



**The Journal of the International Society  
for Prosthetics and Orthotics**

# **Prosthetics and Orthotics International**

**August 1998, Vol. 22, No. 2**

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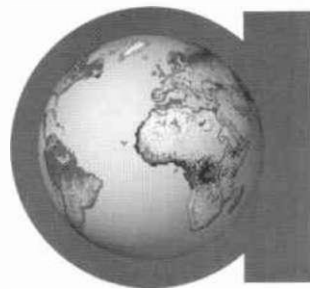
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A full list of Standing Committee Chairman, Task Officers and Consultants will appear in the next issue of the Journal.

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S. Sawamura (1995-1998)	Japan

## *Secretary*

Aase Larsson	Denmark
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## **Editorial**

The Ninth World Congress of ISPO has now come to a close. All the hard work and planning by the Organising Committee under its Chairman, Wim Eisma, Secretary General, Hans Arendzen, and Deputy Secretary General, Jan Geertzzen, has ended and it is now time to take stock of the event.

A total of 3141 people participated in the Congress from a total of 77 countries. There were 1340 participants in the scientific programme, 1620 participants in the exhibition and 181 accompanying persons.

The Scientific Programme, under the Chairmanship of Thijs Soede, was very comprehensive and covered all aspects of prosthetics, orthotics, rehabilitation engineering and related topics. There were a total of 118 sessions comprising 8 Plenary Sessions, 38 Symposia, 56 Free Paper Sessions, 10 Poster Sessions, 3 Audio-visual Sessions, and 3 Help-desk Sessions. As well as printing the abstracts of the presentations in a Conference Book a CD-ROM version was produced and distributed to the participants.

The Instructional Course Programme was very ably organised by Ed van Laar and consisted of 40 Instructional Courses and a further 29 Manufacturers Workshops.

The Commercial Exhibition was the largest that the Society has attracted and was very ably organised by Frank Kuiper. Some 152 companies representing 16 countries participated and housed in two large halls. In addition there were a further 9 non-commercial exhibits.

The Social Programme was well structured and very enjoyable. It was under the organisation of Dirk Kuppeveldt. The Official Opening was a very impressive event. Princess Margriet of the Netherlands opened the Congress and Binks Day gave the Knud Jansen Lecture. The Welcome Reception was held in the Exhibition Hall after the Official Opening allowing the participants to view the Exhibit for the first time. On Monday evening the City of Amsterdam hosted a Municipal Reception in the Oude Kerk the oldest church in Amsterdam and built in the 13th century and situated in a most interesting area in the city centre. The Congress Party was held on the Thursday evening and consisted of a very elegant dinner in Beurs van Berlage, the former Merchant's Exchange, followed by a festive dessert buffet and dance in the Grand Krasnapolsky Hotel. A highlight of the party was the after-dinner speech by Wyn Beasley on a history of the relationship between the Netherlands and Australia.

The Sponsorship activity was in the very able hands of Jo Hanssen, the Treasurer of the Congress and was extremely successful. It is with great sadness and a heavy heart that we learned of Jo Hanssen's sudden death shortly after the Congress ended. As with everything Jo undertook this task in a cheerful and effective manner. Our thoughts and condolences are with his widow, Bertie, and his daughters, Susanne and Karin, at this difficult time. He will be sadly missed. (Editor's note: an Obituary to Jo Hanssen is printed on p78 of this issue of Prosthetics and Orthotics International)

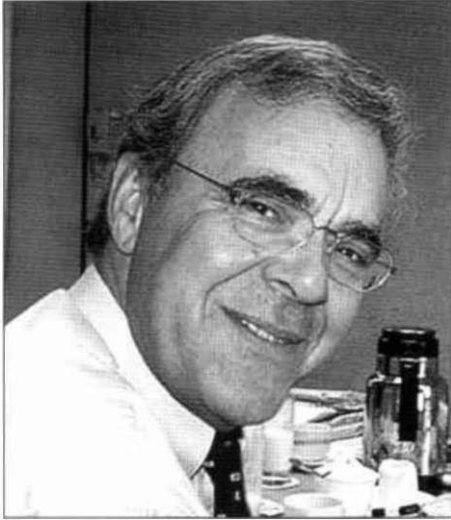
The efforts of Ellen and Carola Kruijmer Congrex Holland,

All told the Congress was a very successful event. The Society's thanks must be given to the Organising Committee for all the efforts that they made in making our stay in Amsterdam a most welcoming and rewarding time.

Norman A. Jacobs  
*President*

## **Obituary**

### **Jo Hanssen (1942 - 1998)**



A fine man is dead. A few days after the closing of the IXth ISPO World Congress the news came that Jo was admitted to hospital with symptoms of a progressive stroke. Shortly after admission he became unconscious and remained in a coma until he died on Thursday 22 July. For the last 5 years Jo Hanssen was the Treasurer in the Organising Committee of ISPO'98 and from 1983 until 1995 he was responsible for finance and membership on the Committee of the National Member Society of ISPO-Netherlands. Some facts are given below for those who read this obituary but never met Jo Hanssen in person.

Jo's death is a tragedy for his wife Bertie, his children Susanne and Karin and for Franc van der Linden, his son-in-law and successor in the Orthopaedic Shoe Company successfully build up by the Hanssen family. For the many friends

and colleagues it is a terrible blow and the true impact will only appear to us in the near future.

It is not difficult to describe Jo Hanssen as a professional. Jo linked his unique technical and creative skills with a warm human interest. A team player by nature made him the perfect professional for the complex rehabilitation processes both respected and beloved by his patients and colleagues. His warm character, reliability and hard working capacities have been an inspiration for his employees and the members of the different committees he served on.

In the many privileged years we worked together on ISPO matters I admired his wisdom, patience and problem solving abilities. Always positive and respectful about his opponents Jo would give his strong opinions and they were difficult not to follow. His life-style combined hard and efficient work with plenty of time for pleasure. This style has been adopted in the ISPO-Netherlands and ISPO'98 committee work and it helped us to make a feast of most meetings. After the Closing Ceremony of the IXth ISPO World Congress plans were made to commemorate the success of the organisation but without Jo Hanssen we have nothing to celebrate. ISPO has lost an outstanding member and we have lost our dearest friend.

Jo and Bertie had a dream: the company in safe hands, a beautiful new place to live and time to take pleasure from children, grand-children and friends. They had almost fulfilled their dream. We mourn with Bertie, who supported Jo so strongly in his professional career and in his ISPO duties. I hope that the remembrance of Jo gives her the strength again to find new perspectives.

*J.Hans Arendzen*



## **Ninth World Congress Opening Ceremony**

### **MEET IN AMSTERDAM**

**J. H. ARENDZEN, SECRETARY GENERAL ISPO '98**

Your Royal Highness, Distinguished Guests, Representatives of the City of Amsterdam World Health Organisation and INTERBOR, Members of ISPO, Ladies and Gentlemen.

Welcome. Welcome to the Netherlands, welcome to the city of Amsterdam and especially warm welcome to the IXth World Congress of the International Society for Prosthetics and Orthotics. It is a great honour and a pleasure for the Organising Committee of ISPO '98 to be your host for the next five days.

Over the last years all my communication with you ended with the words: "Looking forward to meeting you in Amsterdam."

Meet in Amsterdam was the slogan we used in 1992 as we prepared the invitation to host this conference. It was not just another phrase. It was our intention to bring professionals together: professionals with different backgrounds in medical and technical education and training; professionals from all over the world with differences in cultural and socio-economic circumstances; and professionals who communicate in the English language every day and those who find it difficult to understand and speak the language.

We are grateful that you all came to Amsterdam to exchange the results of your scientific work. We are grateful that you came to learn and to teach. But most of all we are grateful that you want to listen to each other in order to obtain a better understanding of the needs and problems of those who depend on our knowledge and skills.

This World Congress has a message. We will focus not only on technological developments but also on the quality of the technology and the service we give to our clients. We will emphasise that different phases in life demand different approaches to the rehabilitation of individuals with a physical disability.

Children and youngsters need protection as they grow up but our medical, technical, and educational efforts should aim at a meaningful and independent future.

For adults with an active life-work, sports and hobbies are fundamental for their existence; but then again in the context of social, economic and cultural differences.

Finally when you come to old age we will be grateful for the protection we get from society but at the same time our physical independence remains of paramount importance.

Please keep in mind that improvements in function is what keeps them and us moving. That is the message. Therefore you came to Amsterdam. Therefore we meet and I sincerely hope we can meet your expectations. Thank you for sharing your interests with us.

After the welcome words it is my pleasure to take up my first official task. On behalf of the President of ISPO Dr Sawamura I have the honour to introduce to you the Knud Jansen Lecturer 1998. This lecture in the name of the founder of ISPO is presented by a doctor who trained initially as an orthopaedic surgeon but became a specialist in amputee rehabilitation and prosthetic services. He developed a particular interest in the care of children with congenital limb deficiency. Today's lecturer knows the world of prosthetics from the early days when Knud Jansen looked and found colleagues with similar interest and ambition. They started the International Society for Prosthetic and Orthotics. Who is more able to acknowledge what has been achieved in the last three decades. On which shoulders we can get a better look into the next century than from sitting on the shoulders of Dr Binks Day. Dr Day may I invite you to present the 1998 Knud Jansen Lecture on "Amputee rehabilitation and ... finding the niche."

*(Editor's note: the full text of the 1998 Knud Jansen Lecture is published on p92).*

**WELCOME ADDRESS**  
**S. SAWAMURA, PRESIDENT OF ISPO**

Your Royal Highness, Distinguished Guests, Ladies and Gentlemen.

On behalf of the International Society for Prosthetics and Orthotics, I would like to welcome you from the bottom of my heart to participate in this IXth World Congress.

The IXth World Congress has brought experts from around the world to Amsterdam. I am sure the membership will share the Executive Board's pleasure in the most modern and outstanding congress facilities of the Amsterdam RAI International Exhibition and Congress Centre.

The Dutch National Member Society which is organising the World Congress is the largest in ISPO. Much effort has been devoted to the preparation of the format and the content of the scientific and social programme under the splendid leadership of Dr Hans J. Arendzen. The International Congress Committee together with the Dutch Scientific Committee have assembled an excellent programme under Chairman, Mr Norman A. Jacobs. At the same time, I wish to thank INTERBOR, our collaborating organisation, for its co-operation. A main theme has been chosen for each day from the following phases of life: children, adults and the elderly. The Plenary Sessions will feature speakers of international renown presenting the latest development in subjects selected for their topicality. Each Symposium will focus in depth on subjects concerning the theme of the day.

The Instructional Courses will provide the opportunity for an educational experience encompassing the state-of-the-art in a variety of subjects. Poster Sessions will also focus on the theme of the day. The Free Paper Sessions, in appropriate groupings, will provide the opportunity for all to present their latest work in research, clinical practice or technological application. The scientific programme will be complemented by a commercial exhibition and we will be able to see the components, equipment, treatment devices and manufacturing materials used in all aspects of rehabilitation. At any time the participant will have the choice of parallel sessions/activities in a programme designed to provide for the needs of all.

Of course, congress attendance is not all work, and our Dutch hosts have arranged an exciting social programme and accompanying persons' programme to give us a generous flavour of their beautiful country.

Amsterdam is eminently qualified as an outstanding city for international conferences with excellent convention facilities where the participants are hosted efficiently in style. As we pursue even higher quality prosthetics and orthotics services in a spirit of comradeship through this Congress, we also aim to make many new friends.

Lastly, I wish once again to thank Dr Hans Arendzen for preparing over several years this wonderful World Congress, as well as all the Dutch Organising Committee members and our many friends for making this event possible.

**OFFICIAL OPENING**

HER ROYAL HIGHNESS, PRINCESS MARGRIET OF THE NETHERLANDS

Mr Chairman, Ladies and Gentlemen.

It was with great pleasure that I accepted the invitation of the organisers of this Ninth World Congress of the International Society for Prosthetics and Orthotics to say a few words in the light of my involvement with the Red Cross.

There is a connection between the Red Cross and the production of prostheses and orthopaedic appliances. The International Red Cross and Red Crescent Movement has for quite some time now been very closely involved in finding solutions to orthopaedic problems, particularly those of amputees. Since 1979 the International Committee of the Red Cross (ICRC) has been widely involved not only in the production of prostheses and orthopaedic appliances for victims of armed conflicts, but also in the rehabilitation of amputees and their reintegration into society. To date 46 rehabilitation projects have been set up in 23 countries, and over 115,000 prostheses and 30,000 orthopaedic appliances have been made. Moreover, during the last 20 years, 160,000 pairs of crutches and over 8,000 wheelchairs have been produced.

At the end of last year the ICRC had 22 orthopaedic workshops in nine countries, including Angola, Afghanistan, Iraq and Tajikistan.

Besides actually being involved in orthopaedic rehabilitation projects, the ICRC also gives financial support to projects through its Special Fund for the Disabled. These are projects that were initially set up by the ICRC and then transferred after a few years to non-governmental or governmental agencies.

The National Red Cross and Red Crescent Societies, too, are involved on a smaller scale in orthopaedic rehabilitation projects. A rehabilitation centre for people with spinal injuries was set up in Armenia, for instance. The Netherlands Red Cross has set up orthopaedic workshops in Lebanon and Angola.

Victims of armed conflicts constitute the largest group receiving orthopaedic help from the Red Cross. Within this group our greatest concern is for amputees with injuries caused by anti-personnel mines. About one third of the people helped in our orthopaedic workshops are those injured by mines. In 1997 the ICRC produced about 11,000 prostheses; 7,000 of these were for victims of landmines, with a high percentage of below-knee amputation.

But these victims are worse off in more ways. For one thing mortality among patients injured by mines is significantly higher and studies show a considerably higher incidence of operations and a very high number of blood units to be transfused with a greater risk from infection. Amputated patients face not only more problems in the initial phase but also at a later stage. Some mine victims still have serious medical and social problems many years after an amputation: a great deal of human suffering – suffering with which the Red Cross is confronted on a daily basis.

Great efforts are being made to heighten awareness of mines and to increase mine clearance programmes. Did you know, by the way, that given the present state of mine clearance technology it will take about two thousand years to clear mines from 15% of the territory of Afghanistan? We have to realise that despite more awareness and mine clearance programmes innocent people will continue to fall victim to anti-personnel mines years and years after the cessation of hostilities.

It was against this background that the International Red Cross and Red Crescent Movement began a global campaign against anti-personnel mines about six years ago. The campaign focuses on a number of areas. One of these is of course surgical and orthopaedic help for mine victims. Lack of money means that the aid provided often falls far short of demand.

That is why the Red Cross is focusing on a third area as well, namely a total ban on the production, storage, distribution and use of anti-personnel mines. Although some progress has been made towards this goal, and a number of countries now support the ban, much remains to be done before a total ban is effected.

It will be clear to you that the Red Cross is confronted with your sphere of work on a day-to-day basis. The progress that you make is also progress for the victims of war. You help people to find their way back into society, and in this way you play a significant role in improving the lives of hundreds of thousands of people. I open this congress with the wish that it will bring you yet another step forward in alleviating human suffering.

## **OPENING COMMENTS**

**J. EBBINK, PRESIDENT OF INTERBOR**

Your Royal Highness, Dr Seishi Sawamura, Ladies and Gentlemen.

It is for me, being a Dutchman, a great honour to be invited by the secretary general, Dr Hans Arendzen and the organisers to address you on behalf of INTERBOR at your opening ceremony. The honour is all the better because Her Royal Highness is amongst us and she is a supporter for physically disabled persons both nationally as well as internationally.

I know from my own experience that to organise an event like this always involves an enormous effort and also a responsibility towards the participants in order to present a high level of scientific programme and a well organised effective exhibition, combined with social events that should reflect the typical Dutch atmosphere and culture. From inside information and from what I have already seen, I believe the organisers have succeeded very well in doing so. The Congress has set an excellent

standard, both from the scientific and the exhibition points of view. This is only possible due to the effort of many persons before and behind the stage. Without the help of technicians, many volunteers, the professional Congress Organiser and of course the Planning Committee this event could not take place.

As a Dutch ISPO member I am also proud you succeeded finally to persuade the Executive Board of ISPO to have the Ninth World Congress on Prosthetic and Orthotics in the Netherlands. The Netherlands National Member Society tried already for more than 20 years to bring it to the Netherlands and probably the help of the previous ISPO President, Professor Eisma, was perhaps of help, he certainly was and still is a big advocate of the Society.

Once again and as usual, INTERBOR has given its full support to your Congress as you do to ours. For instance your collaboration in the INTERBOR Congress in 1999 in Boston is tremendous and only a couple of weeks ago the organisers of the ISPO World Congress in 2001 in Scotland already asked for more details about it. We believe that this collaboration is needed because of the small size of the prosthetics and orthotics profession: everyone knows more or less everyone else! Collaboration between the association that unites the professionals as individuals (ISPO) and the association that represents the trade (INTERBOR) is therefore necessary. All the more because in this profession, we strongly believe in the objective to achieve a better and effectual treatment and service against reasonable and acceptable prices for our customers needing orthopaedic care and provisions.

I am sure you all will experience very well this attitude in this Congress.

That is the reason why I am glad to be here, why I represent INTERBOR and why, I am sure, you are here.

Enjoy your stay!

Thank you very much.

### **INAUGURATION ADDRESS**

**DR E. PUPULIN, CHIEF OF REHABILITATION UNIT, WHO**

Your Royal Highness, Esteemed Members of the Organising Committee, Participants of the Congress, Ladies and Gentlemen.

First of all, I would like to thank ISPO for inviting WHO to say a few words on this special occasion.

The World Health Organisation (WHO) has on many occasions during the past years – and in official relations since 1993 – had the pleasure of collaborating with ISPO. WHO is very committed to this collaboration, which in particular deals with the rehabilitation services in developing countries. This area has proven to be of sincere concern for ISPO, something which is shown in the number of conferences that the Society has arranged in developing countries during the past two decades, in some cases jointly with WHO.

The situation for people with disabilities in developing countries is sometimes extremely difficult. Rehabilitation services are very few and most often out of reach for those who really need them, both geographically and financially speaking.

WHO is studying ways for improving services for disabled people in developing countries. One strategy often used by WHO is called Community-Based Rehabilitation (CBR). It is based on the assumption that much of the rehabilitation work may be done in the disabled people's own communities. Though for example prostheses and orthoses need to be produced and fitted by professionals at orthopaedic centres, it is clear that the complete rehabilitation can be facilitated and more successful if there are resource persons in the community who can assist in needed preparations for fitting, in the training with the new orthopaedic device and in follow-up. It is therefore necessary to find strategies for the linking of rehabilitation services at community level with prosthetic and orthotic services at a country's central level. It is also important to see how a multi-sectoral team approach may be reflected in the training of the different professional groups working for disabled people. To address these issues, WHO has formed a working group, in which ISPO will play a very important role; the professional input is essential, as is openness and the sharing of knowledge and responsibilities, not only between the professional groups, but also with the disabled people themselves and with those

people in the disabled persons' neighbourhood who can be of assistance in the rehabilitation process.

With great hopes that this congress will be able to highlight some of the new and important developments in prosthetic and orthotic rehabilitation in developing countries, but also with genuine interest to look into the complete variety of the latest orthopaedic technology advancements worldwide, I would like to wish the organisers and the participants of the Congress a very successful week.

Thank you very much.

## **President's Report**

SEISHI SAWAMURA

It is my great pleasure to report on the activities of the Society over this triennium.

The Congress in Melbourne at the start of the triennium was outstandingly successful by any measure under the able direction of Secretary General, Mrs Valma Angliss.

Immediately after this Congress was over, the activities of the newly elected Executive Board commenced. The Society set the goal to promote best possible prosthetic/orthotic services not only for the industrial world but also for the low-income countries as a fundamental principal. In order for us to be able to achieve this goal, we initially allocated specific responsibilities to the Executive Board Members additional to their role in supporting and guiding the activities of the Society. Thanks to the generous assistance and support extended to me and my colleagues, and multi-professional teamwork of the Board Members, Task Officers and International Consultants, it was, indeed, very fortunate for me to have accomplished my duties as President over the last three years.

Over the triennium the Society has continued to attract new members. The membership of ISPO at the end of 1997 was 2,635 from 76 countries. Overall membership has increased steadily over the past 12 years at an average rate of about 74 members per year. There are now a total of 33 National Member Societies. New National Member Societies have already been formed in Iran, Turkey, Chile, Russia and Chinese Taipei and others are in the process of forming.

The Honorary Treasurer as a Task Officer for the professional register has worked very hard with the format of the new application form and the software programme over the past two years. The task is now near completion. The membership database has been functioning for about two years and it has in general worked well, but has required some adjustments and trimming procedures along the way.

Over the triennium we have honoured individuals by conferring fellowship status. The UK National Member Society has nominated Mr Robin Cooper, Dr Brendan McHugh, Dr Barry Meadows, Mr John Ronald and Dr Colin Stewart. These nominations were unanimously approved by the Executive Board. I am also pleased to report that Immediate Past President, Mr Melvin Stills and Mrs Valma Angliss who was Secretary General in the Melbourne Congress have been awarded an Honorary Fellowship of the Society. This is in recognition of their outstanding contribution to the Society.

Education and training have been major areas of interest and activity throughout the existence of the Society as shown by the numbers of seminars and courses organised. The Education Committee, under the excellent leadership of Professor John Hughes, has been extremely active. The Society has been working on defining professional categories in the prosthetic and orthotic fields over the years in collaboration with WHO, INTERBOR, GTZ and other international agencies. The Society has detailed appropriate education and training programmes and issued an information package on the Category II Professional, the Orthopaedic Technologist that includes professional profile, learning objectives and examination content and format. The document was drafted by a core group consisting Professor John Hughes, President-Elect Mr Norman Jacobs and Mr Sepp Heim and it has been widely accepted by most of the international governmental and non-governmental agencies. The Society offers an inspection system of the Category II School Programmes related to the curricula, resources and examination procedures. This inspection has been taken up in Cambodia and is now under discussion in Argentina, El Salvador, Ukraine and Fiji.

Currently the first draft of a similar information package for Category I, the Prosthetist/Orthotist has been circulated for comment. ISPO is working with INTERBOR through the Joint Education Committee to establish standards for prosthetists/orthotists education within the European Union at an university degree or equivalent level.

This triennium had an outstanding start with the Consensus Conference on Appropriate Prosthetic

Technology for Developing Countries which was held in June of 1995 in Phnom Penh, Cambodia. Eighty percent of the expenses for this consensus conference were covered by a grant from the United States Agency for International Development, which was very much attributable to the efforts of Mr Melvin Stills, Immediate Past President. I would also like to take this opportunity to express my sincere gratitude to him.

The final draft of the report, edited by Dr Binks Day, Professor John Hughes and the President-Elect, has been produced. Selected material was compiled in a special edition of *Prosthetics and Orthotics International* including key papers and conclusions of the meeting. The idea of setting up a meeting of the major agencies as a follow-up to the consensus conference on Appropriate Prosthetic Technology is being pursued. This consensus conference has made a valuable contribution to the future development of appropriate prosthetic technology in developing countries. However, as a matter of fact, a majority of the developing countries are far from having an ideal education system.

ISPO is currently working on Prosthetic Orthotic Services related to CBR (Community-Based Rehabilitation) with WHO, Handicap International, ICTA and other International Organisations under the leadership of the President-Elect. This CBR programme will be a major subject in the next triennium.

ISPO also works hard to maintain a continuous short term educational programme and, following the Consensus Conference on Amputation Surgery, courses have been arranged under the leadership of Dr J. Steen Jensen in Madras, India 1996; Helsingborg, Sweden 1997; Jaipur, India in 1997 and Makuhari, Japan in 1998.

A Consensus Conference on Lower Limb Orthotic Management of Cerebral Palsy under the leadership of Mr David Condie was conducted at Duke University in 1994. A follow-up course was run at Sunnybrook Science Centre in Canada and a second course will be associated with the Second Central and Eastern European Conference in Slovenia this coming September which is being organised by Professor Črt Marincek. A further outcome of this meeting has been the development of a protocol for the evaluation of the orthotic treatment of cerebral palsy.

A Consensus Conference on the Management of Poliomyelitis has been planned by a steering group over the past two years and was finally held in Tunisia in November 1997 under the excellent leadership of the President-Elect who deserves our compliments for his handling of this complex event. This Consensus Conference was well accepted and in addition to the report a special issue of *Prosthetics and Orthotics International* is to be published.

The Workshop of Quality Management, to encourage and facilitate high level uniform practice in the prosthetic and orthotic fields, was held in Glasgow in April this year under the leadership of Task Officer Mr Bo Klasson with a significant contribution from Dr Derek Jones.

ISPO continues to provide advice to other international organisations and agencies. During this triennium the Society has maintained its Category II consultative status with the Economic and Social Council of the United Nations and official relations with the World Health Organisation and has participated in meeting, seminars and consultations about technology, service provision and education of professionals in relation to prosthetics and orthotics.

Over the years, ISPO has had a close collaboration with GTZ educational programmes for orthopaedic technologists and has participated in important meetings about education and services in Wuhan, China, and Hanoi, Vietnam.

ISPO became a member of Rehabilitation International again and has collaborated in the World Congress of Rehabilitation International in Auckland in 1996 and in the Seoul International Conference on Disability to have much closer relationships particularly through ICTA. Also, ISPO has presented the "ISPO Prosthetic/Orthotic Session" at the 8th World Congress of the International Rehabilitation Medicine Association.

With World Orthopaedic Concern (WOC) and IVO we have had an arrangement with mutual representation at board meetings. I would like to thank the President of INTERBOR, Mr Jan Ebbink. We have had many links related to education, scientific exchanges and consumer issues. The possibility of future active collaboration between ISPO and INTERBOR will be examined by a small group.

The Society continues its efforts in the development of International Standards through the work of the International Standards Organisation and the Standards Organisation of the European Union (CEN).

ISPO members have been kept informed by the Task Officer Mr David Condie on ISO-TC 168, Prosthetics and Orthotics, ISO-TC 173, Technical Systems and Aids Disabled Persons, CEN-TC 293, Technical Systems for people with disabilities. ISO-TC 168 Working Groups were close to publishing standards on categorisation and description of prosthetic components and physical testing of lower limb prostheses and Working Group 2 had embarked on a similar exercise for orthotics. On ISO-TC 173 working group had devised a classification of all technical aids for people with disabilities.

The Task Officer for Consumers, Mrs Margaret Ellis, introduced a draft policy document on "consumers" and has prepared an amended draft on healthy partnerships, access to services and information, definition of standards and services and value of the consumer's view.

ISPO Board appoints International Consultants for specified regions of the World; currently the Middle East, Central and Eastern Europe, Russia, Africa, Central and South America, South-East Asia and the South Pacific. Their role is to inform the Executive Board about regional activities, communicate with appropriate groups in the area, and give advice on prosthetics, orthotics and rehabilitation engineering, as well as advancing the formation of a regional network through collaboration with or establishment of National Member Societies with the purpose of improving quality of patient care through dissemination of information and organising educational activities.

Most of the International Consultants have been active, particularly in Central and South America, Central and Eastern Europe, South-East Asia and the South Pacific. Dr. Eiji Tazawa and I as International Consultant for South-East Asia have tried successfully to nominate a key person from each country which has not yet established a National Member Society. In order to strengthen the network among Asian countries, we held an Asian Prosthetics and Orthotics Workshop '98 this February at the National Rehabilitation Centre in Japan.

In order to strengthen their activities, the ISPO Board has decided to budget financial support for International Consultants and Task Officers. This support will be allocated, on request, to specific projects approved by the Executive Board.

The dissemination and exchange of scientific information has been the remit of the Publications Committee, under the excellent leadership of Mr Gerhard Fitzlaff. This committee has been very active as evidenced by the following:

1. The revised Publicity Brochure will be available in the near future.
2. The advertising package material comprising a flag, banner and drape for a lectern provided to all the National Member Societies for national events.
3. The final report to the Consensus Conference on Orthotic Management of Cerebral Palsy and Appropriate Prosthetic Technology has been printed.
4. To date, 49 possible recipients of sponsored journal subscriptions have been identified. The National Member Societies would be invited to provide sponsorship.

The guideline "Submitting Information for the ISPO Web Pages" was produced by Task Officer for Information Exchange, Dr Derek Jones, and has been sent to National Member Societies with the minutes of Executive Board Meetings. We would welcome any suggestions for additions to the ISPO home page from membership to Derek Jones to improve information exchange.

Though quite a number of consensus conferences, courses and seminars have taken place during the triennium, we continue to enjoy a sound financial base. There are many reasons for this. The triennium started with the successful Melbourne World Congress and we have received financial support from USAID and the Japanese Government for subsequent events. Also SAHVA in Denmark kindly provided office space and other facilities for our Copenhagen Office over the years. More importantly, I would like to acknowledge that strenuous efforts of Honorary Treasurer, Dr Steen Jensen and Financial Committee Chairman, Dr Hans Christian Thyregod who managed the capital investment of the Society with the utmost care and skill. As a consequence, it has been possible to hold the membership fees constant during the triennium.

The triennium for the ISPO Executive Board, commenced with the closing of the 8th successful World Congress. Very fortunately, during my Presidency I have been amply aided by the warm-hearted comradeship and assistance of the board members, over the past three years, which has made it possible for us to have a successful 9th World Congress in Amsterdam. On the basis of my own experience, serving as Secretary General at the 6th World Congress in Kobe, I have been deeply impressed by the



efforts paid to the smallest detail by all the members of the Dutch Organising Committee who made this Amsterdam World Congress such a successful event, and in particular, the painstaking efforts made by Professor W. H. Eisma and Secretary General Dr Hans Arendzen literally touched my heart. Now, let us give a nice round of applause to our friends who made this a World Congress a success.

I once again would like to thank each of the Executive Board members, the Task Officers and Committee Chairmen who shared to work with one another and fulfilled their responsibilities in a wonderful spirit of multi-professional teamwork. This was the result of the teamwork by President-Elect, Mr Norman Jacobs, Honorary Treasurer, Dr Steen Jensen and Honorary Secretary, Dr Brendan McHugh who have exerted influence upon the Executive Board and at the same time assistance and co-operation was ably extended by our Secretary in Copenhagen, Mrs Aase Larsson. My special thanks particularly go to Honorary Secretary, Dr Brendan McHugh who maintained good telephone communication with me although we were on opposite sides of the world and also showed warm-hearted co-operation to me to compensate for my lack of proficiency in the English language.

We can look forward to more exciting and valuable activity in the coming triennium. A newly-elected Executive Board will be starting under the leadership of the new President, Mr Norman Jacobs, who has been devoted to ISPO and been extremely active in his capacity as Honorary Secretary and President-Elect of ISPO.

The discussion has already started about subjects which will become our new goals in the future.

Therefore, I firmly believe that this new Executive Board will definitely guide ISPO to further development and people with disability can enjoy the benefit of higher quality prosthetics and orthotics services which will increase the opportunities of full participation. I would like to thank you again and I sincerely wish our new President, Mr Norman Jacobs and the incoming Executive Board the very best success.

## ISPO – CHILE

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

Following is a list of its officers:

*Chairman:*

Dra. Maria Antonieta Blanco R.  
 Instituto de Rehabilitación Infantil  
 Avda. L. B. O'Higgins  
 4620 Est Central  
 Santiago  
 Chile

*Vice-Chairman:*

Mr Augustin Gutierrez D.  
 Instituto de Rehabilitación Infantil  
 Avda. L. B. O'Higgins  
 4620 Est Central  
 Santiago  
 Chile

*Secretary:*

Mr Erik K. Jensen  
 Instituto de Rehabilitación Infantil  
 Avda. L. B. O'Higgins  
 4620 Est Central  
 Santiago  
 Chile

*Treasurer:*

Mr Rafael Cubillos A.  
 Instituto de Rehabilitación Infantil  
 Avda. L. B. O'Higgins  
 4620 Est Central  
 Santiago  
 Chile

## **Incoming President's Address**

NORMAN A. JACOBS

I thank you for the confidence that you have shown in electing me your President.

It is a great honour to be following in the footsteps of Knud Jansen, our Founding President, and the other Presidents who came after him, all whom have made a significant contribution to the Society. I have had the good fortune to have worked for ISPO in one capacity or another under all the Presidents. I hope that some of their dedication, wisdom and good humour has passed on to me to allow me to carry out this task in a positive and productive manner.

The Society has achieved a great deal since its foundation in 1970.

It has created a truly international and multidisciplinary forum of all those professionals working in the fields of prosthetics, orthotics and rehabilitation engineering through its Congresses, conferences, and regional and national meetings.

It has run workshops and seminars on such topics as the deformed foot, CAD CAM in prosthetics and orthotics and trans-femoral sockets.

It has organised consensus conferences on amputation surgery, the orthotic treatment of the lower limb in cerebral palsy, appropriate prosthetic technology for low-income countries and, most recently, the treatment of poliomyelitis.

It has disseminated information worldwide through its publications, *Prosthetics and Orthotics International* and the reports of its workshops and consensus conferences, and also by offering courses in different regions of the world.

As a result of a series of meetings the Society has laid down standards for education and training of prosthetics and orthotics personnel in low-income countries. These standards have now been accepted by all the major international and national agencies working in this important area. This work has culminated in the publication of a package for education and training of the Category II professional that provides detailed information to those who wish to establish a course in low-income countries.

We could continue to look back at other activities and congratulate ourselves for all that the Society has achieved. However the truth of the matter is that we have only just scratched the surface and much remains to be done.

The World Health Organisation has estimated that there is a need for 20,000 trained prosthetics and orthotics personnel to meet the needs in low-income countries. Altogether there are only about 2,000, a shortfall of 18,000. The overall needs in low-income countries are immense. They have few resources and many problems. It is our duty to ensure that all efforts that are made are part of a strategy to ensure the establishment of long-term prosthetics and orthotics and other rehabilitation services in these countries. It is necessary to examine the components and technologies used in these countries with regard to function and costs as well as the sustainability and effectiveness of the services established.

Many low-income countries require aid as a direct result of present or past conflict. The Society must support, as far as it can, those National and International agencies that are providing prosthetics and orthotics services in these situations.

In the industrial world the standards of education and training of prosthetists and orthotists are extremely varied, from university level in some countries to little or none in others. The challenge in this regard is to produce adequate numbers of well-educated prosthetics and orthotics personnel to an acceptable standard and it is the Society's intention to pursue the implementation of its information package for the education and training of Category I professionals. There continues to be a great proliferation of components and techniques, many of which have reached the market place without any proper independent evaluation of their effectiveness, function or outcome. Much work needs to be done in this direction.

On behalf of the Society I would like to thank our President, Seishi Sawamura, for all the efforts that he and his Executive Board have made in the past triennium. I have had the pleasure of working closely with Seishi during this period and have been impressed by the friendly and open way that he has conducted the Society's business.

We are now nearing the end of our Ninth World Congress. It has been a very successful event with a large participation. The scientific programme has been innovative and varied and the social programme has been enjoyed by all. The best is still to come, I understand, at tonight's party. The exhibition has been comprehensive. It has been well supported by Interbor and the industry and it is the largest that we have ever had at our Congresses. I would like to take this opportunity of thanking Hans Arendzen, Wim Eisma, the organising committee and Congrex Holland for the extraordinary efforts that they have made in running this Congress and for making us so welcome in Amsterdam.

Over the years the Society has built up its membership throughout the world. This widespread membership is the true strength of the Society. The Executive Board will continue to make efforts in this direction and improve the links and communications with the membership at large.

You have elected a strong Executive Board for the next triennium. It has a good representation of the different geographical regions as well as the different professional groups that form the Society. With your help we look forward to a productive three years.

## **ISPO – RUSSIA**

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

Following is a list of its officers:

*President:*

Prof. Anatoly N. Keyer  
76-67 Bolshoy Prospect  
St Petersburg 199026  
Russia

*Vice-Chairman:*

Dr Alexander A. Koriukov  
11-136 Tuchachevskiy Str  
St Petersburg 195253  
Russia

*Vice-Chairman:*

Dr Anatoly P. Kuzhekin  
1-108 Egerskaya  
Moscow 107014  
Russia

*Secretary:*

Dr Valentina M. Volkova  
19-10 Marata Str  
St Petersburg 191025  
Russia

*Treasurer:*

Dr Teymuraz V. Cheminava  
34-8 Moskow Str  
St Petersburg 198013  
Russia

**The Brian Blatchford Prize for the triennium 1995-1998 was awarded to Van Phillips. This paper was based on his acceptance speech which was delivered at the closing ceremony of the Ninth World Congress in Amsterdam, The Netherlands on 3 July, 1998.**

## **The Brian Blatchford Prize acceptance speech**

V. PHILLIPS

*Flex-Foot Inc., Aliso Viejo, California, USA*

As the recipient of the Brian Blatchford Prize for my achievements in innovation in the design and development of the Flex-Foot, I am both gratified and humbled by the presentation. Gratified as it is a personal accomplishment to be honoured by your peers in your chosen profession. But I am also very humbled by the award as it marks for me the passage of some wonderful years spent in the pursuit of developing advanced products for the amputee population.

Flex-Foot products have been in existence for over 14 years and as I look back over those years I am reminded of all the challenges and strides I have realised in my life that have brought me to this point. I lost my leg in the summer of 1976 in a water skiing accident as a boat propeller cut through my leg. Suddenly at 21 years, my life was irrevocably changed. I then faced the challenge of getting my life back and attempting to resume the outdoor activities I loved. After my prosthetic fitting and rehabilitation, I returned to Arizona State to continue my studies in broadcast communications. I think it was at this point in my life that I could no longer accept the limitations of my prosthesis and was intensely motivated to change my situation. I began my prosthetic studies, earned my degree in 1981 and immediately set out with my degree to develop radically new concepts in prosthetic design.

After many trials and errors, finally the product was developed that met my expectations of living an active lifestyle. With this design, Flex-Foot Inc. was founded in 1984 with Bob Fosberg and from my very humble one-room-office beginnings, we set out to change the industry. However to do this, many creative and foresighted individuals were involved in advancing both the company and the product line. These individuals used their talents and skills to attain my goal of life without limitations and support the industry as a whole. Of this support I wish to thank all the practitioners whose innovative skills and techniques helped enhance the Flex-Foot products and made me a better designer in the process.

My philosophy has always been to strive to make things better, to achieve my goals which has translated to my company's mission to create products that provide a life without limitations. It is a hallmark of my work to see this philosophy realised every time I enthusiastically watch an amputee run his first track race or see a parent play catch with a child when before they feared they would never have that opportunity again. I feel that as members of this profession we have to constantly challenge the established thinking and excel the profession as a whole. I have tried to live that idea and make it part of my thinking process whenever we look at the design or development of a product. We are successful at what we do, however, we can never rest on our laurels. This prize inspires me not just to look back on my career, but to look towards the future with the knowledge my designs are regarded as innovative and worthy of this recognition.

One such project being initiated for the future product line will be the development of a more affordable Flex-Foot for the less fortunate and for developing nations. I feel there is an urgency to be more proactive to aid those in need and to be a more active participant in the world community. This is an important mission for me and I would like to take this opportunity to encourage our industry to take up this cause. Not only is it good business, it is also the humane thing to do, which is what we are about.

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All correspondence to be addressed to Mr Van Phillips, Flex-Foot Inc., 27412-A Laguna Hills Drive, Aliso Viejo, CA 92656, USA.

In closing, I would like to thank all those involved in awarding me this prize, the President and members of the Executive Board of ISPO, and the Blatchford family. I would also like to thank the people behind Flex-Foot, the practitioners for their continued support, and most especially for the wearers of Flex-Foot products as their suggestions make me a better designer. This support will ensure the continued success and innovations of Flex-Foot technology for many years to come.

## **The Forchheimer Prize**

The Forchheimer Prize is awarded for the most outstanding paper on objective clinical assessment, clinical evaluations or clinical measurement published in *Prosthetics and Orthotics International* during the three years prior to the Congress. The Forchheimer Prize for 1995-97 was awarded to D. K. Harrison, P. T. McCallum, D. J. Newton, P. Hickman and A. S. Jain for their paper *Amputee level assessment using guideline spectrophotometry* which was published in the December 1995 issue of the Journal.

## **The Free Paper Prize**

The Free Paper Prize was offered by the Netherlands National Member Society of ISPO for the best Free Paper Presentation of the Congress.

The Free Paper Prize was awarded to G. F. Kogler, F. B. Veer, S. E. Solomonidis and J. P. Paul for their presentation *The influence of medial and lateral orthotic wedges on loading of the plantar aponeurosis: an in vitro study*.

## THE KNUD JANSEN LECTURE

# Amputee rehabilitation – finding the niche

H. J. B. DAY

### Introduction

I am very grateful to be given this opportunity to show my appreciation of Knud Jansen, who believed that the rehabilitation of the amputee was best organised by a clinic team. As one of the founders and the first president of ISPO he promoted the multi-disciplinary interest and membership of this society. The theme of this World Congress of technology and services in the field of prosthetics and orthotics for the different age groups reflects this wide interest. I shall be talking more about service than the details of technology, as I want to consider the nature of our rehabilitation goals and now these may be achieved.

Another great orthopaedic surgeon, Sir Harry Platt, disliked the term rehabilitation, which he thought was a "mischievous word", and he was extremely dismissive of rehabilitation medicine. I quote from a lecture, in which he said, "Rehabilitation medicine, so called, is a form of managerial medicine," spoken with a downward inflection of the voice. Despite this condemnation, he was right in his choice of words, because rehabilitation of the amputee is the active management of his problems and disability. Let us consider the situation. The locomotor and manipulation capability of the human increases until maturity and falls off in old age. For an infant or child we should try to restore any abilities which have been lost and encourage normal increase in capability as the child's mental and physical skills develop. The rehabilitation process for the adult should aim to restore an ability which matches the normal, even though it may be at a lower level, whereas the process for the elderly person has to recognise that their pre-amputation ability may

have been reduced by the disease which led to the amputation, and so the final outcome may be adversely affected.

If we use the old World Health Organisation (WHO) terminology, we cannot affect the **Impairment**, part of a human limb is missing; we hope that we can reduce the **Disability** by our rehabilitation process, so that ability and/or activity is improved, but we must also try to reduce the **Handicap**, the disadvantage or unmet needs of the patient consequent upon the impairment and disability. What do these words **ABILITY**, **ACTIVITY** and **NEED** mean?

**ABILITY** is the individual's potential. It is what he can do and is related to his age and condition. For the unimpaired it can be improved by physical training, whilst for the amputee it can be improved by the whole rehabilitation process, including for many the supply of a suitable prosthesis. Ability may be measured by physiological monitoring in lower limb amputees, and by tests of dexterity in those with upper limb loss. The patient's overall condition, including the level of loss, sets the limit on the maximum ability.

**ACTIVITY** is what the individual **ACHIEVES**, being set by his needs, and is related to age, condition and the rehabilitation process, and may be estimated in various ways. However it can never exceed the individual's **ABILITY**. In short, **ABILITY** is the individual's potential and **ACTIVITY** is his **ACHIEVEMENT**.

**NEED** changes in response to many factors and so is unlikely to be constant. It may be related to the physical condition, and indeed may be affected by achievement, and it is difficult to measure.

The main **NEEDS** can be placed in three groups: **IDIOPATHIC NEEDS** include the desire to overcome mentally the loss or bereavement, and to have the body image

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restored. However there is a need to avoid sympathy and dependence, and the loss of manliness or femininity.

**SPECIFIC NEEDS** are those related to the activities of daily living, employment and leisure.

**SOCIOECONOMIC NEEDS** vary depending on the person's age, and include equal opportunities during education; the ability to achieve and maintain full earning potential, and to be able to enjoy a full retirement.

### **The rehabilitation plan**

Before we are able to plan a rehabilitation programme for a patient we must assess a number of factors:

- firstly, the physical state, that is the attributes of the stump and of the rest of the patient;
- secondly, his present and future physical requirements in terms of the activities of daily living (ADL), education or employment, social and recreational activities;
- thirdly, his present and future psychological needs in terms of the loss, its concealment, and its relation to function;
- lastly, his capabilities must be assessed regarding understanding, motivation and ability to manage the hardware and training.

Moreover as many patients have unrealistic ambitions and know little of rehabilitation, we need to explore the expectations both of the individual and his family.

Our rehabilitation process must encourage the subject to become a participating member of the clinic team, and to develop a positive attitude of self help. In the case of the infant born with a congenital limb deficiency, the immediate needs of the child are secondary to those of the parents and family. The birth of a limb deficient child is a devastating blow and they want to know what has gone wrong, why it has happened to them and what can be done. They require adequate, knowledgeable counselling as soon as possible and at the first consultation we must explain both the normal development process and, what has gone wrong with it this time, the reason if we know it, and in the vast majority of cases they must be reassured that it is not their fault. One then has to discuss the immediate treatment and any future alternatives; I always give an audio cassette recording of this consultation as an aide memoire. On this and subsequent occasions I help them to agree the objective "to help their

child to see him(her)self as having the smallest possible handicap both in childhood and later as an adult."

For all patients, we have to plan how to measure, control and improve the level of rehabilitation which has been achieved. Merely replacing the old phrase "looking at our results" by the modern version "Outcome Measures", does little unless it is part of an "Audit" in which the outcome, of each stage, is compared with a previously set standard, so that the stage, whole treatment process or even that standard can be modified, as part of a continuing drive to improve quality.

It is frequently assumed that the end result should be satisfactory, providing the surgeon performed the amputation properly, and the client, having no other significant disabilities, is provided with a well-made, correctly fitting prosthesis, and has been trained in its use.

Satisfactory often refers to our standards, but does it match the client's expectations?

Suppose the outcome is, in our view, unsatisfactory – have the professionals, hardware or system of supply failed? Sometimes yes, but perhaps the subject has lower aspirations and is actually satisfied with the outcome. It is not my intention to comment on the many individual methods of outcome measurement which have been devised, often to suit particular situations, but some confuse ability with activity and many observe them as an absolute, whereas the subject observes their ability relative to their needs. These may not remain constant and so whenever the subject attends after an interval, we should discuss whether the prescription or rehabilitation process is still the optimum, in the light of any improvement or deterioration in the person's general condition, alteration of his needs and capabilities and changes in available prosthetic techniques and components.

### **Lower limb loss**

The basic physical need of the lower limb amputee is to regain his mobility and the first option is to achieve this in a wheelchair. There are environmental and other circumstances in which the amputee, particularly if bilateral, may be better served by a wheelchair. Secondly he can hop or use crutches regularly or occasionally, for example, in the bathroom or when walking over particularly difficult terrain.

A prosthesis, however, will enable him to stand, walk, and possibly run, jump and climb. There is no doubt that a prosthesis is the right choice for a fit young adult who has an uncomplicated trans-tibial amputation; but it is not always so easy to decide whether to fit a prosthesis to someone who is older or more disabled.

I believe there are five types of patient to whom we should not supply a functional prosthesis:

1. those who don't want one;
2. those who are technically impossible to fit, e.g. a gross uncorrectable flexion contracture;
3. the medically impossible, e.g. the presence of dense contralateral hemiplegia making locomotion impossible;
4. the medically unsuitable, e.g. the presence of severe cardiac disease;
5. the socially unsuitable, e.g. those in care where a prosthesis is not going to help and indeed may never be used.

You will note that I stressed the word functional. Even if locomotion is unlikely, we should consider whether a simple prosthesis will aid transfers between bed and chair, and there are those who although chairbound, value cosmetic devices which improve their self respect.

How do we recognise those who are unsuitable? Are we certain? Should we reassess? Some who may appear unlikely to benefit when seen soon after surgery, may present quite a different picture later. How are we to categorise those we think suitable for prosthetic supply when third party funding authorities insist that certain categories of patients are limited to particular prosthetic hardware? We have to guess what will be the outcome before starting the rehabilitation process and one way to make this guess more intelligent might be to study a number of patients and correlate the activity achieved with their clinical features.

### Survey of clinical conditions influencing activity

Twenty years ago I undertook such a research project (Day, 1978). First we had to find a method of expressing the activity achieved as an absolute, unrelated to age, or any other factor. After trials involving over 1,500 patients we established a method of describing activity numerically from the subject's answers to a

formal questionnaire. This included questions about the ability to don and doff the prosthesis, the number of hours worn, the type of housing and the composition of the household, together with a detailed account of the nature of employment, daily living and recreational activities. Details of stair climbing and walking both inside and outside the home and the aids used were required. These answers produced positive and negative scores which were added to produce an overall Activity Score (Day, 1981). This score ranged from -70 to +50 with the idea that the "average" activity would be around zero. The multiplicity of questions ensured that many aspects of the individual's lifestyle, and not merely the distance they could walk, contributed to the final score. As part of the validation process some clients wore step counters on their prostheses for 10-14 days. At the end of that time the individual was questioned about his activity during the test period, and a score derived. This was then compared with the number of steps actually taken. We identified five named categories of activity and suggested a step rate which was appropriate to each (Table 1).

At the same time as this system was being validated clinical details of all new lower limb adult amputee patients were collected. On their first visit data concerning their clinical condition were noted. In order that adequate information would be gained about those who only achieved low activity, the survey protocol demanded that all patients (who agreed) would be fitted with, at the least, a simple prosthesis unless there was a very strong contraindication to prosthetic supply. All went through a period of gait re-education after prosthetic fitting and when it was considered that the subject had reached a plateau in their rehabilitation they were assessed by the clinicians (doctor, prosthetist and therapist) separately and allocated to one of the five grades mentioned. They were questioned, the questionnaire completed, and an activity score

Table 1. Categories of activity.

Description	Activity score	Steps per annum
VERY HIGH	more than +30	more than 2,5 million
HIGH	+10 to +30	1,25 to 2,5 million
AVERAGE	-10 to +10	500,000 to 1,25 million
RESTRICTED	-40 to -10	100,000 to 500,000
INACTIVE	less than -40	less than 100,000



Table 2. Numbers of patients in survey.

Number of patients seen on first visit	854
Number not fitted	35 (4.1%)
Died before rehabilitation completed	193 (22.6%)
Maximum number available for survey	626

Table 3. Gender, age and level of amputation.

	Male	Female	Total
Age:			
Under 65	122	33	161
Over 65	162	81	243
Level:			
Proximal	199	77	276 (69.3%)
Distal	85	37	122 (30.6%)
Total	284	114	389

ascribed without reference to their clinical notes. Only later was the score compared with the pre-rehabilitation clinical findings.

The survey included all new adult lower limb amputee patients referred to the Manchester Centre between March 1976 and February 1978 (Table 2).

By the time the project ended in November 1978, 404 patients had been assessed (64.5% of those available). The 222 remaining were not considered to have reached a plateau in their rehabilitation by the end of the project.

Of the 404, 6 with hip disarticulations or trans-pelvic amputations were excluded from further analysis. Of the 398 remaining 284 were male and 114 female (Table 3). Some 57% of the males were over 65, as were 71% of the females. Approximately 70% of the males, and 67% of the females had a "proximal" amputation level in which the knee joint was lost (i.e. knee disarticulation or trans-femoral).

Table 4. Cause and level of amputation by gender.

	Male	Female	Total
Cause:			
Trauma	24	4	28
Neoplasm	7	8	15
Infection	14	3	17
Other	6	1	7
Non-vascular	51	16	67
Vascular	233	98	331
Total	284	114	398
Vascular as percentage	82%	86%	83%
Non-vascular level:			
Proximal	20	11	31
Distal	31	5	36
Vascular level:			
Proximal	179	66	245
Distal	54	32	86

Dysvascularity was the cause of amputation in 82% of males, and 86% of females (Table 4). Trauma accounted for the amputation in 7% of all cases, neoplasia and infection each accounting for about 4% of the total. In view of the small number involved, amputations for trauma, neoplasm, infection and those labelled as 'other' are amalgamated and referred to in the results as "non-vascular". These latter resulted in proximal amputations in only 46% of cases, compared with 74% of those whose amputations were for dysvascularity.

When considering the results it is important to remember that:

1. this survey was carried out twenty years ago when 70% of amputations were at or above the level of the knee joint;

Table 5. Activity by age, level of amputation and gender – percentages of group surveyed.

	Inactive	Restricted	Average	Very high and high
All in survey	25	47	21	7
Over 65	37	50	12	1
Under 65	9	45	30	15
Proximal	40	48	11	1
Distal	16	47	24	13
Male	21	47	22	9
Female	39	45	11	4

Table 6. Activity by three factors – age, gender and level – percentages of group surveyed.

	Inactive	Restricted	Average	Very high and high
Male: Distal: 65-	4	37	31	28
Female: Distal: 65-	17	42	33	8
Male: Proximal: 65-	6	52	30	12
Male: Distal: 65+	19	52	29	–
Female: Proximal: 65-	27	50	23	–
Male: Proximal 65+	37	47	14	2
Female: Distal: 65+	36	64	–	–
Female: Proximal: 65+	45	49	5	–

2. the modular prostheses fitted to 70% of all the cases were not of the modern lightweight design.

Therefore we should not take the actual figures as being applicable to the situation today but the trends shown are probably still valid.

In all the following tables, the Very High and High activity groups have been combined.

Some 25% of all the patients surveyed were Inactive, 47% Restricted, 21% Average and only 7% of High activity (Table 5). What factors can be associated with activity?

As might be expected the elderly do not do as well as the young, 87% of those aged more than 65 years are in the Restricted or Inactive categories, whereas 45% of the younger group exhibit Average or High activity. Those with higher level amputations do rather less well than those with more distal levels. Only 12% of proximal compared with 37% of distal level patients have Average or High activity. About 45% of both genders have Restricted activity,

but there is an appreciable “shift to the left” towards Inactivity in females.

Table 6 displays the activity achieved against all three factors, and this table has been arranged in descending order of activity, led by young males with distal amputations of whom 59% have Average or High activity, down to the older female with proximal amputations of whom only 5% achieve Average activity.

However there are three other factors: the most important is the cause of amputation. Those whose amputation was for vascular disease do measurably worse (Table 7). Additional disabilities are also of considerable significance. For the purpose of this survey they are divided into two groups:

1. the presence of symptoms and/or signs of vascular dysfunction in the contralateral leg (PVD);
2. the presence of any other concurrent disabilities (CD) which are considered to be likely to affect the patient’s activity with prosthesis.

Table 7. Activity by cause of amputation and other disabilities – percentages of those surveyed.

	Inactive	Restricted	Average	Very high and high
Non-vascular (NVASC):				
No added disability (NCD)	–	12	38	50
Added disability (CD)	10	26	37	26
Vascular (VASC) no PVD other leg (NPVD):				
No added disability (NCD)	–	33	58	8
Added disability	39	30	30	–
VASC + PVD other leg (VASC-PVD):				
No added disability (NCD)	25	55	20	–
Added disability (CD)	32	55	13	–

In the case of non-vascular (NVASC) amputees the presence of a concurrent disability (CD) reduces the percentage of those achieving High activity from 50% to 26% and increases the number in the Restricted and Inactive groups by the same amount, while the percentage who are of Average Activity remains the same.

Some 58% of vascular amputees, without any designs of vascular dysfunction in the other leg, and without other disabilities (VASC - NPVD - NCD) are of average activity (Table 7), but the presence of a concurrent disability (VASC - NPVD - CD) reduces this to 30% whilst the percentage who are Inactive increases from nil to 39%.

The presence of signs or symptoms of vascular insufficiency in the contralateral leg is also very damaging to the activity level achieved by those who have had the amputation for vascular disease (VASC - PVD - NCD) raising the percentage of those who are Inactive or of Restricted activity from 33% to 80%. The addition of a concurrent disability (VASC - PVD - CD) raises this percentage slightly further to 87%.

This survey indicates some tendencies but could not accurately correlate the level of activity with specific clinical factors. Although 50% of uncomplicated amputations performed for non-vascular causes (NVASC - NCD) exhibited High activity, the fact the 12% of cases came into the Restricted category confirms my view that the activity achieved is concerned with trying to satisfy their needs within the upper limit set by their clinical condition. So, although the survey cannot provide an accurate forecast of the activity, it may provide help in guessing.

Having decided that a prosthesis is appropriate we must now consider the prescription details in the light of the patient's condition, ability, and expectations, and our knowledge and experience. The advance in prosthetic technology over the last 25 years, and the enormous increase in choice of systems and components has made it easier to meet the needs of active adults, but does not always help in dealing with the elderly, for whom it may be more appropriate to fit first a prosthesis containing simple functional components, upgrading this later is so indicated, rather than prescribing one which proves to be too sophisticated and therefore leads to disappointment. Increasing publicity and the

media-led concept that all problems can be solved by the application of high technology does to help elderly patients to understand and accept the limitations set for them by their age and clinical condition. I remember well the veteran whose trans-femoral amputation was performed in 1917 when he was 19 years old, bitterly complaining to me when aged 86, that his new prosthesis was no good – “not like the one they made in 1919, I could run on that one.”

So we have decided the prescription details, when should we start? We are told to fit as soon as possible, but amputation is a bereavement and the subject goes through similar stages of denial, anger and depression. One elderly lady asked me, “What did they do with my leg? I wish I had been able to say goodbye to it like I did to my husband at his funeral.” Perhaps sometimes it may be better to give the person a short time to grieve before prosthetic fitting.

Assuming that we have prescribed and carried out the prosthetic fitting and gait re-education let us go forward to that time when we have to determine not only the activity achieved but also whether or not this satisfies the user's needs. When I was validating the activity score method I fitted step counters to two users with trans-tibial amputations on the same day. One was a retired policeman aged 69 whose amputation had been performed for vascular disease. He spent most of his days walking, within the limits of claudication in the other leg, in his local shopping mall. The step counter showed he was walking 1.25 million steps per annum. The other, a 27-year-old accountant whose amputation was for trauma, had no other disability. He spent most of the day sitting, and played squash once a week. he was walking 950,000 steps per annum. The policeman's activity was driven by his need to meet people, and was near to the maximum ability set by his condition and age, but his needs were not satisfied because he wanted to be able to walk more, whereas the young man was pleased with his performance.

Unfortunately I know of no scientific method of measuring satisfaction, one can only question the patient and family, look for tell-tale signs and use one's experience. Good communication between all members of the clinic team, including the user, is vital to gain the necessary information. Sometimes a person may claim to be satisfied because they fear upsetting members

of the team if they admit their needs are not met by their performance. For most users the prosthesis is a tool which helps them to meet their needs. At one end of the spectrum are those who wish to climb mountains or indulge in other extreme activities, perhaps sometimes to demonstrate that, "I'm as good as they are." Their high level of need provides the motivation to raise their achievement towards their maximum ability. At the other end of the scale some, like the policeman, with vascular dysfunction and limitation of walking ability prior to amputation may be dissatisfied because they expected to return to the ability which they had before the disease process started. And unfortunately for a few the prosthesis is something to be blamed whether as a symbol and reminder of their loss, or as an excuse for lack of their perceived success, such as "If it wasn't for this leg I would be chief executive by now."

Appearance is important to many – some want excellent static cosmesis and practise hard to achieve a near normal gait, partly for self esteem, but also to gain employment of their choice. Others demand a high level of static matching but are unconcerned about the visual effect of a poor gait. Appearance is also important for many whose activity is very limited. A young woman with a complete paraplegia from spina bifida had never walked. Following a high trans-femoral amputation she would not leave the house because she felt that people considered her to be a lazy amputee. A

cosmetic prosthesis which could be attached to her chair enabled her to return to work and a full social life. However not everyone wants to conceal their loss, increasingly we see among the more active a need to omit the cosmetic cover on endoskeletal prostheses, and indeed to have pictures on the sockets. Some want unusual function, like the young man with a knee disarticulation who demanded a socket fit which was loose enough for him to rotate the prosthesis on his stump so that he could earn a living appearing on the stage in night clubs.

### Upper limb loss

I must now consider those fewer cases who present with upper limb loss, of whom about one third have congenital limb deficiency, while perhaps 70% of the remainder have had amputations for trauma. Fortunately the human has some spare upper limb functional capacity, in that many tasks can be performed with one arm and hand. I say fortunately, because no prosthesis available can match the immense capability of the human hand and arm. Those with unilateral loss may be so competent using their normal arm as the dominant limb, that many prefer to manage for some of the time without a truly functional prosthesis, but may require some cosmetic restoration because of the vital role played by the hand in our relationships with others. However the bilateral arm amputee is likely to need prostheses in order to function independently.

So there are again three basic treatment options, first to advise and train the individual to

Table 8. Details of patients in Manchester Myoelectric Trial 1978-1988.

	Children	Adult	Total
Assessed	311	107	418
Accepted and fitted	266	93	359
1990 survey	258	89	
Gender: male	55%	69%	
female	45%	31%	
Cause: congenital	96%	27% males	
	-	62% females	
trauma	3%	63% male	
	-	24% female	
Level of loss:			
distal to elbow	91%	60%	
proximal to elbow	9%	40%	
Laterality – left	58%		

Table 9. Age of fitting and percentage utilisation.

Age when first fitted with myoelectric hand	Number	Average percentage utilisation
Under 4 years	116 (33.4%)	67.5%
4 - 8 years	43 (12.4%)	66.1%
8 - 12 years	49 (14.1%)	69.2%
12 - 16 years	50 (14.4%)	70.8%
Adult	89 (25.6%)	76.3%

perform necessary tasks with the normal arm, perhaps using the stump to steady the work, or by encouraging the use of the feet by children with high level congenital deficiencies. The second is to provide aids to facilitate specific tasks. The third option is a prosthesis. In the past the subchoice was between a cosmetic but relatively functionless prosthesis or one with a body powered terminal device. The advent of the electrically powered hand has introduced a third alternative which provides both function and a degree of cosmetic restoration. How can we assess the outcome of rehabilitation of the arm amputee? Various tests of dexterity with terminal devices have been used, but some rely on timed performance of tasks which bear little relation to everyday life.

Between 1978 and 1988, 418 children and adults were assessed for the supply of myoelectric prostheses at the Manchester Centre (Table 8).

The sex distribution of the 311 children considered the myoelectric supply (54.7% male, 45.3% female) did not differ significantly from that of the 266 fitted (55.3% male, 44.7% female). Over 96% of the children had a congenital limb deficiency. A total of 107 adults were assessed and 93 (87%) fitted. The sex distribution – 68.8% male, 31.2% female, reflected the cause of limb loss. A formal survey was carried out in 1990, at which time 12 patients could not be traced and so the report is

on 258 children and 89 adults (Day, 1992).

All individuals were wearing conventional prostheses before being fitted with electric hands. Almost half the children were under the age of four at the first fitting of a myoelectric and (Table 9) while the remainder were fairly equally spread in three age bands.

The percentage of each age group of children who abandoned the prosthesis during the first year ranged from 14% to 20.7%, with an average of 17.4%, and 20.2% of the adults gave up during the first year.

The numbers who gave up in subsequent years can be tabulated, but these do not reflect the acceptance properly because the follow-up period ranged from 2 to 12 years, and children particularly, tend to alter their attitude to any prosthesis. A more accurate way of showing utilisation is needed and the actual number of patient/years worn can be expressed as a percentage of the total possible. Applying this method looking back from the end of 1989 at all 258 children fitted we find the utilisation ranges from 66.1% to 70.8% with an average of 68.2%. That of the 89 adults is higher at 76.3%.

Having confirmed that 190 patients were still wearing electric arms regularly at the time of the survey, we needed to find out how much they were used, for what and why they were liked, and disliked. Each patient was asked to complete a questionnaire, guaranteeing personal anonymity so that future treatment would in no

Table 10. use of electric hand at school or work.

Age fitted	Less than 1/4	1/2 - 3/4	3/4+	All day Every day	Total more than half-time
Under 4 years	4.5%	13.6%	6.2%	66.6%	86.4%
4 - 8 years	16.6%	8.4%	33.3%	33.3%	75.0%
8 - 12 years	7.1%	6.6%	28.5%	57.0%	92.1%
12 - 16 years	29.4%	17.4%	11.7%	35.0%	64.1%
Adult	20.0%	–	–	80.0%	80.0%

way be prejudiced. Some 131 (69%) replies were detailed enough for analysis, and these reflect the age group distribution. The response rate for each group varies between 60% and 73%. Considering first the usage at work or school, we find that between 33% and 66% of children and 80% of adults wear the arm all day every day: 64% to 92% wear it for more than half the time, but 29% of those fitted between 12 and 16 use it for less than 1/4 of the working week (Table 10).

Of those who do not wear the electric arm all day, 14% wear a split hook, 40% a passive hand and 46% no prosthesis at all for the remainder of the time. Table 11 shows the first choice of prosthesis for wearing at home in the evenings and at weekends, and for social occasions.

Comparing the percentage of each age group's usage at work/school, home and in their social life confirms that many wearers value the dynamic cosmesis which hand movement provides. Indeed 60% of both sexes rate its appearance at 8-10 on a ten-point scale, and 72% rate its function at the same level. Some 33% of wearers specifically liked the hand "because it looked real" while 20% disliked its appearance though continued to wear it for its improved function.

The question, "For what activities do you find the electric arm best?" produced many answers, but also some which were surprising. One man said that the electric hand was excellent for his work in pharmaceutical quality assurance but

was not suitable "for his more adventurous activities of rock climbing, abseiling, parascending and casualty handling when on his Red Cross duties." One reply to the question, "What do you like about your electric arm?" came from a man with a congenital deficiency, previously wearing a conventional arm who changed to an electric hand three years before, when aged 21. He said, "For the first time in my life I feel part of the human race. Not only do I have a hand that looks and behaves (at a glance) in a natural way but it also operates in a way that makes me feel human. I could not envisage life without the electric hand and I could not leave the house without it." As for the lower limb loss we must always try to match the rehabilitation process and our technology to the needs of the user. Appearance was vitally important to one young lady for whom we made a passive prosthesis with a polypropylene endoskeletal structure so that she could wear in while bathing in the sea. Another young lady having worn a myoelectric hand successfully for some years prefers to use a passive cosmetic prosthesis as a supermarket check-out assistant. She uses it to steady and push goods about, and the majority of her customers did not notice that she is an amputee. A myoelectric hand provides the appearance and function required by a young man who performs conjuring tricks with cards and coins. However sometimes ability is so compromised that the needs cannot be satisfied, and the goals have to be altered to maintain self

Table 11. Type prosthesis chosen to wear at home and socially.

First choice for use at home			
Fitting age	Electric hand	Passive hand	None
Under 4 years	60.5%	4.6%	34.9%
4 - 8 years	23.1%	30.8%	46.1%
8 - 12 years	38.5%	—	61.5%
12 - 16 years	25.0%	12.5%	62.5%
Adult	60.0%	—	40.0%
First choice for use socially			
Fitting age	Electric hand	Passive hand	None
Under 4 years	65.9%	20.5%	13.6%
4 - 8 years	58.3%	33.3%	8.3%
8 - 12 years	78.6%	14.3%	7.1%
12 - 16 years	70.6%	17.6%	11.7%
Adult	80.0%	20.0%	—

esteem, as for an elderly lady who sustained a left shoulder disarticulation, right trans-humeral and right trans-femoral amputations. Some limited independence was achieved with the aids which enabled her to eat, write, paint, control an electric chair and operate environmental controls. Somehow she maintained at least some of her self respect. the following is an extract from a poem which she wrote:

*I'm tired of this, I'm tired of that,  
Tired of everything in fact.  
Tired of eating such a chore,  
Tired of drinking through a straw,  
Tired of having no hands at all,  
Frustration drives me up the wall.  
Can't hug a child nor pat a dog,  
Just sit here helpless like a log.  
Can't shed a tear unless someone knows,  
Cos I can't dry it up and can't blow my nose.  
Can't scratch an itch or rub my head.  
And I can't turn over in my bed.  
But this does not mean I'm always blue -  
What matter the loss of a limb or two?*

Every prosthesis has advantages and disadvantages, and how the positive and negative factors balance is personal to the patient and takes into account only their present requirements. one young woman with a transverse deficiency in the hand still uses aids for holding a table tennis ball or a fork but required no aids or prosthesis to win three gold medals, one silver and a bronze for swimming at the Paralympics at Atlanta in 1996. At the same meeting a young man won the silver medal in

the high jump whilst wearing a sophisticated trans-tibial prosthesis, only to be beaten for the gold medal position by a trans-femoral amputee who jumped without a prosthesis.

In conclusion, our aim must be to rehabilitate the client to the stage that his achievement satisfies his needs within the limit of his ability. it is now proposed by the WHO that their 1980 classification of Impairment, Disability and Handicap be changed to Impairment, Activity and Participation, a more positive wording which leads me back to the title of this lecture and the word Niche which refers to a quotation from the English novelist John Galsworthy, who said:

“A niche of usefulness and self respect exists for every man however handicapped, but that niche must be found for him. To carry the process of restoration to a point short of this is to leave the Cathedral without a spire.”

#### REFERENCES

- DAY HJB (1978). Clinical factors influencing amputee activity; its description and numeration. In: Standards for lower limb prostheses./report of a conference 1997.- ISPO p235-253.
- DAY HJB (1981). The assessment and description of amputee activity. *Prosthet Orthot Int* 5, 23-28
- Day HJB (1992). Myoelectric prostheses for infants. In: UNB monographs on myoelectric prostheses./edited by Scott RN. New Brunswick: University of New Brunswick. p9-19.
- DAY HJB (1992). Treatment of congenital transverse deficiencies of the upper limb. In: Proceedings of the first conference of the Saudi Benevolent Association for Disabled Children./edited by Al-Swailem AR. p462-473.

## **The influence of prior stroke on the prosthetic rehabilitation of lower limb amputees**

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### **Abstract**

Concurrent stroke is believed to have an adverse influence on the process and outcome of prosthetic rehabilitation, but there is limited published evidence for this. The aim of this study was to establish a clearer picture in order to assist decision making for both patients and professionals.

Demographic and clinical data were collected from all lower limb amputees referred from North and West Yorkshire for prosthetic rehabilitation. Additional data were collected from all new lower limb amputees in three of the referring health districts, irrespective of prosthetic referral.

Patients with prior stroke were less likely to be referred for prosthetic rehabilitation. Improved mobility and independence were seen following prosthetic rehabilitation irrespective of prior stroke. The group with prior stroke compared well with the non-stroke group in terms of walking aid usage, but a smaller proportion of the stroke group were able to walk 30m without stopping and there were trends for smaller gains in independence in the stroke group.

Nevertheless, this study demonstrates that prosthetic rehabilitation can be successful in a selected amputee population with prior stroke. In those who continue prosthetic use for one year, outcome is similar to that in patients without stroke.

### **Introduction**

There is a widely held belief that stroke adversely affects the outcome of prosthetic

rehabilitation; Varghese *et al.* (1978) and Altner *et al.* (1987) have reported that stroke, particularly if it occurs prior to amputation, results in more limited mobility with a prosthesis. Kerstein *et al.* (1974) also found that after neuropsychological and pulmonary symptoms, stroke was the factor most likely to influence placement in chronic care. In fact, Hoover (1964) commented that a hemiplegia renders ambulation unusually difficult frequently contraindicating prosthetic fitting. Is this view justified? To contribute to the understanding of this issue, the authors have examined their own experience in patients with stroke who subsequently underwent lower limb amputation.

The prosthetics department in Chapel Allerton Hospital, Leeds is one of the largest in Britain, providing prostheses to approximately 3,000 amputees from North and West Yorkshire (catchment population approximately 3 million). Between 200 and 250 new referrals are received each year. In October 1992, an electronic database was set up in order to facilitate audit of this service. As part of this audit, referrers in three of the 10 health districts which routinely sent patients to Chapel Allerton Hospital were asked to record demographic, clinical and disability details on all those who had amputations between October 1992 and October 1993, irrespective of whether prosthetic rehabilitation was felt appropriate. This provided an opportunity to examine whether the presence of a stroke influenced the decision to refer a patient for prosthetic rehabilitation following amputation.

By analysing the data from all those actually referred for prosthetic rehabilitation in the same time period, it was also the intention to re-

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examine whether a coexistent stroke adversely affects outcome of prosthetic rehabilitation, compared with amputees without stroke.

The main aim was to ensure that patients, their carers and those arranging referrals were as fully informed as possible about likely outcome of prosthetic rehabilitation at an early stage. It was known for example that patients often deferred decisions about moving house, and either remained in hospital or struggled on in difficult circumstances because they had received no clear guidance on how a prosthesis could be expected to influence their independence. However it was also hoped that it would be possible to identify features of stroke crucial to the success of prosthetic rehabilitation which might themselves be altered by targeted stroke rehabilitation.

It should be stressed that whilst there is a body of literature identifying characteristics which influence the outcome of rehabilitation in stroke *per se* (Wade and Hewer, 1987) findings are not necessarily applicable to the field of amputee rehabilitation. For example the clinical extent of stroke influences mortality. Age, sex, level of independence and the presence of a carer at home may influence place of discharge from hospital (Geddes, 1998). However one might predict that other factors such as the integrity of balance and proprioception would be crucial to the prosthetic rehabilitation process, and there is some evidence to support this view (Altner *et al.*, 1987). It is certainly possible to achieve successful prosthetic mobility, albeit with greater difficulty, in patients (without stroke) who are blind, or have cognitive or communication problems for other reasons. Such patients may remain dependent in other respects but achieving prosthetic mobility may nevertheless influence their care needs. On the other hand, functional independence and autonomy are feasible without ambulation. Thus it would be inappropriate to extrapolate from findings for stroke rehabilitation in patients who have not had amputations.

### Patients and methods

In order to examine whether the presence of a stroke influenced the decision to refer a patient for prosthetic rehabilitation following amputation, referrers in three of the 10 health districts (Leeds, Airedale, Huddersfield) which routinely referred patients to the prosthetics

department at Chapel Allerton Hospital collected data on all new lower limb amputees between October 1992 and October 1993, irrespective of whether referral was planned. The following data were recorded:

1. name, date of birth, occupational status, type of accommodation;
2. reason for non-referral (Table 1);
3. amputation site and reason for amputation (underlying diagnosis);
3. other relevant diagnoses (ischaemic heart disease, stroke, chronic bronchitis, arthritis);
5. dependence in personal care (Barthel scores) following and (estimated) three months prior to amputation;
6. whether an early walking aid (PPAMaid) had been tried.

In order to examine whether a prior stroke influences the outcome of prosthetic rehabilitation, additional data were recorded on all new lower limb amputees referred for prostheses and first seen in the Prosthetics Department over the same 12 month period. Patients were reviewed three, six and twelve months after the supply of the first prosthesis. Data recorded included:

1. whether the patient was still wearing a prosthesis and, if not, why not;
2. if the prosthesis was used for longer than half the day;
3. distances walked without stopping (<10m, 11-30m, >30m) and use of walking aids;
4. Barthel scores;
5. Frenchay activity index (first and last visit only);
6. patient satisfaction with the appearance and function of the prosthesis.

The Medical records of patients with strokes

Table 1. Reasons for non-referral for prosthetic rehabilitation.

Does not wish to wear a limb
Cardiac/respiratory problems limiting stamina
Claudication in remaining limb
Arthritis
Joint contractures
Stroke
Mental state
Death
Other medical problems ... (specified)
Other reasons ... (specified)

were subsequently reviewed to establish, where possible, the side of the body affected and additional clinical features such as the presence of sensory or visual inattention.

Data were analysed using Statistical Package for the Social Sciences.

## Results

### *Comparison of referrals and non-referrals in three health districts*

During the study period, 103 patients from Leeds, Airedale and Huddersfield Districts were referred for prosthetic rehabilitation following lower limb amputation. During the same time period, a further 65 patients in these three districts had lower limb amputations but were not referred for prosthetic rehabilitation.

Stroke was present in 16 (19.3%) of non-referrals, was cited as a reason for non-referral in 15 (23.1%) of these and was the only reason given in 2 (4.6%). Other reasons given included post-operative death in 14 (21.5%), cardio-respiratory problems in 4 (6.2%), cognitive dysfunction in 3 (4.6%), patient's wish in 2 (3.1%), arthritis in 1 (1.5%), or a combination of these reasons. By comparison, stroke was only present in 7 (6.8%) of amputees referred for prosthetic rehabilitation. Stroke was present in a greater proportion of non-referrals (Chi-square,  $p = 0.012$ ).

### *Comparison of all referrals with and without stroke*

Overall 227 patients were referred from all ten health districts during the study period. Referrals with and without prior stroke were not

significantly different in terms of age, sex distribution or amputation level and as expected, bearing in mind the shared risk factors, peripheral vascular disease and/or diabetes were the predominant underlying pathologies in both groups.

### *Prosthetic rehabilitation*

Once referred, four (19%) patients with stroke and 14 (7.9%) patients without stroke were never measured for a functional prosthesis. This difference is not significant.

Of the 209 patients who were prescribed functional prostheses, data were available for analysis on 194 patients, 19 (9.8%) of whom had previously suffered strokes. Walking aid usage and walking distance are summarised in Table 2. The group with prior stroke compared well with the non-stroke group in terms of walking aid usage, but by one year, a smaller proportion of patients with stroke had gained the ability to walk more than 30m (stroke group – 50%, non-stroke group – 78.7%). This difference is significant (Chi-square,  $p < 0.05$ ).

### *Functional independence*

Patients with stroke were more dependent at the initial visit to the prosthetics department (median Barthel scores – no stroke = 17, stroke = 15.5, Pearson  $p = 0.046$ ) and had led more restricted lifestyles in the three months prior to amputation (Frenchay Activity Index, no stroke median = 14.5, stroke median = 11, not significant  $p = 0.08$ ) than patients without stroke. Although Frenchay Activity Index scores improved in both groups (no stroke = 19, stroke

Table 2. Mobility using a prosthesis.

	With stroke		Without stroke	
	6 months	12 months	6 months	12 months
% able to walk ... >30m	50	50	67.8	71.2
... 11-30m	8.3	25	16.1	11
... <10m	33.3	25	9.3	8.5
missing data	8.4		8.6	9.3
% using ... no sticks	8.3	25	9.3	11.9
... 1 stick	25	58.3	27.1	34.7
... 2 sticks/crutches	41.7	8.3	45.8	32.2
... frame	16.7	8.4	11	11.9
missing data	8.3		6.8	9.3

= 11.5) those without stroke were faring significantly better 12 months after being supplied with a prosthesis (Wilcoxon,  $p < 0.05$ ). The non-stroke group also manifested a reduction in dependency (median Barthel at 12 months = 20). Missing data precluded adequate between group analysis of Barthel outcomes.

#### Patients' perceptions

There were no striking differences between patient groups with regard to comfort and satisfaction with the overall performance of the prostheses as shown in Table 3.

#### Completion of one year's prosthetic rehabilitation

63.2% of patients with stroke and 67.4% of those without were still using their prosthesis one year later. Similar numbers of patients in each group died (stroke – 10.5%, no stroke – 10.3%). Second amputations were performed in 10.5% of the stroke group and 6.3% of the non-stroke group. 10.5% of patients with stroke and 8% without stroke stopped prosthetic use for other reasons.

#### Stroke characteristics

The small sample size and incomplete data precluded useful analysis of the influence of stroke characteristics on outcome. In particular the authors were unable to draw any conclusions about the relationship between laterality of the stroke and outcome.

#### Discussion

One of the most striking findings in this survey was that patients with concurrent stroke are less

likely to be referred for prosthetic rehabilitation following lower limb amputation than those without strokes. This almost certainly reflects the view that such patients are less likely to derive benefit from a prosthesis. A separate survey of referring teams in the authors' area confirmed that stroke was one of the main factors likely to prevent referral (Neumann *et al.*, 1995).

Once referred, 81% of patients with stroke and 92.1% without stroke were prescribed a prosthesis at Chapel Allerton Hospital. This implies that referrers have already screened out those with more severe strokes. There is some indication that this is the case (Neumann *et al.*, 1995), but such a relationship between referral pattern and severity of stroke cannot be assumed.

There is also a widely held belief that outlook for prosthetic rehabilitation is worse if the stroke affects the intact limb. Published evidence for this however is based on studies with sample sizes too small to yield significant data (Varghese *et al.*, 1978; Altner *et al.*, 1987; O'Connell and Gnatz, 1989).

It is possible that this belief also influenced referral.

Small sample size in the stroke group and incomplete data in both sets adversely influenced the statistical power of this study. However, the study provides evidence to support the view that patients with stroke fare worse than their counterparts without stroke in prosthetic rehabilitation. Although the majority of patients in both groups were still using their prostheses one year after prescription, during this time the patients with stroke failed to match in some respects the level of mobility and independence

Table 3. Patients' perceptions of comfort and function using their prosthesis.

	With stroke		Without stroke	
	6 months	12 months	6 months	12 months
"Does prosthesis hurt?"... no	41.7	33.3	36.4	48.3
... a little	41.7	58.3	37.3	23.7
... moderate	8.3	8.3	16.9	11
... a lot	0	0	5.1	5.9
Function ... good	33.3	50	44.1	50
... moderate	50	33.3	28	28.8
... not satisfactory	8.3	8.3	20.3	9.3
... missing data	8.3	8.3	7.6	11.8

achieved by those without stroke. Nevertheless as a group the population with stroke were able to make some gains in terms of independence and lifestyle and the importance of such gains, for self respect as well as their relevance to future care costs should not be overlooked.

This retrospective study has not yielded sufficient information to draw conclusions about stroke characteristics which may influence the outcome of prosthetic rehabilitation and which might be addressed by specific therapies. It would be valuable to establish how and why stroke influences outcome in order to select appropriate strategies.

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### REFERENCES

- ALTNER PC, ROCKLEY P, KIRBY K (1987). Hemiplegia and lower limb extremity amputation: double disability. *Arch Phys Med Rehabil* **68**, 378-379.
- GEDDES JM (1998). Assessment of the utility and predictive value of the ICIDH Handicap Code in neurological rehabilitation. PhD thesis. - Leeds: University of Leeds.
- HOOVER RM (1964). Problems and complications of amputees. *Clin Orthop* **37**, 47-52.
- KERSTEIN MD, ZIMMER H, DUGDALE F, LERNER E (1974). Associated diagnoses complicating rehabilitation after major lower extremity amputation. *Angiology* **25**, 536-537.
- NEUMANN VCM, COTTER D, GEDDES JML, MARSHALL S (1995). Prosthetic rehabilitation for lower limb amputees: how are decisions made? *Clin Rehabil* **9**, 173-174.
- O'CONNELL PG, GNATZ S (1989). Hemiplegia and amputation; rehabilitation in the dual disability. *Arch Phys Med Rehabil* **70**, 451-454.
- VARGHESE G, HINTERBUCHNER C, MONDALL P, SAKUMA J (1978). Rehabilitation outcome of patients with dual disability of hemiplegia and amputation. *Arch Phys Med Rehabil* **59**, 121-123.
- WADE DT, HEWER RL (1987). Functional abilities after stroke: measurements, natural history and prognosis. *J Neuro Neurosurg Psychiatry* **50**, 177-182.

## **Comparison of the lightweight Camp Normal Activity Foot with other prosthetic feet in trans-tibial amputees: a pilot study**

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### **Abstract**

Clinically relevant information regarding the useability of prosthetic feet is scarce. The industry is not obliged to perform clinical studies before marketing the product. Clinicians however are limited in their possibilities (organisation and finance) to determine the useability of a technical product. This small study is an example of how in general the useability of a technical product is established in clinical practice.

The Camp Normal Activity Foot (CNAF), a carbon prosthetic foot, was compared objectively and subjectively with a number of other prosthetic feet (same price bracket) in three subjects with trans-tibial (TT) amputations.

The CNAF is low in weight and has favourable stiffness and hysteresis properties. The stiffness of the pylon of the CNAF seems to be limited as also is the possibility of adaptation of the CNAF. The CNAF distinguishes itself, in this study, but not convincingly with respect to the energy consumption in walking, the step-time parameters (symmetry) and the subjective judgement of the users. An additional virtue of the CNAF seems to be its light weight.

### **Introduction**

The characteristics of walking with a TT prosthesis are influenced by the prosthetic foot and the socket. The prosthetic foot has two relevant aspects. These are the weight the functional properties, based on stiffness and the ankle mechanism. Both aspects have their objective and subjective effects on gait.

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Objective effects are identified by kinematic data in the form of joint angles, angular velocities and step time parameters, kinetic data (joint powers and impulses) and energy expenditure data. Subjective findings are: pain (stump load), feeling of heavy weight, exertion and stability.

Research literature only presents a few articles about the integral study of objective as well as subjective findings in respect of prosthetic feet (Donn *et al.*, 1989; Wirta *et al.*, 1991; Colborne *et al.*, 1992; Ehara *et al.*, 1993). Most studies concern comparisons of different foot designs based on the measurements of objective parameters (Casillas *et al.*, 1995; Torburn *et al.*, 1990; Czerniecki and Gitter, 1994; Macfarlane *et al.*, 1991; Lehmann *et al.*, 1993; Nielsen *et al.*, 1988; Perry and Shanfield, 1993; Goh *et al.*, 1994). Differences are measured in the dorsiflexion angle of the ankle, the metabolic or mechanical energy expenditure as well as the comfortable walking speed. In the studies concerned, little attention is paid to subjective findings of the user.

Regarding the weight of the TT prosthesis very little is known about its influence on objective or subjective parameters. Donn investigated the effect of shoe mass on the gait patterns of trans-tibial amputees and their personal preferences (Donn *et al.*, 1989). She concluded that lightweight footwear does not necessarily provide the most symmetrical gait and is not always preferred by the users. Another aspect of the influence of weight is that a relatively large mass at the distal aspect of the TT prosthesis causes large forces acting axially and tangentially on the stump during the swing phase (van de Veen, 1989). These forces can be uncomfortable or even painful. Furthermore the

perception of weight is influenced by the fitting of the socket. When the socket is loose, the TT prosthesis is perceived as being heavier than when the socket fits properly.

The findings of the above mentioned research only give a restricted insight into the useability of prosthetic feet, hence they have a restricted value for the user and prescriber of the prosthesis. Product information regarding prosthetic feet contains little information about the useability of prosthetic feet.

De Laet showed that 29 amputees preferred a prosthesis which caused no stump pain, required little exertion when walking as naturally as possible and felt light in weight (de Laet and de Vries, 1993).

Looking at modern prosthetic feet special attention is paid to reducing the weight of the prosthetic feet with the help of carbon fibre. Until now the available lightweight carbon fibre prosthetic feet are expensive. The CNAF (Camp Normal Activity Foot) is an exception.

Comparing the CNAF with other common prosthetic feet of moderate price little is known about their useability. So it was decided to submit the CNAF to comparative investigation concentrating on potentially clinically relevant parameters. Because the study is an orientating comparison it was decided to restrict the number of patients to three. This connects to the daily clinical practice, where regularly a sort of useability determination takes place purely on an empirical basis in the interaction with patients. Any other approach is difficult for financial reasons.

## Subjects and materials

### Subjects

The study was performed with three healthy adult males each with a unilateral trans-tibial amputation. Each subject was informed about the study and signed an informed consent. Relevant data of the subjects and their TT prostheses are presented in Table 1.



Fig. 1. The CNAF.

### Materials

The CNAF is an integration of a prosthetic foot and a pylon (Fig. 1). It is constructed of carbon fibre reinforced plastic except for the adaptor at the top of the pylon which is made of conventional plastic. It has limited alignment facilities because an ankle adaptor is absent. This results in a reduction of mass especially at the distal post of the prosthesis, which raises the centre of mass. The pylon is adjusted to the required length in accordance to the length of the tibial stump. The well fitting sockets of the CNAF prostheses were made as an exact copy of the subjects' own sockets. The adaptor between the CNAF pylon and the socket was a pyramid adaptor with rotation adjustment. The shaping of the CNAF was performed as described in the

Table 1. Subject and prosthetic information

Subject	M/F	Age (yr)	Body mass (kg)	Cause of amputation	Socket type	Own prosthesis mass including socket and shoe (kg)	CNAF mass including socket and shoe (kg), class CNAF
1	M	68	83	traumatic	PTS	2.0 Multiflex	1.5 yellow class
2	M	64	99	traumatic	PTS	2.3 Quantum	1.4 yellow class
3	M	36	82	congenital	KBM	2.0 SACH	1.7 yellow class

Table 2. Price ranking of the foot prostheses including adaptors and pylon in dollars (US).

Foot type	Price
Geriatric SACH	± 119
SACH	± 130
Dynamic	± 178
Lager	± 186
Multi-axial	± 280
Quantum	± 297
Dynamic Pro	± 311
Rax	± 342
CNAF	± 389
Multiflex	± 428
Seattle	± 525

installation manual. The cosmetic foot lower leg cover was made from low density foam. The subjects used their own comfortable shoes which were the same for both prostheses. All prostheses were built up by the same prosthetist. The weight of the CNAF is 0.7kg, while the weight of the Multiflex, Quantum and SACH feet are, including ankle adaptor and pylon, respectively: 1.0kg, 1.1kg and 1.0kg.

In Table 2 some current prosthetic feet, including adaptors and pylon, have been ranked according to price to make them comparable with the CNAF.

### Methods

The stiffness/hysteresis of the CNAF were measured because these results give information

about the mechanical energy aspect of the rollover pattern of the prosthetic foot. If this pattern differs much from the other prosthetic feet, changes in mechanical energy expenditure cannot be attributed to the lightweight properties of the CNAF. The oxygen uptake was determined because of a reduction in metabolic energy expenditure was expected. Step time was measured determining the symmetry of the gait, being an indicator of the quality of the gait. Questionnaires were used regarding the subjective experiences of walking with a lightweight prosthesis.

### Hysteresis

The hysteresis is defined as:

$$\text{hysteresis} = \frac{\text{energy dissipated (A)}}{\text{energy stored (B)}} \times 100\%$$

The energy storage and the release of the CNAF were tested in the test rig of the Biomechanical Department of the University of Twente. It simulates a standardised stance phase of a subject of 80kg mass. It measures the deformations and forces in three directions. With these test results the stiffness and the mechanical energy pattern can be calculated. The energy storage depends on the stiffness of the foot. A supple foot stores much energy, a stiff foot stores less energy. In Figure 2 and example of energy measurement of the CNAF (A) and a SACH (B) foot is given.

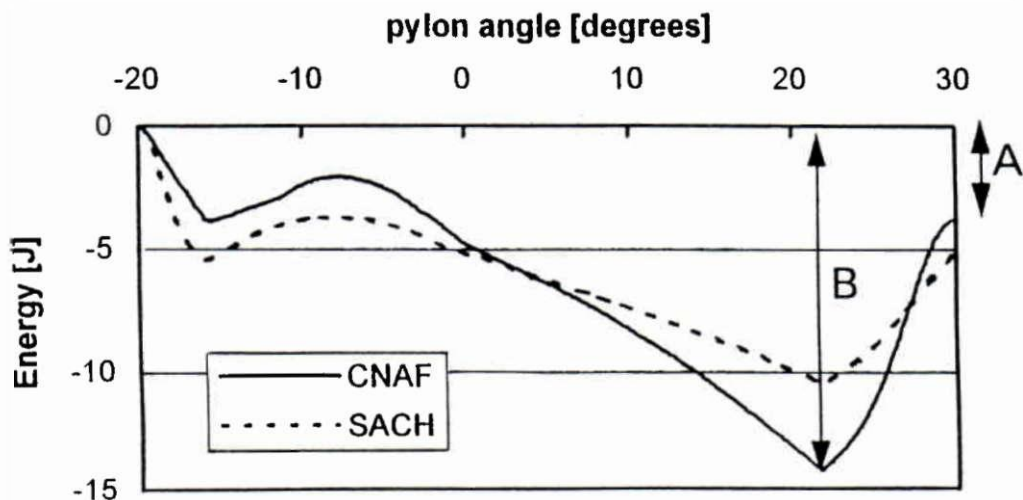


Fig. 2. Energy storage and release patterns of the CNAF and SACH feet.

The measurements performed in the test rig are static. So time dependent features are not taken into account.

#### *Energy cost*

Energy cost was measured by oxygen uptake determination, using an Oxycon alpha system. The Oxycon system measures the pulmonary oxygen uptake ( $\dot{V}O_2$ ), carbon dioxide output ( $\dot{V}CO_2$ ), minute ventilation ( $\dot{V}E$ ) and heart rate (HR). The ratio of  $\dot{V}CO_2/\dot{V}O_2$  is the respiratory quotient (RQ). The RQ is a measure for the kind of nutrition (carbohydrate, fat or protein) used for energy liberation via catabolic processes in the body. The RQ is necessary for calculating the energy because each kind of nutrition liberates a different amount of energy per unit  $O_2$  consumed. So the total amount of energy liberation can be calculated from  $\dot{V}O_2$  and RQ under the condition that the process is in steady state. The progress of  $\dot{V}O_2$  and HR is a measure for reaching the steady state. Heart medication (e.g. beta-blockers) can however influence the cardiac reaction on effort (HR not a reliable measure). The measurements performed with the Oxycon alpha system have an accuracy of 5%. Each subject has to walk at three different velocities for 10 minutes, and at least 5 minutes in steady state. A treadmill was used for making the measurements easier and for standardisation of the walking velocities. Before the walking experiments the subject rested for 30 minutes lying on a bed. The last 10 minutes of the resting period the Oxycon measurement started and was stopped after the measurement with the third walking velocity on the treadmill. The subjects were asked not to drink, eat and smoke two hours before the measurements except for drinking some water. They were also asked (not verified) not to perform strenuous activities during the last two days before the measurements.

#### *Step time parameters*

A Vicon gait analysis system was used to measure the step time parameters: step time, swing time, stance time, double stance time and step length. These parameters are useful to check the symmetry of walking. Therefore the ratios between the right and left leg are compared. For perfect symmetry these ratios should be 1.

#### *Questionnaires*

The questionnaire about standing and walking with a prosthetic foot, developed at our research

department, consisted of 23 questions which were grouped in four categories: 1. stability while standing (level and slope), 2. stability while walking (level and slope), 3. functional aspects (e.g. comfortable speed, powerful/powerless push-off, suppleness of roll-off), 4. special activities (e.g. staircase climbing) (Postema *et al.*, 1997<sup>a,b</sup>). All answers to the questions were scored on a 1 to 10 scale, 10 being best. The average score of all questions was supposed to be the general score of the prosthesis. This score has been used to rank the prosthesis in an order of choice. After the first and the second session an unstructured interview took place with emphasis on the low mass properties of the prosthesis.

#### *Study design*

The complete test period of each subject consisted of three sessions. The first session was performed with the subject's own prosthesis. Step time analysis and oxygen uptake measurement took place. Afterwards the subject answered the questionnaire concerning his judgements about various properties of his prosthesis. Next he was fitted with the CNAF. The second session took place two weeks later and was the same as the first, but now using the CNAF. The third session, two weeks after the second one, was a repetition of the oxygen measurement of the first session, using original prosthesis. The second and the third measurement were used for further analysis. The first measurement has not been analysed to avoid bias due to not being accustomed to the test situation/equipment.

#### **Results**

Because of the limited size useability of this study, the data presented have not been statistically analysed. It is not useful to perform statistical significance analysis with only three subjects. So the results are descriptive and of an indicative character.

First the objective results are presented: concerning the hysteresis, the oxygen uptake and the step time parameters. Secondly the subjective results are presented based on the questionnaire and the unstructured interview.

#### **Objective results**

##### *Hysteresis*

In Figure 2 the energy storage and release of the CNAF is related to the SACH foot. The



Table 3. Hysteresis classification.

Prosthetic foot	Hysteresis
CNAF	26%
Dynamic Pro	27%
Dynamic	28%
Multi-axial	30%
Quantum	31%
Lager	36%
Seattle	40%
SACH	47%
Multiflex	52%
Rax	58%

CNAF curve fits well with the SACH foot which means that the CNAF has average stiffness properties. During the period between shank angle of  $-20^\circ$  and  $-15^\circ$  the CNAF stores 3.7 J after heel strike. At an angle of  $-8^\circ$  2 J is released. As the foot rolls on till  $22^\circ$  (just before push off) 14 J is stored. A good prosthetic foot returns much energy. Such a foot is often called a dynamic foot. After the release at push-off (shank angle  $30^\circ$ ) the energy dissipation of the CNAF is 3.7 J. This is the amount of mechanical energy loss. Looking at Figure 2 the hysteresis of the CNAF is  $A/B \times 100\% = 26\%$ .

In Table 3 the hysteresis data of 10 types of prosthetic feet measured with the test rig are

presented (Postema *et al.*, 1997; van Jaarsveld *et al.*, 1990).

#### Oxygen uptake

The data provided by the Oxycon system are shown in Table 4. Net metabolic energy consumption per second is presented as a function of walking velocity. Net metabolic energy is the gross metabolic energy consumption (total energy consumption) minus the basal energy consumption. For subject 1, the prosthesis with the CNAF shows a higher energy consumption than his own prosthesis for all velocities. For subject 2, the values with the CNAF prosthesis are lower for all velocities. Subject 3 also shows lower energy consumption values for the CNAF prosthesis, though the difference is small at the lowest velocity.

#### Step time parameters

The Vicon system provides step time parameters. With these parameters it is possible to check the symmetry of the gait. Therefore ratios between right and left leg are presented in Table 5.

These symmetry ratios are quite good for all prostheses. For subjects 1 and 3 the symmetry improved slightly with the CNAF prosthesis. For subject 2 the symmetry deteriorated with the CNAF.

Table 4. Net energy cost per second measured at three different velocities ( $v$  is velocity [m/s]) with own and CNAF prosthesis. df. = difference.

Subject 1, energy cost [J/s]				Subject 2				Subject 3			
$v$	Own	CNAF	df. %	$v$	Own	CNAF	df. %	$v$	Own	CNAF	df. %
0.74	191.8	202.6	+5.6	0.83	277.8	243.1	-12.5	1.10	276.5	268.0	-3.0
0.87	210.6	237.6	+12.8	1.17	321.3	298.5	-7.1	1.40	382.9	346.3	-9.6
0.98	245.2	266.1	+8.5	1.43	394.7	363.4	-7.9	1.62	489.2	450.8	-7.7

Table 5. Step time parameters, ratios between right and left leg

Ratio R/L	Subject 1		Subject 2		Subject 3	
	Own	CNAF	Own	CNAF	Own	CNAF
Step time (s)	0.936	0.943	1.026	1.073	1.020	1.014
Swing time (s)	0.919	0.930	1.010	1.040	1.108	1.066
Stance time (s)	1.052	1.044	0.995	0.977	0.940	0.963
Double stance time (s)	1.011	1.019	0.934	0.855	1.264	1.142
Step length (m)	0.980	0.839	0.832	0.893	1.136	1.174

## Subjective results

### Questionnaire

The questionnaire was divided into four categories:

1. Stability while standing (level and slope): 6 questions. 2. Stability while walking (level and slope): 4 questions. 3. Functional aspects (e.g. comfortable speed, push-off): 9 questions. 4. Special activities (e.g. staircase climbing): 4 questions.

Table 6 shows per patient respectively for each type of prosthesis the average scores of each category and overall scores which are the averages of all 23 questions.

All subjects judged the CNAF performance lower than the prosthetic foot of their own prosthesis. The difference in the judgement by subjects 2 and 3 is very small. This can be interpreted as no preference for either prosthesis. Subject 1 however rated the CNAF 1.2 point lower than the prosthetic foot of his own prosthesis. Especially the categories 1 (stability while standing) and 3 (functional aspects) are responsible for this difference.

### Unstructured interview

Each subject was interviewed twice. The first interview concerned their own prosthesis, the second one the prosthesis with the CNAF. Only remarkable differences are reported below.

Subject 1 experienced at the roll over with the CNAF as too stiff. The lateral stability was not sufficient. The judgement of the swing phase was positive: "it swings by itself." At normal walking velocity the CNAF satisfies. He appreciated the low mass of the prosthesis with the CNAF. He preferred a prosthesis with a more supple foot and with more lateral stability.

Subject 2 attached no great value to the reduction of mass. The roll over with the CNAF was said to be good but at toe off the foot turned

into exorotation because of limited stiffness of the pylon. In general he judged the prosthesis with the CNAF as good as his own prosthesis. He preferred to use the prosthesis with the CNAF because he got used to it.

Subject 3 did not use the prosthesis with the CNAF during his work as a prosthetist because he experienced torsion stiffness of the pylon as too small. In his leisure time he however used the CNAF prosthesis. The subject is very content with the mass reduction. His opinion was that the heel strike and roll over features were adequate at normal walking velocity. At higher walking velocities the torsion stiffness should be greater. The toe off with the CNAF was good but the foot turns unwillingly into exorotation. Because of the low mass of the foot the swing phase was very much appreciated.

## Discussion

Because of the limited size of this study only global indications can be given with respect to the useability of the TT prosthesis with the CNAF. Concerning the useability of the prosthesis those factors were considered which are thought to be of greatest interest to the amputees (de Laat and de Vries, 1993). No statements can be made about the possible influence of the CNAF on stump complaints, because these did not occur using their own prosthesis or the prosthesis with the CNAF. Starting with the objective useability parameters in the literature about prosthetic feet a lot of attention is paid to the storage and release of mechanical energy in the stance phase. From the energy point of view a prosthetic foot is better when this foot releases more of the stored energy at toe off, meaning the loss of mechanical energy = hysteresis is smaller. Based on research with a test rig the CNAF shows the best hysteresis properties compared with the other 9 prosthetic

Table 6. Subjective judgement of the prostheses, 1..10 scale, 10 = best.

Categories	Subject 1		Subject 2		Subject 3	
	Own	CNAF	Own	CNAF	Own	CNAF
1	8.2	6.7	9.0	8.0	6.3	6.3
2	7.5	7.8	9.0	8.0	6.0	5.8
3	8.1	7.1	9.1	9.0	7.1	8.1
4	7.8	7.3	8.0	9.0	7.3	6.5
Overall	8.0	6.8	8.9	8.7	6.7	6.6

feet. To what extent this finding is clinically relevant with respect to aspects of exertion remains however disputable.

The metabolic energy consumption in the application of the CNAF resulted in a reduction for two subjects and in an increase for one subject. The differences are less than 10%. Again the question of clinical relevance of the mentioned difference arises. Looking at the step time parameters the attention was focussed on the factor of symmetry, being a measure for a natural gait. It appears that the symmetry ratios of the CNAF do not differ substantially from those of the other prosthetic feet.

Last but not least, the subjective opinion of the amputee is of interest. Compared with their own prosthetic foot (including ankle adaptor and pylon) a mass reduction of the prosthesis of  $\pm 300\text{g}$  can be achieved with the CNAF. Two subjects perceived the mass reduction of the prosthesis as positive and one subject did not think it was important.

Otherwise it is still a question whether an initially noticed difference in mass of the prosthesis still plays a role in the long run on the subjective judgement of the prosthesis. Prosthetic components are frequently recommended by the industry, just because of their low mass but the practical meaning for the user (objectively and subjectively) is not explained. This theme calls for special attention via research.

The answers of the questionnaire correspond with the clinical practice. Being satisfied about their own prosthesis (including the prosthetic foot) an alteration of the prosthesis, meaning another prosthetic foot, will be judged critically by most amputees. This can explain their opinion about the CNAF.

The subjects walked too briefly with the CNAF to be able to give a definitive subjective judgement concerning its useability. The duration of use of the CNAF was however sufficient for the subject, as previously carried out research foot prostheses shows, to acquire an opinion about the most essential walking characteristics of the CNAF (Postema *et al.*, 1997<sup>a,b</sup>). This concerns the characteristics of the heel strike, the foot landing, the roll over and the stability (sidewards and rotation).

One subject experienced insufficient lateral stability with the CNAF. The roll over of the foot was experienced predominantly as adequate, walking comfortably. However two

subjects mentioned a disturbing exorotation with the CNAF at the push-off phase. This aspect needs further attention.

### Conclusions

In contrast to the main other literature findings on the meaning of prosthetic feet this study tried to obtain integral insight in the useability of the CNAF on the basis of objective and subjective parameters from an user's perspective. This way of evaluating a product is recommended for clinical purposes because the insights obtained can help in prescribing a technical aid in a responsible manner.

The CNAF is inclusive of ankle adaptor and pylon, clearly lighter in mass than some other types of often used prosthetic feet (Multiflex, Quantum and SACH foot) with low to moderate price (< 555 Dollars). The stiffness of the pylon of the CNAF seems limited just as the possibilities to adapt the CNAF.

The CNAF has favourable stiffness and hysteresis properties compared to 9 other prosthetic feet in the same price range.

With respect to the metabolic energy consumption in walking and the step-time parameters (symmetry), there are no rational convincing variables found between the CNAF and the subject's own prosthetic foot (Multiflex, Quantum or SACH foot).

The date of the subjective judgements of the prosthetic feet, confirms this. In view of the above mentioned the CNAF seems especially suitable for amputees who are very keen on a low mass prosthesis.

The above mentioned conclusion and statements regarding the CNAF are only based on three patients. This number may be considered just to elicit convincing (without the necessity of applying statistical calculations) clinically relevant differences of the CNAF to other types of prosthetic feet. Any other approach is, without any subsidiary finance, hardly possible in clinical practice. In fact, the producers of prostheses components should, on the basis of integral useability research, deliver adequate product information.

### REFERENCES

- CASSILAS JM, DULIEU V, COHEN M, MARCIER I, DIDIER JP (1995). Bioenergetic comparison of a new energy-storing foot and SACH foot in traumatic below-knee vascular amputations. *Arch Phys Med Rehabil* 76, 39-44.

- COLBORNE GR, NAUMANN S, LONGMUIR PE, BERBRAYER (1992). Analysis of mechanical and metabolic factors in the gait of congenital below-knee amputees: a comparison of the SACH and Seattle feet. *Am J Phys Med Rehabil* **71**, 272-278.
- CZERNIECKI JM, GITTER A (1994). Prosthetic feet: a scientific and clinical review of current components. *Phys Med Rehabil: State Art Rev* **8**, 109-127.
- DONN JM, PORTER D, ROBERTS VC (1989). The effect of footwear mass on the gait patterns of unilateral below-knee amputees. *Prosthet Orthot Int* **13**, 140-144
- EHARA Y, BEPPU M, MOMURA S, KUNIMI Y, TAKAHASHI S (1993). Energy storing property of so-called energy-storing prosthetic feet. *Arch Phys Med Rehabil* **74**, 68-72.
- GOH JCH, TAN PH, TOH SL, TAY TE (1994). Gait analysis study of an energy-storing prosthetic foot - a preliminary report. *Gait Posture* **2**, 95-101.
- VAN JAARVELD HWL, GROOTENBOER HJ, DE VRIES J, KOOPMAN HFJM (1990). Stiffness and hysteresis properties in some prosthetic feet. *Prosthet Orthot Int* **14**, 117-124.
- DE LAAT F, DE VRIES J (1993). Functie comfort en cosmetiek als graadmeter voor gebruikswaarde van beenprothesen. In: 5<sup>e</sup> symposium Revalidatietechniek, gaan en staan II./edited by BMTI press. - Enschede: University Twente. p113-123.
- LEHMANN JF, PRICE R, BOSWELL-BESSETTE S, DRALLE A, QUESTAD K (1993). Comprehensive analysis of dynamic electric response feet: Seattle Ankle/Lite foot versus SACH foot. *Arch Phys Med Rehabil* **74**, 853-861.
- MACFARLANE PA, NIELSEN DH, SHURR DG, MEIER R (1991). Gait comparisons for below-knee amputees using a Flex-Foot versus a conventional prosthetic foot. *J Prosthet Orthot* **3**, 150-161.
- NIELSEN DH, SHURR DG, GOLDEN JC, MEIER R (1988). Comparison of energy cost and gait efficiency during ambulation in below-knee amputees using different prosthetic feet - a preliminary report. *J Prosthet Orthot* **1**, 24-31.
- PERRY J, SHANFIELD S (1993). Efficiency of dynamic elastic response prosthetic feet. *J Rehab Res Dev* **30**, 137-143.
- POSTEMA K, HERMENS HJ, DE VRIES J, KOOPMAN HFJM, EISMA W (1997). Energy storage and release of prosthetic feet part 1: biomechanical analysis related to user benefits. *Prosthet Orthot Int* **21**, 17-27.
- POSTEMA K, HERMENS HJ, DE VRIES J, KOOPMAN HFJM, EISMA W (1997<sup>b</sup>). Energy storage and release of prosthetic feet part 2: subjective ratings of 2 energy storing and 2 conventional feet, user choice of foot and deciding factors. *Prosthet Orthot Int* **21**, 28-34.
- TORBURN L, PERRY J, AYYAPPA E, SHANFIELD SI. (1990). Below-knee amputee gait with dynamic elastic response prosthetic feet: a pilot study. *J Rehabil Res Dev* **27**, 369-384.
- VAN DE VEEN PG (1989). An investigation of design criteria of modular endoskeletal lower-limb prostheses. Ph.D. thesis. - Enschede: University of Technology, Twente.
- WIRTA RW, MASON R, CALVO K, GOLBRANSON FL (1991). Effect on gait using various prosthetic ankle-foot devices. *J Rehabil Res Dev* **28**, 13-24.

## **Morphological changes during early trans-tibial prosthetic fitting**

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### **Abstract**

Morphological changes in the amputation stump may have serious implications regarding the suspension and fit of the prosthetic socket. In an earlier study (Lilja and Öberg, 1997) the authors have shown that the volume of the trans-tibial amputation stump decreases according to a negative power function after amputation, and that the stump volume does not stabilise until four months after the operation. In the present study, Magnetic Resonance Imaging (MRI) technique was used to examine morphological changes in the amputation stump after trans-tibial amputation in a small number of cases. The authors expected to find a decrease in the cross-sectional area of the stump and of the separate muscles similar to the findings in earlier studies. However, two different patterns were found. The cross-sectional area of the entire stump as well as that of the medial muscle group changed according to the authors' hypothesis, i.e. an initial fast decrease, followed by a more moderate decrease of the area. In the lateral muscle group another pattern was found. After an initial rapid decrease the area increased, sometimes to a magnitude larger than the initial value. After the amputation the lateral muscle group may acquire a new function, contributing to the suspension of the socket. Despite the limited number of patients, this study presents findings which may be important in the clinical fitting of trans-tibial prostheses.

### **Introduction**

Changes in the volume, form and internal structures of the stump may jeopardise prosthetic fitting in the early rehabilitation phase after a trans-tibial amputation.

Several studies have examined postoperative volume changes of amputation stumps, e.g. Lilja and Öberg (1997). However, studies concerning qualitative changes, i.e. specifically which morphological structures change, and to what extent, have not been conducted. Do these changes involve a homogeneous development, or is there a considerable heterogeneity among different tissues and muscle components? A better understanding of these processes may contribute to improved prosthetic fitting during the rehabilitation phase.

After a major amputation, severe traumatic oedema and hematoma occur in the stump, which can be reduced by bandaging and physical activity (Levy, 1977; Manella, 1981; MacLean and Fick, 1994). The stump volume decreases gradually during the early maturation process due to a reduction in postoperative oedema. Lilja and Öberg (1997) have shown that the volume of the stump reduces according to a negative power function, but the question remaining is what are the qualitative and quantitative changes occurring inside the stump? Are there any differences in the amount of atrophy between the gastrocnemius muscle, that continues to engage the knee joint, and the other muscles that do not engage any joint, after the trans-tibial amputation?

To examine the structures inside the human body, Magnetic Resonance Imaging (MRI) is a very effective, but expensive and complex method. Jaegers (1993), in her thesis, has shown the usefulness of MRI in studying the

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morphology of trans-femoral amputation stumps. MRI also provides a non-invasive technique for the study of trans-tibial stump muscles.

The process of muscle atrophy begins immediately postoperatively, and continues simultaneously with a reduction in oedema, (Baumgartner and Langlotz, 1980). When only external stump volume is studied, these components cannot be differentiated. The amount of this atrophy is correlated to physical activity, postoperative bandaging and prosthetic fit (Levy, 1980; Renström *et al.*, 1983).

The two heads of the gastrocnemius muscle originate from the medial and lateral condyles of the femur and for trans-tibial amputees, the distal part of the muscle is attached through myodesis to the tibial end. This changes the function of the gastrocnemius muscle from that of a two joint muscle, to a single joint muscle after the amputation. After the amputation the soleus muscle and the anterior tibial muscle do not affect any joint. Such circumstances may influence the amount and rate of atrophy in the stump.

Several authors have described possibilities of controlling movement and suspension of the prosthesis during motion by contracting the stump muscles (Burgess *et al.*, 1974; Kegel *et al.*, 1981). However, this control depends on the function of the muscles in the trans-tibial stump and the patient's ability to activate and control them.

Kegel *et al.* (1981) have shown that exercise of the stump musculature should be a part of routine physical therapy. The amputees must be able to control fully the musculature during gait. Exercises should include specific training of the gastrocnemius muscle as well as the anterior tibial muscle. As described by Burgess and co-workers (1974), these muscles do increase in volume during the exercise period.

Amputees in the western world today have a very high average age, and amputation is due, in most cases, to peripheral vascular disease with or without the presence of diabetes mellitus. Furthermore, many of these patients are also in poor physical condition (Ailaranta *et al.*, 1995; McWhinnie *et al.*, 1994). In an earlier study, Hedberg *et al.* (1989), presented a 50 per cent lower number of muscle fibres in the gastrocnemius muscle in amputated legs compared with non-amputated legs, which is

probably related to the relative inactivity of the amputated leg and to long-standing vascular insufficiency. When a muscle becomes inactive, the muscle fibres begin to degenerate and fat imbibes into the muscle tissue.

The aim of the present study was to describe the morphological changes in trans-tibial stump musculature during the first months after amputation. The hypothesis was that the muscle area decreases due to both atrophy and a reduction in postoperative oedema, and that muscle area reduction follows a similar course to that of stump volume reduction presented in earlier studies (Lilja and Öberg, 1997; Golbranson *et al.*, 1998).

## Material and methods

### Subjects

Inclusion criteria to join the study were: trans-tibial amputation due to arteriosclerosis, the ability to understand the study design, and consent to participate in the study.

Seven trans-tibial amputees, two women and five men, with a mean age of 69.9 (range 57-80) years were included. One patient was bilaterally amputated at one operation session. Therefore, a total of eight amputation stumps were included in the study. All patients were fitted with traditional patellar-tendon-bearing trans-tibial prostheses, PTB, during the study. The prosthetic fittings did not influence the study. One patient, case 5, was re-amputated to a higher trans-tibial level, between the second and third examination, therefore he was excluded. Cases 6 and 7 were excluded after the first examination due to re-amputation at a higher level, trans-femoral. Case 8 died between the first and second examination. For the final evaluation four amputation stumps remained.

### Study design

Three MR examinations were performed on each patient. The first examination was performed during the second week after amputation, the second after six and finally the third examination after 28 weeks. The examinations were performed by a radiologist.

MRI is an exclusive and expensive technique. For this reason the study was designed as a case study.

### Magnetic Resonance Imaging

In order to obtain transverse MR images a

Siemens Magnetom 63 SP 4000 with a spin echo technique, T1 weighted, TR/TE 720/20, with a field of view (FOV) 180mm with a 256 x 256 matrix, was used. The slice thickness was 6.0 mm and the distance between the slices 0.5 mm. Images were obtained from the femoral condyle to the distal end of the trans-tibial stump.

#### *Area and circumference analysis*

The contour of the stump and the separate muscles on the MR images were manually copied to a transparent paper and then scanned into a computer. The circumference and area were calculated and registered with software, BIMAREA, developed at the authors' department. The anterior tibial muscle and the posterior muscle group, including the medial and lateral heads of the gastrocnemius and the soleus muscle, were identified and registered. Each muscle in the posterior muscle group was also identified and registered.

Transverse MR images were chosen from three different levels of the amputation stump, at 33% of the total stump length, 50% and 66% of the total stump length (Fig. 1). The total length of each amputation stump was recorded at every examination.

#### *Normalisation*

All measurement of muscle area and circumference were normalised relative to the first examination, i.e. the first examination was set at 100 per cent.

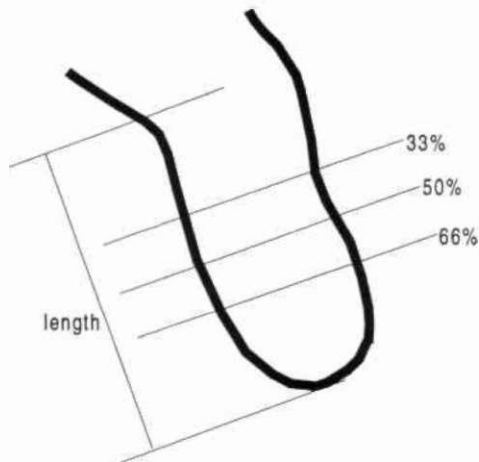


Fig. 1 Different levels for MR images.

## **Case Histories**

### *Case 1*

A 71-year-old, non-smoking male who has had diabetes mellitus for 11 years. He underwent a by-pass operation three years ago and has previously suffered a myocardial infarction. The patient was relatively active and walked without help. He arrived at the hospital with a wound on the lateral side of his right heel. A revision of the wound was performed. Two months later, an orthopaedic surgeon attended to the patient, and calcaneus osteitis was diagnosed. A trans-tibial amputation with a long posterior flap was performed. One month after the amputation, the patient was transferred from the orthopaedic clinic to the geriatric rehabilitation clinic and fitted with a PTB prosthesis. He was subsequently able to walk. Three months after the amputation, the patient was discharged from the hospital.

### *Case 2*

A 63-year-old man, retired farmer, who has had diabetes mellitus for 20 years and a history of heart infarction. The patient was active and walked without any support. He arrived at the hospital with a necrosis on his left big toe. Three months later the entire forefoot was infected. He was treated with antibiotics but with poor results. A trans-tibial amputation with a long posterior flap was performed. One month later he was discharged to his home. He was fitted with a PTB prosthesis, and managed the rehabilitation on his own.

### *Case 3 and 4 (same patient, different legs)*

A 57-year-old woman, retired nurse, with schizophrenia, treated with neuroleptic medicine. She had bilateral venous ulcers for three years, which caused severe pain in both feet. She requested a bilateral amputation several times. The patient could walk, but used a wheelchair because of pain. Bilateral trans-tibial amputations with long posterior flaps were performed. Postoperatively, she suffered severe stump pain and phantom pain, and was referred to a pain clinic. Thereafter, she was treated with slow release ketobemidon. After four months she was transferred to the geriatric rehabilitation clinic and bilaterally fitted with PTB prostheses, but experienced severe stump and phantom pain during training with the prostheses. A few weeks later she was, by her own request, discharged

Table 1. Stump area in per cent at different levels during the study. All figures normalised relative to the first examination.

Level Weeks	Case 1			Case 2			Case 3			Case 4		
	33	50	66	33	50	66	33	50	66	33	50	66
2	100	100	100	100	100	100	100	100	100	100	100	100
6	80	84	79	91	93	98	87	85	86	93	92	88
28	77	73	69	105	109	114	103	96	89	111	104	92

from hospital and declined from participating in gait re-education and prosthetic use.

## Results

### *Changes in total cross-sectional area and circumference*

The total cross-sectional area reduced very quickly between the first and second examination in all cases. Between the second and third examination, the area increased slightly in all cases but one. This pattern of change was recorded at all three levels (Table 1). A similar pattern was seen regarding circumference; first a decrease in circumference followed by an increase (Table 2).

The total stump length remained nearly constant during the course of the study (Table 3). A visual evaluation of the MR images showed an increased amount of subcutaneous fat during the study.

### *Change in cross-sectional area of different muscles (Figs. 2-5)*

The individual muscles could only be evaluated at the 33% and 50% levels. At the

66% level the muscle tissue was too deranged to permit an evaluation.

The cross-sectional area of all muscles decreased quickly between the first and second examination at all levels. Between the second and third examination, however, there was a difference between the individual muscles. In most cases, the medial head of the gastrocnemius, the soleus muscle and the triceps surae decreased in area, but the lateral head of the gastrocnemius and the anterior tibial muscle showed an increase.

## Discussion

The primary focus of the present study was to examine the progress of the soft tissues under the skin after amputation and subsequent prosthetic fitting. It was found that the cross-sectional area of the total stump, and the separate muscles, decreased according to two different patterns. The total stump, as well as the medial head of the gastrocnemius, the soleus muscle and the whole triceps surae complex reduced their cross-sectional area in an expected manner,

Table 2. Stump circumference in per cent at different levels during the study. All figures normalised relative to the first examination.

Level Weeks	Case 1			Case 2			Case 3			Case 4		
	33	50	66	33	50	66	33	50	66	33	50	66
2	100	100	100	100	100	100	100	100	100	100	100	100
6	90	91	88	96	96	98	94	93	93	97	69	68
28	90	86	82	103	106	110	103	99	95	107	102	97

Table 3. Stump length in centimetres during the study.

Weeks	Case 1	Case 2	Case 3	Case 4
2	12.2	14.9	14.6	15.4
6	11.8	15.2	14.2	14.8
28	11.5	15.2	13.9	13.5



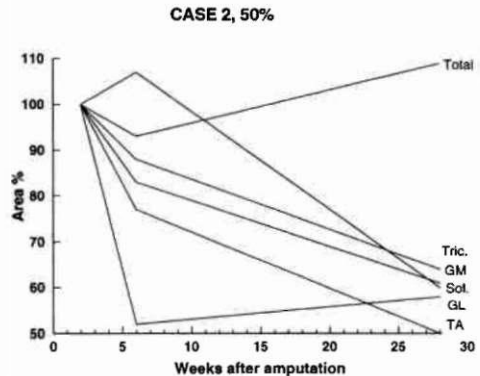
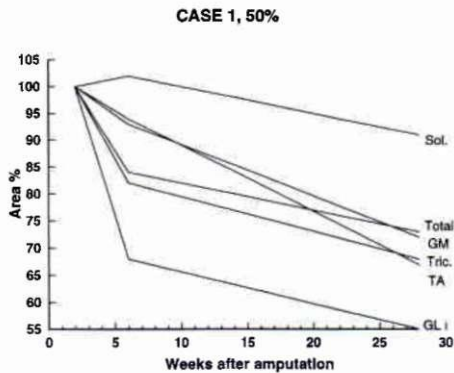
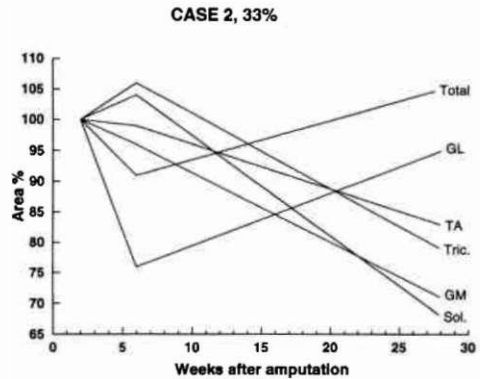
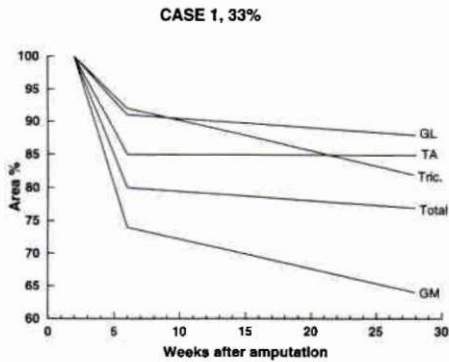


Fig. 2. Area changes in case 1. TA: anterior tibial muscle area, GL: lateral head of gastrocnemius area, GM: medial head of gastrocnemius area, Tric; triceps surae area. Sol: soleus muscle area. Total: stump area.

Fig. 3. Area changes in case 2.

i.e. a relatively rapid initial decrease in area and thereafter a slower decrease between the second and third examination. The lateral head of the gastrocnemius and the anterior tibial muscle (the lateral muscle group), however, showed a different behaviour. These two muscles initially showed a reduction in cross-sectional area between the first and second examination, and thereafter, an increase in area between the second and third examination, to a magnitude that, in some cases, was even larger than the area immediately after surgery. In some cases, the area of the triceps surae increased while the individual muscles decreased. This was due to the increased amount of fat between the muscles but still contained within the triceps surae unit.

The changes in area after amputation can be divided into two different phases, oedema reduction and muscle atrophy. As previously described by several authors, muscle trophy begins immediately after the amputation, and

continues parallel to oedema reduction during rehabilitation (Baumgartner and Langlotz, 1980; Levy, 1980; Renström *et al.*, 1983). Oedema reduction takes place mainly during the first weeks following amputation, i.e. between the first and second examination in the present study. In an earlier study, it was found that the total volume of the stump after a trans-tibial amputation decreased according to a negative power function, with an initial rapid volume reduction and later a more moderate volume reduction (Lilja and Öberg, 1997). The initial changes in volume observed in the present study did correspond to the literature and the authors' hypothesis.

For the medial muscle group the cross-sectional area changed according to this hypothesis, with a fast initial reduction followed by a slow reduction, probably reflecting a more rapid oedema reduction and a slower phase dominated by tissue atrophy. This is in full

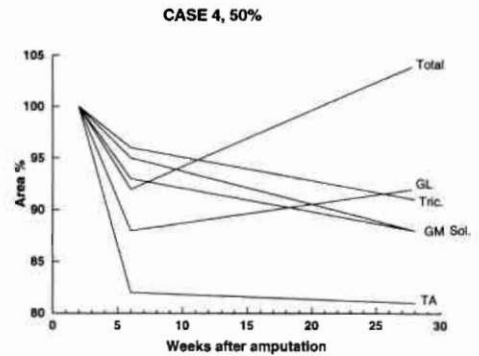
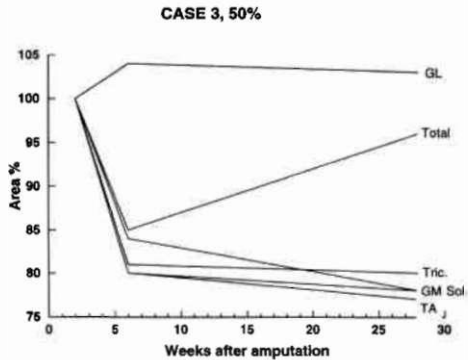
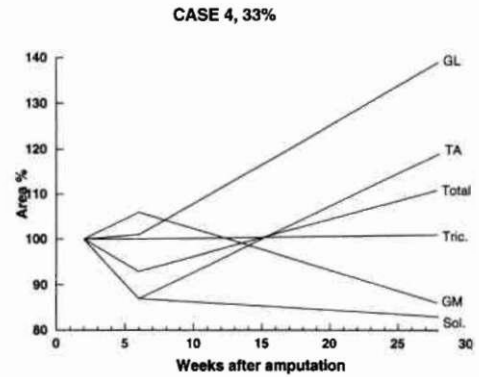
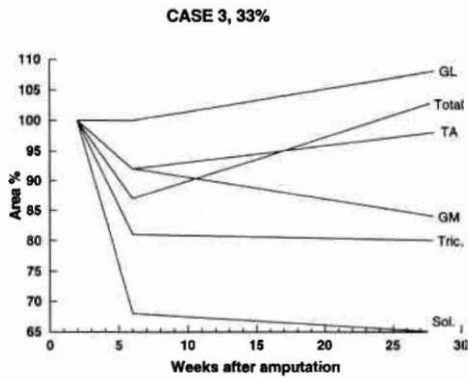


Fig. 4. Area changes in case 3.

Fig. 5. Area changes in case 4.

accordance with our earlier findings (Lilja and Öberg, 1997).

Quite unexpectedly, the lateral muscle group did not reduce in cross-sectional area according to previous studies (Lilja and Öberg, 1997; Golbranson *et al.*, 1988). After the second examination the areas increased, and in some muscles, even to a larger size than the initial value. This behaviour has not been described earlier in the prosthetic literature. However, as one study has shown, the medial and lateral heads of the gastrocnemius muscle, in healthy people, may have different functions (Ericson *et al.*, 1986). Different activity levels were observed in the two heads of the gastrocnemius, during level walking, with about 100 per cent higher EMG amplitude in the medial head compared to the lateral head. No such studies have been found involving amputees. Different activities in the two heads of the gastrocnemius muscle, may explain the different patterns observed. Grevsten and Stålberg (1975) showed that patients walking with a PTB prosthesis have

a different activation pattern of the gastrocnemius muscle compared with healthy subjects. However, they did not differentiate between the two heads of the gastrocnemius muscle, as in the study by Ericson and co-workers (1986).

Trans-tibial amputation in elderly patients – many of them in poor condition, with gangrene and peripheral vascular disease (PVD) – must be classified as major surgery. Due to both the gangrene and the operation itself, the patient enters initially, in to a catabolic phase with a breakdown of muscular tissues. Within a few week, however, the metabolism normally changes and becomes anabolic and the patient can begin the rehabilitation and the rebuilding of his tissues. This build-up of muscle tissue, together with an increased activity level, may explain the changes in area seen in some of the individual muscles. Hedberg and co-workers (1989) found that, among trans-femoral amputees with advanced arterial insufficiency, the loss of muscle fibres in the gastrocnemius

muscle in the removed leg is about 50 per cent, compared with non-amputees. Inactivity, in combination with ischaemia, may cause the loss of many individual muscle fibres and as Hedberg and co-workers (1989) have stated, the connective tissue components were abundant.

A severe amount of fat imbibition can be seen among all cases in the present study (Fig. 6). This fat imbibition can be a result of advanced arterial insufficiency. No other presentation of fat imbibition among trans-tibial amputees have been found in the literature.

During the first six weeks after an amputation the patient can begin light physical training. After this first phase of rehabilitation the training can become more intense and the patient can start his gait re-education with a temporary/definitive prosthesis (Cutson and Bongiorno, 1996; Breakey, 1997). The physical training, together with an anabolic metabolism can stop the atrophy of activated muscles and may explain the difference in muscle area change between the second and third examination compared with the phase between the first and the second examination among the single joint muscles (except the gastrocnemius lateral head).

After a trans-tibial amputation, the anterior tibial muscle does not engage any joint and can therefore be seen as not involved in any motion. But probably, the anterior tibial muscle obtains new function: contributing to socket suspension (Burgess *et al.*, 1974). During the gait cycle the patient can, through muscle activity, increase the stump volume and thereby increase the pressure between the amputation stump and socket. The increased pressure may prevent stump movement and contribute to improved

suspension. As the patient learns how to activate the lateral muscle group at the correct time during the gait cycle, the prosthetic gait may be improved. The present study indicates a difference between the lateral and the medial muscle group in this respect. Consequently, the lateral muscle group might have adopted a new activity pattern and a new function during prosthetic fitting, i.e. contributing to the suspension of the prosthesis. Such a new activity pattern for the muscles, during prosthetic gait, may also result in hypertrophy due to training, and may explain the differences in area between the two muscle groups.

Due to the exclusive and expensive MRI technique used, the present study had to be designed as a case study. The price for one MR examination was approximately US\$ 530, and despite the limited number of patients, 17 examinations were performed. The inclusion criteria were fairly wide, and more or less all patients with a trans-tibial amputation at the orthopaedic clinic were consecutively included during a six-month period. Therefore, patients with late healing problems could not be excluded before the first examination. Due to this procedure several patients required re-amputation to the same or higher level, during the study. Only four out of eight cases completed the study. Eneroth (1997), in his thesis, found that as many as 20 per cent of all trans-tibial amputees undergo a revision or re-amputation, and that mortality after a major amputation varies between 19-40 per cent within one year after the amputation.

The levels chosen for MR images were located at 33, 50 and 66 per cent of the total length of the stump (from the knee joint to the distal end). The MR images at the 66% level were, in most cases, impossible to interpret due to a severely damaged morphology after operation with the muscles having been trimmed and no clear and identifiable muscle borders visible. Therefore, no cross-sectional areas from the 66% level were calculated. However, other studies on longer amputation stumps may show different patterns of atrophy.

The cases presented in this study were few, and did not permit statistical treatment of the findings. However, the results may indicate important changes in muscle function in the limb after trans-tibial amputation, important for further understanding of socket suspension during prosthetic gait.

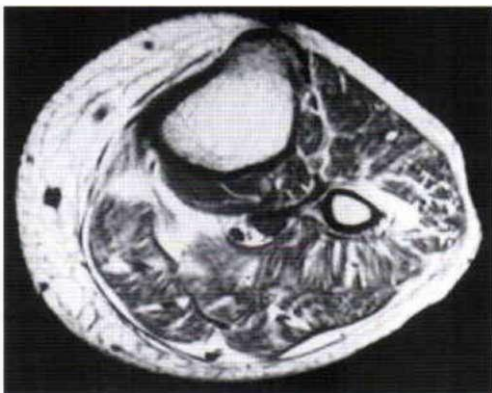


Fig. 6 Transverse MR image of case 4 at 50% level

## Conclusion

This study has documented after trans-tibial amputation, severe changes in cross-sectional area of the total trans-tibial stump and of the separate muscles included in the stump. Two different patterns of change were found. The medial muscle group decreased in area according to an initial hypothesis, with a rapid decrease between the first and second examination and a more moderate decrease between the second and third examination. The lateral muscle group decreased as well, between the first and second examination, but increased in area between the second and third examination.

These two different patterns may indicate a new function of the muscles in the lateral muscle group. Activation of the lateral muscle group can be seen as a contributing factor to the suspension and fit of the prosthetic socket. These findings can be of importance for prosthetic fitting, and, together with earlier studies, indicate the importance of well-planned and functionally designed physiotherapy and prosthetic gait re-education.

## Acknowledgement

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## REFERENCES

- ALARANTA H, ALARANTA R, POHJOLAINEN T, KÄRKKÄINEN M (1995) Lower limb amputees in Southern Finland. *Prosthet Orthot Int* **19**, 155-158.
- BAUMGARTNER R, LANGLOTZ M (1980). Amputee stump radiology. *Prosthet Orthot Int* **4**, 97-100.
- BREAKEY JW (1997). Body image: the lower limb amputee. *J Prosthet Orthot* **9**, 58-66.
- BURGESS EM (1974). Wound healing. *Bull Prosthet Res* **10**, 109-113.
- CUTSON TM, BONGIORNI DR (1996). Rehabilitation of the lower limb amputee: a brief view. *J Geriatr Soc* **44**, 1388-1393.
- ENEROTH M (1997). Amputation for vascular disease: prognostic factors for healing, long-term outcome and costs. Thesis. -Lund: Lund University.
- ERICSON MO, NISELL R, EKHOLM J (1986). Quantified electromyography of lower-limb muscles during level walking. *Scand J Rehabil Med* **18**, 159-163.
- GOLBRANSON FL, WIRTA RW, KUNCIR EJ, LIEBER RL, OISHI C (1988). Volume changes occurring in postoperative below-knee residual limbs. *J Rehabil Res Dev* **25**, 11-18.
- GREVSTEN S, STÅLBERG E (1975). Electromyographic study of muscular activity in the amputation stump while walking with PTB- and PTB-suction prosthesis. *Uppsala J Med Sci* **80**, 103-112.
- HEDBERG B, ANQUIST KA, HENRIKSSON-LARSEN K, SJÖSTRÖM M (1989). Fibre loss and distribution in skeletal muscle from patients with severe peripheral arterial insufficiency. *Eur J Vasc Surg* **3**, 315-322.
- JAEGERS S (1993). The morphology and function of the muscles around the hip joint after a unilateral transfemoral amputation. - Den Haag: Cip-Gegvevens Koninklijke Bibliotheek. (ISBN 90-9005982-2).
- KEGEL B, BURGESS EM, STARR TW, DALY WK (1981). Effects of isometric muscle training on residual limb volume, strength, and gait below-knee amputees. *Phys Ther* **61**, 1419-1426.
- LEVY SW (1977). Disabling skin reactions associated with stump edema. *Int J Dermatol* **16**, 122-125.
- LEVY SW (1990). Skin problems of the leg amputee. *Prosthet Orthot Int* **4**, 37-44.
- LILJA M, ÖBERG T (1997) Proper time for definitive trans-tibial prosthetic fitting. *J Prosthet Orthot* **9**, 90-95.
- MACLEAN N, FICK GH (1994). The effect of semirigid dressings on below-knee amputations. *Phys Ther* **74**, 668-673.
- MANELLA KJ (1981). Comparing the effectiveness of elastic bandages and shrinker socks for lower extremity amputees. *Phys Ther* **61**, 334-337.
- MCWHINNIE DL, GORDON AC, COLLIN J, GRAY DW, MORRISON JD (1994). Rehabilitation outcome five years after 100 lower-limb amputations. *Br J Surg* **81**, 1596-1599.
- RENTRÖM P, GRMBY G, MORELLI B, PALMERTZ B (1983). Thigh muscle atrophy in below-knee amputees. *Scand J Rehabil Med (Suppl)* **No.9**, 150-162.

## **An “appropriate technology” trans-femoral prosthesis, using materials available in Nepal**

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### **Abstract**

The use of western components and materials for prostheses is prohibitively expensive in most developing countries. In addition, local customs and conditions vary considerably from those for which the prostheses were designed. For these reasons, a trans-femoral prosthesis has been developed in Pokhara, Nepal, using entirely locally available materials, and with a view to fulfilling local requirements as far as possible.

This paper describes the materials and fabrication technique for the component parts of the prosthesis, the local conditions for which it was developed, and a three year follow-up of the first prosthesis issued. Only one serious design fault was discovered during this period, and a modification to the fabrication procedure introduced. The authors believe that if this trend continues, this style of prosthesis may be useful in the future for Nepali amputees and perhaps also in other countries, particularly where mass production of components is not practical.

### **Introduction and local conditions**

The Himalayan kingdom of Nepal is a landlocked country, situated between Tibet in the north and India in the south. The country divides into three areas: the high mountains to the north, the plain in the south and the hills in between, where Pokhara is located. In this area travel is mainly by foot, some villages being several days walk from the nearest motorable road. In addition to porters, pack ponies are used to transport goods, but it is fairly unusual to see people on horseback. Travel often involves

wading across rivers which are sometimes waist deep during the rainy season. Paths are stony and often steep, although many people live on land where the immediate environment around the home is flat.

Much of life in Nepal takes place at floor level. Cooking, washing, eating and toileting are usually carried out sitting or squatting on the ground. Inability to do this is clearly a handicap in Nepali society. Piped water is available only in some homes, the majority of households relying on water carried from a nearby source by the women. Small children are traditionally strapped to the back of their mother or carried on the hip. Nepal is essentially reliant on subsistence agriculture, with the result that many people carry out manual work in the fields. In the hilly areas, both barefoot and shod walking are commonplace, with canvas shoes being preferred in the cooler climates. Footwear is generally removed on entering a home or a place of worship. Generally, both men and women wear long clothes covering their legs, though it is socially acceptable for male manual workers to wear shorts. For the above reasons, it is important for prostheses in Nepal to be durable, waterproof, and able to be repaired locally as far as possible. It is also important that the amputee can reach floor level comfortably, and for women, particularly, to be able to carry loads, like water and children. Cosmesis, on the other hand is not so critical as it would be for western women wearing short skirts. Ideally, a prosthesis should be able to be worn with or without shoes, with the footwear being easily removable.

The use of entirely locally available materials in the prosthesis described here (Fig. 1) ensures that major maintenance can be carried out in the hospital where it is made, while minor repairs

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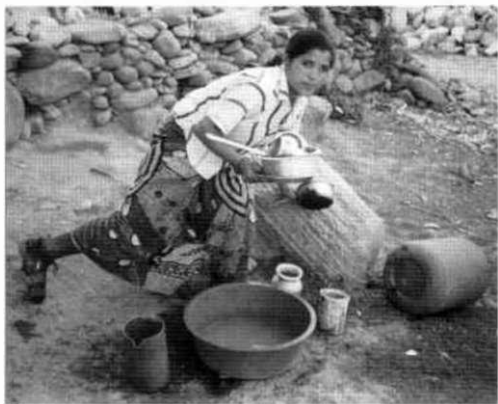


Fig. 1. The first prosthesis is being used at the home trial stage.

can be carried out by shoe-makers anywhere in the country. Standard biomechanical and functional principles are used in the design.

Thermoplastics have been introduced into prosthetic and orthotic production in developing countries in the last few years (Fago, 1992; Meanley, 1991; Moll, 1991; Oberg, 1991; Ortholetter, 1993, 1994 and 1995; Theuvenet *et al.*, 1994; Garachon, 1996). In the prosthesis described here, durability and water resistance are addressed by the use of High Density Polyethylene (HDPE), which is available as drainage piping in Nepal.

Film canisters may seem to be a more western commodity, however, as tourism is the country's biggest foreign currency generator, the photographic industry is well advanced, and such accessories plentiful.

Although the SACH foot has neither the cosmetic appearance nor the mobility of the Jaipur footpiece (Sethi *et al.*, 1978; Sethi, 1989), it requires little maintenance, is cheap and easy to make from materials available in Nepal.

The cycle axle knee, based on a design by Girling and Cummings (1972), also allows for easy access to replacement parts. The knee permits up to 100° of flexion which, while insufficient for deep squatting, does enable the amputee to reach floor level with ease.

#### *The suspension*

The suspension of the prosthesis is a combination of suction and a modified Silesian belt. The belt has the standard pivot attachment to the lateral wall of the socket and a buckle or double D-ring attachment anteriorly. In addition

to the pelvic band giving suspension over the contralateral iliac crest, a lateral band passes from the posterior over the ipsilateral iliac crest to a D-ring at the mid-line anteriorly and from there to the anterior buckle attachment.

The belt is made from water buffalo leather, and the pelvic band lined with softer goat leather. The lateral band and anterior D-ring are joined to the pelvic band with speedy rivets, and both attachments to the socket are made with 4mm diameter nuts and flat headed bolts. The heads are smoothed and the bolts are trimmed to length. They are inserted from the inside of the socket, and once the belt and nut are in place the cut end is hammered to prevent the nut from coming loose. The belt is reinforced with metal washers between the layers of leather wherever a hole is punched for a speedy rivet or bolt.

#### *The knee*

The knee is based on a design described by Girling and Cummings (1972). It is a single axis joint with adjustable friction control, and uses the front axle and hub of a bicycle as its main components.

The proximal and distal blocks are fabricated from a medium density wood (*Mangifera Indica*) and are finished with a waterproof varnish for protection against water and insects. The proximal block is made from three wooden components and houses the axle, hub, extension stop bar and friction adjust bolt. The wooden blocks are shaped to give a similar appearance to exoskeletal knees which are commercially available in the west.

The extension stop bar is fitted to the axle, and bears on the inner surface of the distal block, preventing hyperextension. When the friction adjust nut is tightened, it moves a leather block, which bears through the extension stop bar onto the axle, thus increasing the friction in the system. A double piece of tailor's elastic with a leather tab at either end is used anterior to the knee to provide an extension assist.

#### *The foot*

The SACH foot made in Pokhara is by no means unique to Nepal (Girling and Cummings, 1972). It is made from a local hard wood (*Shorea Robusta*) and microcellular rubber (MCR). It is attached to the ankle block with a nut and bolt.

A hole is drilled for the attachment bolt, a countersunk distally to allow room for a socket

wrench and the nut. The lateral pattern is then drawn on the wood block and the anterior and posterior wedges cut from the distal surface. After smoothing the surfaces a laminated MCR wedge is glued to the heel section and a shaped MCR sole piece to the plantar surface of the foot block.

Saw cuts are made from the proximal surface to the top of the lateral pattern, the base of these cuts marking the extent of the wood to be removed proximally. Finally the foot is shaped and smoothed in three dimensions and a countersunk hole made in the rubber heel.

#### *The socket*

The socket is made from HDPE pipe and uses a film canister for pull sock access and air seal. It is a suction socket and is used as partial suspension for the prosthesis. Until now a quadrilateral design has been fabricated, although this technique could equally be used for an ischial containment socket.

A hand cast is taken of the stump, and the positive model modified in the normal way. A length of pipe is split so that it will open flat when heated in an oven. Precautions are taken to prevent it collapsing in on itself. Once it is hot and soft, the plastic is stretched over the model and sealed on the lateral side. The surface is rubbed with cloth and smoothed into the concave areas of the model. These areas are then packed with cloth and the socket wrapped tightly with elastic bandage.

Once it is cool and contact between the plastic and the model is ensured, the socket is trimmed and the edges finished. A hole is made antero-medially to accommodate the film canister. The base of the canister is removed and the remainder is glued into the hole. Finally, the edge of the film canister is smoothed where it contacts the amputee.

#### *Assembly and finishing*

To assemble the prosthesis from its component parts, the following procedure is followed:

Ankle and shin blocks are cut from a light soft wood (*Bombyx Malabaricum*) measuring 120mm x 120mm. Their total length is calculated using the height of the sound leg from the heel to the top of the knee in sitting. The ankle block is drilled and countersunk to allow for the attachment bolt of the SACH foot. The

ankle block is then bolted to the foot, with the nut distal. The proximal end of the bolt is prevented from rotating within the block by pouring a mix of polyester resin and sawdust into the countersunk hole.

The measurement from the ischial shelf to the proximal end of the knee in extension is calculated using the ground to ischial tuberosity measurement of the sound limb. Another block of soft wood is cut and hollowed out to seat the socket at the required height.

The socket is set in the proximal soft wood block with a sawdust and resin mix, and aligned with the posterior and medial shelves horizontal. The prosthesis is then assembled and aligned according to standard principles. The height and shelf alignment are checked and the blocks joined with wood glue. Once the glue has set, the wood block joints are also stapled to reinforce them during trial use. The suspension belt is attached, and the prosthesis is checked with the amputee for comfort, alignment and friction control of the knee.

Once necessary adjustments have been carried out, the prosthesis is ready to be finished. First, the thigh and shin sections are prepared for the plastic cosmesis. The proximal and distal blocks of the knee are disconnected, the suspension belt removed, the SACH foot unbolted and the staples removed. The shin and thigh sections are shaped on a router, with additional microcellular rubber or cork added to increase the bulk as necessary. The film canister is removed from the socket and replaced with a cylindrical wood block. Then the socket is filled with plaster of paris and a mandrel inserted. This prevents the socket being misshapen when the outer plastic cover is applied.

HDPE pipe is split and heated as in the socket fabrication technique, and pulled round the thigh and shin sections. The plaster of Paris is removed from the socket and the edges of the cosmesis trimmed and smoothed. The canister is re-inserted in the socket and the proximal edges of the socket and thigh cosmesis welded together using a heat gun and strips of HDPE pipe. The cosmesis is smoothed and the distal end of the thigh cosmesis screwed onto the proximal block of the knee. The holes for attachment of the suspension belt are then drilled in the cosmesis.

HDPE pipe is only available in black in Nepal, so the prosthesis is coloured by gluing nylon stocking onto the exterior of the cosmesis with

neoprene cement, and then painting it with a mix of wood glue and fabric paint. Finally, the elastic extension assist and suspension belt are re-attached. The finished prosthesis weighs approximately 2.5kg and has an appearance which has proved cosmetically acceptable to amputees and relatives alike.

#### *Optional knee lock*

To date, a total of seven prostheses of this design have been issued at Green Pastures Hospital. One of the amputees concerned lives in an extremely hilly area, and also had a trans-tibial prosthesis on her contralateral leg. To provide her with greater stability, a manual knee lock was fitted on her trans-femoral prosthesis (Fig. 2).

The lock was a length of spring steel bar, with a right angle bend 10mm from one end. The bar was passed through slots cut in the proximal block of the knee, and ran posterior to the extension stop bar. By bearing on the extension stop bar, the knee lock prevented knee flexion. This could be inserted or removed manually, the right angle bend allowing for greater purchase on the bar. A leather sheath screwed to the side of the shin section housed the lock when not in use.

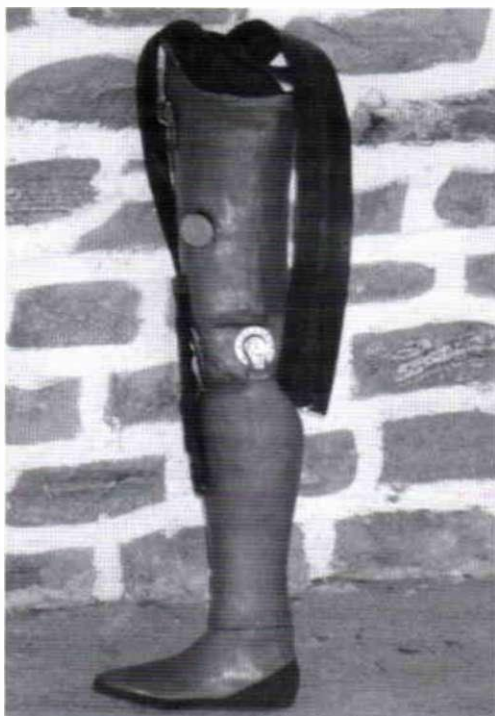


Fig. 1. The finished prosthesis.

#### **Follow-up**

The first prosthesis made to this design was fitted in March 1994. Although the authors acknowledge that prostheses should ideally be tested in laboratory conditions first (Day, 1996), this was not possible in the setting described. The first prosthesis was therefore issued to an established amputee who was young, strong and highly motivated to make maximum use of it, often carrying loads of up to 15kg of water or young children. She was intelligent and fully understood that this was a trial design. She lived locally to the hospital where the prosthesis was fitted, and was easily able to return should any problems arise. She was very enthusiastic to take part in the trial. Below is a follow-up report of this prosthesis:

At the first fitting, a regular Silesian belt slipped distally, so a lateral strap was added. Knee flexion was insufficient to allow floor sitting, so this was increased to 100°. Both these became standard techniques for subsequent prostheses.

After 6 weeks, hospital trials were complete and the prosthesis was finished and issued for home trial (Fig. 3).

After 3 months, the stump had shrunk and suction was lost, so the socket was padded to compensate for this. The elastic extension assist had stretched and was replaced with double high quality elastic in this and later prostheses. The side bars of the knee had worked loose so were set in resin to re-attach them. Subsequent knee joints were made with side bars attached to the distal block with nuts and bolts.

At 4 months, further stump shrinkage necessitated more socket padding. Later amputees were fitted with a temporary prosthesis and given walking training to induce shrinkage prior to the fabrication of the definitive limb. The extension stop rubber in the knee was worn, resulting in audible contact at full extension. This was replaced with rubber covered with leather, and subsequent knees were made with this modification. The leather suspension belt had stretched, and additional holes were punched so that the belt could be tightened.

After 7 months, the film canister was split as a result of repeated stress from the pull sock. This was replaced with as little of the canister protruding as possible to ensure maximum support for the thin plastic. There was damage to the periphery of the rubber sole of the SACH



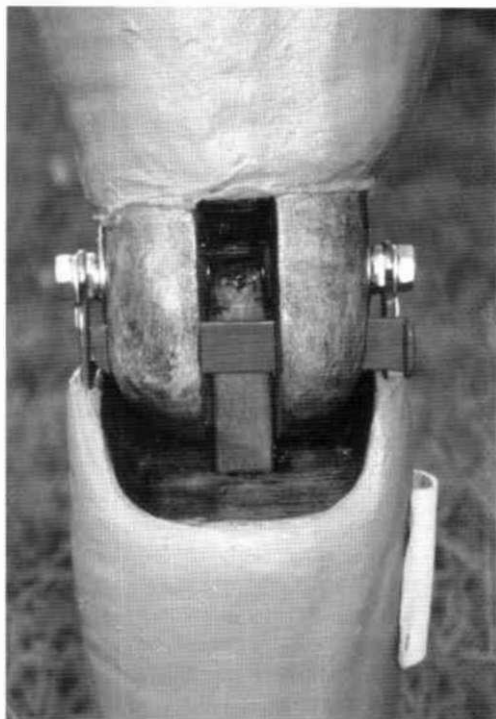


Fig. 2. Optional knee lock used for bilateral amputee.

foot. This was replaced and bevelled to give a better fit in the shoe. Damage to the posterior thigh of the cosmesis was repaired with leather. There was also some wear of the proximal block of the knee from contact with the distal block during extended floor sitting.

At 9 months there was further stretching of the suspension belt lateral strap. Subsequent prostheses used a double D-ring attachment anteriorly to allow for easy compensation for stretching of this strap. Other minor damage was repaired on the belt and socket attachments.

At 12 months there was a crack down the posterior of the shin cosmesis, further damage to the periphery of the rubber sole and a torn socket attachment all of which were repaired.

After 2 years of constant wear, the suspension belt and rubber sole had been replaced again, as had the film canister, which had split. The shin piece had been repaired, and due to a fall, the extension stop bar had broken. This was replaced with a hard wood bar. The amputee had lost weight, and was losing suction in the socket, so padding was added.

During the third year of use, apart from replacement of the extension stop and sole rubber,

it was necessary to repair the wood glue joints between the different wooden blocks. This was considered to be a serious fault, and all joints between the wood blocks were reattached with a resin and sawdust mix, as this form of adhesive between the socket and the thigh block had shown no signs of weakening over the three years of use.

### Conclusions

In conclusion, no major design faults were discovered during the two years of use of this prosthesis, however the wood glue connections were not strong enough to last a third year, so a resin and sawdust mix was used for these joints in subsequent prostheses. Apart from this, minor repairs and replacements of belts, the elastic extension assist and the sole rubber were necessary. These could have been carried out by a local shoe-maker if the amputee had not had access to the prosthetics facility. The extension stop bar was replaced with a harder wood to reduce the likelihood of a repeat failure. The amputee herself reports that this prosthesis compares favourably with the second hand prosthesis with which she was previously fitted. She continues to use it constantly, and lives a life not dissimilar to many other Nepali people with no physical impairment.

The results of this follow-up are encouraging, and as this is continued, and appropriate modifications made if necessary, it is hoped that the fabrication of this style of prosthesis will be useful for Nepali trans-femoral amputees in the future.

### REFERENCES

- DAY HJB (1996). A review of the consensus conference on appropriate prosthetic technology in developing countries. *Prosthet Orthot Int* **20**, 15-23.
- FAGO J (1992). Tutor with Handicap International. Personal Communication.
- GARACHON A (1996). Report on ICRC technical orthopaedic programme for war disabled. *Prosthet Orthot Int* **20**, 31-38.
- GIRLING J, CUMMINGS G (1972). Artificial limb fabrication without the use of commercially available components. *Prosthet Orthot Int* **4**, 21-25.
- MEANLEY S (1991). The development of a prototype patella tendon bearing prosthesis using high density polyethylene piping (the drainpipe leg). *J Eng Med* **205**, 121-123.
- MOLL K (1991). Prosthetist/Orthotist with ADD Mobility, India. Personal Communication.

- OBERG K (1991). Cost benefits in orthopaedic technology by using thermoplastics in developing countries. *Prosthet Orthot Int* **15**, 18-22.
- ORTHOLETTER (1993). Thermoplastics in prosthetics and orthotics. **1**, 5-6.
- ORTHOLETTER (1994). Low cost polypropylene prosthesis. **1**, 1-5.
- ORTHOLETTER (1995). Thermoplastic technology. **5**, 2-7.
- SETHI PK, UDAWAT MP, KASLIWAL SC, CHANDRA R (1978). Vulcanised rubber foot for lower limb amputees. *Prosthet Orthot Int* **2**, 125-136.
- SETHI PK (1989). Technological choices in prosthetics and orthotics for developing countries. *Prosthet Orthot Int* **13**, 117-124.
- THEUVENET WJ, RUCHAL SP, SOARES DJ, ROCHE P (1994). Advantages, indications, and the manufacturing of melted PVC waterpipe splints. *Lepr Rev* **65**, 385-395.

## **Conventional versus microchip controlled pneumatic swing phase control for trans-femoral amputees: user's verdict**

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### **Abstract**

A questionnaire survey of 22 selected trans-femoral amputees who were switched from pneumatic swing phase control knee joints (PSPC) to microprocessor controlled intelligent knee joints (IP) is presented. On overall rating all respondents considered the IP to be an improvement or a great improvement compared to the PSPC and none decided to revert back or wished to use their previous PSPC prosthesis on a regular basis. However the IP was not rated to be superior in every area of the questionnaire. Walking at different speeds, walking further, reduction of energy consumption were the main areas where subjective improvements were perceived by the amputees themselves. It is strongly believed that patients' own views should be an important and integral part of the evaluation of new prosthetic technology.

### **Introduction**

The microprocessor controlled pneumatic swing phase knee joint for trans-femoral amputees was first demonstrated in Japan in 1989. The license for this technology was obtained by Chas A. Blatchford, UK who developed and then marketed the first commercially available product in 1993 as the intelligent prosthesis (IP) (Zahedi, 1993).

The IP provides a varying damping action for flexion/extension of the knee joint depending on the amputee's gait speed. This is in contrast to a conventional pneumatically dampened knee mechanism (pneumatic swing phase control or (PSPC) which is adjusted by the prosthetist to

one particular gait speed as judged 'optimum' or 'preferred' for an individual amputee.

The IP is claimed to provide a number of benefits including reduction of energy cost of gait, increased range of walking speed and more natural gait (Zahedi, 1993).

The authors designed a study to compare and evaluate the benefits or otherwise of the IP for trans-femoral amputees compared to the usual and common practice of using PSPC. Results of the energy consumption tested, gait analysis and cognitive demands will be published separately. In this paper the authors report the results of the questionnaire survey to gain knowledge of the patient's own views of the IP compared to the previously used PSPC. The authors feel it is mandatory to obtain patients' own views when evaluating prosthetic components as well as obtaining the more objective outcome measures.

### **Methods**

Twenty-two established unilateral trans-femoral amputees who were wearing Endolite prostheses with PSPC, were recruited from the clinic for this study. This was a selected sample of patients who had no stump problems were otherwise fit and were generally fairly active.

The profile of the study group is presented in Table 1.

All patients were fitted with a new PSPC knee unit, multiflex ankle joint and new cosmetic foam and were changed to a new knee unit of IP, new multiflex ankle and a new cosmetic foam 8-10 weeks later. Socket adjustments, alignment alterations or knee joint readjustments were carried out, if necessary, 3 weeks after the initial fitting and delivery of both types of prosthesis. The original comfortable sockets were retained in use for all prosthesis for all the patients

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Table 1. Profile of the study group (N = 22)

Male: 14	Female: 8
Age (range):	39.9 yrs (25 yrs - 76 yrs)
Side of amputation:	Right: 11 Left: 11
Aetiology of amputation:	Trauma: 16
	Malignancy: 5
	Osteomyelitis: 1
	Occupation:
	Student: 2
	Housewife: 2
	Unemployed: 2
Mean time since amputation (range):	19.2 yrs (5 yrs - 53 yrs)
Prostheses used prior to change to IP:	Endolite* with ESK and PSPC and multiflex ankle
Mean time since provision of IP (range):	17.4 months (7 months - 41 months)

\*Endolite - is the trade name of a modular prosthesis manufactured by Chas A. Blatchford UK.  
ESK = Endolite Stabilised Knee.  
PSPC = Pneumatic swing phase control.

throughout the stages of the study.

All prosthesis were fitted by one prosthetist (JH). Local ethical committee approval was obtained prior to the commencement of the study. All participants in the trial had the research protocol explained and signed consents were obtained.

Users' views were obtained by a carefully constructed semi-structured questionnaire (Appendix 1). Most of the questions were 'closed' with 5 possible responses. Two questions were 'open' inviting users' own comments and opinions.

The anonymous questionnaires were sent out after at least 7 months of acclimatisation with IP, 18 out of 22 questionnaires were returned promptly. A telephone reminder was given to all patients 3 weeks later, to return the questionnaires if they had not already done so.

## Results

All 22 questionnaires were returned (100% response). Compilation of responses for the closed questions are presented in Table 2. Answers to the questions are related to their IP compared to their previously used PSPC.

*Walking at different speeds:* 95.4% (21/22) found this a lot easier or easier; 14 out of these

21 found this a 'lot easier'.

*Walking distance:* 81.8% (18/22) said they could walk further or a lot further; only 5 out of the 18 however felt they could walk 'a lot further'.

*Ascending stairs:* 77.2% (17/22) found no difference in ascending stairs with their IP.

*Descending stairs:* 77.2% (17/22) found no difference in descending stairs.

*Walking on slopes and hills:* 59% (13/22) found this a lot easier.

*Walking on rough/uneven ground:* 63.6% (14/22) found this easier though 12 out of these 14 felt this was easier rather than a lot easier.

*Energy level:* 95.4% (21/22) found walking with IP or a lot less tiring, only one did not feel any difference.

*Gait pattern:* 95.4% (21/22) felt that their walking was more normal. There was almost an even split between more normal and much more normal.

*Mechanical reliability:* 63.6% (14/22) thought their IP prosthetic limb was mechanically more reliable.

*Learning to walk:* 81.8% (18/22) felt that they adjusted to their IP within a short time or found it easy with no problems at all. Only 3 out of 22 found some initial problems to adjust to walking with their IP.

*Gait pattern - comments by others:* 86.3% (19/22) commented that they have received very positive or favourable comments on their gait pattern.

*Overall comment:* all 22 (100%) felt that the IP was improved or much improved compared to their PSPC. 72.7% (16/22) felt that this was much improved.

*Use of spare limb with PSPC after provision of IP:* all patients were in possession of a spare limb with PSPC. Six out of 22 (27%) did also make use of their spare prosthesis. This was due to battery failure in 3, computer breakdown in 1 and socket discomfort in 1 patient. The cause of using the spare prosthesis in 1 patient was not clear. As soon as the problems were rectified they reverted back to IP.

Twenty-one out of 22 patients (95.4%) did not want to return to wearing a prosthesis with PSPC on a regular basis.

The wearing time for the IP did not alter for the study group compared to PSPC. Average time wearing the IP was 14.38 hours/day (range 6-18 hrs/day).

Table 2. Compilation of total number of responses of questionnaire survey.

<p><b>Q. A. Walking at different speed</b>  A lot easier = 14  Easier = 7  No difference = 0  Difficult = 1  A lot more difficult = 0</p>	<p><b>Q. H. Walking style</b>  Much more normal = 11  More normal = 10  No difference = 1  less normal = 0  A lot less normal = 0</p>
<p><b>Q. B. How far can you walk?</b>  A lot further = 5  Further = 13  No difference = 3  Less than before = 1  A lot less than before = 0</p>	<p><b>Q. I. Mechanical reliability</b>  Much increased = 7  Increased = 7  No difference = 7  Less reliable = 1  A lot less reliable = 0</p>
<p><b>Q. C. Ascending stairs</b>  A lot easier = 0  Easier = 5  No difference = 17  Difficult = 0  A lot more difficult = 0</p>	<p><b>Q. J. Learning to walk</b>  Easy = 10  Adjusted within a short time = 8  No difference = 0  Initial problems = 3  Very difficult = 0</p>
<p><b>Q. D. Descending stairs</b>  A lot easier = 2  Easier = 3  No difference = 17  Difficult = 0  A lot more difficult = 0</p>	<p><b>Q. K. Comments by others re: walking style</b>  Very positive = 11  Favourable = 8  No comments = 3  Unfavourable comments = 0  Very negative comments = 0</p>
<p><b>Q. E. Negotiating slopes and hills</b>  A lot easier = 6  Easier = 7  No difference = 8  Difficult = 1  A lot more difficult = 0</p>	<p><b>Q. L. Overall rating</b>  Much improved = 16  Improved = 6  No different = 0  Performed worse = 0  A lot worse = 0</p>
<p><b>Q. F. Walking on rough uneven roads</b>  Much improved = 2  Improved = 12  No difference = 7  Worse = 1  A lot worse = 0</p>	<p><b>Q. M. Use of prosthesis with PSPC since delivery of IP</b>  Yes = 6  No = 16</p>
<p><b>Q. G. Energy level on walking</b>  Lot less tiring = 8  Less tiring = 13  No difference = 1  More tiring = 0  A lot more tiring = 0</p>	<p><b>Q. N. Would they be happy to wear PSPC again regularly?</b>  Yes = 1  No = 21</p>
	<p><b>Q. O. Was programming for IP difficult?</b>  Yes = 1  No = 10  Indifference = 1</p>

Some of the comments given by the amputees in the questionnaire are given in Table 3.

### Discussions

The study was undertaken in a specialised rehabilitation centre, servicing a sizeable amputee population. The intelligent knee joint is the first commercial application of microcomputers in lower limb prosthetic technology. The results of some research work evaluating the IP have been published in peer reviewed journals but these have mainly concentrated on the effects on oxygen consumption or gait parameters. (Buckley *et al.*, 1996; Taylor *et al.*, 1996; Kirker *et al.*, 1996).

The Medical Devices Agency in England carried out a questionnaire evaluations of 85 units of IP in 24 centres in the UK and published their results in their own MDA evaluation report (Medical Devices Agency, 1994). While these results were compiled from the patients' opinion about the IP – no information is available as to the type of knee joints or types of prosthesis they were wearing previously or indeed any other conditions which might make any comparative evaluation more satisfactory. Kirker *et al.* (1996) however in their assessment of IP also included a questionnaire using a visual analogue response scale and their research methodology was more explicit.

Though this study was carried out in a selected group of patients it was felt this allowed a more valid comparison of patients' views as by selection it was possible to eliminate any other patient and stump condition which might affect the outcome. By giving the patients new knee units, ankle joints and new cosmetic foam, it was also possible to reduce the number of variables which might have affected the outcome.

The patients overwhelmingly favoured their IP and *all* of them wished to continue wearing their IP on a regular basis. This is felt to be significant as all these patients were doing extremely well, active, mostly in employment or full-time students with their previous prosthesis with PSPC. Contrary to the usual experience where it is found difficult for established amputees to change to a different type of prosthetic component, unless they have problems, the study group quickly adjusted to the IP and did not wish to revert back to PSPC.

The authors are aware of the subjective nature of questionnaire surveys and the bias that might have been introduced to a patient by the publicity of this actively marketed prosthetic technology. However, it is believed that in this study patients' perceptions are genuine as 77.2% of the patients did not find negotiating stairs any easier and responses to walking on slopes, hills and on rough and uneven ground were much less

Table 3. Some of the comments made by the patient on their questionnaire.

- |   |
|---|
| <p>"IP has made a tremendous difference in 95% of daily movements."</p> <p>"I was perfectly happy with the PSPC, but IP is superior."</p> <p>"Lot easier, less tiring, more natural."</p> <p>"Quality of life has improved greatly."</p> <p>"Some difficulty in reaching faster speed – as had been previously unable to walk fast."</p> <p>"I am an amputee for the last 30 years ... I had some difficulty in accepting/realising that I could vary speed."</p> <p>"Backache has improved."</p> <p>"Backache has improved dramatically though hip has become painful."</p> <p>"Easier to walk and feels more natural."</p> <p>"Slight problem on uneven grounds."</p> <p>"Less physical discomfort in the groin."</p> <p>"IP knee almost feels elastic – no matter what the walking speed – the leg always follows through at the right speed."</p> <p>"Pleasure to experience the walk at ground level – but on uneven ground – this is a problem as it gives you a 'false sense of security' – with the old type of limb you gave it a resounding kick forward automatically."</p> <p>"IP is the best thing that happened to me."</p> <p>"Cosmetic foam lets the leg down."</p> <p>"Less tired after a round of golf and thus we were able to enjoy the 19th hole!"</p> |
|---|

enthusiastic. Biased views or placebo effect would have been expected to produce general blanket praise response for IP. This was not the case, suggesting a genuine and critical appraisal by the subjects in this study.

The response to gait pattern as perceived by patients as well as by others (friends, relatives, etc.) were reported to have improved. The improvements however were not at all obvious when 9 of these patients when video recorded in a laboratory environment on a separate section of the study reported elsewhere (Datta *et al.*, 1997). This discrepancy may be possibly explained by the fact walking in daily living activities may be different from walking in artificial laboratory conditions. The perception of better walking may be related also to ease of walking by spending less physical and cognitive efforts thus making walking more enjoyable.

The patients have shown a strong preference for the IP when compared to PSpC in a survey by questionnaires, in a controlled study. None of the patients were given any specific gait re-education physiotherapy programme for their IP, though some advice was given by the prosthetist during the time of fitting and readjustment. The main benefits from this subjective study for the IP appears to be ability to walk at various speeds, reduction of effort of walking and patients' perception of improvement of walking pattern. Whether patients do walk further, walk at different speeds, have reduced cognitive effort, have improved gait as measured by sophisticated gait analyses and have any reduction on oxygen consumption are addressed as objective measures and are to be reported separately. Nevertheless, the authors feel, that irrespective of the results of the objective outcome measures, users' own

views are also vital in the evaluation of a new prosthetic product.

### Acknowledgement

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### REFERENCES

- BUCKLEY JG, SPENCE WD, SOLOMONIDIS SE (1996) The energy cost of walking: comparison of intelligent prosthesis with conventional mechanism *Arch Phys Med Rehabil* **78**, 330-333.
- DATTA D, HOWITT J, HELLER B, BILLINGHAM G (1997). Cognitive demands and dynamic cosmesis of walking of amputees using intelligent knee: a comparative evaluation. In: Proceedings of the 8th World Congress of the International Rehabilitation Medicine Association, Kyoto, 1997. p649-650.
- KIRKER S, KLYMER S, TALBOT J, LACHMAN S (1996). An assessment of the intelligent knee prosthesis. *Clin Rehabil* **10**, 267-273
- Medical Devices Agency (1994). Evaluation report. Prosthetics: Endolite intelligent prosthesis. - HMSO, London.
- TAYLOR MB, CLARK E, OFFORD EA, BAXTER C (1996). A comparison of energy expenditure by a high level trans-femoral amputee using the Intelligent Prosthesis and conventionally damped prosthetic limbs. *Prosthet Orthot Int* **20**, 116-121.
- ZAHEDI S (1993). The results of the field trial of the Endolite Intelligent Prosthesis. In: Proceedings of the XII International Congress of INTERBOR, September 1993.

## Appendix 1

**INTELLIGENT PROSTHESIS (IP) QUESTIONNAIRE**

Circle appropriate answer that corresponds as close as possible with your views/observations (i.e. circle 1, 2, 3, 4 or 5)

- A.** How would you compare walking at different speeds with your IP when compared with your previous knee joint?
1. A lot easier
  2. Easier
  3. No difference
  4. Difficult
  5. A lot more difficult
- B.** How far can you walk with your IP compared with your previous knee joint?
1. A lot further
  2. Further
  3. No difference
  4. Less than before
  5. A lot less than before
- C.** Is ascending stairs, steps, etc. any different with your IP compared with the previous knee joint?
1. A lot easier
  2. Easier
  3. No difference
  4. Difficult
  5. A lot more difficult
- D.** Is descending stairs, steps, etc. any different with your IP compared with the previous knee joint?
1. A lot easier
  2. Easier
  3. No difference
  4. Difficult
  5. A lot more difficult
- E.** Is negotiating slopes and hills any different with your IP compared with the previous knee joint?
1. A lot easier
  2. Easier
  3. No difference
  4. Difficult
  5. A lot more difficult
- F.** When walking over rough or uneven ground, how does your IP perform compared to the previous knee joint?
1. Much improved performance
  2. Improved performance
  3. No difference
  4. Performs worse
  5. A lot worse performance
- G.** How does you rate your energy levels when walking with the IP compared to the previous joint?
1. A lot less tiring
  2. Less tiring
  3. No difference
  4. More tiring
  5. A lot more tiring
- H.** Do you think that your walking style has improved since you have been using the IP?
1. Much more normal
  2. More normal
  3. No difference
  4. Less normal
  5. A lot less normal
- I.** Assess the mechanical reliability of your IP compared to your previous knee joint?
1. Much increased reliability
  2. Increased reliability
  3. No difference
  4. Less reliability
  5. A lot less reliability
- J.** What are your views regarding learning to walk with the IP after using the previous knee joint?
1. Easy, not considered a problem
  2. Adjusted within a short time
  3. Noticed no real difference
  4. Initial problems
  5. Very difficult with lots of problems
- K.** Since having your IP have you had any comments from other people (i.e. family, friends, etc) about the way you walk with the IP compared to your previous knee joint?
1. Very positive comments
  2. Favourable comments
  3. No comments at all
  4. Unfavourable comments
  5. Very negative comments
- L.** Overall how do you rate your IP compared to your previous knee joint?
1. Much improved
  2. Improved
  3. No difference
  4. Performs worse
  5. A lot worse performance
- Please answer the following questions along with your observations and views (please circle numbers appropriate to you)



**INTELLIGENT PROSTHESIS (IP) QUESTIONNAIRE**

**M.** Have you used your prosthesis with the previous knee joint since taking delivery of your IP?

1. Yes      2. No

If the answer to the above is Yes

Number of days approximately using previous knee joint =

or number of weeks approximately using previous knee joint =

Please state reasons for using previous knee joint.

**N.** How many hours on average per day do you wear your IP? =

How many hours on average per day did you, or still do, wear your prosthesis with the previous knee joint? =

**O.** Would you be happy to wear your prosthesis with the previous knee joint on a regular basis again?

1. Yes      2. No      3. Indifferent

Please add some comments if required.

**P.** Have you had any major problems using the IP since taking delivery?

Please comment accordingly.

**Q.** Did you find the programming of the IP at the fitting stage, difficult or complicated, in being able to give the prosthetist good feedback about different walking speeds, etc.

1. Yes      2. No      3. Indifferent

Please add some comments if required.

**R.** Have any of the problems associated with being an amputee improved or got worse since you took delivery of your IP?

(i.e. socket/stump comfort, backache, vaulting with good foot, etc)

**S.** What general comments do you have about IP?

(i.e. areas for improvement, good/bad points etc)

*Some questions about yourself*

1. Age      2. Weight      3. Sex

4. Marital status

5. Occupation

6. Sports/hobbies etc

7. Reason for amputation

8. Date of amputation (approx)

9. Length of time wearing prosthesis

10. Indicate your average activity level

A. Number of hours standing per day? =

B. Number of hours walking per day? =

11. Do you have any other medical conditions?

12. Any other comments

## **An audit of the quality of the stump and its relation to rehabilitation in lower limb amputees**

**B. K. CHAKRABARTY**

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### **Abstract**

An audit was undertaken amongst the lower limb (adult) amputees, 60 unilateral trans-femoral (TF) and 72 unilateral trans-tibial (TT), who attended a Disablement Services Centre (DSC) during a one year period, to determine whether amputees with better quality stumps (as assessed by a scoring system used at the Centre) achieve better outcome from prosthetic rehabilitation and whether there is any relation between the construction of the stumps and the grade of surgeons. At eighteen months (minimum follow up of six months) there were 31 (52%) TF and 54 (75%) TT amputees wearing prostheses. Some 44 amputees with Grade A stumps (score of 60 and over, out of a possible 100) needed 154 days to achieve the predicted mobility grade, 15 (34%) of them needed alteration of prosthesis, attended the Centre every 42 days and achieved the activity score of -25.7; 41 amputees with Grade B stumps (scores less than 60) needed 206 days to achieve the predicted mobility grade, 24 (58.5%) of them needed alteration of prosthesis, attended the Centre every 29 days and achieved the activity score of -39.1 (less active than Grade A).

The trainee surgeons (registrars, staff grade surgeons and SHO's) produced 26 Grade A stumps out of 67 amputations (40%) and the Consultants and the Senior Registrars (senior team) produced 37 Grade A stumps out of 65 amputations (57%).

However, only 36% of amputees were prescribed prostheses at their first attendance (60% Grade A, and 40% Grade B).

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### **Introduction**

Despite various attempts to improve the overall mobility and independence of the lower limb amputee, the result has been rather depressing (Dormandy and Ray, 1995; Collin and Collin, 1995). The majority of amputees belong to the dysvascular group and are aged. They suffer from additional medical and/or physical conditions which can influence the process of rehabilitation. As the longevity of this group is short (Stewart *et al.*, 1992; Finch *et al.*, 1980) it is desirable that the rehabilitation process is not unduly prolonged.

Quality of the stump is one of the many factors influencing the rehabilitation of an amputee (Fig. 1). The level and length of stump influence the energy requirement of the amputee (Gailey and Wenger, 1994; Waters *et al.*, 1976; Gonzalez *et al.*, 1974) and the shape dictates the fit of the prosthesis, as does fluctuation of the stump volume. The shape, length and relative bulk of soft tissue significantly influence the interface pressure distribution (Silver-Thorn and Childress, 1996). In general, the longer the stump the less the energy requirement but one has to take account of the prosthetic constraints and cosmesis, as well as the underlying pathology. Too long a stump, especially in a dysvascular patient, invites wound breakdown, stump revision, stump claudication or greater stump shrinkage (Persson and Liedberg, 1983). Even with tremendous advances in prosthetics, the energy requirement of mobility with a prosthesis has not been reduced to any appreciable extent. In an earlier observation (Chakrabarty, 1995), it was noted that amputees with better quality stumps fared well with regard to their rehabilitation.

The aim of this prospective study was to

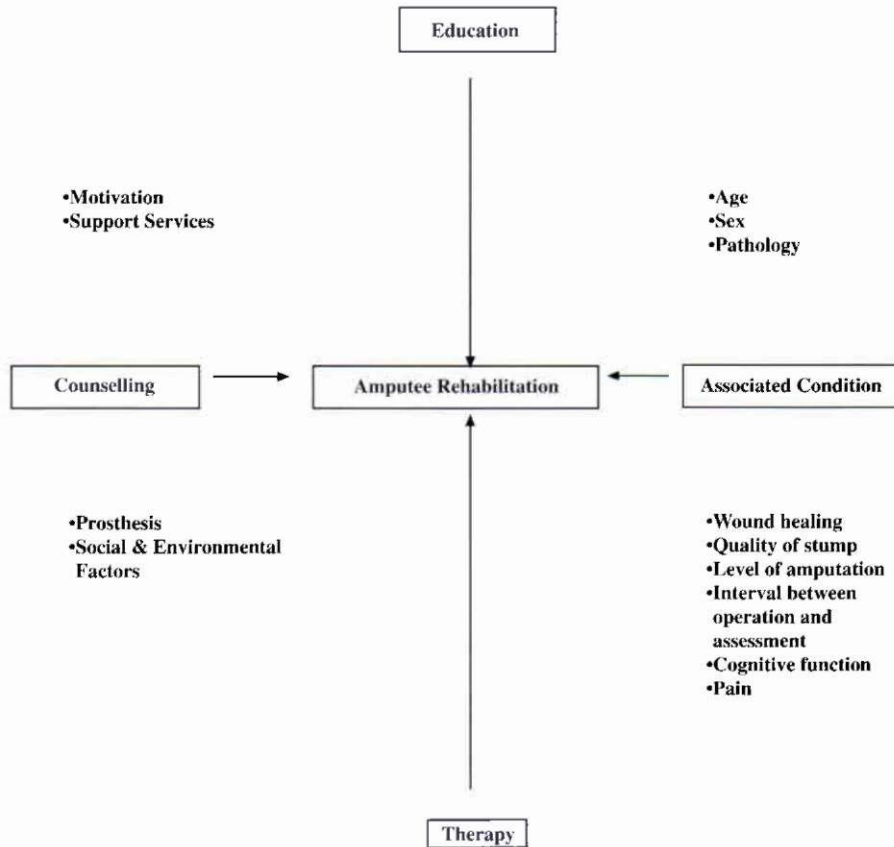


Fig. 1. Factors influencing amputee rehabilitation

determine whether this was true and whether construction of the stumps was influenced by the level of training of the surgeons.

### Patient and methods

In 1994 (1 January to 31 December) 60 unilateral trans-femoral (TF) and 72 unilateral trans-tibial (TT) amputees attended the DSC for their assessments for prosthetic rehabilitation. Individual hospitals sent a referral form with particulars of the patient and with the name and designation of the operating surgeon. When the form was incomplete the hospital concerned was contacted for the missing details.

The stumps of the amputees were with consent, photographed, and were graded according to the format shown in Figure 2. This is slightly different than that used in 1993 (Chakrabarty, 1995). Stumps scoring +60 and over out of a possible +100, were considered to be of better quality (Grade A) and stumps scoring less than

+60 were considered to be of poorer quality (Grade B). A mobility grade (Harold Wood and Stanmore Mobility grade (Hanspal *et al.*, 1991)) was predicted after a multidisciplinary team assessment and with the help of the pulse-oximeter reading and peak expiratory flow estimation. The team consisted of: consultant in rehabilitation, nurse, physiotherapist, occupational therapist and prosthetist. There was also a counsellor who exercised a supportive role towards the patient. In the mobility assessment, Grade I was used for an amputee who was likely to use the prosthesis for cosmetic purposes only (cosmetic user), Grade II was used for someone who was likely to use the prosthesis for transfers (therapeutic user), Grade III for someone who was going to be limited to indoor mobility (indoor user), Grade IV for someone who would use the prosthesis for outdoor (and indoor) mobility, Grade V for an independent user and Grade VI for normal mobiliser. Handgrip strengths were also

Name ..... DoB ..... Ref.No .....

Operator ..... Hospital .....

Date of Amp ..... Amp.Site R/L Level .....

Date of Assessment .....

<b>Wound</b>	Healed	+10	
	Unhealed	-5	
	Infected	-10	

<b>Tenderness</b>	None	+10	
	Moderate	+5	
	Severe	-10	

<b>Oedema</b>	None	+10	
	Minimal	+5	
	Significant	-5	

<b>Proximal Joint Contracture</b>	None	+10	
	<20°	+5	
	>20°	-20	

<b>Scar</b>	Fully Mobile	+10	
	<1/4 Adherent	-5	
	>1/4 <1/2 Adherent	-6	
	>1/2 Adherent	-10	

<b>Bone End Sculpted (&amp; Covered)</b>	Satisfactory	+10	
	Acceptable	+5	
	Unsatisfactory	-10	
	Bone End Exposed	-20	

<b>Skin</b>	Sensate	+6	
	Insensate	-6	
	Insufficient	-6	

<b>Dog-ears</b>	None	+6	
	Minimal	0	
	Significant	-6	

<b>Length</b>	Suitable*	+10	
	Acceptable	+5	
	Unsuitable	-10	

<b>Redundant Tissue</b>	None	+6	
	Minimal	3	
	Significant	-6	

<b>Shape</b>	Conical/Cylindrical	+6	
	Bulbous	-6	

<b>Additional Scars or Other Factor†</b>	No	+6	
	Yes	-6	

(†To affect prosthetic fitting)

\*For trans-femoral stump, at least 10 cm of space available above the knee joint line, 14-16 cm distal to the knee joint line or 30 cm above the ground level, whichever is longer for trans-tibial stump.

Maximum Points = 100

Photo Yes/No

Fig. 2. Stump grading

measured.

Those amputees who were provided with prostheses were seen at four weeks and subsequently assessed by the team at three, six and twelve months. A modified questionnaire regarding the amputee's activities was completed at six and twelve months by direct questioning by the team and scored afterwards (Day, 1981).

The activity score depends on the amputee's ability to don and doff the prosthesis, use of aids and wheelchair, hours of use indoor/outdoor, various household chores, spare-time activities and if at work (full or part time) the nature of the work involved. According to Day (1981) those who score +30 (no one in this study) are considered to be very highly active, +10 to +29 are highly active, -9 to +9 are of average activity, -40 to -10 have restricted activities and less than -40 are inactive. However, the author considered amputees scoring -50 to -30 were less active and those scoring less than -50 were inactive.

No attempts were made to evaluate the frequency of therapy and the quality of training, nor the influence of other variables. The environmental status and the factors supposed to influence re-integration into the community were not considered, although the occupational therapist and the counsellor assessed all amputees.

Those who became bilateral amputees before the six monthly assessments were excluded from the study. However, those amputees who became bilateral amputees after six or twelve monthly

Table 1. Wound classification used in the study

Wound:	
● When integrity of the skin is intact healing ridge palpable	Healed
● When integrity of the skin is broken	Unhealed
● When there is sero-purulent discharge and/or obvious clinical infection	Infected
● With scab, if adherent if loose	Unhealed Healed
● With necrotic skin margins	Unhealed
● With stitches <i>in situ</i> , if dry if moist	Healed Unhealed

assessments were included.

The wounds were classified according to the format shown on Table 1. Prostheses were provided in five working days after prescription in 99.5% of cases. Amputees from sixteen health districts attended the centre (population 3 million).

## Results

Activity scores (AS) at six monthly assessments were used in the study. AS improved in two TF amputees (Grade A) but deteriorated in five at twelve months (A1, B4) whereas AS improved in eight (A5, B3) and deteriorated in eight (A2, B6) TT amputees at twelve months.

Table 2. Amputees excluded from the study

(a) Trans-femoral amputees	(29)	(b) Trans-tibial amputees	(18)
	14 grade A 15 grade B		5 grade A 13 grade B
● Prosthesis not prescribed	9(A4,B5)	● Prosthesis not prescribed	7(B)
● Deceased (within 6 months)	3(A2,B1)	● Deceased	3(A2,B1)
● Abandoned limb wearing	6(A3,B3)	● Abandoned limb wearing	3(B)
● Lost to follow up	5(A3,B2)	● Lost to follow up	1(A)
● Became bilateral amputees	3(A1,B2)	● Became bilateral amputees	2(A1,B1)
● Refashioning of stump	1(B)	● Fell out of wheelchair and fractured femur	1(A)
● Cosmetic prosthesis user	1(B)	● Did not collect prosthesis	1(B)
● Did not collect prosthesis	1(A)		

The results are presented here according to the type of amputees.

*The trans-femoral (TF) group (n=60)*

Some 29 amputees (14 Grade A, 15 Grade B) were excluded from the study, details are shown in Table 2a.

The operating surgeon and the state of the wounds of the total (60) and the study group (31) are shown in Table 3a. There were 31 (52%) amputees with Grade A and 29 (48%) with Grade B stumps.

The senior team produced 16 (60%) Grade A stumps out of 27 amputations. The trainee surgeons produced 15 (46%) Grade A stumps out of 33 amputations. Total number of healed wounds was 37 (62%). In the study group, only 14 operated by the senior team were included with 10 Grade A stumps. Some 17 amputees operated by the trainee surgeons were included with 7 Grade A stumps. The number of healed wounds was 20 (65%).

The stump score, interval between operation

and assessment at the DSC, prescription of prostheses, attendance interval and requirement for refits are shown in Table 4a. Mobility grade predicted (MGP) and achieved (MGA), with total time taken (from the date of operation) to achieve the grades, activity scores and age in each group are shown in Table 5.

Assessment was earlier by almost 13 days, prostheses were prescribed earlier by 26 days, interval between attendances to the DSC were longer by almost 9 days and the need for refits was in 41% of amputees with Grade A stumps as opposed to 71% in amputees with Grade B stumps. Average time to achieve the correctly predicted mobility grade in 16 (94%) was 135 days and the mean activity score was -29.3 (range -65 to +15) in the Grade A group. In the Grade B group, average time required to achieve the correctly predicted mobility grade in 8 (57%) amputees was 178 days and the mean activity of these amputees was -41.4 (range -72 to -7). Five amputees in this group failed to achieve the predicted mobility grade.

Table 3. Operating surgeons and state of wounds

<b>(a) TF Group (n=60)</b>					<b>The Study Group (n=31)</b>			
	<b>Grade A (31)</b>		<b>Grade B (29)</b>		<b>Grade A (17)</b>		<b>Grade B (14)</b>	
	<b>H</b>	<b>UH</b>	<b>H</b>	<b>UH</b>	<b>H</b>	<b>UH</b>	<b>H</b>	<b>UH</b>
Cons	10	2	3	4	7		2	1
SR	3	1	3	1	3			1
Reg	7	3	4	10	4	2	1	5
SG	1			1	1			1
SHO	4		2	1			2	1
	25 (81%)		12 (41%)		15 (88%)		5 (36%)	
<b>(b) TT Group (n=72)</b>					<b>The Study Group (n=54)</b>			
	<b>Grade A (32)</b>		<b>Grade B (40)</b>		<b>Grade A (27)</b>		<b>Grade B (27)</b>	
	<b>H</b>	<b>UH</b>	<b>H</b>	<b>UH</b>	<b>H</b>	<b>UH</b>	<b>H</b>	<b>UH</b>
Cons	7	7	2	14	3	7	2	10
SR	6	1		1	5	1		
Reg	4	3	5	17	4	3	4	10
SG	1				1			
SHO	2	1		1	2	1		1
	20 (63%)		7 (18%)		15 (56%)		6 (22%)	

Key: H = Healed  
 UH = Unhealed  
 Cons = Consultant  
 Reg = Registrar  
 SHO = Senior House Officer  
 SR = Senior Registrar  
 SG = Staff Grade Surgeon

Table 4. Stump score, assessment, prosthetic prescription and refits of TF and TT study group

(a)	TF Group (31)		(b)	TT Group (54)	
	Grade A (17)	Grade B (14)		Grade A (27)	Grade B (27)
Stump score	Mean + 75.4 (range + 61 to + 87)	Mean + 49.9 (+40 to + 57)	Mean + 67.7 (+60 to + 87)	Mean + 47.1 (+28 to +58)	
Assessment (interval from operation)	Mean 36.3 days (18 to 114)	Mean 49 days (11 to 129)	Mean 92.2 days (17 to 247)	Mean 46 days (18 to 153)	
Prosthesis (prescribed after operation)	Mean 43.2 days (22 to 118)	Mean 69 days (29 to 118)	Mean 60.2 days (21 to 247)	Mean 85.8 days (30 to 244)	
Attendance interval	Mean 39.8 days (25 to 74)	Mean 31.2 days (16 to 47)	Mean 38.8 days (19 to 70)	Mean 26.6 days (14 to 48)	
Refits (socket alteration of prosthesis)	Mean 0.7* 7 (41%) needed refits	Mean 1.2 10 (71%) needed refits	Mean 0.41 8 (30%) needed refits	Mean 0.7 14 (52%) needed refits	

\*One needed two refits due to change of prescription.

One needed to attend more and needed 2 refits due to trial of a new knee unit.

A total of 64% of amputees with Grade A stumps were prescribed prostheses at the first attendance (average 40 days, range 27 to 114 days) whereas 28% of amputees with the Grade B stumps were prescribed prostheses at the first attendance (average 48 days, range 32 to 129 days).

Age of amputees was 69 median (range 32-85) in the Grade A and 68 median (range 51-82) in the Grade B group.

#### *The trans-tibial group (n=72)*

A total of 18 amputees (5 Grade A, 13 Grade B) were excluded from the study and the details are shown in Table 2b.

The operating surgeons and the state of wounds of the total (72) and the study group (54) are shown in Table 3b. There were 32 amputees (44%) with Grade A and 40 (56%) amputees with Grade B stumps of which 27 amputees with Grade A stumps and 27 amputees with Grade B stumps were included in the study.

The senior team produced 21 (53%) Grade A stumps out of 38 amputations of which 16 were included in the study. The trainee surgeons produced 11 (32%) Grade A stumps out of 34 amputations and all were included in the study. The total number of healed wounds was 27 (38%) and in the study group it was 21 (39%).

The stump scores, interval between the

operation and assessment, prescription of prostheses, attendance interval and requirement for refits are shown in Table 4b. Mobility grade predicted (MGP) and achieved (MGA) with total time taken to achieve the grades, activity scores and age in each group are shown in Table 6.

Although assessment of amputees with Grade B stumps was earlier by 46 days, prostheses were prescribed later than for amputees with Grade A stumps (25 days). Interval between attendances was longer (12 days) for the group with Grade A stumps. Alteration of prosthesis was needed for 52% of amputees with Grade B stumps but only for 30% of amputees with Grade A stumps.

Three amputees with Grade B stumps achieved normal mobility (Grade VI) but their ages were 36, 43 and 59 and the time required was quite long (376 days).

Mobility grade was correctly predicted in 96% and 81.5% respectively of amputees with Grade A stumps and with Grade B stumps. Four amputees (15%) in the latter group failed to achieve the predicted mobility grade. Average time required for the amputees who achieved the predicted mobility grade was 159 days for the amputees with Grade A stumps and 220 days for the amputees with Grade B stumps.

Some 55% of amputees with the Grade A stumps were prescribed a prosthesis at the first

Table 5. Mobility grade predicted/achieved, time taken, activity level, age (trans-femoral group)

Grade A (17)				Grade B (14)			
MGP/ MGA	Time (days)	Activity Score	Age	MGP/ MGA	Time (days)	Activity Score	Age
V/V -5 Independent walker	Mean 124.8 (112 to 138)	Mean -5.2 (-18 to +15)	Median 44 (32 to 53)	V/V -1	139	-7	58
IV/IV -2 Outdoor/ Indoor walker	Mean 163.5 (117 to 205)	Mean -18 (-22 to -14)	Median 59 (54 to 63)	IV/IV -3	Mean 202 (187 to 212)	Mean -26.7 (-36 to -21)	Median 68 (67 to 72)
III/III -9 Indoor walker	Mean 135.3 (115 to 208)	Mean -41.2 (-65 to -10)	Median 74 (68 to 85)	III/III -3	Mean 156 (138 to 187)	Mean -50.7 (-60 to -40)	Median 71 (60 to 75)
<b>Values for the 16 achieving predicted mobility grades</b>	<b>Mean 135.2 (112 to 208)</b>	<b>Mean -29.3 (-65 to +15)</b>	<b>Median 69 (32 to 85)</b>	II/II -1	210	-72	76
III/IV -1	134	-14	69	<b>Values for the 8 achieving predicted mobility grades</b>	<b>178.0 (138 to 212)</b>	<b>-41.4 (-72 to -7)</b>	<b>69.5 (58 to -76)</b>
<b>Values for all 17</b>	<b>135.1 (112 to 208)</b>	<b>-26.6 (-65 to +15)</b>	<b>69 (32 to 85)</b>	V/IV -1	119	-28	51
				III/II -4	Mean 161 (147 to 187)	Mean -69.7 (-79 to -60)	Median 74 (68 to 82)
				III/IV -1	129	-29	67
				<b>Values for all 14</b>	<b>Mean 165.5 (119 to 212)</b>	<b>Mean -46.2 (-79 to -7)</b>	<b>Median 70 (51 to 82)</b>

attendance (average 55 days, range 17 - 247) whereas only 1 amputee (3.5%) with a Grade B stump was prescribed a prosthesis at the first attendance (34 days).

Age of amputees was 65 median in both the groups (Grade A - range 30-84, Grade B - range 31-83).

### Discussion

There is no dispute about the expected and desirable outcome after an amputation of the lower limb (Pinzur *et al.*, 1993; Fyfe, 1992; Campbell *et al.*, 1994; Collin *et al.*, 1992;

Narang *et al.*, 1994). Apart from regaining some lost function of mobility in pursuit of daily activities, integration into the community, socially and psychologically, will improve the quality of life of the amputee. There is also growing evidence that multidisciplinary involvement in rehabilitation of amputees is beneficial (Pinzur *et al.*, 1993; Malone *et al.*, 1979; Houghton *et al.*, 1992) and that trans-tibial amputees rehabilitate better (Castronuovo *et al.*, 1980; Steinburg *et al.*, 1985; Kegel *et al.*, 1978; Pohjolainen *et al.*, 1990) as the energy requirement is less (Gailey and Wenger, 1994;



Table 6. Mobility grade predicted/achieved, time taken, activity level, age (trans-tibial group)

Grade A (27)				Grade B (27)			
MGP/MGA	Time (days)	Activity Score	Age	MGP/MGA	Time (days)	Activity Score	Age
V/V -3	Mean -126.3 (107 to 158)	Mean +1 (-9 to +10)	Median 36 (30 to 60)	VI/VI -3 Normal	Mean 376 (310 to 413)	Mean +5 (-2 to +15)	Median 43 (36 to 59)
IV/IV -12	Mean 160.3 (111 to 250)	Mean 19 (-45 to -3)	Median 64 (55 to 78)	V/V -2	Mean 154 (153 and 155)	Mean -14 (-45 and +17)	Median 43 (31 and 55)
III/III -11	Mean 165.2 (117 to 337)	Mean 44.5 (-67 to -21)	Median 77 (62 to 87)	IV/IV -6	Mean 157 (120 to 224)	Mean -30.7 (-49 to -13)	Median 64 (47 to 71)
<b>Values for the 26 achieving predicted mobility grades</b>	<b>Mean 158.7 (107 to 337)</b>	<b>Mean -27.8 (-67 to +10)</b>	<b>Median 64.5 (30 to 87)</b>	III/III -11	Mean 224 (134 to 348)	Mean -42.6 (-67 to -22)	Median 70 (64 to 83)
III/IV -1	128	-14	75	<b>Values for the 22 achieving predicted mobility grade</b>	<b>220.2 (120 to 413)</b>	<b>Mean -30.3 (-67 to +17)</b>	<b>Median 65 (31 to 83)</b>
<b>Values for all 27</b>	<b>157.6 (107 to 337)</b>	<b>-27.3 (-67 to +15)</b>	<b>65 (30 to 87)</b>	V/IV -1	410	-42	63
				IV/III -2	Mean 186 (152 and 220)	Mean -49 (-53 and 45)	Median 62 (58 and 67)
				III/II -1	239	-53	65
				III/IV -1	139	-17	58
				<b>Values for all 27</b>	<b>Mean 222.4 (120 to 413)</b>	<b>Mean -32-44 (-67 to +17)</b>	<b>Median 65 (31 to 83)</b>

Waters *et al.*, 1976; Gonzalez *et al.*, 1974). The working party of the Amputee Medical Society of UK (Amputation Rehabilitation: recommended standards and guidelines, 1992) endorsed all these in their report.

The author believes that wound healing plays an important part in the rehabilitation process. Apart from delaying the rehabilitation process non-healing may also represent technical inadequacies and/or underlying pathology. The classification of wounds used may appear rigid but this format was arrived at after a postal survey amongst 34 consultants involved in the rehabilitation of amputees and 32 practising surgeons including 17 professors and directors in England and Wales, and after studying the

world literature.

Sometimes it is difficult to determine how much of the scar would become adherent when an open wound is healed; the assessments at three, six and twelve months help to clarify the situation. Only 62% of TF and 38% of the TT group had healed wounds when seen at the DSC.

Although the International Society for Prosthetics and Orthotics devised a clinical standard for measurement and classification of stumps in 1982, the author found it difficult to use in a day to day clinic setting (Persson and Liedberg, 1983). However, after a trial period of two years, the present format was found easy to use.

With the use of the pulse-oximeter reading

and peak expiratory flow estimation, the author's prediction for mobility grade has improved from 57% to approximately 80%. These predictions have been especially useful for the assessments of bilateral amputees.

This study asked two questions: (1) does the quality of stump influence the outcome of rehabilitation of a lower limb amputee and (2) does the operating surgeon have a role to play?

**Mobility:** 17 out of 17 (100%) TF amputees with Grade A stumps achieved their mobility grade (one with improved grading) in three months whereas 8 out of 14 (57%) amputees with grade B stumps achieved the predicted grade in the same time. A total of 27 out of 27 (100%) TT amputees with Grade A stumps achieved their mobility grades (one with improved grading) in three months but 17 out of 27 (63%) amputees with Grade B stumps achieved their mobility grades in the same time.

It was found to be extremely difficult to assess the exact time when an individual did achieve the mobility grades and as such it cannot be considered a precise measure. However, the total time required by the amputees with Grade B stumps was longer in both TF and TT groups. Greater number of amputees with Grade A stumps were mobile in a shorter time.

**Interval between attendances:** The interval was longer for amputees with Grade A stumps at both TF level, (approximately 9 days,  $P < .05$ ,  $t$  value = 1.92 against a critical value of 1.699 at the 5% level) and TT level, (12 days,  $P < .002$ ,  $t$  value = 3.30 against a critical value of 1.683 at the 5% level and 2.42 at the 1% level).

**Need for alteration of prosthesis:** some 34% of amputees with Grade A stumps of the combined TF and TT Groups needed refits whereas 59% of amputees with Grade B stumps needed refits.

**Activity:** Mean activity score of TF amputees with Grade A stumps was -27 as opposed to -46 for those with Grade B stumps and in the TT group it was -27 for those with Grade A stumps and -32 for those with Grade B stumps. Amputees with Grade A stumps were more active than amputees with Grade B stumps.

The activity scoring system for the amputees devised by Day (1981) favours a person at work but it has been used in this study as a measure of activities for amputees with both Grade A and Grade B stumps.

Although the TT amputees with Grade B stumps were seen earlier than those with Grade

A stumps, they were prescribed prostheses much later. It is possible that the amputees with Grade A stumps were not referred until the wounds were healed.

**Role of operating surgeons:** It is arguable whether staff grade surgeons should be considered as trainee surgeons. However, the number of operations they performed were few in numbers. Trainee surgeons performed 33 (55%) TF amputations with wounds healed in 55% and with 15 (48%) Grade A stumps. In the TT group, they performed 34 (47%) amputations with wounds healed in 35% and with 11 (32%) Grade A stumps. The trainee surgeons produced 40% of Grade A stumps out of 67 amputations.

The senior team performed 45% TF amputations with 60% Grade A stumps and wounds were healed in 70% of cases. In the TT group, they performed 53% amputations with 55% Grade A stumps. Wounds were healed only in 39%. On the whole the senior team produced 58% of Grade A stumps out of 65 amputations.

Contrary to previous findings (Pohjolainen and Alaranta, 1991), age did not seem to influence the outcome, except perhaps in the TF group with Grade B stumps, as 5 out of 14 (36%) could not achieve the expected mobility grade.

In the present climate of economic considerations and especially if there is the ultimate desire to improve the quality of life for lower limb amputees, the quality of stump is an important factor. Amputees should arrive at the DSC as early after operation as possible with a stump for which a prosthesis can safely be prescribed.

Long periods of stay in hospital for the wound to heal and subsequent delayed prosthetic prescriptions, frequent attendances at the DSC, often by ambulances, and frequent alterations of prostheses, all incur increased expenses and exaggerate frustrations of amputees (Narang *et al.*, 1984). It also reduces the period of effective use of the prostheses for a great number of amputees because of their short span of life (Stewart *et al.*, 1992; Finch *et al.*, 1980). One cannot expect a good result with a poor quality stump. The lower activity levels displayed by amputees with Grade B stumps suggests that their quality of life could have been better with a better stump.

### Limitations and conclusions

The results of this study reflect the difficulty

of conducting field studies using complex sets of variables as unit analysis. In this study the influence of associated conditions has not been considered. At this centre, 59% of amputees with peripheral vascular disease and 54% of amputees with diabetes have three or more (up to five) concurrent medical conditions.

Practical and perhaps ethical constraints prevented the isolation and controlled manipulation of various components of the rehabilitation process. As the multidisciplinary assessments were carried out at three, six and twelve monthly intervals, the exact time any amputee achieved the mobility grade in between the assessments was not recognised. However, the procedure was applied to all the groups. The possibility of variable treatment interaction and multiple treatment interference could not be eliminated in this investigation.

It should be accepted that outcome measurement in rehabilitation should be every provider's responsibility, (Malone *et al.*, 1979). The goal of rehabilitation is not to cure a specific organ or body system pathology but to enhance individual function e.g. mobility in lower limb amputees (Keith, 1984).

If the challenge is to be accepted of achieving the goal in amputee rehabilitation, surgical practice needs re-examination and training of trainee surgeons needs reappraisal (DeJong, 1987; Reed, 1993) even if it proves time consuming and expensive (Pietroni, 1993). We may have been getting away with sub-optimal service regarding stump construction, perhaps because of a mistaken philosophy about amputees being a 'lost cause' but the time has come for rectification with proper supervision of the trainee surgeons and adherence to good surgical practice by all.

This study represents an attempt to address the quality of stump and its relation to rehabilitation. Future outcome research should be designed to evaluate the nature and type of support services and the importance of concurrent conditions in greater numbers of amputees, probably in a multi-centre study for proper evaluation and implementation of any procedures (Williams *et al.*, 1995).

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#### REFERENCES

- Amputee Rehabilitation: recommended standards and guidelines: a report of the Working Party of the Amputee Medical Rehabilitation Society -London: ARMS, 1992
- BUTLER P, ENGELBRECHT M, MAIOR R, TAIT JH, STALLARD J, PATRICA JH (1984) Physiological cost index of walking for normal children and its use as an indicator of physical handicap. *Dev Med Child Neurol* **26**, 607-612.
- CAMPBELL WB, KERNICK VFM, JOHNSTON JA, RUTTER EA (1994) Lower limb amputation: striking a balance. *Ann R Coll Surg Engl* **76**, 205-209.
- CASTRONUCOVO JJ, DEANE LM, DIETLING RA, O'DONNELL TF, O'TOOLE DM, CALLOW AD (1980) Below-knee amputation: is the effort to preserve the knee joint justified? *Arch Surg* **115**, 1184-1187.
- CHAKRABARTY BK. Lower limb amputation: striking a balance. (letter) (1995). *Ann R Coll Surg Engl* **77**, 157-158.
- COLLIN C, COLLIN J (1995). Mobility after lower limb amputation. *Br J Surg* **82**, 1010-1011.
- COLLIN C, WADE DT, COCKRANE GM (1992) Functional outcome of lower limb amputees with peripheral vascular disease. *Clin Rehabil* **6**, 13-21.
- DAY HJB (1981). The assessment and description of amputee activity. *Prosthet Orthot Int* **5**, 23-28.
- DEJONG G (1987) Medical rehabilitation outcome measurement in a changing health care market. In: Rehabilitation outcome: analysis and measurement, edited by MJ Fuhrer - Baltimore: Paul Brookes, p255-206.
- DORMANDY JA, RAY SA (1995). The fate of amputees. *Vasc Med Rev* **5**, 331-346
- FENCH DRA, MACDOUGAL M, TIBBS DJ, MORRIS PJ (1980) Amputation for vascular disease: the experience of a peripheral vascular unit. *Br Surg* **1980** **67**, 233-7
- FYFE NCM (1992). Assessment of the rehabilitation of amputees. *Curr Pract Surg* **41**, 95-99
- GAILEY RS, WENGER MA (1994) Energy expenditure of trans-tibial amputees during ambulation at self-selected pace. *Prosthet Orthot Int* **18**, 84-91
- GONZALEZ EG, CORCORAN PJ, REYES RL (1974). Energy expenditure in below knee amputees: correlation with stump length. *Arch Phys Med Rehabil* **55**, 111-119.

- HANSPAL RS, FISHER K, CHAKRABARTY BK, MORTON M, ROBERTS A (1991). Mobility grades in amputee rehabilitation (abstract). *Clin Rehabil* **5**, 344.
- HOUGHTON AD, TAYLOR PR, THURLOW S, ROOTS E, MCCOLL I (1992). Success rates for rehabilitation of vascular amputees: implications for pre-operative assessment and amputation level. *Br J Surg* **73**, 753-755.
- KEGEL B, CARPENTER MI, BURGESS EM (1978). Functional capabilities of lower extremity amputees. *Arch Phys Med Rehabil* **59**, 109-120.
- KEITH RA (1984). Functional assessment in programme evaluation for rehabilitation medicine. In: Functional assessment in rehabilitation medicine./edited by CU Granger, GE Gresham. - Baltimore: Williams & Wilkins.
- MALONE JM, MOORE WS, GOLDSTONE J, MALONE SJ (1979). Therapeutic and economic impact of a modern amputation programme. *Bull Prosthet Res* **10(32)**, 7-17.
- NARANG IC, MATHUR BP, SINGH P, JAPE VS (1984). Functional capabilities of lower limb amputees. *Prosthet Orthot Int* **8**, 43-51.
- PERSSON M, LIEBERG E (1983). A clinical standard of stump measurement and classification in lower limb amputees. *Prosthet Orthot Int* **7**, 17-24.
- PIETRONI M (1993). The assessment of competence in surgical trainees. *Ann R Coll Surg Engl (Suppl)* **75**, 200-202.
- PINZUR MS, GOTTSCHALK F, SMITH D, SHANFIELD S, DE ANRADE R, OSTERMAN H, ROBERTS JR, ORLANDO-CROMBEHOLME P, LARSEN J, RAPPAZZIN P, BOUCKERMAN P (1993). Functional outcome of below knee amputation of peripheral vascular insufficiency: a multicenter review. *Clin Orthop* **286**, 247-249.
- POHJOLAINEN T, ALARANTA H, KARKKAINEN M (1990). Prosthetic use and functional and social outcome following major lower limb amputation. *Prosthet Orthot Int* **14**, 75-79.
- POHJOLAINEN T, ALARANTA H (1991). Predictive factors of functional ability after lower limb amputation. *Ann Chir Gynaecol* **80**, 36-39.
- REED MWR (1993). Evaluation of surgical training-urgent improvement needed. *Ann R Coll Surg Engl* **75**, 198-199.
- SILVER-THORN MB, CHILDRESS DS (1996). Parametric analysis using the finite element method to investigate prosthetic interfac stresses for persons with trans-tibial amputation. *J Rehabil Res Dev* **33**, 227-238.
- STEINBERG FU, SUNWOO I, ROETTGER RF (1985). Prosthetic rehabilitation of geriatric amputees patients: a follow-up study. *Arch Phys Med Rehabil* **66**, 742-947.
- STEWART CPU, JAIN AS, OGSTON SA (1992). Lower limb amputee survival. *Prosthet Orthot Int* **16**, 11-18.
- WILLIAMS MH, BLAZEY JM, EACHUS J (1995). Current challenges for outcome measurement in surgical practice. *Ann R Coll Surg Engl* **77**, 401-403.
- WATERS RL, PERRY J, ANTONELLI D, HISLOP H (1976). Energy cost of walking of amputees; the influence of level of amputation. *J Bone Joint Surg* **58A**, 42-46.

## **Criteria for prosthetic provision: "he who pays the piper calls the tune"**

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### **Abstract**

Previously instituted policies regarding prosthetic limb provision had been deemed dependable. A follow-up home visit study showed that 18 of 60 patients that had been provided with prostheses, did not make use of them. Analysis showed that three categories of patients made up the large majority of the non-users; double amputees, blind persons and those with psychiatric disorders. In order to attempt to eliminate the wastage of prosthetic provision to non-ambulators a new policy decision was made. Doubtful ambulators and those from the three aforementioned categories will be initially provided with temporary prostheses. Only after a period of months of temporary prosthetic usage at home will a decision be made as to whether a permanent prosthesis will be issued.

### **Introduction**

The Lewis Institute of Rehabilitation is responsible for the administration of the provision of prostheses, orthoses and orthopaedic shoes on behalf of the Ministry of Health. Throughout the country there are accredited doctors who are certified to order these provisions on behalf of the Institute. The great majority of these doctors are senior staff members who work within rehabilitation centres. It was anticipated that these physicians, in the light of their experience, would be able to predict which amputees had ambulatory potential and that prostheses would only be ordered for those that filled this criteria. The Ministry of Health does not supply cosmetic prostheses.

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A randomised study was carried out to examine whether the amputees who had received prostheses were in fact using them.

### **Material and methods**

Two of the authors (AM and GM) were both final year physiotherapy students at the time and visited 60 patients in their homes. In order to simplify the logistics of carrying out such a study the only selective criteria were patient amputation due to diabetes and/or vascular disease and the patients' addresses. Sixty patients who had received their prostheses between 1991-1994 were included in the study. Patients were visited at their homes, interviewed as to their activities of daily living, their ambulatory capabilities and were then asked to perform certain tasks. Patients donned and doffed their prostheses, and walked within the home. Those that reported that they were able to use the prosthesis outside were then examined descending and climbing the stairs to their apartments and walking in the neighbourhood. Table 1 records the sex, average age of the group, and level of amputation.

### **Results**

The use made by the amputees of the prosthesis was divided into four self-explanatory groups and the results are shown in Table 2. Of the 60 amputees reviewed only 42 used their prosthesis; the duration of usage is shown in Table 2. In order to understand more fully the relationship between the patients' intrinsic ability and prosthetic usage, three criteria were used to categorise the amputees. Patients were assessed as to whether they were independent, minimally handicapped (could walk if the prosthesis was donned by another person) and

Table 1. Age, sex distribution and level of amputation of the patients visited at home.

Sex	Number	Age	Level of amputation	
Female	17	35-90 Average 68	TF	4
			KD	1
			TT	10
			TF + TT	2
Male	43	45-90 Average 64	TF	13
			TT	25
			TT + TT	2
			TT + TF	2
			TF + TF	1

TT = trans-tibial KD = knee disarticulation TF = trans-femoral

Table 2. A summary of the findings regarding the use made of the provided prostheses.

	All day	Occasional – a few hours every day	Minimal – a few hours a week	Never wear the prosthesis
Prosthetic usage	19 of 42 31.6%	16 of 42 26.6%	7 of 42 11.6%	18 of 60 30%

whether they required constant assistance in almost all activities of daily living. Table 3 shows the patients' capabilities in the light of their prosthetic usage. Eighteen of the 60 patients never don a prosthesis.

### Discussion

Most systems of health provision suffer from a common problem – insufficient funding – hence optimal value is essential in the spending of these valuable funds (Pruitt *et al.*, 1996; Perler, 1995). Many critical decisions need to be taken at an administrative level e.g. are all amputees entitled to receive a limb prosthesis? If the answer to this question is affirmative then no problem exists. The prosthesis will serve a cosmetic function in addition to being an ambulatory aid. If on the other hand a decision is

made to save money and to provide prostheses only to ambulators then an effective patient assessment mechanism is necessary.

It had been presumed prior to this study, that this mechanism was in place. A limited number of trained physicians working within orthopaedic/rehabilitation departments were accredited to order prostheses on behalf of the Institute. Despite this controlled prescription almost half of the patients examined barely functioned with their prostheses.

In order to understand the pitfalls in the decision-making process the information on non-ambulatory patients was analysed to search for any common denominators (Cutson and Bongiorno, 1996). It became apparent that double amputees, other than bilateral trans-tibial amputees, patients with psychotic disturbances

Table 3. The usage made of the prostheses in the light of the patients' functional capabilities.

	All day	Occasional	Minimal	Non-users
Totally independent	19	3	1 (TT + TT)	1
Minimal handicap		11	2 (TT + TT)	3
Constant assistance		2	4	14 (4 x double amputation other than TT + TT)

TT = trans-tibial

and those who were blind dominated the non-ambulators.

Another group of patients who were non-ambulators can be categorised as "change of status patients". They were patients who were provided with prostheses and ambulated until a further deterioration occurred in their medical status e.g. advancing claudication, a problem in the remaining limb or a cerebrovascular accident. When this change of status, which was not predictable at the time of prosthetic provision was eliminated from the group of non-ambulators, the aforementioned medical conditions represented the vast majority of the non-ambulators.

Because of the desire to provide a better method of assessment and to avoid the non-provision of a prosthesis to a potential ambulator an alternative modality of assessment was implemented. New amputees from the three problematic categories will be provided with temporary prostheses initially and only after they have proved their ability to walk over a number of months will a definitive prosthesis be prescribed. Any other amputee whose ambulatory potential is questionable will also initially receive a temporary prosthesis. Temporary prosthetic construction kits are commercially available. They contain interchangeable modular components including stump sockets and brims of varying sizes. These

adaptive components (Nielen *et al.*, 1994) provide the main benefits of reusability and hence financial saving. It is hoped that this method of assessment will do away with the wasteful provision of unused methods.

Objective criteria are the essence of policy making decisions (Polliack and Moser, 1997) and although in medicine one should refrain from using words such as 'always' or 'never' one should understand that *he who pays the piper calls the tune*.

#### REFERENCES

- CUTSON TM, BONGIORNI DR (1996). Rehabilitation of the older lower limb amputee: a brief review. *J Am Geriatr Soc* **44**, 1388-1393.
- NIELEN D, LEMAIRE ED, GOUDREAU L (1994). A trans-femoral brim adapter for CAD CAM measurements. *Prosthet Orthot Int* **18**, 40-42.
- PERLER BA (1995). Cost efficacy issues in the treatment of peripheral vascular disease: primary amputation or revascularisation for limb-threatening ischaemia. *J Vasc Interv Radiol* (**6-suppl 2**), 111s-115s.
- POLLIACK AA, MOSER S (1997). Facing the future of orthotics and prosthetics proactivity: theory and practice of outcomes measures as a method of determining quality of service. *J Prosthet Orthot* **9**, 127-134.
- PRUITT SD, VARNI JW, SETOGUCHI Y (1996). Functional status in children with limb deficiency: development and initial validation of an outcome measure. *Arch Phys Med Rehabil* **77**, 1233-1238.

## Powered prosthetic hands in very young children

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### Abstract

Myoelectric prostheses are generally not provided in the United Kingdom for children before the age of 3½ years. Following the introduction of a smaller sized electric hand in the United Kingdom in 1993 the authors decided to introduce electrically powered hands for a group of congenital upper limb deficient children at a much younger age compared to normal practice.

Eleven children were introduced to powered prosthetic hands at an average age of 20.6 months. At the review carried out for the purpose of this paper, 72.7% of these children appeared to be successfully using these powered prostheses. Fitting these young children with powered prostheses and encouraging acceptance and operation of the prostheses appeared to be much less of a problem than might have been anticipated. The parents of all these children have very much liked the introduction of powered hands at this early age and have contributed positively to the prosthetic programme.

The authors' experience suggests that introduction of a powered prosthesis at a much earlier age can be a more suitable alternative than provision of a body-powered prosthetic device while waiting to reach an older age before a powered prosthesis is considered.

### Introduction

In the management of upper limb deficient children, early prosthetic fitting is now generally

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accepted to be beneficial. Children are usually advised to be fitted with a cosmetic passive device as early as between 3 months to one year (Datta and Brain, 1992; Patton, 1989). Progression from a passive cosmetic prosthesis to an externally powered prosthetic device has generally been determined by the enthusiasm and expertise of the individual centre, availability of resources for payment for the prosthetic limbs, availability of suitable and appropriate prosthetic hardware, as well as other selection criteria used by the rehabilitation team. Historically in the United Kingdom (UK) children generally progress to receiving their first myoelectrically controlled prosthesis between the ages of 3½ to 5 years, usually having used a body-powered device, like a split hook or mechanical hand since about 18 months of age (Datta *et al.*, 1989; Mendez, 1985). Applications of electrically powered prostheses in young children as early as between the ages of 12 to 18 months has been reported by a centre in Canada (Hubbard *et al.*, 1992).

When the SCAMP hand was launched in the UK in 1993 by Hugh Steeper UK Limited, the possibility of application of powered hands for younger children in the UK became a more available option. Therefore, with the availability of a more affordable smaller electric hand and encouraged by the initial reports from the Canadian group, the decision to prescribe these powered hands to a much younger group of children was taken in the centre in Sheffield. This report describes an experience of using powered prosthetic hands in very young children.

### Patients and methods

During 1994/95, eleven children with



Table 1. Profile of subjects (N=11).

Level of congenital loss	Male	Female
Right below elbow	1	2
Left below elbow	1	6
Right through elbow		1

unilateral congenital upper limb transverse deficiency were considered to be ready to progress from their passive cosmetic prostheses to more functional devices. Details of these children are presented in Table 1.

Ten out of these 11 children were being seen regularly at the authors' clinic from an average age of 4 months (range 0-8 months), the remaining child was transferred from another centre at the age of 33 months. Prior to prescription of powered prostheses, 7 were wearing passive cosmetic prostheses, and 4 were wearing body-powered grippers.

The decision to change to the SCAMP hand was for the reason of introduction of a more efficient functional device to allow improvement in age appropriate independence and to encourage bimanual activities which the body-powered or cosmetic devices were not fulfilling. These children were selected to be included in this programme for powered hands as they had already demonstrated their developmental readiness and the family showed commitment to fully participating in the programme.

Use of the Otto Bock Myo-trainer and the occupational therapists involvement are described later. The prosthetic details of the new powered devices are given in Table 2.

All sockets had a pull hole so that the use of a silky pull-through 'stump sock' could be used to enable easier application. All had a single electrode sited over the lateral aspect overlying the common finger and wrist extensor muscle group for below elbow deficiency to allow



Fig. 1. SCAMP myoelectric hand in use by a child with below elbow deficiency.

voluntary hand opening. For the child with through elbow level of deficiency, the single electrode was placed overlying the triceps muscle. No on/off switches were fitted. In all cases Liberty-Mutual half size 6 volt batteries were incorporated in the prostheses (Figs. 1 and 2).

A brief questionnaire was devised to gauge parental opinion and sent to the parents at the time of review.

## Results

Myoelectrically controlled SCAMP hands were introduced to these children at an average

Table 2. Details of powered prostheses.

Self suspending socket	10
Additional strap (above elbow cuff)	5
Through elbow socket with hinge elbow joint (side steels)	1
2" SCAMP hand	5
1 1/2" SCAMP hand	6
Otto Bock electrode	2
Steeper electrode	9
Liberty-Mutual Batteries	11



Fig 2 SCAMP myoelectric hand in use by a child with through elbow deficiency.

of 20.6 months (range 15 months to 34 months). The use and utilisation of the prosthesis for these children were reviewed at an average of 25 months (18-34 months).

At this review, 7 children were continuing to use their powered prostheses only, while the remaining 4 also continued to use their cosmetic prostheses for some parts of the day while they were not wearing their powered prostheses.

Eight out of 11 (72.72%) were successfully wearing powered prostheses for an average of 6 hours per day (range 4-9 hours) on an average of 6.3 days per week (range 5-7). One child has currently abandoned wearing the prosthesis after 15 months of good use and 2 others are showing great reluctance – which may be related to persistent fitting and other electro-mechanical problems with their prosthesis.

All 11 children learned to open the SCAMP hand relatively quickly, though some in more controlled fashion than others.

All 11 questionnaires were returned by the parents which revealed that all the parents felt that the powered prosthesis had been provided at the right time. Nine children accepted the new prostheses readily when the programme was started and all could be encouraged to operate and use the powered hand in the house during play and some daily living activities appropriate to their age group. Eight families felt that electro-mechanically the prostheses were very reliable and 3 were less enthusiastic. There was general consensus that battery life span was too short and some children needed up to 3 batteries per day. The heaviness of the prosthesis was commented on by 3 parents causing a problem with the arm dangling when the child was tired. One parent commented on the bulkiness of the

hand and prosthesis as a whole in respect of clothing.

### Discussion

A number of reports have supported the effectiveness of providing myoelectric prostheses as rehabilitation aids for upper limb deficient subjects.

Improved cosmesis, elimination or reduction of harness, improved grip force controlled by more natural body movements, decreased effort, ability to work close to the body and at various planes for electrically powered prostheses have been well documented (Datta and Brain, 1992). These advantages generally out-weigh the disadvantages of increased weight, lack of durability in play activities with sand and water and the possibility of more frequent maintenance according to the parents of the children, which is similar to the authors' observation.

In their past experience, body-powered prosthetic devices used between the ages of 18 months to 3½ years which is the common practice in the UK, have been rather restrictive and many children tended to use them as passive devices. Split hooks, which probably can be the most functionally effective terminal device are generally not favoured by parents because of social and cosmetic reasons and for fear of injury to the children themselves or to others. The CAPP device has not found favour by children and parents in this centre. Poor grip force offered by mechanical body-powered hand or gripper devices, discomfort and restriction created by wearing a harness and unnatural body movements to perform bimanual tasks may encourage some children to become one handed when such devices are prescribed, rather than become as naturally bimanual as possible. It is important to be able to provide these children with a prosthetic device which is most efficient for their needs.

There have been 3 main concerns regarding application of electrically powered prostheses in children under 3-3½ years of age, i.e., the availability of very small sized electric hands, uncertainty of correct location of electrodes in the socket and training strategy in the use of myoelectric prostheses.

Though Variety Village market a small powered hand suitable for very small children, they have not been used much in the UK because of the import costs and uncertainty of technical

back up.

The introduction of 1¾ inch and 2 inch SCAMP hands in Britain by Hugh Steeper Ltd., filled a major gap in Britain for younger children. Use of single electrodes in operating a voluntary opening hand with automatic closure was adequate for the needs of the youngsters in the trial. In a previous report of the SCAMP hand it was noted that though existing users of myoelectric hands using 2 electrodes had no difficulty in changing to a single electrode SCAMP hand, though bimanual tasks were more difficult and took longer for timed performance tests. (Kingston *et al.*, 1995).

The authors preferred to use myoelectric control rather than pull switches for use with SCAMP hands in these patients, as pull switches would have required the use of restrictive operating loop and harness and the unnatural action of pushing the hand away from the body to activate the hand operations.

The location of the single electrode over the lateral aspect of the below elbow stump was chosen because of the anatomical location of the hand extensor muscles. Formal location of electrode site to obtain best electro-myographic signals are not possible in such young children. A little trial and error at fitting stage and adjustment of the sensitivity of the electrode were sufficient to obtain a reasonably optimum location of the electrodes.

In this series, 8 children were given between 1 and 4 training sessions with the Myo-trainer (Otto Bock) using a toy train set which moved and stopped by using EMG signals generated from the stump. The impression was that the children who used the Myo-trainer transferred more easily to the SCAMP hand, though this cannot be proven. There was, however, no correlation between the use of the Myo-trainer and eventual usage pattern of the powered prostheses. The occupational therapist found the Myo-trainer to be excellent diversionary equipment to engage children to identify potential candidates and also an informal training aid for use of powered prosthetic hands.

In this group of 11 children, 72.7% appeared to be successful in using their myoelectric prostheses in terms of the extent of wearing their prostheses as well as subjective observation of using their prostheses actively and passively in their play and other daily activities. This is similar to 69% success in the use of myoelectric

prostheses for a group of 29 children under 16 years of age of congenital below elbow transverse limb deficiency who went through the usual, but conventional practice of not receiving the myoelectric prosthesis before the age of 3½ years, (Datta *et al.*, 1989). A longitudinal follow up and a larger study will be required to form any definitive conclusion whether early provision of powered prostheses can make a significant difference to the rehabilitation programme, compared to a later provision.

There is no doubt that parental involvement and commitment has a positive effect on the child conforming and co-operating with an early powered prosthetic programme. Monitoring will be needed on these children to see how they develop in future.

There has been no significant increase in the amount of time required to assess and fit the powered prostheses and no increase in the number of appointments to the clinic have been necessary. In the authors' clinic it is usual practice to see children at 3 monthly intervals unless a significant change necessitates an earlier intervention. The occupational therapist's involvement with these children outside the multi-disciplinary clinic also has not shown any significant increase in the time element.

Early referral to develop good relationship with the multi-disciplinary team of a specialised centre, regular reviews, input of specialist occupational therapist at the centre, at home and school/nursery, peer support from other children and parents, specialist technical and "drop in" prompt and efficient repair facilities are necessary. Suitable surroundings conducive to training with age appropriate toys have all positively contributed to the management of these children.

No child in this project was refused the opportunity to progress to the powered hand, but when the authors were not convinced that the timing was right, their concerns were discussed with the parents and provision deferred until circumstances were more favourable. Of course there are children attending the centre where an electrically powered prosthesis has not been provided, but this is outside the subject of this paper.

It appears to be an attractive option to switch to electrically powered prosthetic hands for much younger children than previously practised in the UK. The rejection rate is not higher than

other previously reported use of myoelectric prostheses in children with below elbow deficiency. The electrically powered prostheses are very much liked by parents and therefore parental participation has been positive. Most children in the group learned to operate the hand reasonably quickly and demonstrated the beginning of control in a relatively short space of time.

The key to success of a prosthetic and rehabilitation programme is to be able to provide the appropriate prosthesis for these children, at the appropriate time together with appropriate and continuing support from a specialist centre. Regular monitoring and review is necessary as the children continue to grow and their needs change.

The additional expenditure of providing electrically powered compared to body-powered prosthesis in this age group did not cause financial difficulties in the centre which is funded by the National Health Service. The additional cost was the difference between a body-powered prosthesis and the powered prosthesis. As the number of children with congenital limb deficiency attending any one centre is likely to be small, it is not thought that the additional expenditure in earlier provision of electrically powered prostheses, when indicated, is likely to be significant. It certainly appears to have increased parental contribution as "co-therapists" and may have decreased rejection or

very poor use of inefficient body-powered prosthetic devices. The actual fitting process of electrically powered prostheses in such young children and their tolerance to wear this prosthesis and the ability to gain some control of the hand has not proved to be as problematic as one might have expected.

#### REFERENCES

- DAITA D, BRAIN ND (1992). Clinical applications of myo electrically-controlled prostheses. *Crit Rev Phys Rehabil Med* **4**, 215-239.
- DAITA D, KINGSTON J, RONALD J (1989). Myo-electric prostheses for below-elbow amputees: the Trent experience. *Int Disabil Stud* **11**, 167-170.
- HUBBARD S, BUSH G, KURTZ I (1992). A developmental approach to myo-electric fitting and training. In: Proceedings of 7th World Congress of the International Society for Prosthetics and Orthotics, Chicago, Illinois, p355.
- KINGSTON J, RONALD J, COOPER R, DYKES W, DAITA D (1995). The clinical trial of the SCAMP 2 inch hand. In: Proceedings of the Annual Scientific Meeting, International Society of Prosthetics and Orthotics, Hull, England, p49.
- MENDEZ MA (1985). Evaluation of a myoelectric hand prosthesis for children with a below-elbow absence. *Prosthet Orthot Int* **9**, 137-140.
- PATTON JG (1989). Developmental approach to paediatric prosthetic evaluation and training. In: Comprehensive management of upper limb amputee./edited by Atkins DH, Meier RH. - New York: Springer-Verlag, p137-149.

## Low-bandwidth telemedicine for remote orthotic assessment

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### Abstract

A model for performing remote orthotic assessments using low-bandwidth computer communication technology (video conferencing) was developed, tested, and evaluated. System evaluation involved comparing a series of remote assessments with on-site assessments. While most on-site and on-line results were similar, discrepancies which occurred were attributed to between-clinician differences, measurement technique differences, technical and learning obstacles at the start of the project, and within subject variations during the day. On-line assessment efficiency improved with each on-line session and corresponded with increased confidence in the system, easier system use, and better overall satisfaction. An on-line debriefing session was held with all project clinicians. These clinicians supported continued use of the communication system for rehabilitation consultation and education. Clinically, preliminary face-to-face meetings and a regular practice schedule were recommended. Technically, the system was considered good; however, suggested improvements included using a high quality speaker-phone system, streamlining the video capture process, and providing more reliable telecommunication connections.

### Introduction

The combination of computer technology and telecommunications is an exciting prospect for the rehabilitation field. Recent advancements in video conferencing systems and Internet access

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provide the infrastructure for remote assessment and consultation at a reasonable cost. By using computer/telecommunication links to send sound, data, graphics, and video between two or more sites, remote areas can access clinical assessment and follow-up services without travelling to a central rehabilitation facility.

Telemedicine, the use of communication technologies to provide health care services and education over a distance, has been in existence since the late 1950s when microwave links were used for telepsychiatry consultations (Wittson *et al.*, 1961). Since then many applications have been initiated in the fields of radiology (Reponen *et al.*, 1995; von Hanwehr *et al.*, 1995) dermatology (Perednia and Brown, 1995; Solomon *et al.*, 1996), pathology (Ferrer-Roca *et al.*, 1995; Kayser and Drlicek, 1992), neurology (Chaves-Carballo, 1992), and other specialties (Allen and Hayes, 1994; Hubble *et al.*, 1993; Jerome, 1993; Rafuse, 1994; Lewis and Boyd Moir, 1995). In addition, some telemedicine initiatives have provided remote diagnosis and consultation tools for general health care (Carlson, 1994; Jennett *et al.*, 1995; Perednia and Allen, 1995; Padeken *et al.*, 1995; Sanders and Tedesco, 1993). Unfortunately, most of these programmes could not be sustained after the initial project funding was spent (Perednia and Allen, 1995).

The technological requirements for performing a remote medical intervention are directly related to the clinical application. For radiology and pathology, static images can be digitized at a remote site using commercial image processing hardware and software. A computer modem can then be used to send the data file to a central facility for analysis (Reponen *et al.*, 1995). For surgical interventions, virtual reality or

telepresence is required so that the surgeon has sufficient visual and tactile feedback to perform an operation. Such a system might include a high speed telecommunication link, remote robotic controlled surgical instruments, three-dimensional (3D) video display, high quality audio, and computer-enhanced instruments that allow the surgeon to feel what the remote surgical instrument is doing - all functioning in real-time (Dumay, 1995; Ling, 1993; Satava, 1995<sup>a,b</sup>). While remote rehabilitation consultations would benefit from a full virtual reality interface, a more reasonable approach can be taken to provide reliable clinical interventions and education sessions (Ball 1994; Lemaire, 1993; Lemaire *et al.*, 1997). Simple, but effective, telemedicine implementations have generally had the most success (Pushkin, 1992).

While the benefits of on-line communication are well documented (McNamara, 1994; Williams *et al.*, 1995), little research has been published concerning the application of this technology to physical rehabilitation. Until recently, the high cost and inadequate capabilities of computer communication hardware and software made rehabilitation telemedicine inaccessible; however, recent developments have reduced the cost of distance communication systems to a level that is compatible with the budgets of most medical clinics. Also, the proliferation of Internet service providers makes the task of connecting remote sites to rehabilitation centres easier and more cost-effective (Bergman, 1994). This document will describe outcome results from using a low cost, low-bandwidth distance communication solution for orthotic assessment.

## Methods

The procedures used to develop and validate a distance communication system for remote orthotic assessment are outlined. These involved defining key clinical and technical parameters, installing and pre-testing the communication system, and evaluating the new assessment process.

One central rehabilitation site (The Rehabilitation Centre, Ottawa) and two remote sites (Arnprior and District Memorial Hospital, Hawkesbury General Hospital) were involved with this study. All interactions between the remote communities and the Rehabilitation Centre occurred through the Terry Fox Mobile

Clinic (Wilson *et al.*, 1995; Greene, 1993). The Mobile Clinic is an interdisciplinary rehabilitation team that travels to communities in eastern and northern Ontario, Canada. Two certified orthotists from The Rehabilitation Centre completed all orthotic assessments. Four physiotherapists and one occupational therapist from the remote hospitals worked with a central orthotist to complete all on-line assessments.

A total of 22 people who required an ankle-foot-orthosis (AFO) were recruited to participate in this study. These subjects lived in the regions serviced by the remote hospitals and had been previously seen by the Mobile Clinic staff. Ten additional people were recruited from The Rehabilitation Centre for on-site training and testing of the assessment protocol. Informed consent was obtained from all participants before initiating the assessments.

To determine the methods and procedures for orthotic assessment, an inventory of current orthotic assessment practices on the Mobile Clinic was amassed. This information was collected through interviews with Mobile clinic certified orthotists and other members of the Mobile Clinic team. The assessment information was combined with existing forms (Sarrafian, 1985; Berger *et al.*, 1981; England *et al.*, 1977; McCollough *et al.*, 1970; Weber, 1990) to develop a standard assessment form and database for use in this study.

Once the assessment method was defined, two certified orthotists were trained to use this protocol. A group of five lower limb orthotic users was assessed through the Prosthetics and Orthotics Service at The Rehabilitation Centre to ensure that both orthotists were employing the same technique. Both orthotists independently assessed each user and recorded the results on the assessment form. Data are collected from a second group of five subjects to help describe the differences that can be expected due to inter-clinician variability.

After a thorough description of orthotic clinical assessment method was documented, the assessment protocol was adapted to accommodate a computer conferencing link. These adaptations included developing a computer database version of the assessment form and determining how to use the communication tools to obtain the assessment information. The computer hardware and software components were assembled at this time.

When the computer hardware and software were functioning, clinical staff at the Rehabilitation Centre and the two remote sites received training on the computer communication system. The first training sessions were done at the remote sites. Subsequent training sessions were performed using the conferencing link and on-line tutorials (i.e., instructor at the central site and participants at the rural sites).

Following the training, four people were assessed using the distance communication protocol during the first-on-site visit to Arnprior. These tests ensured that the computer assessment methods were appropriate for people who require lower limb orthoses. These pre-tests also permitted debugging of the computer link and gave the participants some experience using the system with users before data collection began.

All test subjects were assessed by an on-site orthotist and by the remote orthotist/local therapist team (using the computer communication link). Both assessments were completed on the same day. Both orthotists used the established assessment protocol and recorded the results on an assessment form.

A computer assessment questionnaire was completed by the on-line orthotist for each assessment. These questionnaires described the time requirements for on-line assessments, factors related to system function, and satisfaction with the system/process.

In addition to the questionnaires, each subject was video taped in the sagittal and frontal planes while walking. Three to five representative strides were selected from the tape, digitized into the computer, and sent to the central orthotist over the communication link for visual gait analysis. The orthotist could replay the digital video clip as many times as required, step through the video frame by frame, and pause the video at any point. The on-site orthotist did not have access to the tape because video analysis was not part of the standard on-site assessment.

Upon completion of the user data collection phase, a debriefing session was held on-line with each community and The Rehabilitation Centre. A preset series of questions concerning the benefits, contraindications, and future developments of the distance communication system were discussed by the participating clinicians.

Using an Internet connection, all three hospitals shared an interactive Chalkboard and Chat

window. The Chat feature was used to record all the ideas that came up during the meeting so that all sites could follow, comment on, or add to the written record. A conference call was used for verbal communication. Although the Chalkboard was available, it was only required at the start of the session.

All the data were analysed using descriptive statistics. A Spearman correlation coefficient was used to assess the linearity between ordinal data from the two assessments. The differences between the on-line and on-site assessments should be comparable to the differences when both orthotists completed an on-site assessment.

### **Hardware/software solutions**

IBM's Person to Person (P2P) video conferencing system, running under OS/2 Warp 3.0, was used for this study. P2P provided an interactive chalkboard, chat mode communication, window mirroring, and file transfer capabilities as part of the OS/2 Warp Bonus pack (i.e., software bundled with the operating system). With the addition of a video capture card, P2P could send video and high resolution still images between sites. Audio communication was through a separate telephone line connected to a speaker phone. The OS/2 Bonus Pack also provided a word processor/spreadsheet/database programme and Internet related software.

### **System setup**

IBM hardware was used for this project, although any IBM compatible system could have been used. A Pentium 90 (host site) and two Pentium 75 (remote sites) based systems were used for most of this study. An 80486DX-66 computer was employed for initial system and communication tests. All computers were equipped with 16Mb RAM and a 17-inch monitor. The 17 inch monitor was beneficial since the additional screen space permitted many windows to be open and visible simultaneously (i.e. video window, Chalkboard, database, etc.). System setup and configuration were performed by the research team.

Setting up a P2P session that incorporated live video took much longer than initially planned (approximately three months). Most of the problems were related to faulty device drivers and hardware conflicts. The lengthy system configuration time would be a problem for small

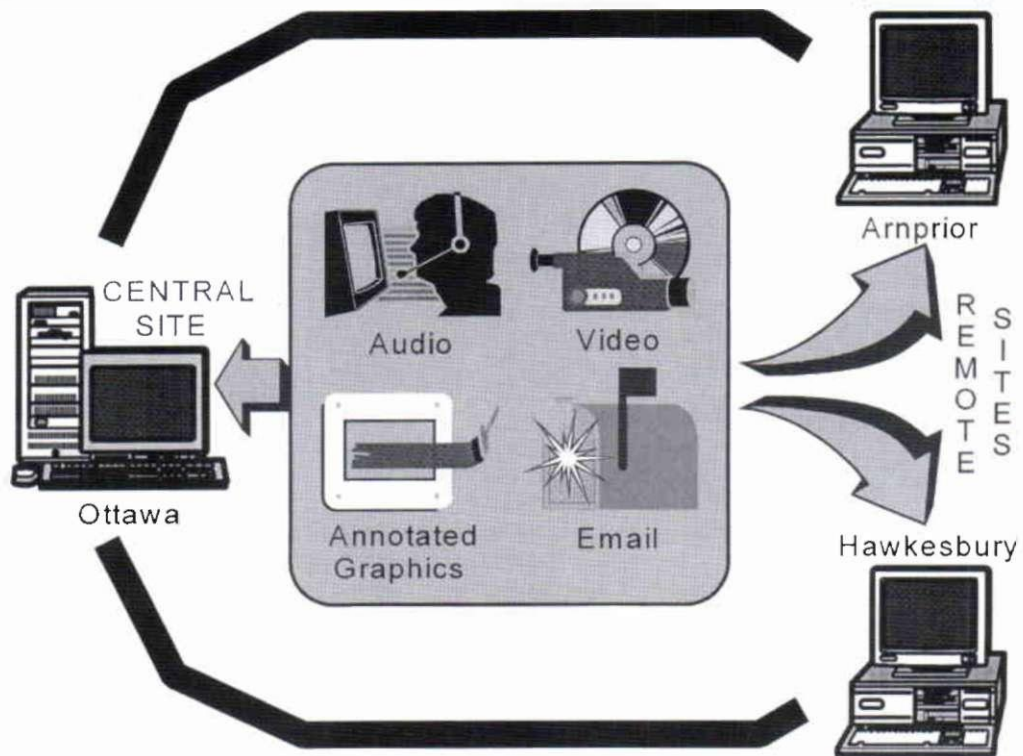


Fig. 1. Computer communication system

health care centres with little computer experience or unavailable computer research personnel. Having the system completely pre-installed and configured for the specific application is essential to build consumer confidence, reduce frustrations, and reduce expensive remote servicing costs.

### **Communication tools**

#### **Video**

A live video signal was sent between sites over standard telephone lines (28.8 Kbps) at approximately one frame/second. While this frame rate was too slow for human motion assessment, it allowed both sites to see each other, show an assistive device, or show a problem area on a patient. Since this project focussed on remote communities with limited financial/technical resources and no access to high-speed data lines, the feasibility of standard telephone communications for digital clinical assessment was addressed, as opposed to high-speed ATM networks or satellite links. Since full screen, 20 frames/second video is

appropriate for analysing slow walking, a secondary process was initiated to share full speed video data.

#### **Video motion analysis**

An essential part of an orthotic assessment is the visual evaluation of a person's walking style. This information is used to help define the problem, determine the best orthotic intervention, and evaluate orthotic function.

An IBM ActionMedia video capture board was used to digitize video approximately 20 fps and save the data on the hard disk (file size approximately 10 Mb). The resulting data file was sent to the central orthotist using the file transfer function. Internet E-mail could also have been used to send the video file to the rehabilitation centre. Software that came with the capture card was used to record, play, pause, and step through the video frame by frame.

#### **Drawing**

P2P's Chalkboard could be considered the most important visual communication feature



for remote assessment. Any image that is displayed on the Chalkboard can be seen and annotated by all "on-line participants". By displaying and annotating images of an orthosis, walking characteristics, or educational materials, all people connected to the communication system can discuss a problem while seeing and drawing on related images. Since any other programme can be "mirrored" into the Chalkboard (i.e., the contents of the programme's windows are automatically displayed in the Chalkboard as a bitmap), the

common viewing area could be used to solve software problems, look at CAD images, or work on reports and documentation. Previous work with the Chalkboard method of remote communication demonstrated the usefulness of this medium, as long as the proper visual material is used (Lemaire, 1993).

#### Image capture

The image capture function obtained a stationary, 640x480 image from a camcorder and displayed the image in a separate window.

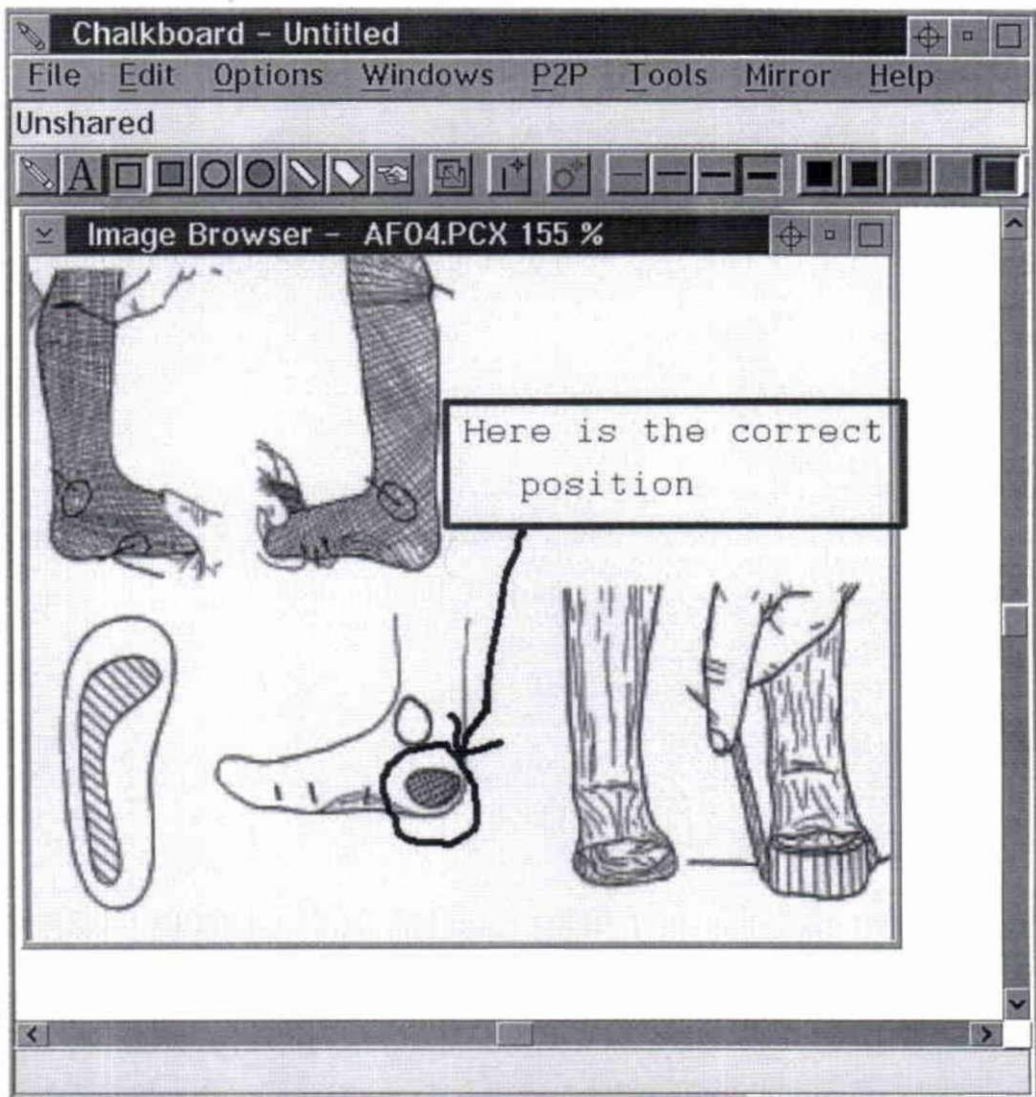


Fig. 2. AFO database – design section

This image could be transferred to the Chalkboard for discussion. Capturing and displaying a large, full colour image allowed the orthotist to see limb redness, chaffing, and the orthosis condition.

#### Database

An orthotic database programme was initially set up using the IBM Works Datafile application; however, software problems lead to rewriting the database in Microsoft (MS) Access for Windows 3.1. When the programme errors are corrected, Datafile should be adequate for maintaining an on-line database for distance communication. The advantage of the Datafile application is that it is included with the operating system at no extra cost.

A runtime version of the MS Access programme ran in a MS Windows session under OS/2. Database records were shared between sites by copying the record(s), saving these records as a separate data file, sending the data file to the other site using the communication link, and importing the data into the host database. In cases where the data did not have to be transferred to the other site, the database window was mirrored into the Chalkboard for discussion.

#### Reference images

Before the first on-line session, a series of reference images were scanned and saved as bitmap graphic files. These images were grouped in Light Table folders for easy access (an OS/2 feature for organizing multimedia files by displaying the information as a series of small slides). Since a Light Table was used for image organization, the user can easily share pictures by clicking on the images slide to display a full size picture and mirroring the enlarged picture into the chalkboard. The reference images were very useful for the training sessions and during on-line discussions regarding patient or orthosis characteristics.

#### Direct modem connection/Internet

For most of this study, direct modem connections were used for communication. While the Internet can be used for remote communication, data transfer can be slow during periods of high Internet traffic. A direct 28.8 Kbps modem connection between two sites was the best medium for communications over a telephone line.

While telephone line data connections were satisfactory, connections between sites were not always reliable. The main connection problems

The screenshot displays a Microsoft Access form titled "AFO DESIGN SPECIFICATIONS". The form contains several input fields and checkboxes for configuring an ankle-foot orthosis. The fields include:

- AFO Type: Plastic Semi-Rigid Ankle
- Calf Strap Style: Loop
- Ankle Strap Style: Flap
- Dorsiflexion Angle: 5 deg
- Foot Plate Length: Full Foot Plate
- Plantar Flexion Stop:
- Ankle Hinges:  Hinge type: [ ]
- Heel Lift:
- Wedge: [ ]
- Padding: [ ]
- Padding Location: [ ]
- Other Add: PPT, Felite

The form also shows a status bar at the bottom indicating "Record: 1 of 3" and "Form View".

Fig. 3. Reference images

were based on running the system through hospital switch boards. In particular, The Rehabilitation Centre's PBX-based telephone system created data communication problems during the initial stages of this project. Switching to a direct, outside telephone line solved most of these problems. Hawkesbury had more reliable data communications than Arnprior. This could be due to better telecommunication links between Ottawa and Hawkesbury or interference from the Arnprior District and Memorial Hospital switchboard system (the telephone line was routed through the main switchboard).

As small communities with inferior telecommunication links are connected to a clinical consultation system, data line failures can be expected. Generally, this is not a problem since it is a simple task to reconnect and resume the assessment. Frequent connection problems, however, are detrimental to the efficiency of remote clinical communication and user confidence. It is recommended that the telephone system be pre-tested before installing a computer distance communication system to ensure a reliable data flow between sites.

Internet connections were easy to initiate and the connections were reliable. For site-to-site communication, the Chalkboard and live-video functions worked; however, the video frame rate was slower than with a direct 28.8 Kbps modem and a longer time lag occurred between the live action and remote video display. Even with these limitations, an Internet connection was considered a viable medium for cost-effective site-to-site communication.

Multi-site Internet communications involved Ottawa, Arnprior, and Hawkesbury simultaneously sharing the same Chalkboard and Talk window. This feature performed very well when each location took turns accessing the shared resources; however, if all sites continuously used the on-screen pointer function for more than a few minutes the system would lock up (i.e., a continuous data stream from all participants using the Chalkboard). No errors occurred if the participants interacted with short to medium bursts of activity. Live-video was not reliable for multi-site Internet connections. Higher bandwidth TCP-IP connections would be required before live-video could be used between more than two sites. A recommended multi-site setup would involve:

- using the Talk window to keep minutes of a meeting, display/paste text for the group to read, or write words which were difficult to spell;
- using the Chalkboard window to share captured images, previously prepared graphics, or as a sketchpad to illustrate an idea;
- using the Stills Capture programme to grab video images and share them with the group (these images can take between one and two minutes to be displayed at all sites, depending on Internet traffic);
- using the File Transfer programme to send video files, database records, word processed files, or reports between sites.

## Results

Twenty-two subjects were assessed during four Mobile Clinic visits: 10 assessments in Arnprior and 12 in Hawkesbury. The first Mobile Clinic visit was used as a test session and was not included in the validation results. With these four subjects removed, data from a total of 18 subjects were used for the evaluation. At the start of the project, clinicians in Arnprior and Hawkesbury had minimal, or no, computer experience and no previous exposure to OS/2. The combination of clinician training on the system, system trouble shooting, and database errors made data from the first clinic visit unreliable. The following sections will describe the questionnaire and debriefing results.

### Assessment questionnaire results

The assessment data sheet was divided into three areas: client data, physical data, and gait data.

#### Client data

The client data section provided information on the client's medical status, social factors, and environmental factors. Orthotic assessment questionnaires have traditionally provided a space to write a description based on patient assessments, discussions, and a medical chart review. To compare these clinical data, the information was coded into three groups: same information (1), same information with some additional details (2), different information (3). Since it is expected that different clinicians will have slight variations in what information they decide is most relevant, group one and group

two results were acceptable.

For most measures, the remote and on-site responses were similar in more than 88 percent of the cases. These measures included date of birth, height, weight, gender, diagnosis, date of onset, main problem, occupation, activities, social factors, cognitive status, mobility aids, walking distance, and footwear. Four areas with unsatisfactory results were prescription (72%), history (61%), goals (72%) and complications (39%). It was reasonable that differences occurred with prescription and goals since the subjects, while being potential candidates for an AFO, were not being assessed to receive a device from an established prescription (i.e., they were at the clinic to take part in the pilot project and not for a specific orthotic problem). If a written prescription was available for each subject, the prescription results would have been much better since the team would have had specific clinical goals.

Differences in medical history and possible complications were attributed to differences between orthotic methods and physiotherapy / occupational therapy methods. The various fields of rehabilitation have different focusses when reviewing the medical history and determining what constitutes a potential complication. These differences became apparent when reviewing the responses from the on-site orthotist and the combination of an orthotist / physiotherapist / occupational therapist team. It is suggested that these areas be replaced by a predefined list of choices to help focus the assessment on the needs of the orthotist.

Since the medical history, goals and complications sections were based on subject feedback, some differences could have been due to the subject supplying different information, or a different focus, during the two assessments. Problems with the speaker-phone could have also led to problems of hearing the subject.

#### Physical data

The physical data section recorded information on muscular function, joint function, vascular problems, and balance. For the strength measurements, individual variations were accommodated by grouping the Oxford Muscle Strength Scale values into three sections: no functional strength (0,1,2), weak functional strength (3), acceptable functional strength (4,5).

Range of motion values were grouped into normal or abnormal sections. These groupings were required since orthotists typically do not perform strength and range of motion assessments in the same manner as physiotherapists. This probably occurs because physiotherapists and occupational therapists are concerned with the physical improvement of the patient while an orthotist is concerned with production of a device based on the patient's functional condition. More precise measurements would be required to show how the subject is progressing as part of treatment. Broader scales were considered sufficient by the orthotists for this study and were better aligned with current clinical orthotic practices.

The general physical measures were similar in all cases except spasticity and balance. The similar measures included sensation, unstable joints, skin problems, and vascular problems. Upon reviewing the raw data, the spasticity values were found to differ by only one level (i.e., non-mild or mild-moderate). Since the two assessments could be at different times of the day, variations in spasticity of up to one level can be expected. This possibility was supported upon review of the assessment schedule and the subject's medical condition. The difference in balance assessment cannot be accounted for with the data from this study; therefore, the assessment criteria must be modified to provide a better definition of balance.

In terms of range of motion, plantar flexion and hip extension measurements showed the largest between-assessment differences (70 percent the same). For these cases, the on-site orthotist indicated no range of motion problem but the orthotist/therapist team recorded a range of motion problem. These results could be attributed to differences in subject's position during measurement (i.e., whether the subject was measured sitting or lying down), confusion between angular conventions (i.e. is the angle measured clockwise or counter clockwise), and/or what normal values were used (i.e., what is functionally normal). The other lower limb range of motion measures had acceptable between-group similarity scores (mean = 86.0%, standard deviation = 7.1).

Strength measures were the most variable assessment results (mean = 68.8%, standard deviation = 11.21). Dorsiflexion strength was the most similar measure while inversion, hip

flexion, hip extension, and hip abduction were the least similar. General trends showed that, of the ankle and knee measures that were different, the on-site orthotist rated strength higher than the orthotist/therapist team. The orthotist/therapist team generally rated the hip strength higher than the on-site orthotist. These differences were very consistent within subjects since the strength rating trends differed for only two cases over all lower limb measurements. Strength measurement discrepancies could be attributed to individual differences in the way strength is measured by an orthotist compared with a physiotherapist or occupational therapist.

#### Gait data

The gait data section of the clinician questionnaire described how the person walked. Since the video record from one subject was corrupted, gait data analysis was completed for 17 subjects. Discrepancies between the on-site and remote assessments were found for inversion/eversion, lateral trunk flexion, excessive knee flexion, and knee hyperextension (all with 71% similarity score). The remaining measures included foot drop, hip hike, vaulting, genu valgum or varum, protective pain gait, and rhythmic disturbance (average = 86.6, standard deviation = 6.0).

In three of four different inversion/eversion assessments, the on-site orthotist indicated inversion/eversion while the on-line orthotist did not indicate a problem. This result was consistent with the pretest sessions where the on-site orthotist consistently indicated inversion/eversion problems while the on-line orthotists did not record a problem. The clarity of the video may have been a factor for picking up fine motions, such as inversion/eversion. Since only two to three walking strides were captured, the inversion/eversion problems may not have been available in the video clip. Often inversion/eversion problems are due to fatigue and take some time to notice. The on-line orthotist must rely on the on-site therapist to choose a representative video clip for analysis.

For lateral trunk flexion, the orthotist/therapist team consistently indicated that excessive lateral bending occurred. The on-site orthotist only indicated excessive lateral bending for one client. This difference could be attributed to the availability of a frontal-view video tape for the remote orthotic assessment. It may be easier to

identify excessive lateral trunk bending by slowing a video clip or stopping the video to look at representative images during the gait cycle.

Most of the excessive knee flexion and knee hyperextension discrepancies were found on the last clinic visit and occurred with subjects that had numerous gait deviations. No pattern was found for between-clinician differences at the knee.

#### Computer assessment results

The data for all four Mobile Clinic trips were included in the computer assessment analysis since data from the first trip helped show the progression from a novice to an experienced user. The temporal results are shown in Table 1.

Improvement in remote assessment efficiency was shown for the first three trials. In fact, almost 50 percent improvement occurred between the first and third sessions. Results from the third session were comparable with the time required to do an on-site assessment. For the fourth trial, some telecommunication problems adversely affected the time required to complete each assessment. The communication system, had to be restarted many times due to bad telephone connections.

These results show the importance of training. A medical distance communication system should not be expected to work at peak efficiency during the first session. Staff training on using the computer, using the distance communication tools, and "live" practice sessions are essential to

Table 1. Computer and off-line time for orthotic assessments

Trip	Measure (min)	Mean	Std Dev
1	Computer time	83.75	38.60
	Off-line time	13.75	4.79
2	Computer time	53.33	15.38
	Off-line time	12.50	2.74
3	Computer time	43.33	16.02
	Off-line time	15.00	0.00
4	Computer time	60.83	14.29
	Off-line time	27.50	12.14
All	Computer time	58.18	23.98
	Off-line time	17.50	8.96

optimize the distance communication process.

The system ratings also improved between sessions. None of the measures had poor ratings and below average ratings were only recorded for the first session. The majority of responses were above average or excellent in all areas except ease of assessment and confidence of assessment (Table 2). It was not surprising that the on-line orthotist considered the ease of assessment and assessment confidence to be average since the distance communication system should be at least as good as a regular assessment. Cases where the rating was above average or excellent may be related to improved gait analysis tools or obtaining a different perspective from the remote clinician. Subjectively, it appeared that the expectations of the on-line orthotist may have increased as the study progressed. Increased expectations, in association with telecommunication problems, may account for the less favourable overall satisfaction rating in trial four.

#### Debriefing

A series of questions related to the distance communication system, system training, clinical factors, and future possibilities were answered during the debriefing session. While issues raised during this session are covered in discussion, the following factors should be emphasised:

- distance communication should provide more efficient and more available rehabilitation services for remote communities;
- a reliable modem connection does not always occur (i.e., the modem may disconnect during a session);
- a good quality speaker-phone is essential;
- adequate time must be given to learn how to use the communication system and to develop confidence in the measurements/ information;

- an on-site technical person should be designated to provide hardware and software support;
- this technology is also applicable to other areas of physical rehabilitation.

#### Discussion

The results and debriefing feedback supported the use of distance communication technology for remote orthotic assessment. While it is recognised that a larger sample size is required to ensure that this assessment method is valid, these test results have provided insight regarding system requirements, setup, and clinical considerations.

The computer distance communication system used in this study was an effective tool for remote orthotic assessment. The P2P software and hardware provided some setup difficulties; however, it provided an effective means of sharing images between sites using a variety of communication protocols (i.e., modem, Internet).

Of prime importance was the ability of the central orthotist to see the client "live". Even with the slow frame rate, the consulting orthotist considered the verbal and visual interactions with the client to be an essential part of the assessment. By seeing the client, the orthotist could perceive nonverbal feedback that may not be expressed in a verbal exchange. This visual feedback provided insight into the person's status. The orthotist could also monitor any measurements or interventions that were done at the remote site. Since live-video uses much of the available bandwidth, the live-video mode was often deactivated to increase overall system performance. Improvements in data compression and data transfer rates should improve live-video speed and quality.

While video is essential for adding a personal element to the assessment session, the

Table 2. Responses from computer assessment questionnaire (% of responses from all trips)

Measure	Below average	Average	Above average	Excellent
Ease of use	18,2	4,5	63,6	13,6
Ability to understand remote person	4,5	9,1	27,3	59,1
Ease of assessment	13,6	59,1	18,2	9,1
Confidence in assessment results	13,6	45,5	18,2	22,7
Overall satisfaction	-	13,6	59,1	27,3

Chalkboard feature was the most beneficial for discussions and system training. The Chalkboard was typically used to discuss captured still images, reference images, or to learn how to use related programmes or features. Once a person knows how to turn the system on and use the Chalkboard, most other system functions can be taught on-line.

A low-end speaker-phone proved to be unacceptable for interactive clinical assessments. Since the clinic area may have background noise, more than one person will be involved with the assessment, and the subject may not be close to the speaker-phone (i.e., on an assessment table), a good quality audio system is required. Language problems (french/english) were exacerbated with inferior audio quality. An ideal full-duplex system would detect sound from at least three meters away and play back the sound with a quality comparable to a regular telephone conversation. The system should also function well during a conference call.

The clinician's efficiency and confidence with the system improved over the four test trials. This improvement could be attributed to growing experience with the communication system and with general computer operations. The quality of interactions between the remote therapist and the on-line orthotist may have also improved throughout the study.

While the distance assessment pilot testing was successful, improvements could be made in certain areas. These areas included medical history, prescription and complicating factors, spasticity, range of motion, and strength. Discrepancies between the on-site and on-line orthotists could be attributed to:

- the subjects being assessed as part of the study and not necessarily because of a specific problem. If a specific problem existed, the assessment would be more focussed and related reference documents would be present (i.e., prescription, referral, related medical history);
- measurement, interpretation and clinical techniques vary between fields of orthotics, physiotherapy and occupational therapy. These differences can especially affect strength and range of motion measurements and reporting;
- a client could give different information during an interview with a familiar therapist

than an orthotist they are meeting for the first time;

- personal differences in interpretation can adversely affect gait analysis results;
- since the two assessments occurred at different times in the day, the person's strength and range of motion may vary. The patient may also give a different focus to the medical history depending on when they are interviewed;
- poor audio quality could adversely affect interview responses;
- video quality may make it difficult to detect small variances in walking gait. Care must be taken to videotape the user in the best conditions (i.e., good lighting, camera angle, lift trousers up to show brace, etc.). The orthotist must also rely on the remote therapist to select an appropriate video clip for analysis.

Inter-assessment discrepancies for range of motion, strength, and gait analysis showed consistent trends. These trends involved one group reporting slightly higher results than the other group (usually within one rating). Since the differences are consistent, the discrepancies are likely protocol or interpretation related as opposed to random error. Further instruction should help coordinate these assessment results.

An on-line database was an effective tool for remote orthotic assessment. The assessment database provided a consistent method of approaching an orthotic problem. This consistency should reduce communication errors due to terminology, measurement technique, or data entry methods. To achieve this consistency, staff at the remote and central sites must be adequately trained with the assessment protocol. Without adequate training, inter-discipline differences could affect the test results. This database/training combination is very important when providing consulting services to a variety of remote locations. As distance communication technology is adapted to different fields, databases and protocols specific to the discipline are required to accommodate different assessment perspectives.

The need for a good rapport between the central and remote clinicians was frequently mentioned as an important factor. Clinicians will work in a much more efficient and accurate manner when they understand how each other works, know the other person's abilities, and know how each other uses the distance

communication tools. Since the consulting clinician must rely on the remote clinician as an extension of his or her hands and clinical eye, confidence in each others skills is essential to prolonged success. The project clinicians suggested that face-to-face meetings/educational sessions would help maintain a confident medical distance communication relationship.

Other initiatives that would benefit a distance communication programme include designation of on-site technical expertise, scheduling of regular on-line sessions, and organizing a network of expertise between centres. While the consulting site should assume some leadership regarding the technical aspects of setting up, using, and maintaining the computerized communication system, developing on-site experience with system use and maintenance is important. The on-site technical person would help train new people on the system, help troubleshoot problems, and help integrate the system into hospital specific networking initiatives. The technical person would also support communications between other remote sites (i.e., communications that do not involve the central rehabilitation site).

A regular on-line consultation session would be beneficial from a scheduling and skill maintenance perspective. If regular on-line rounds or on-line clinics were scheduled, both sites could be assured that the appropriate clinicians are present for consultation. This time could also be used for educational sessions. Regular on-line communications would also ensure that the remote clinicians maintain their computer system skills. While these interactions would be beneficial to the patient and medical professional, long-term funding and resources for these on-line clinics and consultations must be considered.

In addition to consultations with a specialized rehabilitation centre, the remote hospitals could connect with each other to share local expertise or hold meetings. On-line meetings would work best if limited to two sites with no more than four people around the computer screen.

### Conclusion

Based on the test results and the clinician feedback, computerized distance communication can be considered an appropriate technology for consultations in orthotics and many areas of physical rehabilitation. The low-cost solution

presented in this report should make remote assessment accessible by most clinics in Canada since existing communication lines can be used, low-end computers are required, and the system is easy to use. Methods for applying this technology could also be exported internationally so that developing countries may take advantage of foreign medical expertise.

While this assessment approach was considered effective, assessment discrepancies were found between clinicians. To reduce the chance of communication error a consistent and reliable assessment protocol should be employed. This protocol would be enhanced by maintaining a rapport between the remote and central rehabilitation sites. An evaluation of assessment/follow-up reliability with a larger sample size should be performed; however, many sites must be on-line to provide the subject base to carry out such a project.

### Acknowledgments

Clinically, the efforts Nathalie Anglehart, David Nielen (The Rehabilitation Centre - Ottawa); Sheila McBride, Linda Buttle and Sheila Cameron (Arnprior and District Memorial Hospital); and Leslie Bangs, Andrée Campbell, Rachel Bertrand (Hawkesbury General Hospital) were essential to this project. Gayle Greene and the Terry Fox Mobile Clinic team are acknowledged for sharing their community-based experience and providing physical space for the host system. Guy Morazain, Colin MacKenzie (ROHCG) and the IBM Ottawa staff are also acknowledged for their technical assistance. This project was funded by the National Strategy for the Integration of Persons with Disabilities (Industry Canada), the Labatt's Relay Research Fund, and IBM Canada.

### REFERENCES

- ALLEN A, HAYES (1994). Patient satisfaction with telemedicine in a rural clinic. *Am J Public Health* **84**, 1693.
- BALL K (1994). Riding the superhighway of education with video teleconferencing. *Minimal Invas Surg Nurs* **8**, 114-115.
- BERGER N, EDELSTEIN JF, FISHMAN S, HOFFMAN E, KAUFMAN M, KRETZS D, SPRINGER WP (1981). Lower limb orthotics: including orthotists' supplement. - New York: New York University Medical Center
- BERGMAN R (1994) The world at their fingertips: rural providers turn to Internet. *Hosp Health Netw* **68(14)**, 52.



- CARLSON B (1994). Telemedicine comes of age. *Alabama Med* **94**(3), 11-18.
- CHAVES-CARBALLO E (1992). Diagnosis of childhood migraine by compressed interactive video. *Kansas Med* **93**, 353.
- DUMAY ACM (1995). Medicine in virtual environments. *Technol Health Care* **3**, 75-89.
- ENGLAND CF, FANNIN RF, SKAHAN JE, SMITH HW (1977). A manual of lower extremity orthotics./edited by MH Anderson. - Springfield: CC Thomas.
- FERRER-ROCA O, DIAZ-CARDAMA A, PITTI S, RAMOS A, GOMEZ E, TEJERA A, SPENCER J (1995). Telemedicine in the Canary Islands. *Lancet May* **6** **354**, 1177-1178.
- GREENE G (1993). The Terry Fox Mobile Clinic: out-reach rehabilitation in eastern and northern Ontario. *Can J Rehabil* **6**, 219-224.
- HUBBLE JP, PAHWA R, MICHALEK DK, THOMAS C, KOLLER WC (1993). Interactive video conferencing: a means of providing interim care to Parkinson's disease patients. *Mov Disord* **8**, 380-382.
- JENNETT PA, WATANABE M, HALL WG (1995). The use of advanced computer technology to enhance access to health care and to respond to community needs: the results of the evaluation of a technology-based clinical consultation service. In: MEDINFO 95; proceedings./edited by RA Greenes. **8**(2), 1497-1481.
- JEROME L (1993). Assessment by telemedicine (Letter). *Hosp Community Psychiatry* **44**(1), 81.
- KAYSER K, DRLICEK M (1992). Visual telecommunication for expert consultation of intraoperative sections. *Zentralbl Pathol* **138**, 395-398.
- LEMAIRE ED (1993). Distance education technology for prosthetic CAD/CAM instruction. *J Prosthet Orthot* **5**, 82-87.
- LEMAIRE ED, JEFFREYS Y, MORAZAIN G, GREENE G (1977). A model for remote lower-extremity orthotic assessment and modification using distance communication technology. *Saudi J Disabil Rehabil* **3**(1), 1-13.
- LEWIS M, BOYD MOIR AT (1995). Medical telematics and telemedicine: an agenda for research evaluation in Scotland. *Health Bull (Edinb)* **53**, 129-137.
- LING R (1993). Telemedicine: treating the patient by remote control. *Jr Nav Med Serv* **79**, 145-147.
- McCullough NC, Fryer CM, Glancy J (1970). A new approach to patient analysis for orthotic prescription - part 1: the lower extremity. *Artificial Limbs* **14**(2), 68-80.
- McNamara DM (1994). Health-orientated telecommunication: a community resource. *Nurs Manage* **25**(12), 40-41.
- PADEKEN D, SOTIRIOU D, BODDY K, GERZER R (1995). Health care in remote areas. *J Med Syst* **19**, 69-76.
- PEREDNIA DA, ALLEN A (1995). Telemedicine technology and clinical applications. *JAMA* **273**(6), 483-488.
- PEREDNIA DA, BROWN NA (1995). Teledermatology: one application of telemedicine. *Bull Med Libr Assoc* **83**, 42-47.
- PUSHKIN DS (1992). Telecommunications in rural America: opportunities and challenges for the health care system. *Ann NY Acad Sci* **670**, 67-75.
- RAFUSE J (1994). University of Alberta program links northern hepatitis patients with southern consultants. *Can Med Assoc J* **151**, 654-655.
- REPONEN J, LÄHDE S, TERVONEN O, ILKKO E, RISSANEN T, SURAMO I (1995). Low-cost digital teleradiology. *Eur J Radiol* **19**, 226-31.
- SANDERS JH, TEDESCO FJ (1993). Telemedicine: bringing medical care to isolated communities. *J Med Assoc Ga* **82**, 237-241.
- SARRAFIAN SK (1985). Functional anatomy of the upper limb. In: Atlas of orthotics: biomechanical principles and application/ American Academy of Orthopedic Surgeons. - St. Louis: CV Mosby. p35-41.
- SATAVA RM (1995<sup>a</sup>). Medical applications of virtual reality. *J Med Syst* **19**, 275-280.
- SATAVA RM (1995<sup>b</sup>). Virtual reality and telepresence for military medicine. *Comput Biol Med* **25**, 229-236.
- SOLOMON PA, TORMA MJ, STRICKLAND RM, MARTIN PS, CASON V, ANDERSON D, RAINWATER P, STERNS B (1996). Dermatology screening with telemedicine (Letter). *J Fam Pract* **42**, 84-85.
- VON HANWEHR R, POPESCU GF, TAYLOR HE, WINKLER KH, SWENBERG CE (1995). Interventional telemedicine for noninvasive neuroradiology: remote-site high-performance computing, mathematical optimization, and virtual scenario simulation. *J Med Syst* **19**, 219-262.
- WEBER D (1990). Clinical aspects of lower extremity orthotics. *Elgan Enterprises* p83-86.
- WILLIAMS ME, RICKETTS TC, THOMPSON BG (1995). Telemedicine and geriatrics: back to the future. *J Am Geriatr Soc* **43**, 1047-1051.
- WILSON KG, CRUPI CD, GREENE G, GAULIN-JONES B, DEHOX E, KOROL CT (1995). Consumer satisfaction with a rehabilitation out-reach program. *Arch Rehabil Med* **76**, 899-904.
- WITTONSON CL, AFFLECK DC, JOHNSON V (1961); Two-way television group therapy. *Ment Hosp* **12**, 22-23.

## Book Reviews

### **A primer on amputations and artificial limbs**

**G. Murdoch, A. Bennett Wilson Jr.  
Charles C. Thomas, Springfield, USA, 1997  
ISBN 0-393-06800-3  
\$63.95 (Cloth): \$49.95 (Paper)**

New monographs on the topic of amputation and prosthetics do not appear often. Two years ago, however, the same authors published "Amputation. surgical practice and patient management." Butterworth Heinemann, Oxford, England (ISBN 0-7506-0843-9). This book, however, was produced with about 30 authors and based on the consensus conference held in Glasgow 1992 and comprised 390 pages. The new book called a primer based on the same material but now brought together by the authors themselves although a lot from the first book can be recognised. Good news can well be repeated. The paper quality of the older and bigger book is somewhat nicer to turn over the pages in.

George Murdoch was professor of orthopaedic surgery at the University of Dundee and Bennett Wilson mechanical engineer at the University of Virginia. Both have been prominent in ISPO. They express a combined century of experience in amputation surgery and prosthetic fitting as said by John Bowker from Miami in his foreword.

The book is condensed and excellently written with focus on relevant details. It is sectioned separately in surgery and prosthetics rather than taking it level by level. All the major contributions and contributors to the development are referred to from the SACH foot to the FLEX foot and from wooden handcraft to high tech modular systems. It acknowledges also the users through the Amputee Coalition of America and the International Standards Organisation for its work in unifying nomenclature etc.

Of course there must be something missing

even in a good book. No reference has been made to Eneroth's and Dickhauts' works on the importance of improved nutrition in the elderly to improve healing at amputation. It does not mention vital microscopy for classifying skin circulation but the chapter on level selection as all the others are well balanced. For the skew flaps on page 86 they say they are posteromedial and anterolateral which should be posterolateral and anteromedial instead. There is no advice to use a tourniquet for knee disarticulation which would be helpful. I also question their advice to have the patient placed prone for knee disarticulation. It is usually much easier for the operating room staff with a supine position and I would say at least equal for the surgeon and assistant. Gottschalk's sagittal incisions with adductor longus myodesis for the transfemoral level is suggested as the standard. I question their repeated advice that stumps should have their bandages changed three to four times daily with massage of the skin at each change. I question whether there is any scientific base for this advice. Silicon liners according to Kristinsson are described but not the polyurethane TEC interface material which has provided new possibilities to reduce pain and improve socket fit.

There are special chapters concerning child amputees and elderly. The last one could have more on nutrition and the importance of the standing balance etc. Maybe we also miss a chapter on special limbs for athletes like the Reflex foot etc. The book ends with a good subject index and illustration index.

In total, the book is needed and recommended for orthopaedic surgeons in training and for prosthetists.

Bjorn Persson  
Department of Orthopaedics  
Helsingborg Hospital  
Sweden.

**An atlas of lower limb orthotic practice**  
**David N. Condie, Michael S. Turner**  
**Chapman & Hall, London, 1996.**  
**ISBN 0-412-727706**  
**pp85, illustrated**  
**£39.**

This is not a textbook of orthotics, but properly titled an Atlas of Lower Limb Orthotic Practice. It is a hard cover, high quality book. With few exceptions the illustrations are of high quality as well.

The Foreword by Professor Rowley best expresses the philosophy practised at the Dundee Centre as it should be practised everywhere. The team approach to orthotics management and the admission that people other than physicians have certain know-how and "acknowledgement of one's limitations and of others' value is not an admission of weakness but rather of strength". This is the finest attribute of a physician in the rehabilitation setting.

Another philosophy expressed throughout the book is that one should treat the disability rather than the disease. The chapter on biomechanics is standard and includes a short section on pathomechanics and orthotic biomechanics.

Generally throughout the chapters on orthotics, there are illustrations of the physical problem followed by a schematic of the biomechanics and the appropriate orthoses indicated for the problem. The chapter on foot orthoses is especially well done following this pattern.

While most of the principles for orthotic indications are well illustrated, except for torsional, i.e., transverse rotational control, the number and variety of orthoses shown is limited. This is particularly true in the chapter on knee orthoses. There is a dearth of illustrations of orthoses commonly used in North America. The list of Further Reading is also quite limited.

Overall the book is based on the fine practice of orthotics at the Dundee Teaching Hospitals NHS Trust which has a deservedly fine reputation.

H. Richard Lehneis  
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 Medicine  
 New York University Medical Center, USA.

**Amputation und Prothesenversorgung der oberen Extremität**  
**Amputation and prosthetic fitting of the upper limb**  
**R. Baumgartner, P. Botta**  
**Ferdinand Enke Verlag, Stuttgart, 1997**  
**ISBN 3-432-27281-2**  
**308 pp., 684 Illustrations (73 of these in colour), 4 Tables**  
**DM 228.- : ÖS 1664 : SFr 202.-**

This excellent and comprehensive German language text addresses all aspects of rehabilitation following upper limb amputation. Topics include etiology, indications/contraindications for amputation, choice of amputation level, surgical procedures, prosthetic fitting, physical therapy and occupational therapy interventions, issues related to the management of the stump and rehabilitation outcomes. Readers will recognize the format as identical to "Amputation and prosthetic fitting of the lower limb" (1st edition 1989, 2nd edition 1995) by the same authors. All illustrations (photographs, drawings and diagrams) are of prime quality and enhance the text.

The aim of all upper limb rehabilitation teams is to train recent amputees to achieve not only their highest level of functional ability, but also the best possible reintegration into family, occupation and society, with or without a prosthesis.

#### **Etiology, amputation levels, surgery**

A thorough preoperative assessment, treatment planning and surgical management are prerequisites for a successful rehabilitation outcome. Rationale is given for the level selection of fingers and hand and arm segments severance and is related to the reason for amputation i.e. trauma, pathological and congenital conditions. As amputations are irreversible, the surgeon's choice of the amputation level is critical.

The chapter on amputation surgery is divided into a general and a specific section. The general section identifies preoperative issues such as informing the patient, anesthesia, positioning, operative principles, surgical instruments and the nature and condition of tissues (skin, musculature, nerves, bones). The specific

section offers a wealth of surgical information based on clinical experience from the loss of a finger segment to the forequarter amputation. Specific procedures for fingers and the hand, including replantation, reconstructive surgery and amputation are described as the goal of these procedures is the preservation of tissues and maintenance of motor and sensory functions. The author holds the view that, if possible, wrist disarticulation and elbow disarticulation are preferable to mid trans-radial or trans-humeral amputation because with present day technology any stump length can be fitted.

High amputation levels or bi-lateral amputations are most debilitating and thus require an extremely complex rehabilitation process.

Surgical revisions such as angulation osteotomies and segment lengthening may be indicated to improve the quality of the stump (comfort, sensation, function). Two unique revision techniques namely the Sauerbruch biceps cineplasty and the Krukenberg amputation, although seldom practiced, should not be overlooked entirely as they are indicated under certain circumstances.

The author also highlights that immediate postoperative care requires meticulous ongoing control of the wound healing process, positioning and appropriate drug management.

### **Prosthetic fitting**

An amputation has a profound effect, both physically and emotionally on the client's life style. Nowhere else in medicine is there a greater challenge to bridge the gap between the amputee's expectations and reality. In spite of technological advances no prosthesis to date can duplicate the skills and coordinated mobility of the human hand. Furthermore, the key to successful rehabilitation remains client choice. The team has a responsibility to support the decision of clients regardless of whether they choose to use a prosthesis or not.

Several prosthetic systems can be utilized for prosthetic fitting. These include passive (cosmetic) and active prostheses. A passive device having limited functional value can still contribute to independence, primarily for high level amputations. Active prostheses are either muscle powered, cable operated conventional

units or they are externally powered, motor-battery operated myoelectric systems. Conventional prostheses permit sensory feedback and with it gradient grip control. Myoelectric prostheses do not. Sight and hearing assist in controlling prehensile movements. A hybrid prosthesis is a combination of the above systems. These systems are outlined in detail in this chapter.

Socket fabrication techniques describe how shape, alignment and materials determine function and comfort. Passive and active terminal devices (hooks and hands), wrist and elbow units (with and without locking mechanism) and suspension systems are discussed and related to function and client's needs. The unique needs of young children are also addressed. Consideration is given whether to fit them myoelectrically or not. Readers are introduced to individual fitting methods for all amputation levels. The indications for prosthetic fitting, passive and active prostheses, sockets with and without liners are presented. Temporary postoperative fitting techniques are compared to definitive fittings following stump maturation.

### **Physical therapy and occupational therapy**

Clients must understand that a prosthesis, no matter how sophisticated is only an assistive device and that the use of a prosthesis is a learned skill. This learning process is guided by physical therapists and occupational therapists.

Physical therapists are primarily responsible for chest care and increasing the exercise tolerance for the entire body. Treatment objectives are to maintain and increase muscle strength and joint mobility, and to stimulate and improve coordination which in turn should help to integrate the stump movements into functional activities.

Occupational therapists concentrate on activities of daily living (ADL) and prosthetic training. All treatments are task-specific. Activities include practising donning and doffing the prosthesis, opening and closing the terminal device, reaching for and holding objects, dressing, eating, writing, personal hygiene, household chores, driving, office skills and computer training as well as job skills and recreational activities. The sound limb becomes

dominant, quite a challenge if the former nondominant limb has to carry out one-handed activities (e.g. writing). For two-handed activities the affected side is trained to assist. Compensatory movements and the use of a variety of assistive devices help clients to accomplish their task. Assistive devices range from simple gadgets such as eating utensils to car adaptations. The iSystem Franzî (foot control design) enables armless clients to drive. Preprosthetic evaluation trial periods with different components determine which prosthetic design is best for the client.

Clients who prefer not to use a prosthesis also need an exercise programme and ADL training to help adapt to an altered mobility pattern and to preserve postural symmetry.

Although functional mobility is a key component during rehabilitation emotional and psychological support is also critical for the successful reintegration of the client into society. Physical therapy and occupational therapy interventions and progression related to biopsychosocial needs of the client during the rehabilitation process are outlined in this chapter.

### **The stump**

The stump has to develop into a motor and sensory organ which must be maintained beyond the prosthetic fitting and rehabilitation phase. The results of clinical examinations (measurements, shape, mobility, skin/muscle condition, pain/sensation and images) are recorded for future management and research projects. This chapter outlines the causes and treatment of upper limb stump problems (i.e.

delayed wound healing, oedema, skin conditions, tumors, exostosis) and indications for stump revisions.

### **Outcomes**

The closing chapter addresses the challenges of identifying measurable and researchable outcomes in upper limb rehabilitation. The population sample size (upper limb amputees) and specific numbers of different levels of upper limb amputees is not sufficient to apply rigorous research methods to a randomized controlled clinical trial. In the absence of research based measurable outcomes physicians evaluate outcomes by assessing iimpairmentî (e.g. amputation level), idisabilityî (e.g. loss of grip) and ihandicapî (e.g. personal and social effects).

This text is organized in a way which clearly outlines the process of upper limb amputation rehabilitation. It is informative, dynamic and at times thought provoking. The presentation of traditional and not so traditional approaches and philosophies are of tremendous value as they challenge clinicians, academics, learners and researchers to question and grow to contribute to the body of knowledge for the benefit of all upper limb amputees.

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Canada

and

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Assistive Devices Branch, Ontario Ministry of  
Health, Canada.

## **Calendar of Events**

### **National Centre for Training and Education in Prosthetics and Orthotics Programme of Short Courses 1998-99**

#### **Courses for Physicians, Surgeons and Therapists**

NC 504	Lower Limb Orthotics;	16th - 20th November 1998
NC 505	Lower Limb Prosthetics	11th - 15th January 1999
NC 518	Upper Limb Prosthetics	27th January 1999
NC 510	Wheelchairs and Seating	2nd - 4th March 1999
NC 514	Orthotic Management of Diabetic Foot	11th - 12th March 1999
NC 511(A)	Clinical Gait Analysis	16th - 17th March 1999
NC 506	Fracture Bracing	24th - 28th May 1999
NC 511(B)	Clinical Gait Analysis	7th - 8th September 1999

#### **Courses for Orthotists and Therapists**

NC 224	Hand Trauma	12th February 1999
NC 225	Orthoses for Brachial Plexus Injuries	26th February 1999

#### **Courses for Technicians**

NC 604	Orthotic Technician Training (4 modules)	7th - 18th December 1998 5th - 15th January 1999 4th - 14th May 1999 17th - 28th May 1999
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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 Road, Glasgow G4 OLS, Scotland. Telephone: (+44) 141-548-3298, Fax: (+44) 141-552-1283, E-mail: [annette.hepburn@strath.ac.uk](mailto:annette.hepburn@strath.ac.uk)

#### **2-8 August, 1998**

3rd World Congress of Biomechanics, Sapporo, Japan.

Information: WCB '98 Congress Office, Biomechanics Laboratory, Dept. of Mechanical Engineering, Faculty of Engineering Sciences, Osaka University, Osaka 560, Japan.

#### **14-18 August, 1998**

North American Congress on Biomechanics, Ontario, Canada.

Information: S. McGill, Dept. of Kinesiology, University of Waterloo, Waterloo, Ontario N2L 3G1, Canada.

#### **23-28 August, 1998**

11th Rehabilitation International Asia and the Pacific Regional Conference, Hong Kong.

Information: Conference Secretariat, Elite Business Services Ltd., GPO Box 847, Hong Kong.

#### **9-11 September, 1998**

Instructional Course on lower limb Orthotic Management of Cerebral Palsy, Ljubljana, Slovenia.

Information: Ela Loparic, Institute for Rehabilitation, Linhartova 51, 1000 Ljubljana, Slovenia.

**11-13 September, 1998**

2nd Central and Eastern European ISPO Conference, Portorose, Slovenia.

Information: Ela Loparic, Institute for Rehabilitation, Linhartova 51, 1000 Ljubljana, Slovenia.

**16-19 September, 1998**

AOPA National Assembly, Chicago, USA.

Information: Annette Suriani, AOPA, 1650 King St., Suite 500, Alexandria, VA 22314, USA.

**17-18 September, 1998**

23rd Annual Congress of the French Society of Biomechanics, Lyon, France.

Information: M.Lionel Maifreddy, Congress Secretary, INSA de Lyon-Mecanique Generale, Batiment 302, 20 Avenue Albert Einstein, 69621 Villeurbanne Cedex, France.

**28-30 September, 1998**

3rd Combined Meeting of Orthopaedic Research Societies of USA, Canada, Europe and Japan, Hamamatsu, Japan.

Information: Dr. Hayato Hirotoni, Shigetomi Health Care Group, 1-1521 Shikenyu, Moriyamaku, Nagoya, Japan 463.

**9 October, 1998**

Orthotic Treatment for the Impairments of Complete and Incomplete Paralysis and Cerebral Palsy, Oswestry, UK.

Information: Erica Wilkinson, Course Organiser, Institute of Orthopaedics, The Robert Jones and Agnes Hunt Orthopaedic Hospital NHS Trust, Oswestry SY10 7AG, UK. Tel: (+44) 01691 404570. Fax: (+44) 01691 404071

**2-6 November, 1998**

12th Congress of the Western Pacific Orthopaedic Association, Fukuoka, Japan.

Information: Yoshiharu Takemitsu M.D., Secretariat, Western Pacific Orthopaedic Association, c/o Japan Convention Service, Daido-seimei Building 7F, Nishinakasu, 12-33, Chuoku, Fukuoka-810, Japan.

**5-6 November, 1998**

ISPO-France Third Scientific National Congress – 5th Symposium TOI, Lyon, France.

Information: Bawan Evenements, Immeuble Le Rive Gauche, 12 rue Cavenne, 69007 Lyon, France.

**6-7 November, 1998**

ISPO UK Annual Scientific Meeting, Dunblane, Scotland.

Information: Mrs.J.Kingston, DSC Nottingham City Hospital, Hucknall Rd., Nottingham NG5 1PJ, England.

**11-14 November, 1998**

13th World Congress of the International Federation of Physical Medicine and Rehabilitation, Washington, USA.

Information: AAPM&R, One IBM Plaza, Suite 2500, Chicago, IL 60611-3604, USA.

**13-16 November, 1998**

American Academy of Physical Medicine and Rehabilitation Annual Meeting, Seattle, USA.

Information: AAPM&R, One IBM Plaza, Suite 2500, Chicago IL 60611-3604, USA.

**29 November-3 December, 1998**

7th European Regional Rehabilitation Conference of Rehabilitation International, Jerusalem, Israel.

Information: Conference Secretariat, c/o CARMEL Organizers of Conferences and Events, PO Box 1912, Ramat Gan 52532, Israel.

**1-4 December, 1998**

Russian National Congress on "People and Health", St. Petersburg, Russia.  
Information: "People and Health", PO Box 204, 191025, St. Petersburg, Russia.

**7-9 December, 1998**

2nd International Workshop on Biomedical Aspects of Manual Wheelchair Propulsion, Amsterdam, The Netherlands.

Information: Faculty of Human Movement Sciences, Dept. of Kinesiology, Van der Boechorststraat 9, 1081 BT Amsterdam, The Netherlands.

**1999****4-8 February, 1999**

Annual Meeting of the American Academy of Orthopaedic Surgeons, Anaheim, USA.  
Information: AAOS, 6300 North River Road, Rosemont, IL60018, USA.

**3-6 March, 1999**

AAOP Annual Meeting, New Orleans, USA.

Information: Annette Suriani, AOPA, 1650 King St., Suite 500, Alexandria, VA 22314, USA.

**22-25 March, 1999**

1st Arab Regional Conference of Rehabilitation International and 2nd Gulf Congress in Medical Rehabilitation, Kuwait.

Information: Conference Secretariat, PO Box 4070, 13041 Safat, Kuwait.

**26-28 March, 1999**

BAPO Annual Conference, Harrogate, England.

Information: BAPO Secretariat, Sir James Clark Building, Abbey Mill Business Centre, Paisley, Renfrewshire, PA1 1TJ, Scotland.

**2-4 April, 1999**

18th Southern Biomedical Engineering Conference, Clemson, South Carolina, USA.

Information: Subrata Saha Ph.D., Director, Bioengineering Alliance of South Carolina, 313 Rhodes Research Center, Clemson University, Clemson, SC 29634-0906, USA.

**14-17 April, 1999**

2nd World Congress in Neurological Rehabilitation, Toronto, Canada.

Information: American Society of Neurorehabilitation, 5841 Cedar Lake Road, Suite 204, Minneapolis, MN 55416, USA.

**18-23 April, 1999**

SICOT 99-21st World Congress, Sydney, Australia.

Information: Conference Secretariat, SICOT 99 Sydney, Suite 203, 83 Longueville Road, Lane Cove, New South Wales, NSW 2066, Australia.

**26-28 May, 1999**

11th European Congress of Physical Medicine and Rehabilitation, Gothenburg, Sweden.

Information: Gunnar Grimby, Kongresshuset AB, Massans gata 14, 4 tr, S-41251 Gothenburg, Sweden.

**14-17 July, 1999**

14th Interbor World Congress, Boston, USA.

Information: Annette Suriani, AOPA, 1650 King St., Suite 500, Alexandria, VA 22314, USA.



**8-13 August, 1999**

17th Congress of the International Society of Biomechanics, Calgary, Canada.

Information: Secretary General, 1999 ISB Congress, Faculty of Kinesiology, University of Calgary, 2500 University Drive N.W. Calgary, Alberta T2N 1N4, Canada.

**6-9 October, 1999**

AOPA National Assembly, Nevada, USA.

Information: Annette Suriani, AOPA, 1650 King St., Suite 500, Alexandria, VA 22314, USA.

**2000**

**1 June-31 October, 2000**

Health Futures, Expo 2000, Hanover, Germany.

Information: Ms. Monika Gehner, Office of the Director, Division of Health Promotion, Education and Communication, World Health Organization, 20 Avenue Appia, CH-1211 Geneva 27, Switzerland.

**2001**

10th World Congress of the International Society of Prosthetics and Orthotics, Glasgow, UK.

Information: ISPO 2001 Congress Secretariat, c/o Meeting Makers, Jordanhill Campus, 76 Southbrae Drive, Glasgow G13 1PP, UK. Tel: +44 (0) 141 434 1500. Fax: +44 (0) 141 434 1519. E-mail: [ispo@meetingmakers.co.uk](mailto:ispo@meetingmakers.co.uk)