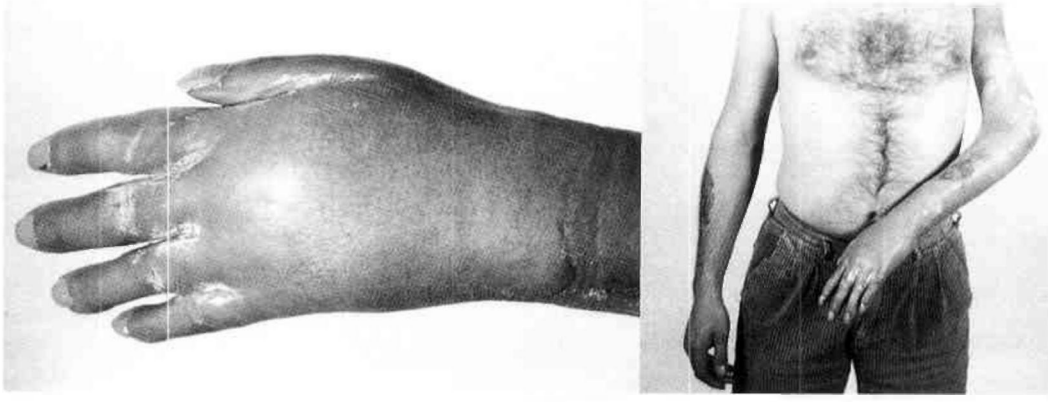

Figure 1. The patient with afunctional arm.

Figure 2. The protective orthosis.

## Discussion

RSD occurs in 5-7% of all traumas (Hardy and Meritt, 1988). This syndrome is characterized by chronic (burning) pain, restricted range of motion, oedema and vasolability. There are many described therapies with reported results. All treatments are based on elimination of the etiological factors.

In the case reported here all signs of a RSD were present. However this patient showed an extensive medical and psychiatric history. An earlier psychiatric consultation and treatment might have averted this amputation. In the Department of Rehabilitation many patients with an RSD are seen but this is the only one who resulted in amputation. There is much discussion about whether to amputate in the end stage of an RSD syndrome or not. Despite the relatively good result reported here, the patient stopped complaining and is mainly painfree, however, it is stressed that an amputation in case of an RSD must be withheld if possible. Because the psychological patterns become stronger in the duration of the RSD syndrome a recurrence of a new pain (RSD) syndrome may arise after an amputation. There is sparse literature on this subject, so in each case one has to weigh the advantages and disadvantages for the patient. Nowadays the therapy provided consists of giving free radical scavengers (Goris *et al.*, 1987), occupational therapy, physiotherapy and if necessary psychotherapy (stress management).

The authors believe that the early diagnosis of the RDS gives the best functional outcome for the patient.

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**Technical note**

# A CAD analysis programme for prosthetics and orthotics

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**Abstract**

A CAD (computer aided design) analysis software package (CADVIEW) was designed for use with prosthetic and orthotic CAD CAM (computer aided design/computer aided manufacture) systems. Using the Microsoft Windows 3.1 environment, CADVIEW provides a series of anatomical shape viewing and analysis tools. These tools include simultaneous display of multiple sockets and multiple views, two dimensional (2D) and three dimensional (3D) measurement, shape statistics, multi-shape alignment, cross-sectional comparison, colour coded 3D comparison, resolution enhancement, and image copying capabilities. This programme should be of benefit to clinicians and researchers who wish to assess and/or compare CAD data generated by MS-DOS based CAD CAM systems.

## Introduction

As prosthetic and orthotic CAD CAM systems become integrated into clinics and workshops, the assessment and analysis capabilities available with this digital storage format can create new opportunities for patient evaluation. The potential of CAD CAM as an educational and analytical tool has previously been documented in a variety of sources (Bednarczyk *et al.*, 1992; Fernie *et al.*, 1984; Sidles *et al.*, 1989).

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To analyse changes in limb volume, a manual digitiser/computer analysis system was developed by Bednarczyk *et al.* (1992). Analysis software was written to determine the effects of clinical interventions on limb oedema. By digitising an anatomical shape into a computer and using the resulting three-dimensional (3D) coordinates to estimate limb volume at various stages during treatment, a quantitative measure of volume changes with time was obtained. Although this system was sufficient for measuring volumes, it lacked the graphical and analytical tools necessary to examine prosthetic and orthotic devices.

Fernie *et al.* (1984) used a laser scanning CAD system to examine student prosthetist fitting methods. Plaster positive models from sixteen students (96 fittings) were digitised before and after modification and input into a graphical display package. The teacher and student could examine sagittal and coronal profile views and three transverse cross-section images. Initially the clinicians had difficulty interpreting the two-dimensional (2D) output; however, interpretation improved as these people became familiar with the system. This quantitative method was considered beneficial since more information was available to assess student fittings over the brief trial period. While this approach was better than the technique of Bednarczyk *et al.* (1992), the necessity of using a laser scanner and the lack of 3D graphical display and analysis limited the global application of this system.

Sidles *et al.* (1989) outlined a software tool

that used 3D graphics to compare the results of two socket designs. Their software package compared two digitised socket shapes based on the distances between the surfaces and graphically displayed a composite view of the differences (for example a CAD CAM socket and a manually made socket). The composite view involved displaying one socket on the screen with the differences at each point on the surface represented by a corresponding colour or shade. This technique was effective for education (comparing a student's sockets to an "ideal fitting"), clinical studies, research, and in improving fabrication design tools.

Although previous systems have addressed specific educational and analytical needs, a comprehensive analysis package would provide the tools necessary to examine patient shape characteristics from CAD generated data. This document describes a computer programme (CADVIEW) which offers a series of analysis tools for MS-DOS based, prosthetic and orthotic CAD CAM systems. This software provides features that are presently unavailable in current, MS-DOS based, prosthetic CAD CAM programmes including: display of multiple sockets and multiple views, 3D measurement, shape statistics, multi-shape alignment, cross-sectional comparison, colour coded 3D comparison, and resolution enhancement.

## Methods

The CADVIEW software package was developed to offer a consistent and user friendly environment for viewing, comparing, and analysing CAD generated anatomical shapes. To fulfil these objectives, the Microsoft Windows 3.1 environment was selected as the appropriate software platform since it was:

- a common system for MS-DOS based computers
- a standardised, user friendly, graphical interface
- compatible with most computer hardware (i.e., graphic cards, printers, etc)
- able to run multiple programmes concurrently
- able to transfer data and images between programmes.

While CADVIEW can work with data from any prosthetic CAD CAM system, current input options include CANFIT-PLUS and IPOS Systems II CAD data files. The user may load either raw digitised data, measurement generated data, or CAD modified data. Anatomical landmarks are loaded and displayed as part of the raw digitised or CAD modified data file. The following sections will describe the viewing, analysis, and comparison tools included with this software.

### *Image presentation*

#### *Multiple document interface*

CADVIEW implements a multiple document interface approach for image presentation. This environment allows the user to open a series of socket data files or socket views from within the main CADVIEW window. The ability to display and simultaneously view multiple images is only limited by available memory and screen space. A multiple document interface is beneficial for viewing a series of sockets from the same client, teacher versus student sockets, or different fitting approaches. Multiple 2D images can also be displayed, thereby permitting visual comparison of cross-sections or profiles at different positions on the 3D shape.

#### *Three dimensional view*

A satisfactory 3D representation of the socket/orthosis shape is very important for viewing and comparing CAD data files. By combining the graphics capabilities of Microsoft Windows, facet shading techniques, and a resolution enhancement function, a lifelike on-screen image can be displayed. In addition to the shaded view, the 3D image can be displayed as a wireframe or composite (shaded imaged with superimposed wireframe). The wireframe view is the fastest to redraw on screen and provides useful reference marks when measurements are being taken from specific locations on the shape. A shaded view, while taking longer to redraw, provides the best representation of surface contour. Anatomical landmarks recorded during the digitising process may be displayed on the 3D shape to provide comparison reference points.

The 3D shape may be rotated in the frontal plane, sagittal plane, and about the image longitudinal axis, thereby displaying the shape in any 3D orientation. A cubic reference box is located in the rotate window to help with shape positioning. Since the three rotation angles are entered numerically, the user can ensure that

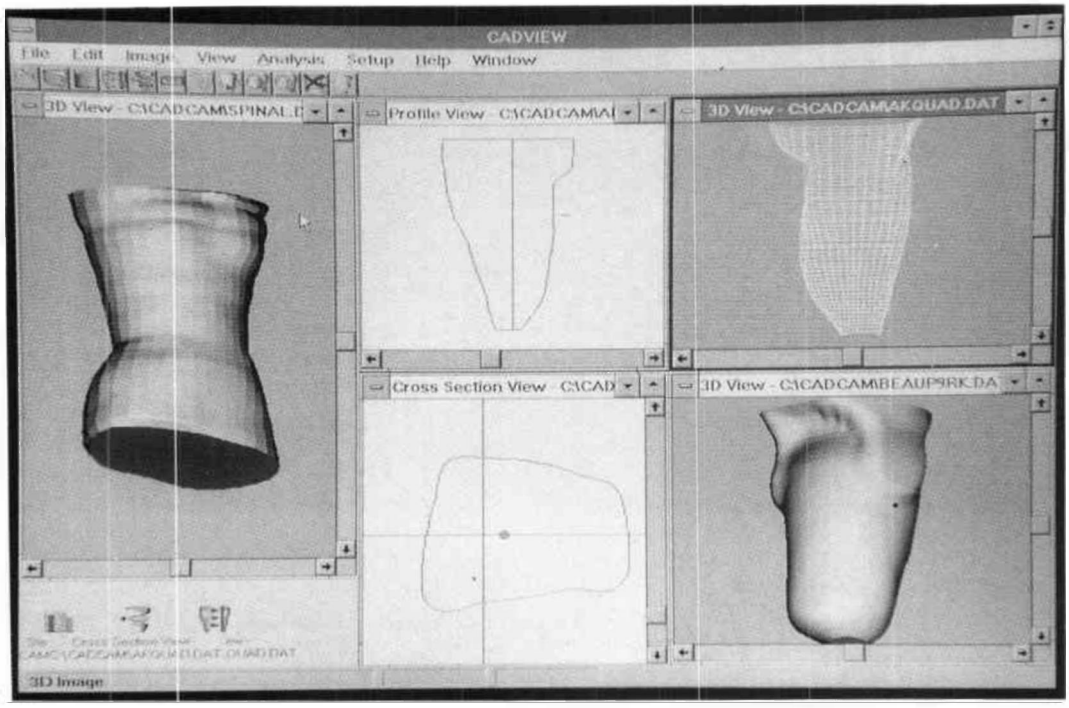


Fig 1. Multiple document interface.

multiple shapes are aligned correctly before comparison. As well as shape rotation, the image may be moved about the screen or enlarged to better assess individual regions.

*Resolution enhancement*

In cases where insufficient digitised data points are available to create a satisfactory on-screen image, a mathematical interpolation option is provided to increase image resolution. Initially, a linear interpolation was used to add points to the cross-section and profile views; however, this approach did not have any effect on improving the 3D image. Since the slope between data points remained constant the angle between new surfaces and the light source was unchanged, thereby causing all surrounding surfaces to be shaded the same colour. To deal with this problem, a cubic spline interpolation was used to calculate new cross-sections along the length of the shape and new data points on each cross-section. While increasing the image resolution increases redraw time, a three to five factor resolution enhancement can produce a near photographic quality image of the prosthetic/orthotic shape.

*Two dimensional views*

Multiple cross-section and profile views can be displayed on screen for each 3D image. Cross-section or transverse slice images are useful for viewing shape contour, taking medio-lateral or anteroposterior measurements, and changing the socket statistics display. Profile sections, or longitudinal slices, are useful for viewing the complete shape at different angular positions, making length measurements, and changing the symmetry statistics. To help compare 2D or 3D images, the cross-section and profile locations are simultaneously displayed on the 3D image as a thin line.

***Image transfer***

Using the standard *Copy* transfer procedure, a clinician may transfer 2D or 3D images between CADVIEW and most other Microsoft Windows programmes. This feature is useful for copying a 3D image to a drawing or painting programme, annotating the image with highlight boxes or text, and transferring the annotated image to a word processor for inclusion in internal or external correspondence (i.e. patient

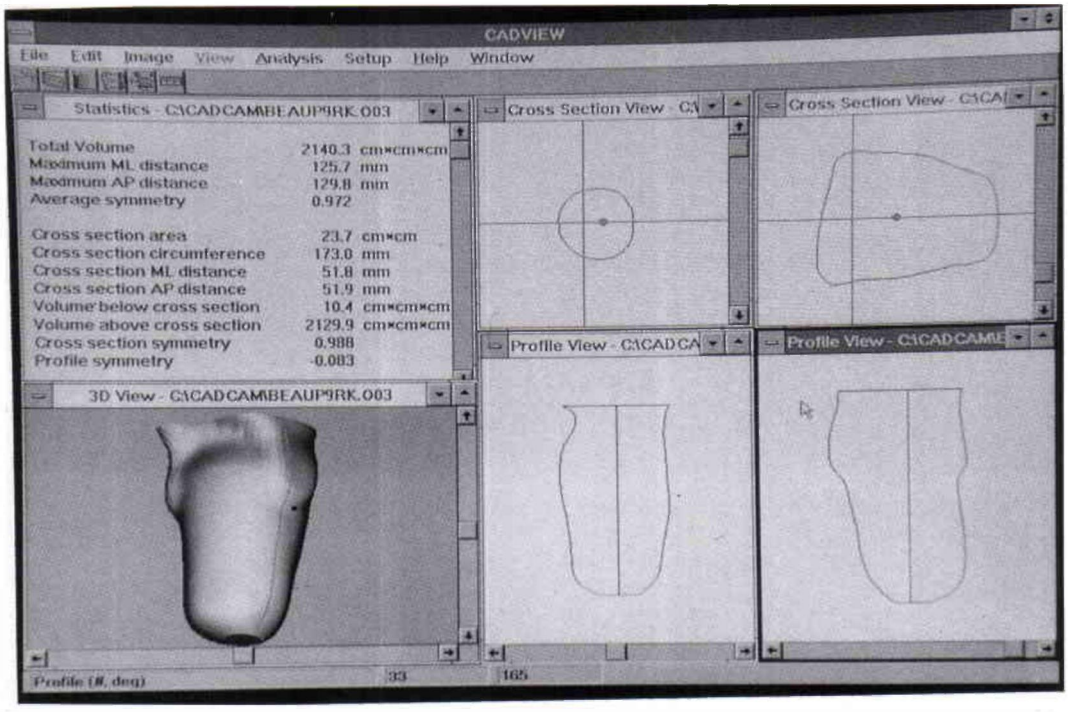


Fig 2. Two dimensional views.

file, insurance companies, etc.). The image transfer programming routine employed the Windows Metafile format for data exchange and followed standard Windows guidelines.

It should be noted that a 256 colour shaded image (SuperVGA) can only be successfully copied to programmes that can process the size of colour palette; therefore, 3D wireframe images are often recommended for data transfer. To deal with image transfer/printing limitations, a print feature was included in CADVIEW which sends the active window contents directly to the default printer. Test cases on a Hewlett Packard Laserjet III provided accurate reproductions of 256 colour shaded shapes. Since most printers provide Microsoft Windows drivers, CADVIEW can be used as an intermediary between existing CAD software and non-postscript printers.

### *Analysis*

Quantitative assessments of individual prosthetic/orthotic shapes are accomplished by using the statistics and/or measurement features.

#### *Statistics*

The predefined measurements and statistics can be divided into overall and cross-section components. Overall information includes total volume, maximum mediolateral (ML) distance, maximum anteroposterior (AP) distance, and average symmetry. Calculation of the total volume involved multiplying each individual cross-sectional area by half the longitudinal distance between the slice above and the slice below and summing these values over the entire shape.

Cross-section information includes area, circumference, ML distance, AP distance, volume above the cross-section, volume below the cross-section, and symmetry. A symmetry statistic was also included for the profile view. The cross-sectional data window is updated as different 2D images are displayed on screen, thereby simultaneously providing the user with cross-section or profile display, the position of the slice on the 3D image, and statistics related to the slice being displayed.

Cross-sectional areas were obtained by summing the triangular areas defined by adjacent radial length values. Symmetry statistics were calculated by dividing the cross-section or profile into two halves. The cross-section division point was at the main reference

mark and the profile division point was along the vertical, polar coordinate, axis. Corresponding radial lengths from the origin to the 2D surface coordinates were used to calculate a Pearson correlation coefficient between the two halves. The closer the correlation coefficient is to one, the better the symmetry between the two sides. It should be noted that this method only considers the surface shape and not differences in magnitude.

$$\text{Area} = \sum_{n=1}^{\#\text{sections}} \left(\frac{ab \sin(C)}{2}\right)$$

where: a = length of first triangle side
b = length of second triangle side
C = angle between and a and b

AP and ML distances are initially set at the main reference position (AP) and at 90 degrees to the AP line (ML). A user may graphically change the AP or ML measurement location to any point along the socket by positioning the cursor on the AP or ML division line (located in the cross-section window), pressing the mouse button, and dragging the line to the new location. The division line is maintained at the same relative position for all cross-sections.

*Measurement*

On-screen measurement capabilities allow the clinician to obtain the linear distance between any two visible points. This measurement is similar to taking a caliper reading off a plaster positive. By pressing the mouse button and dragging the cursor about the screen, the distance between the initial and current mouse position is continuously displayed in millimetres.

Measurements in 2D windows are accomplished by scaling the number of pixels between the initial and current mouse position. This allows the user to take measurements at locations that are not necessarily on the shape; such as, from the centre of a cross-section to the edge. To obtain valid measurements from the 3D shape, the 3D coordinate at the current mouse position is obtained from the image data file and used to calculate the inter-point distance. This provides accurate measurements at any image orientation,

***Comparison***

The comparison section provides a means to compare two shapes graphically and statistically. Shape comparison is useful for examining modifications on the original anatomical shape and/or comparing client progression over time. Using a currently loaded data file as the base, a second data file is opened for comparison. If these two shapes are not aligned on the same axis (i.e. two different digitisations) the programme can attempt to align both shapes to a common axis using the following procedure:

- calculate the centroid of each cross-section
- determine the line of best fit through the centroids
- rotate all data points about the origin until the line is positioned along the vertical axis
- calculate new perpendicular cross-sections using a cubic spline interpolation

This procedure is repeated five times to obtain a satisfactory result. Inter-shape comparison can now be performed since the new 3D data points are at the same angle and the same cross-section height. A root mean square error statistic is calculated using the distance between corresponding 3D data points on the original shape and comparison shape.

To test this positioning method, a series of trans-tibial stump casts were digitised using the CANFIT-PLUS software (VORUM Research) and the Seattle Digitizer (MIND). These shapes were redigitised at a five to ten degree angle to the original alignment and loaded into CADVIEW for comparison. The root mean square error between the shapes was 1.7 mm ($\sigma$=1.0). Examination of the effect of this procedure on shape alignment showed that the origin, which is set at the longitudinal midpoint of the shape, is not necessarily the optimal pivot point for rotational positioning. By introducing a graphical method for repositioning the origin before manually rotating or translating the shape, inter-shape error was reduced to under one millimetre.

Graphical comparison features include a dual wireframe view, colour mapped view, and dual cross-section view. A dual wireframe view superimposes a wireframe image of the comparison shape on the original shape. This view is helpful for assessment of inter-shape alignment and for locating areas that are not common to both shapes. The colour mapped view shades the original shape based on the distance between 3D data points. A negative

distance (concave) is shown as a shade of red while a positive image (convex) is shown as a shade of blue. Maximum and minimum shade values can be defined by the user. The inclusion of a minimum shaded threshold is useful for locating areas of change since areas without substantial modifications will not be coloured. Dual cross-section views superimpose corresponding cross-section slices from the original and comparison shapes on screen. This view is helpful in visualising local changes between shapes.

### *User services*

An on-line help facility and programme customising options have been included with CADVIEW to assist the user with programme function and to accommodate individual tastes. Using the standard Microsoft Windows help interface, the clinician can search for information on any feature available in CADVIEW without leaving the programme. The customising section allows the user to change background, line, and shading colours; adjust the picture plane for 3D imaging; and change the mouse sensitivity for measurements.

## Conclusion

A prosthetics and orthotics CAD analysis programme was developed to provide a graphical and quantitative means for comparing and analysing anatomical shapes. The ability to view multiple shapes on screen, perform measurements, obtain total and sectional statistics, and compare two related images allows the user to examine the effects of prosthetic and orthotic interventions in a qualitative and quantitative manner. In combination with the user interface, data sharing, and graphical features of Microsoft Windows, this programme is a beneficial tool for both clinicians and researchers.

## Acknowledgements

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## Technical note

# A body powered prehensor with variable mechanical advantage

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**Abstract**

The purpose of this research was to improve body powered, voluntary closing (VC) prosthetic prehension. A prototype prehensor with variable mechanical advantage was fabricated and tested. The device operates at low mechanical advantage during sizing of an object to reduce cable excursion requirements. It shifts to high mechanical advantage during gripping to allow high prehensile forces to be generated with reduced cable tension. The prototype provides a mechanical advantage of 2.4, nearly five times that of conventional VC devices. The prototype also acts as a holding assist; after grip forces are applied, they can be maintained with a cable tension of only 3 lb (13.34N). Field testing indicated that the device performs well in many tasks. The mechanism allows greater range of motion while an object is grasped than standard voluntary closing prehensors. However, the device performed poorly in grasping very compliant objects. To address this problem, a switch has been incorporated into the prototype to allow it to be used in a free-wheel mode.

**Introduction**

The purpose of a prosthetic prehensor is to replace some of the functions of the hand. Primarily, the prehensor should allow the amputee confidently to grasp and manipulate objects. The ability to maintain grasp is a function of the prehensor shape, the friction between the object and the gripping surface, and the grip force. The purpose of this research has been to improve prosthetic prehension by increasing the amount of grip force that an amputee can generate and maintain.

Upper limb prostheses are most often body powered. Despite advances in externally powered prostheses, body powered prostheses still afford important advantages to the amputee. These include sensory feedback through the harness, lighter weight, lower cost, and quiet, fast operation. One limitation of body powered prehensors is that the grip force is limited by the strength of the amputee. With a conventional body powered harness and cable system, an amputee can typically generate 2 in (5 cm) of cable excursion (Taylor, 1954). To be able to open adequately and close fully with only 2 in (5 cm) of input cable excursion, a conventional body powered prehensor is usually limited to a mechanical advantage of 0.5; 1 lb (4.45 N) of grip force is generated per 2 lb (8.9N) of input cable tension. Most trans-radial amputees can generate 60 lb (266.9N) of cable tension and, therefore, about 30 lb (133.45N) of gripping force with a conventional VC prehensor. Although that is more force than the hand of an adult male can generate in most prehension patterns (Taylor, 1954), those who cannot generate as much cable tension or excursion (trans-humeral amputees, shoulder disarticulation amputees, and amputees using cineplasty) may not achieve adequate grip force

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with currently available body powered devices.

Body powered prehensors can be classified as either voluntary opening (VO) or voluntary closing (VC). VO prehensors, particularly split hook type prehensors, are most widely prescribed. However, there are some important advantages to VC control. In VC control, the cable tension directly generates the gripping force. This allows the amputee better control of the amount of prehension. It also results in more natural feedback patterns: the higher the grip force, the greater the tension on the harness. One major drawback to VC control is that, in order to maintain grip force, cable tension must be maintained. One means of addressing this concern is to provide a lock. VC prehensors incorporating locking devices (e.g. the APRL hook and hand) have not been very successful due to poor reliability and safety concerns. Any locking hand should allow the user to release grip immediately when the need arises. Currently available devices require a conscious effort of the amputee to unlock the prehensor. An alternative to locking devices is the "holding assist", a device that maintains grip forces as cable tension is relaxed yet releases the grip when cable tension approaches zero (Fig. 1). Such a device could alleviate the disadvantages of VC control, yet would be safe and simple to operate. Carlson and Heim (1989) incorporated a holding assist into a VC prehensor. Their design achieved the desired performance, but functioned only briefly due to rapid part wear. A commercially viable holding assist mechanism has yet to be developed.

**The variable mechanical advantage prehensor**

Grasping is a two stage process: sizing by the fingers to contact an object, followed by generation of grip force. The NU-VA synergetic prehensor decouples these two stages. It incorporates two motors: a high speed, low torque motor for sizing, and a low speed, high torque motor for gripping. Thus, high speed and large grip forces can be achieved in an

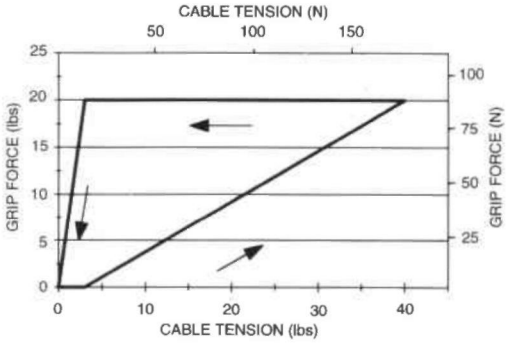


Fig. 1. Idealized gripping performance of a voluntary closing prehensor with a holding assist.

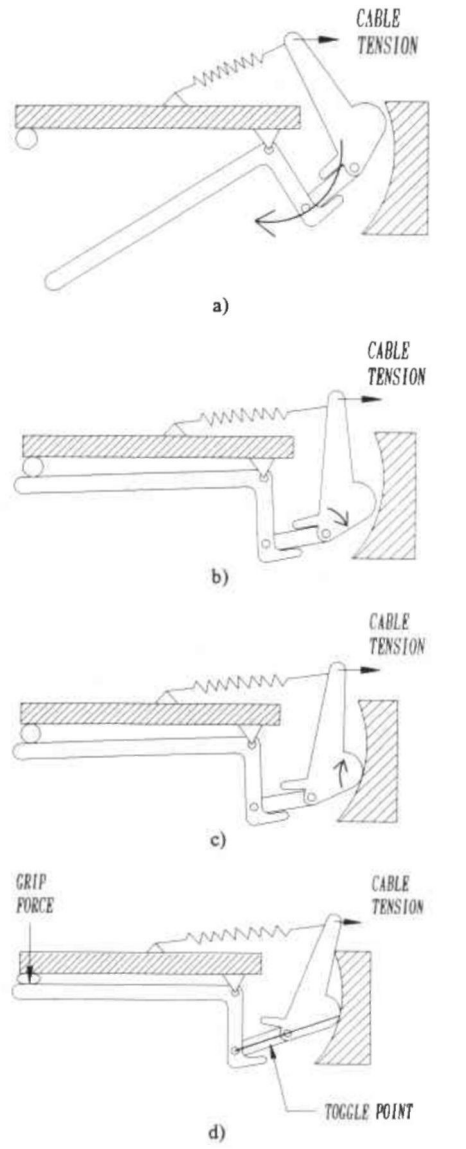


Fig. 2. Operation of the VMA prehensor. a) The VMA prehensor sizing an object. b) When an object is met, the mechanism shifts into high mechanical advantage operation. The input lever comes into contact with a quadrant. c) In high mechanical advantage operation, the lever rolls along the quadrant. d) Finally, the mechanism reaches a toggle point and a holding assist function is activated.

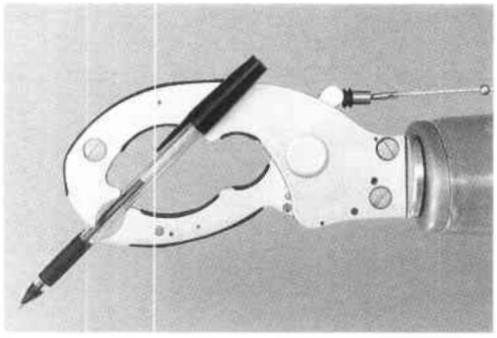

Fig. 3. The VMA prehensor prototype. The button on the side is used to switch between "VMA" and "free-wheel" modes.

externally powered prehensor with reduced energy requirements (Childress and Grahn, 1985).

The Variable Mechanical Advantage (VMA) prehensor applies a similar principle to body powered prostheses. For sizing of an object, it employs low mechanical advantage to reduce cable excursion requirements (Fig. 2a). For generating grip force, it shifts (Fig. 2b) into high mechanical advantage operation (Fig. 2c) to reduce cable tension requirements.

The mechanism was designed to approach the "toggle point", the point at which three joints of the mechanism are aligned (Fig. 2d). At this "toggle point", the mechanism will not transmit forces from the gripping surfaces to the input lever; high gripping forces can be maintained by minimal input cable tension. Thus, a holding assist function was incorporated into the design.

A prototype VMA prehensor (Fig. 3) was fabricated. Its configuration is based on the TRS GRIP[1] prehensor. All of the linkages and springs of the mechanism are hidden from view throughout the range of motion of the device. The gripping surfaces are lined with rubber.

Also included in the prototype was a switch to allow the device to be operated as a conventional, free-wheeling VC prehensor. By pushing a button on the side of the device, the user can lock the mechanism so that the shift into gripping mode cannot occur. Thus, the prototype has two modes of operation: a VMA mode that affords the advantages of the new mechanism, and a free-wheel mode to be used when the properties of the mechanism are not required or desired.

## Testing methods

An apparatus was constructed to evaluate the gripping performance of the prototype (Fig. 4). It included a pinch gauge to measure the grip force, a load cell to measure the input cable tension, and a linear variable differential transformer to measure cable excursion.

To perform a test, the pinch gauge was placed at the distal end of the fingers of the prototype. Cable tension was then manually incremented in small, discrete amounts. Gripping performance was also measured as cable tension was manually decreased. For

[1] Available from TRS Inc., Boulder, Colorado, USA.

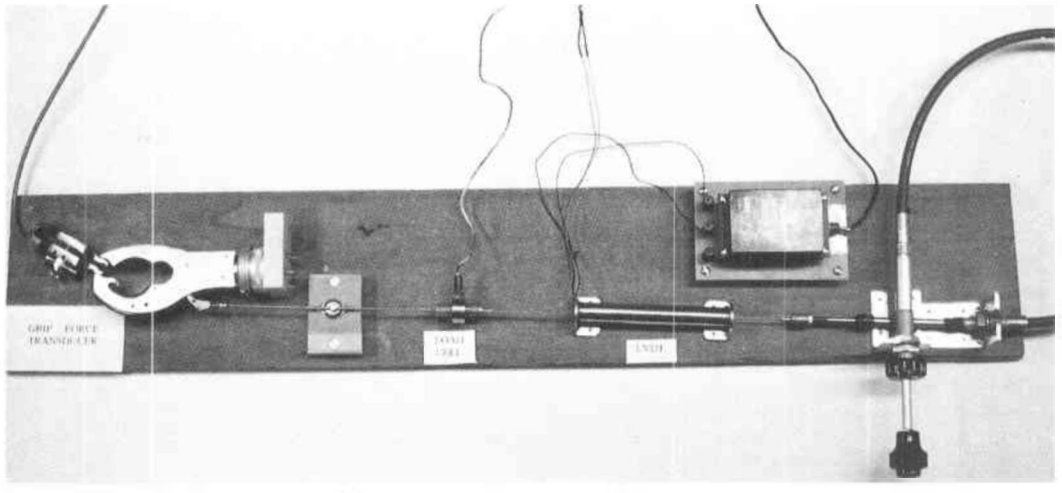

Fig. 4. The grip performance testing apparatus.

comparison, the performance of a standard VC device (The TRS GRIP II) was also measured.

To make an initial evaluation of the practical value of the prototype, field testing was performed. A unilateral, trans-radial amputee wore the prototype prehensor for 20 hours over the course of several days. A variety of common domestic and office tasks was performed with the device. The field tester maintained a log of his activities in which notes on the perceived advantages and drawbacks of the prototype were recorded.

**Results and discussion**

Figure 5 shows the substantial improvement in gripping performance afforded by the VMA prototype. To generate 20 lb (88.96N) of grip force, the VMA prehensor requires only 8 lb (35.59N) input cable tension, whereas the GRIP II requires about 40 lb (177.93N). The mechanical advantage of the VMA prototype is about five times greater than that of conventional body powered devices.

As input cable tension to the VMA prehensor is reduced to 3 lb (13.34N), 90% of the generated grip force is maintained. When cable tension is relaxed further, the grip force is reliably released. Thus, the VMA design provides a holding assist function: after grip forces are initially generated, they can be maintained with minimal effort.

Another benefit of the device is illustrated by Figure 6. Here, grip force is plotted as a function of cable excursion rather than cable tension. The slope of the data is a measure of the sensitivity of a prehensor to errors in input cable excursion. The VMA prehensor is about one fifth as sensitive to errors in cable excursion as the GRIP II. The field tester perceived that the VMA prehensor provided an increased "margin of error" in the manipulation of objects. Once an object is grasped, the VMA

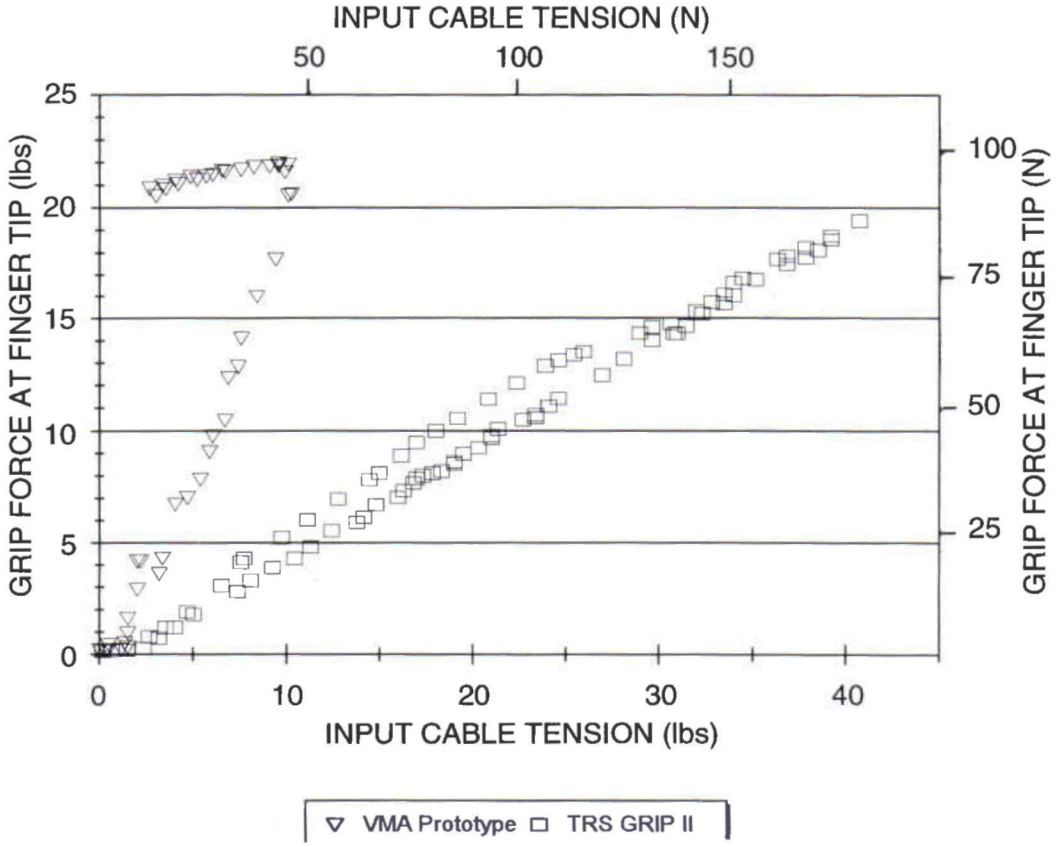


Fig. 5. The gripping performance of the VMA prehensor compared to that of a conventional voluntary closing device (the TRS GRIP II).

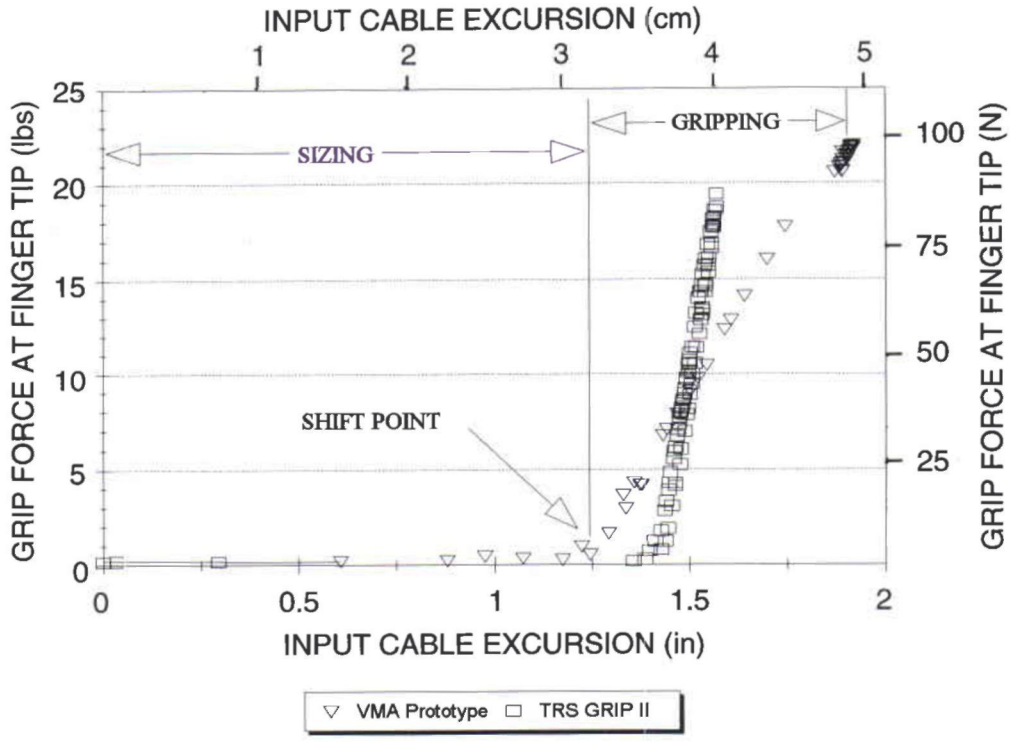


Fig. 6. Sensitivity of the VMA prototype and TRS GRIP II to errors in input cable excursion.

prehensor allows the amputee to move the object without maintaining as rigid a body position as with conventional VC prehensors. This benefit of the prototype was most evident in heavy duty tasks involving gross body movements (e.g. shovelling gravel).

Figure 6 also illustrates that the VMA prehensor requires less cable excursion for sizing, but more cable excursion for gripping than the GRIP II. For relatively compliant objects, this can result in higher overall excursion requirements. In sizing and grasping the pinch gauge, the VMA prototype required 1.90 in (4.83 cm) of cable excursion, while the GRIP II required only 1.55 in (3.94 cm). In field testing, it was noted that the additional cable excursion requirement was occasionally troublesome. For instance, with the prototype in its VMA mode, it was difficult to maintain grasp on objects when held along the side of the body. However, if high mechanical advantage is not required, the free-wheel switch can be engaged. In free-wheel mode, the VMA prototype requires about 37% less cable excursion than the GRIP II. Therefore, the prototype may improve the ability of amputees to maintain grasp in situations in which it is difficult to generate cable excursion.

The most significant limitation of the prototype was its poor performance in grasping very soft objects. After the shift into gripping mode, the mechanism can compress an object by only 1/8 in (0.32 cm). For very soft objects, this amount of compression creates little reaction force. The field tester found that, with the prototype in its VMA mode, he could not confidently grasp objects such as folded towels or rolled newspapers. The free-wheel mode was incorporated to address this concern. In this mode, no problems with handling soft objects is apparent. Also, the button used to switch between modes was found to be easy to access and activate.

## Conclusions

Through laboratory and field testing, the prototype VMA prehensor demonstrated some significant advantages over conventional voluntary closing prosthetic prehensors. These include: increased mechanical advantage, a

holding assist function, improved amputee mobility while maintaining grip, and reduced cable excursion in free-wheel mode. It has not been demonstrated, however, that these advantages justify the additional complexity and cost of the VMA prehensor design. Clinical evaluation appears to be necessary to explore if and how this device can be of benefit to upper limb amputees. Field evaluation by those who have difficulty in generating adequate cable tension or excursion with body powered prehensors would be of particular value.

**Acknowledgments**

The authors wish to thank the NCMRR (grant no. 1-RO1-HD30101-01) for its financial support. The contributions of Bob Radocy as both design consultant and field evaluator are gratefully acknowledged.

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# Letter to the Editor

Dear Sir,

**Re: "Fatigue testing of energy storing prosthetic feet", pp 180-188, Volume 17, 1993**

We have many years field experience of the quality and performance of Proteor's SACH feet, confirmed by testing in France and very recently the MDD (Medical Devices Directorate) in the UK, which contradict a finding of this paper. We have recently successfully tested at MDD three feet to 1,000,000 walking cycles, including heel strike, foot flat and toe off at a load of about 70 kgs. The MDD testing programme which includes a monitored defect reporting system, has for over 10 years proved to correlate well with field performance.

This paper has reported a potentially useful piece of work but its purpose has been confused by inappropriate sample selection and its credibility reduced by the small sample size. It is statistically unsupportable to select one foot at random from any of the world's leading foot manufacturers and publish the results. No manufacturer produces 100% perfect feet all the time – all are manufactured to specific standards and cost requirements. The usefulness of including a SACH foot in a comparative test with an energy storing foot must also be questioned. My opinion is that it would have been better to select, from feet with a known field record, a range of, say, five SACH feet, five energy return feet and five "performance" feet, and anonymously test these perhaps three or more times to establish some basis of reproduceability for the testing machine and the feet. If manufacturers' names were used, given a sufficient number of feet were tested, then it would have been far more useful for prosthetists to see the energy return Lambda foot compared to feet of similar type and cost, that is, to see oranges compared with oranges.

Yours sincerely,

Steven J. Cousins BASc, MASc, PhD, PEng
Technical Director

Rehability Limited
36 Station Road
Billingshurst
West Sussex RH14 9SE
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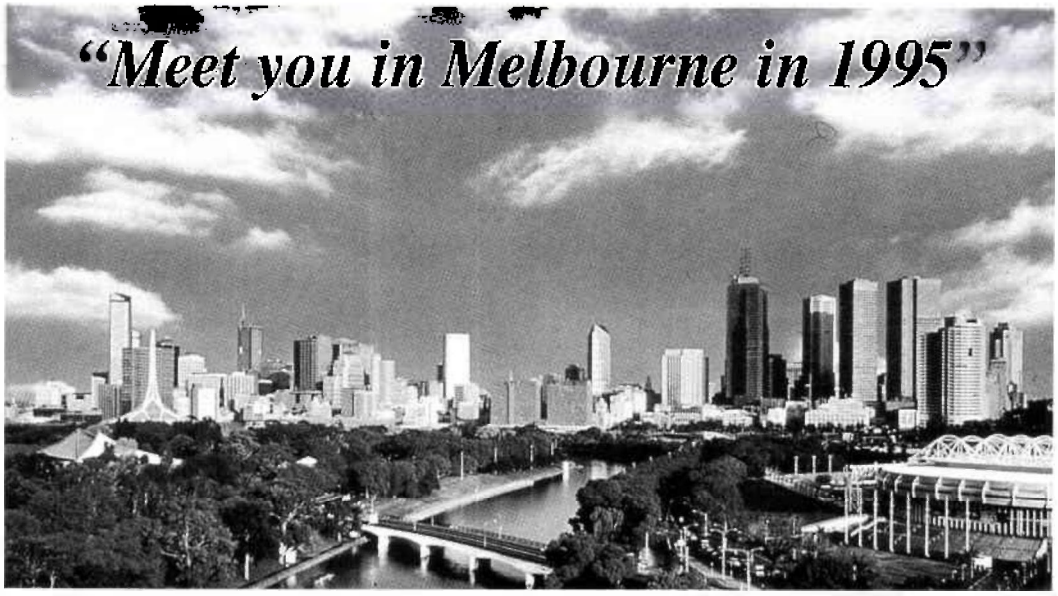
*Prosthetics and Orthotics International, 1994, 18, 125-136*




# VIII World Congress
# 2 – 7 April, 1995, Melbourne, Australia

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8TH
WORLD CONGRESS
ISPO
MELBOURNE, AUSTRALIA
APRIL 2-7, 1995
INTERNATIONAL SOCIETY FOR PROSTHETICS AND ORTHOTICS

# Message from the President

ISPO's World Congress is the largest international scientific event which covers all aspects of prosthetics, orthotics and rehabilitation engineering. This Congress occurs every three years and brings together all the disciplines involved in the rehabilitation of the physically challenged – orthotists, prosthetists, physicians, surgeons, therapists, nurses, engineers, educators – all those who work each day to restore or provide function to individuals with neuromuscular skeletal disorders.

This 8th World Congress, our Silver Jubilee, will bring experts from around the world to Melbourne, Australia. This is the first time the ISPO World Congress will take place in the Southern Hemisphere. It is the opportunity to hear the latest in scientific information and technical advances. The organisers have chosen the theme of "East meets West-ISPO in the Western Pacific meeting the rest of the world". It is also an opportunity for all of us to explore the world "Down Under".

The 8th World Congress scientific programme will be of interest to the entire rehabilitation team. The scientific programme includes the popular instructional course lecture series early each morning followed by symposia presentations. Symposia presenters are all invited and include experts from each of the disciplines involved in prosthetics, orthotics and rehabilitation engineering delivery. After lunch the Australian organisers have introduced sessions called "Expert Viewpoint". Again, these are given by invited experts presenting their viewpoints on selected topics, followed by response of an invited discussant. This discussant may concur with what has been presented or may have a different viewpoint. This programme is designed to stimulate thought and discussion. You can be sure the organisers have selected some topics where controversy exists.

The free paper section of the programme provides the opportunity to bring the newest information to participants. Researchers and clinicians from around the world have submitted abstracts of their work, and we will all have the opportunity to see the future direction in which our profession is heading. The commercial exhibit will give us the big picture. We will be able to see the components, manufacturing materials, and equipment, and treatment devices used in all aspects of rehabilitation.

Poster presentations and videos provide another format of education. We will be able to fill every moment while at the Congress with information and knowledge that we can use when we return home.

The Congress will not be all work. We will all have an opportunity to experience the Australian hospitality and culture. I encourage all of you to take the opportunity to visit and experience the natural beauty of this part of the world. Melbourne itself is a beautiful city with something to offer each of us.

The programme is organised, events are scheduled, and all plans have been made. The Australian Organising Committee has participated in all the past World Congresses, and they are well aware of what is expected. All we need to do is register and go to Melbourne. You will take home the experience of a lifetime.

Melvin L. Stills

# Message from the Secretary General

The ISPO World Congresses had their genesis at the ISPO International Symposium in Australia in August 1972, which was held so successfully.

In 1995 the first ISPO Triennial World Congress in the Southern Hemisphere is being held in Melbourne, Australia.

A very special effort has been made to present a stimulating and challenging Scientific programme. Additionally delegates can experience our unique culture during and after the Congress.

It is a great honour that His Excellency, the Honourable Richard McGarvie, Q.C., Governor of Victoria is giving his official support to this 8th ISPO World Congress.

The theme of the Congress is "East meets West – ISPO in the Western Pacific meeting the rest of the world".

There is a high and diversified standard of rehabilitative care in Australia. The ISPO Congress is adopting a multi-cultural approach to ensure that the needs of particular groups are met in the best possible way. The opportunity will be available to study the wide and diverse network of services which are available to people in the area.

For many, attendance at our Congress will be the first opportunity of visiting our country "down-under" and I strongly recommend that you take advantage of this occasion to extend your stay to visit other parts of Australia. The choice is endless from the beautiful beaches and spectacular coral of the Barrier Reef to the sunburnt centre of Central Australia and Ayers Rock; the unique fauna and flora throughout the continent to the spectacular rainforests of the tropics; the national parks and mountains in the southern parts of Australia.

Please come and join us on this historic occasion of the Silver Jubilee of ISPO.

Valma Angliss

# Scientific Programme

The scientific programme has been designed to place special emphasis on a discussion to place special emphasis on a discussion and investigation of current problems and the relevant research across the entire field of ISPO, as we approach the 21st century. Each day has been allocated a special theme relevant to the issues of our profession and within that theme, topics will be addressed segmented into different categories.

### Expert Viewpoint

These presentations provide an opportunity for experts to present an overview of a state-of-the-art topic drawing on personal experience, ideas and research in summarising significant changes over the past three to five years. The presenter's paper will be followed by a response, either endorsing the views of the presenter or challenging the statements by providing alternate viewpoints. Interaction and discussion from the floor will be encouraged throughout the latter part of the session.

The provisional programme of Expert Viewpoint sessions includes:

- Changing attitude to amputation surgery

- Knee orthoses
- CAD CAM update
- Prosthetic and orthotic education in the developing world
- Management of limb fractures
- Assessement of foot disorders
- Lower limb prosthetic socket technology
- Prosthetic and orthotic education in the industrial world
- Early management of the lower limb amputee
- Adolescent scoliosis
- Upper limb prosthetics
- Low back pain.

# Symposia

Symposia are multidisciplinary sessions or panel sessions on reasonably specialised topics, equivalent to free paper sessions except that they have been pre-planned. The selected speakers will present different aspects of a topic or different approaches to the topic. These sessions will feature current trends and recent developments, presented by prominent speakers chosen according to their international reputation.

The provisional programme of Symposia topics includes:

- Interdisciplinary prosthetic care in a community based rehabilitation setting
- Intelligent prosthetic knees/electro-mechanical prostheses
- Footwear and management of foot deformities
- Late effects of post-poliomyelitis
- The elderly amputee
- Ischial containment sockets
- Prosthetic and orthotic services in the Western Pacific and South East Asia
- Mobility for the adult paraplegic
- Management of the diabetic foot ulcer
- CAD CAM in clinical practice
- The technical approach for prosthetic provision in developing countries
- FES and hybrid orthotic systems
- Pain in the amputee
- Energy storing feet
- Consumer focus
- Management of spasticity to improve function in the adult
- Cultural attitudes to limb losses and prostheses
- Assistive technology for severe disabilities
- Prosthetic and orthotic education in developing countries
- Management of spasticity to improve function in children
- Amputee athletes
- Clinical gait analysis
- Surveys of upper limb amputees.

# Instructional Courses

The objective of the instructional courses is to provide practical education in a specific topic by covering information on methods that instructors have found to be clinically effective. The courses are designed to cover the technical aspects of accepted practice in a workshop environment.

The topics were chosen mostly with a clinical emphasis and give a wider coverage of non-prosthetic areas. The aim is to cover in a ninety minute period all the facets of each topic Another aim is to attract and bring together all appropriate disciplines for the topic in the one integrated session.

The overall approach is to encourage full week attendance by offering several parallel series, each consisting of related topics dealt with sequentially. On each day there is also a range of topics to allow a choice for each discipline. The weekly programme will allow each discipline a topic throughout the week for a variety of disabilities.

Instructional courses will be scheduled daily for 90 minutes duration. As the cost of attendance is not included in the registration fee please study the topics offered and indicate the choice of courses you wish to attend by filling in the appropriate box on the application form. The cost of attendance is $AUD 50 per session which must be remitted in addition to the registration fee.

The provisional programme of instructional courses includes:

***Sunday, April 2, 10.30-12.00***

- Amputation in vascular disease (S1/90)
- Spinal cord injury – a team approach to patient management (S2/90)
- Fracture cast bracing (S3/90)
- Management of the limb deficient child (S4/90)
- Management of cerebrovascular accident patients (S5/90)

***Monday, April 3, 08.00-09.30***

- Syme and partial foot amputation: surgery, prosthetics, orthotics and rehabilitation (M1/90)
- Management of degenerative disease of the spine (M2/90)
- Amputations in trauma and cancer (M3/90)
- Upper limb orthotics (M4/90)
- Anaplastology/optimising cosmesis (M5/90)

***Tuesday, April 4, 08.00-09.30***

- Trans-tibial amputation: Part 1 – surgery (T1/90)
- Scoliosis and kyphosis: surgical, conservative and orthotic management (T2/90).
- Functional independence for amputees (T3/90)
- Assessment and management of the insensitive foot (T4/90)
- Management of burn patients (T5/90)

***Wednesday, April 5, 08.00-09.30***

- Trans-tibial amputation: Part 2 – prosthetics and rehabilitation (W1/90)
- Seating: design and assessment of the patient (W2/90)
- Management of foot disorders (W3/90)
- Upper-limb amputation: Part 1 – surgery (W4/90)
- Management of the unstable knee (W5/90)

***Thursday, April 6, 08.00-09.30***

- Knee disarticulation and trans-femoral amputation: Part 1 – surgery (TH1/90)
- Wheelchair design and prescription (TH2/90)
- Footwear and orthotics (TH3/90)
- Upper limb amputation: Part 2 – prosthetics and rehabilitation (TH4/90)
- Orthotics for arthritis (TH5/90)

***Friday, April 7, 0800-09.30***

- Knee disarticulations and trans-femoral amputation: Part 2 – prosthetics and rehabilitation (F1/90)

- Prosthetics and orthotics for sports applications (F2/90)
- Computer information systems for prosthetics (F3/90)
- Principles and practice of myoelectric technology (F4/90)
- The ICRC system of component manufacture (F5/90)

# Free Papers

Authors of accepted papers will present the results of their research, clinical and technological experience, to benefit those who are interested and engaged in the same field of activity. This will provide the opportunity for discussion and interchange of information.

An invitation for application for scientific presentations has already been circulated in a separate brochure. Authors worldwide are invited to submit abstracts to be included in the Free Paper Sessions or the Poster or Video presentations and deadline for receipt of abstracts for any of the session categories is September 1, 1994. Please contact the Congress Secretariat if you require further information.

# Poster Sessions

Poster presentations will be exhibited daily during the lunch break.

# Video Sessions

Several sessions will be held during the Congress for video presentations.

# Manufacturers' Sponsored Workshops

Three workshops will be held from Monday through to Friday concurrently with the instructional courses.

The format of the Workshops will allow Manufacturers to instruct a wide range of health practitioners about their

- Products
- Prescription principles
- Applications
- Special techniques/alignments.

An additional fee of $AUD 25 is applicable for each workshop attended. Please select your choice by completing the appropriate box on the application form and remit payment in addition to the registration fee.

The programme of Manufacturers Workshops includes:

***Monday, April 3, 08.00-09.30***

FLEXFOOT INC.: Optimising clinical results with the flexfoot (MW1).

BLATCHFORD: The criteria with functionality of high activity (MW2).

M + IND, SEATTLE MEDICAL SYSTEMS GROUP: Maximising efficiency in a cost conscious environment. Effective use of CAD/CAM and appropriate limb systems (MW3).

***Tuesday, April 4, 08.00-09.30***

BOSTON BRACE INTERNATIONAL INC.: Treatment of ACL deficient knee using a Boston knee brace (MW4).

OTTO BOCK: Time saving tips in orthotic manufacture (MW5).

USMC: The new USMC series of energy storing lower extremity prosthetic components (MW6).

***Wednesday, April 5, 08.00-09.30***

FILLAUER INC.: New application for carbon composites – PolyCar-C for thermobonding to plastic and metal (MW7).

OTTO BOCK: A biomechanical approach to prosthetic knee selection (MW8).

COMFORT & FIT AUSTRALIA: Pedonthic management of the diabetic foot (MW9).

***Thursday, April 6, 08.00-09.30***

BLATCHFORD: The benefits of a Microprocessor controlled lower limb system (MW10).

OTTO BOCK: Myoelectric prosthesis: basic troubleshooting (MW11).

USMC: Technical update of USMC lower extremity modular prosthetic systems (MW12).

***Friday, April 7, 08.00-09.30***

FILLAUER INC.: Silicone suction socket (38) update – upper and lower extremities (MW13).

BLATCHFORD: The prescription criteria of knee componentry (MW14).

HOSMER: Lower extremity endoskeletal systems (MW15).

# Knud Jansen Lecture

Knud Jansen, M.D. was the founder of the International Society for Prosthetics and Orthotics (ISPO), and was its President from 1970-1977. He was an esteemed Orthopaedic surgeon in Denmark, having been Chairman of the Danish Orthopaedic Association and the Danish Society of Orthopaedic Surgery.

He was also Secretary General of the Scandinavian Orthopaedic Association and for many years served as editor of one of the most prestigious international journals, Acta Orthopaedica Scandinavica. Knud Jansen was a staunch supporter of the concept of the clinic team and his influence has carried that important concept to prosthetics and orthotics care worldwide. Jansen was a champion of technical orthopaedics and rehabilitation. His vision created ISPO and his influence still guides the organisation.

The lecture in Knud Jansen's name was established by ISPO as a memorial to its founder. The lecture is presented by a distinguished member of the society at each Triennial World Congress.

The Knud Jansen lecture for 1995 will be delivered by Sepp Heim and will be presented immediately after the Opening Ceremony in the John Batman Theatre on Sunday, April 2.

# Awards

**The Brian Blatchford Prize**

The Brian Blatchford Prize has been established by the Blatchford family to honour the memory of Brian Blatchford. It is awarded every three years at the World Congress of the International Society for Prosthetics and Orthotics

The prize of £2,500 will be awarded to an individual who has an outstanding record of innovative achievement in the field of prosthetics and/or orthotics. The achievement should be related to prosthetic and/or orthotic hardware, or scientifically based new techniques which result in better prostheses or orthoses. The

President, in seeking to identify the recipient of the award, will also consider nominations or applications from National Member Societies or individuals. Such nominations or applications should contain a justification together with a curriculum vitae of the candidate and should reach the President of ISPO by November 1, 1994, at the following address:

M. L. Stills
Orthopaedic Surgery Department
UT Southwestern Medical Center
5323 Harry Hines Boulevard
Dallas, Texas 75235-8883, USA.

The prizewinner shall make a presentation based on his work at the World Triennial Assembly on Thursday April 6 and the paper shall be duly published in Prosthetics and Orthotics International.

The President and Executive Board of the International Society for Prosthetics and Orthotics and the Blatchford family reserve the right to withhold the prize should no suitable candidate be identified.

**The Forchheimer Prize**

The Forchheimer Prize has been established by the Forchheimer family to honour the memory of Sylvia and Alfred Forchheimer. It is awarded every three years at the World Congress and will be presented at the World Triennial Assembly.

The prize will be awarded for the most outstanding paper on Objective Clinical Assessment, Clinical Evaluation or Clinical Measurement published in Prosthetics and Orthotics International during the three years prior to the Congress.

The President and Executive Board of the International Society for Prosthetics and Orthotics and the Forchheimer family reserve the right to withhold the prize should no suitable paper be published.

# Exhibition

The commercial and scientific exhibitions will be held in the You-Yangs Exhibition Hall at the world Congress Centre.

As this is the first time the Congress will be held in the Southern Hemisphere the event will draw delegates from the Asian/Pacific region and provide exhibitors with a valuable platform for sales opportunities and for opening up new markets. Additionally, the Congress expects to attract a worldwide audience of prosthetists, orthotists, therapists, physicians, surgeons, engineers, nurses, rehabilitation specialists, and others.

The Exhibition will be officially opened on Sunday April 2, immediately following the Congress opening and Knud Jansen Lecture and delegates will be given ample time to view the exhibits throughout the Congress week.

Companies are invited to contact the Congress Secretariat for further information on participation.

# Registration Information

Please complete the registration form and return with payment to the Congress Secretariat. Each delegate must complete a separate form. Clear photocopies or facsimiles are acceptable, however, in the case of the latter you are requested to mail the original copy noting that a facsimile has previously been forwarded.

**Congress Secretariat**

All registration forms and enquiries should be made to:

ISPO Congress
ICMS
84 Queenbridge Street
South Melbourne
Victoria 3205
Australia
Telephone +613 682 0244
Fax +613 682 0288

**Entitlements**

Delegates are entitled to:

- Attend the Opening Ceremony and all Scientific Sessions;
- Attend the Welcome Reception;
- Attend the Farewell Lunch;
- Lunches daily (excluding Wednesday);
- Morning/afternoon teas;
- Congress satchel;
- Receive a copy of the Proceedings.

Accompanying persons are entitled to:

- Attend the opening ceremony;
- Attend the Welcome Reception;
- Meet the Partners Coffee;
- Half day tour;
- Attend the Farewell Lunch.

Please note fees do not include admission to the Instructional Courses or Manufacturers' Workshops, the Congress Dinner, Technical tours, Orientation and optional sightseeing tours or accommodation costs. Please remit additional payment for these with your registration fee.

**Payment of fees**

Payment of fees must accompany all registration forms. Fees can be paid either by:

- Credit card (Visa, Mastercard, Bankcard only)
- Bank draft in Australian dollars;
- Australian registrants only – personal cheque.

**If you have any difficulty with remittance of payment by any of the above caused by your country's foreign exchange regulations, please contact the Secretariat for advice before forwarding any other form of payment.**

Your registration will be ackowledged in writing confirming your requirements according to your Registration Form. Attendance at the Congress will be confirmed only on receipt of payment.

**Registration fees**

Payment received prior to December 31, 1994.

| Delegates: | |
|---|---|
| Members | $AUD650.00 |
| Non-members | $AUD775.00 |
| Accompanying Persons: | $AUD200.00 |
| Students: | $AUD200.00 |
| Day Registrants: | $AUD200.00 |

AN ADDITIONAL FEE OF $AUD100.00 WILL APPLY TO ALL DELEGATE AND STUDENT REGISTRATION FEES RECEIVED AFTER

DECEMBER 31, 1994.

In order to qualify for membership fee, please advise ISPO membership number on the registration form.

**Cancellations and Refunds**

Cancellations must be notified in writing to the Congress Secretariat. Cancellations received prior to February 15, 1995 will receive a 75% refund of registration fees paid. After this date no refunds will be applicable. Refunds of accommodation deposits are subject to individual hotel policies on application.

**Attendance Verification**

Certificates of attendance at the Congress will be available on request.

**Letters of Invitation**

The Organising Committee will be pleased to send letters of invitation to prospective delegates making such a request. It is understood that such an invitation is intended to help potential attendees to raise travel funds or to obtain a visa. It is not a commitment on the part of ISPO to provide any financial support.

**Liability**

In the event of industrial disruption, the Congress organisers accept no responsibility for loss of monies incurred by delegates.

**Keyword Programme Section**

Please indicate up to six keywords of topics or your particular field of interest on the registration form as coded below:

A01 Cerebral palsy
B01 Cerebral vascular accident (CVA)
C01 Diabetes
D01 Education and training
E01 Foot disorders
F01 Fracture bracing
G01 Independent living
H01 Leprosy
I01 Measurement technology
J01 Muscular skeletal disabled
K01 Orthopaedic footwear
L01 Orthotics-lower limb
M01 Orthotics-upper limb
N01 Paraplegia and quadraplegia
001 Performance appraisal of programmes
P01 Poliomyelitis
Q01 Public health and epidemiology
R01 Recreation, leisure, music, sport
S01 Scoliosis
U01 Sockets-prosthetic
V01 Symes and partial foot amputee
W01 Technology
X01 Trans-femoral (above-knee) amputee
Y01 Trans-tibial (below-knee) amputee
Z01 Upper limb amputee

# Social Programme

**Welcome Invitation**

Your first opportunity to officially experience the fun and friendly spirit of your Australian hosts, whilst catching up with old acquaintances and meeting some new ones. The reception will be held in the Atrium of the World Congress Centre and we hope to tantalise the taste buds with our unique Australian fare and entertain you with the folk lore of our more recent beginnings. There could even be the opportunity for some toe tapping with our bush friends.

Date: Sunday, April 2, 18.00-21.00
Dress: Casual
Fee: Included in delegate and accompanying person registration fee.

**Melbourne Dine-out**

Epicurean delights abound in Melbourne, the culinary capital of Australia. The variety of Melbourne's restaurants is a gourmet's delight as there are over 3,000 of them representing 70 national cuisines. We recommend that you sample an appetising cross-section of these restaurants during your stay and we have dedicated this night for you to start your gastronomique experience. Our restaurant advisory service will be on site on Sunday, April 2 to assist with recommendations and bookings according to your budget.

Date: Monday, April 3
Fee: Pay direct to restaurant of your choice
Bookings: On site at the World Congress Centre

**Congress Dinner**

Our Congress Centre transforms to a backdrop for the Congress Dinner, where the theme of Australia's multi-cultural background will be reflected. Dinner will combine the best of Australia's fresh produce presented in the many tastes of our ethnic population. The entertainment for the night will also reflect the same theme as a pot-pourri of talent will entice you to join them in a night of great fun and enjoyment.

Date: Tuesday, April 4, 19.30-23.00
Fee: $AUD85.00
Bookings: Registration Form
Dress: Lounge Suit.

**Performance by the Australian Opera**

A limited number of seats have been booked for the Australian Opera's performance of Gilbert & Sullivan's Patience. Starring Anthony Warlow, well known to Australian audiences for his superb lead role in the local production of Phantom of the Opera and also included in the cast acknowledged Gilbert & Sullivan specialists Dennis Olsen and Heather Begg. The performance will be staged at the Victorian Arts Centre, a renowned complex well worth the visit. Deadline for bookings is January 15, 1995.

Date: Thursday, April 6, 1995
Fee: $65.00
Bookings: Registration Form

**Farewell Lunch**

Join us to throw a "Prawn on the Barbie" at our farewell barbeque. The opportunity to finally farewell your international colleagues.

Date: Friday, April 7, 12.00-14.30
Fee: Included in delegate and accompanying person registration fee
Dress: Casual.

# Accompanying Persons Programme

The Organising Committee welcomes delegates' partners to join us in Melbourne in 1995. A special programme has been designed to allow you the time to explore our city and surrounds independently but also includes the choice of some special tours which are not readily available to the public.

**Inclusive Tours – Monday**
*(Accompanying persons)*

Please select one of the three tours listed below and indicate your choice on the registration form. Although the cost of the tour is included in the accompanying person registration fee, a booking will not be held if the form is not completed.

• KOORI WALKABOUT: The Kooris – the mighty Kulin – indigenous people of the Western Plains in South Eastern Australia. We visit their Traditional hunting grounds in the You Yang ranges where countless thousands of Koori women have met for 40,000 years. As we sit together overlooking the plains where the women gathered food, Janine, our guide, will help you explore their culture – as it was, and as it is today. This is a rare opportunity for you to discover this timeless and nearly extinct people. Numbers are limited, so book early.
Includes: Coach, guide, admission fees and morning tea
Duration: 10.00-14.00 hours

• SHOP TILL YOU DROP: We all love to shop. Discover the many secrets of Melbourne shopping as we visit some unique wholesale outlets. Melbourne is definitely the home of fashion and style. You won't be able to resist the bargains. All outlets visited manufacture quality Australian-made products. Morning tea is included by Gemtec – one of Australia's leading opal merchants
Timing: 10.00-13.00 hours
Includes: Coach, guide and morning tea.

• THE AUSTRALIAN BALLET CENTRE: A look behind the scenes of this world renowned ballet school and centre. The interior has many unique facilities, in particular, the eight superb rehearsal studios and the Production Department where the costume and millinery are designed, created and manufactured for all the Australian Ballet's performances. View dance archive exhibitions and rehearsal activities in the dance studios.
Includes: Transfer, guide, admission fee and morning tea
Duration: 10.00-12.30 hours.

**Orientation Tour – Sunday**

This tour will orientate you with your host city – Melbourne. The inhabitants of Melbourne love her elegant layout, her Victorian grandeur and architecture, her wide tree-lined streets. Let us introduce you to the hustle and bustle of this thriving metropolis. At the termination of the tour we visit Gemtec, one of Australia's lead ng Opal Merchants, who will give you a brief introduction and educational film on where opals are mined, cut and polished into the finished product.
Cost: $30.00 per person
Includes: Guides, 5 star coach equipped with toilet
Timing: 09.30-11.30 hours
Minimum: 25 passengers

**Meet the Partners – Morning Coffee**

An informal morning coffee at the Congress Centre to meet up with the accompanying persons and your Melbourne hosts – a great opportunity to chat to our local tour experts on shopping, touring or just general information on what Melbourne has to offer before departing on a tour.
Monday, April 3, 09.00-10.00

# Sightseeing Tours

The Programme Committee has purposely left Wednesday afternoon free of any scientific sessions to allow time for delegates to join their partners to participate in a choice of either a technical or sightseeing tour.

The sightseeing tours are subject to minimum numbers.

Please indicate your choice of tour on the registration form and remit payment with your registration fee.

The tours desk will also book individual tours to many of Melbourne's unique attractions including the Victorian Arts Centre complex housing our performing arts theatres and Sovereign Hill where the early gold digging era is reproduced.

• **Penguins on Parade**

Travel to Phillip Island in Westernport Bay to view these special species of the animal world

Perhaps the most amazing and delightful tour of all, the Penguin Parade is unique among animal displays. Completely uninfluenced by man, the penguin extravaganza takes place at dusk as these charming 'fairy' penguins waddle through the twilight up the beach, over the sand dunes to their burrows. We also come face-to-snout with some koalas and kangaroos.
Cost: $64.00 per person
Includes: 5 star coach equipped with toilet.
Admission fees: Summerland Beach
Fauna Reserve
Timing: 13.00-22.00 hours
Optional add-on: Hot lobster dinner: $55.00 per person.

• **Victorian Wineries**

The elixir of life is certainly produced and bottled – so Victorians believe – in the foothills of the Yarra Valley. This picturesque valley is home to some delightful wine producing vintners. Domaine Chandon, built by the world French champagne house Moet Chandon, will be delighted to show us the intrigues of champagne production with a little sampling – of course. St. Hubert's, de Bortoli and Yarra Ridge are smaller producers who each have very distinct wines. We will wend our way through the valley sampling wine with some of these producers. Cheers!!
Cost: $99.00 per person
Includes: 5 star coach equipped with toilet
Wine tastings: Domaine Chandon; de Bortoli; St. Huberts; or Yarra Ridge.

Lunch at The Grand Hotel in Yarra Glen.
1 glass of house wine with lunch
Timing: 12.15-18.00 hours.

- **Australian Animals**

If you want to see Australian animals in their natural bush environment, then our visit to Healesville Sanctuary will enthral you. This wonderful sanctuary recreates each animal's natural habitat. You'll smell the eucalypt forest and hear the many sounds of the Australian bush as you peak at koalas, kangaroos, platypus, emu, echidna – just to name a few. To complete this experience enjoy a traditional "Aussie BBQ".

Cost: $99.00 per person.
Includes: 5 star coach equipped with toilet
Admission fee
BBQ dinner with beer, red and white wine
Timing: 12.30-20.30 hours.

# Technical Tours

*Please indicate your choice on the registration form*
*TOUR 1: (Code TT01)*
**Centre Of Integrated Equipment Services**

This centre incorporates many areas. We will be confining our visit to three of them, the Independent Living Centre, the Microcomputer Applications Centre and the Equipment Library. Experienced staff are available for assessment and advice with regard to the specialised equipment on display. Arrangements can be made to hire equipment for trials prior to expensive purchases being made.

Tour Time: 13.30-15.30
Cost: $30.00

*TOUR 2: (Code TT02)*
**The Alfred Group Of Hospitals**

The Alfred Group of Hospitals is a large tertiary referral centre providing a wide range of services. This tour will include the Road Trauma Unit, a specifically equipped and staffed centre to care for road trauma patients. This centre is supported by the facilities of the Alfred Hospital, which has a complete range of specialist services and investigational facilities. The centre can be rapidly accessed by both ambulance helicopter and surface transport. The Hyberbaric Unit will also be open for delegates to visit. Hyberbaric medicine involves the use of barometric pressure greater than that at sea level for the treatment of diseases.

The tour will then visit the Caulfield campus to view the Amputee Unit; a purpose adapted and fully equipped unit which houses all staff with clinical, theraputic, technical and manufacturing facilities and the Monash Rehabilitation Technology Research Unit consisting of an inter-disciplinary team with medical, theraputic, and engineering expertise, which work toward the enhancement of quality of life of the musculo-skeletal disabled patient.

Tour Time: Alfred Hospital (Acute): 13.30-15.00
Caulfield Campus (Rehabilitation): 15.00-17.00
Cost: $30.00

*TOUR 3*: (Code TT03)
**Austin Hospital**

The Austin hospital is a teaching hospital with both acute and rehabilitation campuses. Delegates will be concentrating on the rehabilitation area of this hospital. Client Groups catered for by this hospital include, Amputees, Spinal Cord Injuries, Orthopaedics, Neurology, and Acquired Brain Injuries. Tours of the following areas will be available; Spinal Cord Injuries Unit, Prosthetic and Orthotic Department, Physiotherapy Department, Occupational Therapy Department, Amputee Unit, and the Gait Clinic.

Staff will avail themselves for brief introductions to all areas or for more detailed visits, depending on the interest from delegates.

Tour Times: Spinal Cord Injuries Unit, Prosthetic & Orthotic Department Gait Clinic: 13.30-15.15
Physiotherapy, Occupational Therapy, Amputee Clinic: 15.15-17.00
Cost: $30.00

*TOUR 4 (Code TT04)*
**Demonstration of Amputee Athletes**

In the recent past it had been considered appropriate to discourage physical activity among amputees. Now modern prosthetic technology allows many a level of function almost equal to their pre-amputation potential. The demonstration will show how individuals with amputations can realise their full physical abilities.

A group of amputee athletes (including many who have represented Australia) will perform a range of sporting activities.

Standard componentry will be demonstrated in addition to more advanced componentry and equipment specifically designed and manufactured to accommodate particular sporting needs.

Athletes will be available to discuss features of their sporting prosthesis and how that prosthesis differs from the prosthesis they wear on a daily basis.

Cost: $30.00.

# General Information

**Venue**

The World Congress Centre, Melbourne is a new, modern Convention Centre conveniently located in the heart of the city, within walking distance of city hotels and is well serviced by public transport. It is incorporated in a modern complex which also includes the hotel, Centra Melbourne on the Yarra, the World Trade Centre and a Casino. This complex contains facilities for banking, postal and secretarial services, photocopying and facsimile transmission. A number of restaurants, lunch and coffee bars are situated in the area. Hairdressers, pharmacy, medical centre and newsagents are also available.

World Congress Centre
Corner of Flinders and Spencer Streets
MELBOURNE VIC 3000
Phone (61) (03) 629 4100
Fax: (61) (03) 614 6565

**Registration and Information Desk**

The registration desk will be located at the World Congress Centre. We advise you to collect your documents as soon as possible after your arrival. The registration desk will be open during the following hours:

Saturday, April 1 – 12.00-17.00

Sunday, April 2 to Thursday April 6 – 07.30-17.00
Friday, April 7 – 07.30-12.30

**Passport and Visa**

Travellers require a passport and visa for entry into Australia and applications may take some time to process. The airline or travel agent will advise you regarding the procedures for lodgement of the visa application. It is essential to purchase a return ticket.

**Quarantine**

Australia is free from many plant and animal diseases prevalent in other countries. Very strict quarantine rules apply to the importation of animals and plants which cannot be brought into the country without prior application. Animal and plant products are also restricted.

**Travel**

For international passengers, we suggest that you allow at least a day in which to adjust to the time difference and relax after the flight. Travellers across the Pacific are reminded that they will lose a day by crossing the International Date Line. This will be reversed on the return journey.

**Arriving in Melbourne**

It is recommended that international delegates select flights which operate direct to Melbourne to avoid possible transfers from international to domestic terminals in other Australian airports.

Foreign exchange facilities are available at the international terminal. Transfers to the city from the domestic and international terminals are easily accessed. A taxi will cost approximately $AUD25.00. Alternatively, airport buses will take you to the Central Business District and, during weekdays only, to most major city hotels for around $AUD9.00 per person.

**Time Difference**

Australian Eastern Time is GMT + 10 hours.

**Climate**

April is mid-autumn in Melbourne and you can expect the weather to be pleasantly mild. The average maximum temperature is around 22 degrees C (72 degrees F). However, evening temperatures could be as low as 12 degrees C (54 degrees F).

**Official Airline**

Quantas Airways Ltd has been appointed the official international carrier. Under this arrangement, Quantas offices in all parts of the world will be pleased to discuss with you and your travel needs and itineraries, and will explain airfare structures for the most economical travel to Australia.

When making enquiries please quote reference number JB58VU.

# Associated Meetings

**Pre-Congress Tour: New Zealand**

The 7 day tour incorporates a one-day scientific meeting in Wellington and visits to artificial limb centres throughout New Zealand.

The tour will commence in Auckland and will visit both the North and South Islands before departing to Melbourne from Christchurch.

Please indicate your expression of interest on the registration form and further detailed information will be forwarded.

# Accommodation

Melbourne is well-supplied with hotels of all standards and styles. A wide selection of excellent hotels and apartments has been reserved for the Congress with a range of room rates.

A special Congress rate has been secured and can be obtained only by booking your accommodation via the Registration Form prior to 15th February, 1995. Any bookings received after this date cannot be guaranteed at the Congress rate. Accommodation will be allocated in order of receipt of bookings and payment. Early registration is advised.

The Secretariat will do everything possible to place you according to your preference within our room allotments and you will be notified of your hotel's name in a letter of confirmation.

**Pre-registration**

Many international flights arrive in Melbourne in the very early morning and as check-in time at most hotels is 2.00 pm, it is possible that your room will not be ready for occupancy on your arrival. Hotels try to accommodate their guests' needs. However, if you feel it necessary, you can ensure immediate availability by paying an extra day's tariff and booking the room for the night before you are due to arrive. If you take this precaution, please advise the Secretariat in a covering note so that the hotel management understands the room is "pre-registered".

**Late Arrivals**

Please indicate on your Registration Form if you will arrive at your hotel after 6.00 pm; failure to do so may mean that your room will be released.

**Deposit**

The deposit for your chosen hotel as listed on the Registration Form must accompany your reservation. Please include this payment with your registration fees. The deposit will be forfeited if the room is not occupied on the advised date of arrival.

**Batman's Hill Hotel**
*$AUD 110.00*
Accommodation comprises stylishly appointed rooms offering a wide range of facilities ensuring your every comfort. A five minute walk to the World Congress Centre.
66-70 Spencer Street,
MELBOURNE VIC 3000.
Phone: (61) (03) 614 6344
Fax: (61) (03) 614 1189

**Centra Melbourne on the Yarra**
**(Congress Hotel)**
*$AUD 160.00*
Situated on the Yarra River close to Central Business District and Southgate. Attached to the World Congress Centre and equipped with full business facilities. Accommodation room facilities include air-conditioning, mini-bar, refrigerator, tea and coffee-making facilities,

AM/FM radio, direct IDD/STD, iron and ironing board, remote colour TV, hairdryer, heated outdoor swimming pool, gymnasium, currency exchange
Corner Flinders & Spencer Streets,
MELBOURNE VIC 3000,
Phone: (61) (03) 629 5111
Fax: (61) (03) 629 5624

**Hotel Enterprise**
*Single $AUD 69.00 Double $AUD 79 00*
Comfortable, affordable accommodation in the city. Country hotel atmosphere in older style property. 300 metres to World Congress Centre and trams at the door. Each room has private facilities air-conditioning, tea and coffee making facilities and TV.
44-54 Spencer Street,
MELBOURNE VIC 3000,
Phone (61) (03) 629 6991
Fax: (61) (03) 614 7963

**Le Meridien at Rialto**
*$AUD 195.00*
In the heart of Melbourne's commercial district, with the World Congress Centre within 5 minutes walking distance. Each room features, IDD/STD phones, mini bar, toaster, hairdryer, tea and coffee making facilities, 24 hour room service.
495 Collins Street,
MELBOURNE VIC 3000,
Phone: (61) (03) 620 9111
Fax: (61) (03) 614 1219

**Novotel Melbourne on Colins**
*$AUD 144.00*
Most centrally located hotel in the city. Each room features electronic cardlocking, individually controlled air conditioning, remote control TV with complimentary in-house movies. There are STD/IDD phones, mini-bar, tea and coffee making facilities, daily newspapers, hairdryer and 24 hour room service.
270 Collins Street,
MELBOURNE VIC 3000,
Phone: (61) (03) 650 5800
Fax: (61) (03) 650 7100

**Riverside Apartments**
*1 bedroom $AUD 140.00*
*2 bedrooms $AUD 176.00*
Serviced apartment accommodation situated on the top four floors of a new 18 storey building featuring panoramic views of the Yarra River, Port Phillip Bay and the city skyline. Choice of one or two bedrooms. Lounge/dining room, bathrooms with full size bath, hairdryer, washing machine and clothes dryer. Fully equipped gourmet kitchen includes microwave and dishwasher ISD/STD indial exchange phone system, iron/board, liquor and pantry service and individually controlled air conditioning.
474 Flinders Street,
MELBOURNE VIC 3000,
Phone: (61) (03) 283 7633
Fax: (61) (03) 629 7582

**Savoy Park Plaza**
*$AUD 150.00*
The hotel features two restaurants, and bar, gymnasium and close proximity to the Congress Centre. Rooms feature IDD/STD telephones, mini bar, tea and coffee making facilities.
630 Little Collins Street,
MELBOURNE VIC 3000,
Phone: (61) (03) 622 8888
Fax: (61) (03) 622 8877

**Sheraton Towers Southgate**
*$AUD 235 00*
Melbourne's newest hotel. Rooms feature individually controlled air-conditioning and heating, remote control TV, in-house movies, AM/FM radio, IDD/STD phone access, mini-bar, tea and coffee making facilities, hairdryer, butler service and full buffet breakfast. Non-smoking rooms are available and there is a health club for guests' use. A 10 minute walk to the World Congress Centre.
One Brown Street,
SOUTH MELBOURNE VIC 3205
Phone: (61) (03) 696 3100
Fax: (61) (03) 690 5880

**The Sebel of Melbourne**
*$AUD 250.00*
The Sebel is an all suite hotel located a 5 minute walk to the World Congress Centre. Each room has IDD/STD phone, insuite ironing facilities, invidually controlled air-conditioning and windows that open.
321 Flinders Lane,
MELBOURNE VIC 3000
Phone: (61) (03) 629 4088
Fax: (61) (03) 629 4066

**The Victoria Hotel**
*Single $AUD 52.00*
*Double $AUD 64.00*
In the heart of Melbourne's best shopping, theatres and restaurants, this "Old World" hotel caters to the budget-conscious. Rooms feature colour TV, direct dial telephones, refrigerator, tea and coffee making facilities.
215 Little Collins Street
MELBOURNE VIC 3000
Phone: (61) (03) 653 0441
Fax: (61) (03) 650 9678

**Welcome Hotel**
*$AUD 100.00*
The Welcome Hotel features air conditioning, colour TV, in-house movies, radio, mini bar, tea and coffee making facilities, toaster and direct dial ISD/STD telephone. The hotel is located in the centre of Melbourne and is close to public transport.
265-281 Little Bourke Street,
MELBOURNE VIC 3000
Phone: (61) (03) 639 0555
Fax: (61) (03) 639 1179

# 8TH WORLD CONGRESS OF THE INTERNATIONAL SOCIETY FOR PROSTHETICS AND ORTHOTICS

**MELBOURNE APRIL 2-7, 1995**

# REGISTRATION FORM

## REGISTRATION

*PLEASE TYPE OR PRINT IN BLOCK LETTERS*

Family Name _____ Title (Prof. Dr. Mr. Mrs. Ms.)

Given Name _____ Department _____

Organisation _____

Address (Number/Street) _____

Town/Suburb _____ State/Province _____

Country _____ Post/Zip Code _____

Telephone Number ( ) _____ Facsimile Number ( ) _____

Accompanying person's name if participating in Congress programme:

Given Name _____ Family Name _____

**Please indicate if already faxed to secretariat*

## KEYWORD PROGRAMME SELECTION

INDICATE YOUR KEYWORD SELECTION BELOW:

| | | | | | |
|---|---|---|---|---|---|
| | | | | | |

## REGISTRATION FEES

| | | No. of Tickets | Total Cost AUD |
|---|---|---|---|
| **Delegate Fees** | | | |
| Member | $AUD650.00 | | |
| Non-Member | $AUD775.00 | | |
| Accompanying Persons: | $AUD200.00 | | |
| Students | $AUD200.00 | | |
| Late Fee (after 31 December 1994) | $AUD100.00 | | |

ISPO Membership No.

**REGISTRATION FEE SUB TOTAL AUD:**

## INSTRUCTIONAL COURSES

**COST: $AUD50.00 PER COURSE PER DAY**

*PLEASE INDICATE THE CODE OF THE INSTRUCTIONAL COURSE YOU WISH TO ATTEND EACH DAY.*

| Sunday | Monday | Tuesday | Wednesday | Thursday | Friday |
|---|---|---|---|---|---|
| | | | | | |

**INSTRUCTIONAL COURSE FEE SUB TOTAL AUD:**

## MANUFACTURERS WORKSHOPS

**COST: $AUD25.00 PER COURSE PER DAY**

*PLEASE INDICATE THE CODE OF THE MANUFACTURERS WORKSHOPS YOU WISH TO ATTEND EACH DAY.*

| Monday | Tuesday | Wednesday | Thursday | Friday |
|---|---|---|---|---|
| | | | | |

**MANUFACTURERS WORKSHOP FEE SUB TOTAL AUD:**

## TECHNICAL TOURS

**COST: $AUD30.00 PER PERSON**

*Please indicate ( ✔ ) which tour you wish to attend on Wednesday April 5*

| TT01 | | TT02 | | TT03 | | TT04 | |
|---|---|---|---|---|---|---|---|

**TECHNICAL TOURS FEE SUB TOTAL AUD:**

## ACCOMMODATION

*I/We will require (tick which required)*

Single ☐ Double ☐ Twin Share ☐

Suite ☐ Apartment ☐

**(Note suites and apartments apply to certain hotels only)*
*Please indicate (✔) selected hotel in the appropriate box.*

Date in ___/___/95 Date out ___/___/95

Estimated time of arrival (if known) _____

| HOTEL | | Deposit required per room AUD | |
|---|---|---|---|
| ☐ Batman's Hill Hotel | | $110.00 | |
| ☐ Centra Melbourne on the Yarra | | $160.00 | |
| ☐ Hotel Enterprise | Single | $69.00 | |
| | Double/Twin | $79.00 | |
| ☐ Hotel Swanston | | $120.00 | |
| ☐ Le Meridien at Rialto | | $195.00 | |
| ☐ Novotel Melbourne on Collins | | $144.00 | |
| ☐ Riverside Apartments: | One Bedroom | $140.00 | |
| | Two Bedroom | $176.00 | |
| ☐ Savoy Park Plaza | | $150.00 | |
| ☐ Sheraton Towers/Southgate | | $235.00 | |
| ☐ The Sebel of Melbourne | | $250.00 | |
| ☐ The Victoria Hotel: | Single | $52.00 | |
| | Double | $64.00 | |
| ☐ Welcome Hotel | | $100.00 | |

If sharing please give full name of person sharing room:

_____

***No accommodation booking will be accepted unless accompanied by the mandatory deposit per room.***

**ACCOMMODATION DEPOSIT SUB TOTAL AUD** _____

## SOCIAL FUNCTIONS & TOURS

*Please indicate number of tickets required.*
*Tickets will not be issued unless requested, even when events are included in the registration fee.*

| | No. of tickets | Cost per person | Total cost AUD |
|---|---|---|---|
| **Sunday 02 April** | | | |
| Orientation Tour | ____ | $30.00 | ____ |
| Welcome Reception | ____ | Inclusive in delegate & accompanying person fee | |
| **Monday 03 April** | | | |
| Meet the Partners - Morning Tea | ____ | Inclusive in accompanying person fee only | |
| ***Select one of the following three tours:*** | | | |
| Koori Walkabout | ____ | Inclusive in accompanying person fee only | |
| Shop till you Drop | ____ | | |
| The Australian Ballet | ____ | | |
| **Tuesday 04 April** | | | |
| Congress Dinner | ____ | $85.00 | ____ |
| **Wednesday 05 April** | | | |
| Sightseeing Tours: | | | |
| ● Penguins on Parade | ____ | $64.00 | ____ |
| ● Victorian Wineries | ____ | $99.00 | ____ |
| ● Australian Animals | ____ | $99.00 | ____ |
| **Thursday 06 April** | | | |
| Gilbert & Sullivans "Patience" | ____ | $65.00 | ____ |
| **Friday 07 April** | | | |
| Farewell Lunch | ____ | Inclusive in delegate & accompanying person fee | |
| **Pre-Conference Tour - New Zealand** | *I wish to receive additional information of the pre-conference tour.* | | ____ |

**SOCIAL FUNCTIONS & TOURS SUB TOTAL AUD** _____

## PAYMENT SUMMARY

| | |
|---|---|
| **Registration Fees** | |
| **Instructional Courses** | |
| **Manufacturers Workshops** | |
| **Technical Tours** | |
| **Accommodation Deposit** | |
| **Social Functions/Tours** | |
| **GRAND TOTAL AUD** | |

All payments must be made in AUSTRALIAN DOLLARS only.
Payment in any other currency will NOT be accepted.
Overseas delegates please note that personal cheques will not be accepted and will be returned to sender.
If you have any difficulty with remittance of payment caused by your country's foreign exchange regulations, please contact the Secretariat for advice before forwarding any other than the acceptable form of payment.
Please make cheques/bank drafts payable to:
8th ISPO WORLD CONGRESS or please charge my credit card:

*Please indicate which card:* Mastercard ☐ Visacard ☐ Bankcard ☐ *(Australian delegates only)*

Signature of cardholder: _____

Card Number: ☐☐☐☐ ☐☐☐☐ ☐☐☐☐ ☐☐☐☐

Name of cardholder: _____ Expiry Date: ___/___

## OFFICE USE ONLY

Cheque/Draft No. _____ Drawer _____

Bank _____ Branch _____

*Prosthetics and Orthotics International, 1994, 18, 137-138*

# Calendar of Events

## National Centre for Training and Education in Prosthetics and Orthotics Short Term Courses 1994-95

### Courses for Physicians, Surgeons and Therapists

NC512 Orthotic Management of the Foot; 24–25 October, 1994
NC502 Upper Limb Prosthetics and Orthotics; 7–11 November, 1994
NC504 Lower Limb Orthotics; 12–16 December, 1994
NC505 Lower Limb Prosthetics; 23–27 January, 1995
NC510 Wheelchairs and Seating; 7–9 February, 1995
NC511 Clinical Gait Analysis; 3–5 May, 1995
NC506 Fracture Bracing; 9–12 May, 1995

### Courses for Prosthetists

NC222 Ischial Containment Trans-Femoral Socket; 10–14 October, 1994
NC227 Trans-Tibial Prosthetics; 5–9 December, 1994
NC226 Advanced Trans-Femoral Prosthetics; 30 January–3 February, 1995
NC212 Hip Disarticulation Prosthetics; 27 February–3 March, 1995
NC221 Trans-Tibial Suction Socket; 6–10 March, 1995

### Courses for Orthotists

NC223 Casting and Plaster Techniques; 20–21 October, 1994
NC224 Reciprocating Gait Orthotics; 3–4 November, 1994

### Courses for Orthotists and Therapists

NC225 Direct Application Upper Limb Orthotics; 16–18 January, 1995
NC217 Ankle-Foot Orthoses for the Management of the Cerebral Palsied Child; 26–28 April, 1995

Further information may be obtained by contacting Prof. J. Hughes, Director, National Centre for Training and Education in Prosthetics and Orthotics, University of Strathclyde, Curran Building, 131 St. James' Rd., Glasgow G4 0LS, Scotland. Tel: 041-552 4400 ext. 3298.

**4-9 September, 1994**
6th European Regional Conference of Rehabilitation International, Budapest, Hungary.
Information: Rehabilitation Secretariat, ISM Ltd., The Old Vicarage, Haley Hill, Halifax HX3 6DR, England.

**13-16 September, 1994**
Biomechanics of Man '94, Prague, Czechoslovakia.
Information: Jitka Jirova, ITAM AS CR, Pod vodarenskou vezi 4, 18208 Prague 8, Czechoslovakia.

**16-17 September, 1994**
Independent Living for the Elderly, Collobarative Meeting of ISPO Netherlands and ISPO UK, Noordwijkerhout, The Netherlands.
Information: Dr. B. McHugh, NCTEPO, University of Strathclyde, Curran Building, 131 St. James' Rd., Glasgow G4 0LS, Scotland.

**21-23 September, 1994**
Biological Engineering Society AGM and Annual Scientific Meeting, Keele, England.
Information: Mrs. B. Freeman, BES, RCS, 35 Lincoln's Inn Fields, London, England.

**21-24 September, 1994**
2nd International Symposium on Computer Methods in Biomechanics and Biomedical Engineering, Swansea, Wales.
Information: J. Middleton, Biomechanics and Biomedical Engineering Centre, Engineering Building, University College of Swansea, Swansea SA2 8PP, Wales, UK.

**26-28 September, 1994**
5th International Symposium on Biomedical Engineering, Spain.
Information: Congress Secretariat, Laboratorio de Fisica Aplicada e Ingenieria de Conocimiento, Facultad de Fiscia, Universidad de Santiago de Compostela, 15706 Santiago de Compostela, Spain.

**28 September-1 October, 1994**
International Meeting on Knee Prostheses, Naples, Italy.
Information: Prof. V. Monteleone, II Divisione Ortopedia e Traumatologia, Ospedale Cardarelli, Via A. Cardarelli 9, 80131 Napoli, Italy.

**9-13 October, 1994**
6th Biennial Conference of the International Society for Augumentive and Alternative Communications, Maastricht, The Netherlands.
Information: Van Namenand Westerlaken, PO Box 1558, 6501 BN Nijmegen, The Netherlands.

**14-16 October, 1994**
Biomedical Engineering Society Annual Fall Meeting, Tempe, Arizona, USA.
Information: BMES, PO Box 2399, Culver City, CA 90231, USA.

**11-15 October, 1994**
American Orthotic & Prosthetic Association: Annual National Assembly, Washington, USA.
Information: AOPA, 1650 King St., Suite 500, Alexandria, VA 22314, USA.

**23-25 November, 1994**
British Orthopaedic Association Practical Course on Casting Techniques for Surgeons and Physicians in Training, Glasgow, Scotland.
Information: Mrs. E. Arnold, BOA, 35–43 Lincoln's Inn Fields, London WC2A 3PN, England.

**7-10 December, 1994**
8th International Conference on Biomedical Engineering, Singapore.
Information: The Secretary, 8th ICBME 1994, Dept. of Orthopaedic Surgery, National University Hospital, Lower Kent Ridge Rd., Singapore 0511.

**1995**

**17-18 February, 1995**
ISPO (UK) Annual Scientific Meeting, Hull, England.
Information: Mr. D. Simpson, ISPO Hull '95, NCTEPO, University of Strathclyde, 131 St. James' Rd., Glasgow G4 0LS, Scotland.