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for Prosthetics and Orthotics

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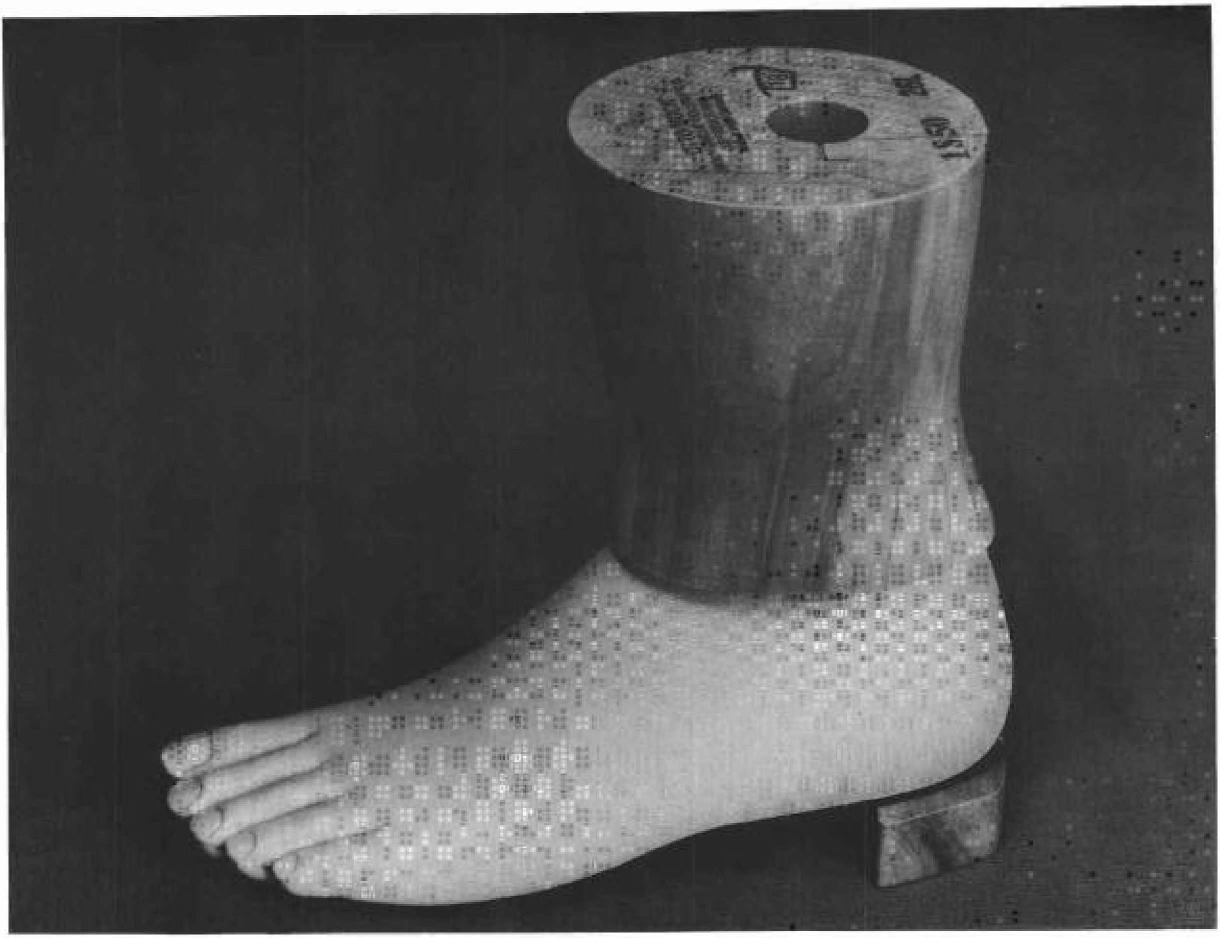

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Executive Board of ISPO

Elected Members:

E. Marquardt (President)	Germany
J. Hughes (President Elect)	United Kingdom
E. Lyquist (Vice President and Hon. Treasurer)	Denmark
S. Fishman (Vice President)	United States
W. H. Eisma	Netherlands
H. R. Lehneis	United States
G. Mensch	Canada
S. Sawamura	Japan
N. A. Jacobs (Hon. Secretary)	United Kingdom

Ex Officio Member:

G. Murdoch	United Kingdom

Secretary

Aase Larsson	Denmark

A full list of Standing Committee Chairmen and International Consultants will be published in the next issue.

Prosthetics and Orthotics International, 1983, 7, 125

Editorial

The President

I would wish to thank the membership for the confidence they have placed in me by electing me as President of our International Society.

It is appropriate for me at the beginning of my period of office to consider the direction which we should follow in the coming triennium.

Firstly, I think we have to put much more work back into the membership at large. There are a number of ways in which I believe we can do this. We should be seeking a big improvement in our communication with National Member Societies so that they are more aware of, and more involved in, international activities. We should be finding ways of communicating the successful activities of our National Societies to the other National Member Societies so that more activity may be stimulated. We should be looking to ways of increasing membership, particularly in those many countries where we only have a handful of members. This, in turn, implies the formation of more National Member Societies, which in itself will require us to provide organizational help to these formative groups. We really must find ways of strengthening and enlarging our membership and knitting it into a more coherent body.

Secondly, I believe we should attempt to improve the services which we provide to our fee paying members. Our journal has, I believe, been a success story, but we have to continue to work to improve it in content, perhaps to enlarge it, and certainly to increase advertising and subscriptions—hopefully to the point where instead of being a charge on the Society, it is a source of income.

We are working towards the improvement of the information services which we make available to the individual member. This may be achieved in a number of ways. I believe we could establish a consultative network—directing specific questions to the expert best able to respond.

Thirdly, we within the Executive Board must examine and improve our procedures, making better use of the many people who are willing to work for us. In this triennium I hope that we will also accomplish the establishment of our computerised Professional Register to give us easy access to our membership when we need them for consultative or teaching duties.

On the question of education we do, as you know, have plans for two major education meetings, one in Canada and one in Sweden. I do believe this is one of the areas where we have shown a lead and where we may continue to influence world opinion. I hope that these two meetings will make further progress and may perhaps extend our interest in this field further into the developing world.

The last area in which I suggest we must be more active, or at least more effective than we have been before, is in the developing world. I mention this subject after the others, not because I believe it is less important, quite the contrary. However, I do not believe that we can make any contribution unless we have a strong, healthy, Society and provide a good service so that we may attract all the best people in our professions.

In September, in London, we held a Pre-Congress meeting of people who are actively involved in the developing world and who provided us with guidelines for our future activities. I hope that this may prove to be the "spring board" for real advancement.

The Congress in London was a great success and I would like to thank the United Kingdom National Member Society for hosting this meeting and particularly the Secretary General of the Congress, George Murdoch, and his hard working team.

Lastly, I would also like to thank the Past President, Eric Lyquist and the past Executive Board for all their activities during the last triennium.

Ernst Marquardt

Prosthetics and Orthotics International, 1983, 7, 126

Fourth Triennial Assembly, 1983

JOHN HUGHES

Honorary Secretary, ISPO

The Fourth Triennial Assembly of the International Society for Prosthetics and Orthotics was held on Friday, 9th September, in London, at the time of the World Congress. The Assembly was opened by the retiring Acting-President, Erik Lyquist, whose report to the Assembly follows. In presenting the report the Acting-President indicated that to avoid repetition it incorporated the reports from the Standing Committees. He invited comment on any aspect from the membership present.

The Honorary Secretary then briefly summarized change to the Constitution which had been published to the membership in the April 1983 issue of "Prosthetics and Orthotics International", and subsequently approved by the International Committee.

Mr. Lyquist then introduced the new Executive Board which had been elected by the International Committee prior to the Assembly. The membership is:—

President	Prof. Ernst Marquardt (FRG)
President-Elect:	Prof. John Hughes (UK)
Vice-Presidents:	Mr. Erik Lyquist (Denmark) Prof. Sidney Fishman (USA)
Fellows:	Prof. Willem Eisma (Netherlands) Dr. Richard Lehheis (USA) Mrs. Gertrude Mensch (Canada) Dr. Seishi Sawamura (Japan)
Honorary Secretary:	Mr. Norman Jacobs (UK)
Honorary Treasurer:	Mr. Erik Lyquist (Denmark)

Professor Marquardt then assumed the Chair and briefly addressed the Assembly. He identified the areas where he felt the Society's priorities should be directed in the coming Triennium. He referred to improvements in the services to the membership and to the need to enhance communication throughout the membership and between National Member Societies. The Society could clearly help in providing improved information services both through the medium of the journal and in response to more specific requests.

Important meetings were scheduled in education to emphasize the importance which was placed on this area. In particular he referred to the need to improve our contribution to activities in the developing world based on a strong and successful International Society.

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President's Report

ERIK LYQUIST

It is a matter of deep regret to open the President's Report by reporting on the untimely death of our Founding President, Knud Jansen who passed away in 1982. The Executive Board were fortunately able to honour Dr. Jansen with the unique title of "The President Emeritus" at the time of the meeting in Køge shortly before his death.

The membership of the Executive Board suffered some changes during the last triennium. Firstly, Dr. Balu Sankaran resigned as Vice-President in 1981, following his appointment to the World Health Organization, which automatically required him to sever his formal relationships with any such Society. Dr. Seishi Sawamura of Japan was invited to join the Board, with the approval of the International Committee, to maintain global representation. Anthony Staros tendered his resignation as President in 1982, at which point I agreed to accept the role of Acting-President for the remainder of the triennium.

These resignations highlighted to the Executive Board deficiencies in the Constitution in respect of procedures to permit replacement in the case of vacancies arising and, consequently, amendments to the Constitution have been proposed by the Board, published to the membership, and will be discussed by the International Committee when it meets in London.

Our World Congresses remain an important aspect of the work of the triennium and this Congress in London is expected to prove extremely successful in all respects. It must be reported that the Bolgona Congress has given rise to very serious problems for the Executive Board. The Executive Board were unable to obtain properly audited accounts from the Congress Organizers, Studio BC of Bologna. Subsequent investigation displayed irregularities in both income and expenditure. The dispute has given rise to a Deed of Summons being presented to ISPO/INTERBOR to appear before the Court in Bologna. These organizations have jointly appointed Counsel and are defending the position of the Society.

With regard to future World Congresses, bids to hold the 1986 Congress have been presented by Israel and Denmark. These bids have been scrutinized by the Officers of the Board, who are unanimous in recommending that the 1986 Congress be held in Copenhagen. The Japanese National Member Society has indicated its intention to submit a proposal that the 1989 Congress be held in Japan.

The Society has continued to maintain and extend its interactions with other international and national bodies. These activities have been in the spirit of the Declaration of the International Year for Disabled People which the Society proclaimed following the last World Assembly. Relations have been maintained with Rehabilitation International in retaining our membership of RI, representation at their World Assembly in Budapest by our President-Elect, Ernst Marquardt, and specifically through our contacts with the International Commission on Technical Aids. Our Past-President, George Murdoch, attended the last meeting of ICTA in Copenhagen in April of this year. I myself attended the World Assembly of the World Veterans Federation in Nice in 1982. Sidney Fishman attended the IYDP Seminar in Vienna in 1981. He also attended the Conference of Non-Governmental Organizations Interested in the Handicapped in New York in 1982. These activities have all been concerned with improving our communication with, and influence on, the activities of these various international agencies. We have attempted to improve our communication with IVO (the

International Orthopaedic Shoemakers Organization) through personal contact by President-Elect, Ernst Marquardt. We have also, during this period, collaborated in different ways in scientific meetings of other national and international societies.

We have maintained our interest in the developing countries which led to the establishment of the Task Force. The Board has specifically invited Sepp Heim to develop a Design and Lay-Out manual to assist those nations who are attempting to set-up local facilities, and have also invited him to collaborate with Jørgen Fischer in producing a manual on Lower Limb Orthotics using constructions and techniques appropriate to the developing countries. Prior to this meeting a two-day meeting was held in London of invited experts with substantial personal experience in the developing countries to provide information to the Board indicating how ISPO may best contribute.

On the educational front an extremely successful international course was organized in Køge, Denmark, on Through-Knee and Below-Knee Amputations and Prosthetics. Selected contributions from that meeting formed the basis of a special edition of "Prosthetics and Orthotics International", which is referred to later. Plans have also proceeded for the organization of two international educational meetings, one to be held in Sweden and one in Canada. These meetings are seen as a continuation in the series which commenced in Holte, and then in Strathclyde, to establish the basis of educational systems in prosthetics and orthotics. Specifically, they will address themselves to such matters as practical instructional techniques and standards of training, and will also consider the requirements of the developing world and of courses for instructors who will work there.

During the triennium the Information Centre has been transferred from the National Prosthetics/Orthotics School in Oslo to the National Centre in Glasgow, where "Prosthetics and Orthotics International" continues to be produced. Our journal continues to improve in quality, and through improved circulation and advertising income to reduce the drain on the Society's resources. The number of subscribers is currently about 350. Committee members will know that the August issue of the journal constituted the special through-knee edition, based on the Køge course. This special issue was under the guest editorship of Dr. Steen Jensen of Copenhagen, who is to be commended for his initiative and his hard work. I am sure that the International Committee will join the Executive Board in extending our thanks to him for his efforts. It is the intention that such special issues providing source information on specific problems in prosthetics and orthotics and under the guest editorship of prominent practitioners will form a regular feature of the journal. We are also grateful to A. Bennett Wilson for producing the Fact Sheet on the Society, which provides a useful flyer at conferences and in other situations in providing information to prospective members.

A new Directory of Members has been produced in Glasgow, and will, after final scrutiny by National Societies, be available to the membership. The Executive Board decided, following representation from a number of National Member Societies, that all classes of member should have a Membership Certificate. These were produced in a new elegant format and have been distributed.

The Society has continued to collaborate closely with the International Standards Organization in the development of standards within our area of interest. In particular we have worked in ISO TC 168 on prosthetics and orthotics, and in TC 173 on Technical Aids and Systems for Disabled or Handicapped Persons. We have played an important role in co-ordinating certain aspects of the work of these committees which is common to our field. The work of Bjorn Persson on stump classification is currently being evaluated and will be used as appropriate in these ISO committees.

The membership of the Society has continued to grow at a slow, but steady rate. It currently stands at about 1,500 members (excluding journal subscribers). It is intended that within the next few months work will commence on the development of the Professional Register, which will provide, in a readily accessible form, further information about such things as the professional discipline of the individual member, his activities and his availability for teaching or consultative duties. This will be achieved at relatively little cost by changes in the processing of our membership file by our computer organization. It will, of course, require the co-operation of the membership and it is hoped that National

Member Societies will play a role in enabling this important work to proceed as quickly as possible.

It has proved possible to maintain the membership fee at the same level in 1982, 1983 and 1984, with, in the same period, a small but steady increase in the journal subscription costs to the point where in 1984 the membership fee will be $40 (U.S.) while the journal subscription will be $45 (U.S). The financial situation, as displayed in the Society's balance sheet is a healthy one. The Board now hopes that it will be possible to support a number of projects in the coming triennium to enable committees and National Member Societies to work towards the identified goals of the Society. It will, of course, be necessary to maintain a contingency fund to ensure stability.

The National Member Societies continue to develop and to provide important national activities for our membership. Many successful scientific meetings and other events are held each year. It is hoped to improve communication between National Member Societies and to improve our interaction with them.

The activities of the last triennium may be seen as a consolidation of the Society and of the continued expansion of its international influence.

Congress Report

GEORGE MURDOCH

Our Fourth World Congress is now over and by all accounts it seems to have been a very successful event. Despite the indicators we had fine Autumn weather with lots of sunshine. This good fortune and the abundant delights of London provided an excellent backcloth to our activities. Her Royal Highness, The Duchess of Gloucester opened the Congress and the Exhibition. Her evident interest and concern for our objectives gave a wonderful send off to the week.

More than 700 participants from 48 countries attended the Congress. The subject matter covered all aspects of prosthetics, orthotics and rehabilitation engineering and the unique multi-disciplinary structure of ISPO ensured comprehensive discussion and lively debate. The papers presented by international authorities in plenary session provided an overview of progress made in the last triennium and indicated something of the promise for the future. These presentations included amputation surgery, upper and lower limb prosthetics and orthotics, spinal problems and a special section on the severely disabled. In the afternoons concurrent sessions permitted in-depth discussion of the subjects covered in plenary session and an opportunity for the presentation of papers by contributors from 28 different countries over a wide range of subject areas, from the special problems of the elderly and the developing countries to control theory, gait analysis and biofeedback. On each day there was a concurrent programme of films and video-tapes covering some 30 different subject areas. Following the pattern established in New York and repeated in Bologna we offered instructional courses in some 25 subject areas. These courses presented a body of knowledge on techniques and procedures which have been tried and tested in the field enabling the participants to go home and apply them to their patients with confidence.

The exhibition, housed on two floors of Imperial College, included over 40 commercial exhibitors and a substantial number of high quality scientific exhibits. The mixing of commercial and scientific exhibits spiced with two bars ensured an excellent meeting place for all participants and the exhibitors were assured of excellent exposure of their products. An innovation on this occasion was the inclusion of scientific posters which further served to embellish the exhibition. However, it is a pity that more commercial exhibitors did not find it worthwhile to come to the Congress. I feel sure that with hindsight they will have regretted their absence.

The social events provided opportunities for participants from distant lands to renew their friendships and exchange experiences. The United Kingdom government in the person of the Minister for the Disabled, Mr. Tony Newton, hosted a Reception in the Geological Museum; this was a splendid affair with generous hospitality against a fascinating background. The event was much appreciated by our overseas visitors. Many members and friends joined a boat trip down the Thames on the Wednesday evening and danced to disco music. The final social event, a Gala Evening, held in the Porter Tun Room of the Whitbread Brewery, was a happy and enjoyable evening for all with music provided by John Florence and his Riverside Jazz Band, excellent food and wine and varied entertainment from itinerant magicians and Russian dancers.

We can look back on another successful Congress and the membership, I am sure, will join me in thanking the people from many parts of the world who gave advice, co-operation and assistance in the planning and organization.

Finally, I believe it appropriate to acknowledge the financial support we received from the British Limbless Ex-Servicemen's Association and the Bureau for Action in Favour of Disabled People in accordance with the Commission of the European Communities programme to promote the social integration of disabled people.

Prosthetics and Orthotics International, 1983, 7, 131-140

A microcomputer-based system for measuring temporal asymmetry in amputee gait.

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School of Engineering, University of Guelph, Ontario, Canada.

Abstract

This paper reports the development of a microcomputer-based system for measuring the temporal factors of amputee gait. The system has been designed for possible use in a standard clinical environment. It consists of a simple walkway, two photoelectric beam relays, a control unit and an APPLE II Plus microcomputer.

Preliminary clinical assessment of the system has been conducted. The gait characteristics of eight amputees during their ambulation training were investigated with the use of the new system. A comparison of the results from different groups of subjects, selected primarily on level of amputation, is presented.

Introduction

Human gait is an intricate combination of the neuromuscular and skeletal systems working together to produce a smooth and efficient form of locomotion. In upright bipedality, man's normal mode of locomotion, the lower limbs are the prime structures which not only support the body but provide power and control. The lower limb amputee has been deprived of part of his natural locomotor system and, in order to restore some functional mobiliy, he must learn to walk on an artificial limb. Thus one of the major goals in rehabilitating the amputee is to improve his ability to walk on his prosthesis. To monitor the progress made, if any, during the rehabilitation programme, assessment of the amputee's walking pattern must be made.

Subjective assessment techniques have been commonly used to evaluate gait. Although it is easy enough for a clinician to recognise major improvements in the walk of a patient, minor changes are more difficult to detect. More importantly, recording accurately the manner in which the patient walks such that comparison of a patient's walking performance can be made with others of similar disability and age is a very difficult problem. Hence the need for objective measurements of gait becomes apparent.

Many techniques have been developed to measure human gait objectively. These gait assessment methods attempt to measure the following parameters: temporal and distance factors, force analysis, angular displacements of body segments, electromyographic activity, and metabolic cost (Wall et al, 1976). The measurement of all these parameters simultaneously would be necessary for a reasonably complete analysis of gait and would be ideal for research purposes. However, it would provide an unwieldy amount of data for clinical purposes. For clinical applications, it is desirable to provide a simple objective measurement of some parameters of gait which could aid in the assessment of the quality of gait. Obviously, the parameters have to be chosen according to the pathology being studied.

Many investigators have included the measurement of the temporal factors of gait in their studies of amputees (Zuniga et al, 1972). These temporal factors include stride time, support time, swing time, double support time, and their derivatives. Table 1 is used to summarize the results for the temporal and distance measurements from these studies. These results indicate that one of the gait characteristics of amputees is an asymmetrical walking pattern. The asymmetry can be seen in the measurements of step lengths and the various temporal factors. It seems reasonable to hypothesize that "good" gait is more symmetrical than "bad" gait, and it is suggested that the degree of symmetry should increase as

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one's walking ability improves. Therefore, the quality of amputee gait may be indicated by the degree of symmetry in the measurements of step lengths or temporal factors.

The differences in gait between amputees and normals are ones which appear to provide a sense of safety, minimize pain and compensate for the problems related to walking with a prosthetic limb. Due to these anomalies, the amputee is walking at a higher metabolic cost than normal. The level of amputation has proven to be important in dictating the severity of the gait deviations.

The data shown in Table 1 are obtained mostly from studies on amputees who have used their prostheses for a considerable period of time, and who have been judged clinically to have good gait patterns. In addition, the age of these amputees averaged about 45. Therefore, it is not unreasonable to presume that the deviations would be more pronounced for new amputees during the gait training period. It is felt that objective measurement of gait during this period can be of great benefit to the therapist in assessing and treating the amputee. Such measurement may also be of assistance to the prosthetist in making decisions regarding modifications to the artificial limb.

Since the temporal factors appear to reflect the anomalies of the amputee's gait and these parameters are relatively simple to measure, it was decided to develop a system for their measurement. Various techniques have been developed to determine these temporal factors. Winter et al, (1972) have developed micro-switches for affixing to the subject's shoes. Drillis (1958) and Gardner and Murray (1975) have used metal walkways with conductive strips on the subject's shoes. Special instrumented mats have been developed by Wall et al, (1976), Gabel et al, (1979) and Taylor (1980). Photographic techniques have been used by

Table 1. Temporal and distance factors for normal individuals, above-knee amputees and below-knee amputees.

Parameters	Normal Individuals	Unilateral AK Amputees		Unilateral BK Amputees	
Preferred walking speed (m/s)	1.51	1.00 [2] 1.03 [3] 0.94 [4]		1.07 [5]	
Cadence (steps/min)	113 [1]	87 [2] 91 [3] 85 [4]		96 [3]	
Stride Time (s)	1.06 [1]	1.38 [2] 1.41 [4] 1.43 [6]		1.26 [5]	
		Prosthetic	Anatomic	Prosthetic	Anatomic
Step Length (m)	0.78 [1]	0.72 0.68	0.64 [2] 0.62 [4]	0.68	0.63 [5]
Support Time (% stride time)	61 [1]	58 57 58	68 [2] 65 [4] 66 [6]	61	65 [5]
Swing Time (% stride time)	39 [1]	42 43 42	32 [2] 35 [4] 34 [6]	39	35 [5]
Double Braking Support Time (% stride time)	11 [1]	14 11 13	12 [2] 11 [4] 10 [6]	—	—
Swing Support	0.63 [1] 0.62 [6]	0.72 0.75 0.72	0.47 [2] 0.54 [4] 0.52 [6]	0.64	0.54 [5]

[1] Murray et al, (1964)
[2] Murray et al, (1980)
[3] Drillis (1958)
[4] James and Oberg (1973)
[5] Robinson et al, (1977)
[6] Zuniga et al, (1972)

Murray et al, (1964). The feasibility of employing any system in a clinical setting must be evaluated in terms of cost, simplicity of construction, portability, simplicity of use, encumbrance to the patient, time taken to obtain the results, the manner of result presentation, and finally, speed and accuracy (Wall et al, 1980).

The advent of relatively low cost and more readily available microcomputers has opened up new possibilities in the area of gait assessment. It is felt that incorporating general purpose microcomputers with the existing gait measurement techniques will provide systems which have the potential for clinical applications. This paper describes the development of one such system designed to measure temporal asymmetry of amputee gait.

Methods

The system consists of a walkway, two sets of photoelectric beam relays, a control unit and an APPLE II Plus microcomputer. The walkway is designed to provide an electrical circuit which can detect the moments of double limb support during the subject's walk. To provide both portability and flexibilty, a modular approach has been taken in constructing the walkway. It is made up of four individual sections. Each of the mid-sections consists of two sheets of aluminium foil (1.22m × 0.45m) glued to a piece of pressboard (1.22m × 0.91m), leaving a gap of 0.5cm in the centre. The end sections are made in a similar fashion, except that a non-conductive surface of 0.44m in length is left at one end. This surface is used to allow the subject to stand on the walkway prior to each test session without interfering with the electrical circuit of the walkway. The four sections are connected by metal connection plates to form a walkway 4.88m in length. To provide a non-slip walking surface the aluminium surface is coated with a black conductive rubber paint. The remaining portions of the walkway are painted with a non-conductive rubber paint to provide a uniform appearance. The walkway is shown schematically in Figure 1. It should be noted that the walkway can be shortened or lengthened by removing or adding sections to the middle of the walkway. The dimensions given above were dictated by the parallel bars between which the walkway was designed to be used.

One side of the walkway is connected to a 5v DC power supply and the other side is connected to the input of a Schmitt trigger circuit. Each of the conductive surfaces of the walkway serves as one contact of a switch. Each piece of the self-adhesive aluminium tape affixed to the subject's shoes serves as the other contact of the respective switch. Electrical continuity between the two pieces of tape is provided by clipping a thin wire to the tape. This wire runs from one foot to the other. Placement of the foot on the metal surface of the walkway closes the

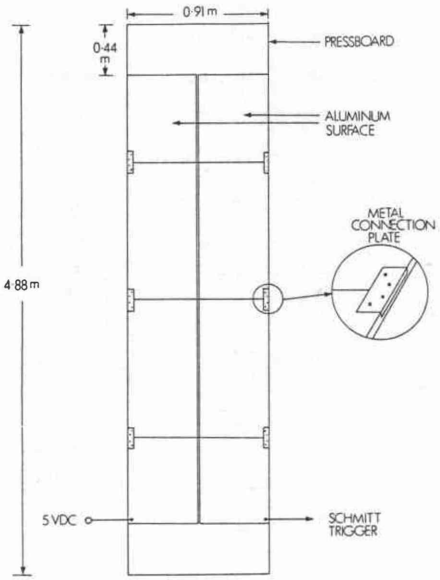

Fig. 1. Schematic representation of walkway.

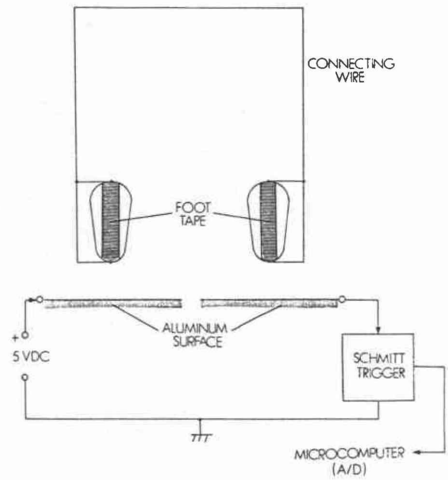

Fig 2. Basic circuitry of the walkway.

respective switch. The basic circuit of the walkway is shown in Figure 2.

If the subject stands on one side of the walkway with one foot in contact, the circuit remains open until the second foot comes into contact with the other side of the walkway. The circuit then closes and a 5v signal appears across the input part of the Schmitt trigger. The circuit remains closed during the time interval when both feet are in contact (i.e. double support phase). At the moment either foot is removed from the walkway and swings forward (swing phase or single support phase on the contralateral side), the circuit is re-opened and the input signal to the Schmitt trigger drops to zero. Figure 3 shows diagrammatically the level of the Schmitt trigger output at different phases of the gait cycle. Thus, while the subject is walking, the output signal changes state in an alternating fashion at the onset, and at the end, of each double support phase. By monitoring the status of the signal, the temporal phase of gait can be resolved.

The system also employs two sets of photoelectric beam relays to determine the time required by the subject to tansverse a fixed distance, hence the average walking speed. The outlet from each relay is connected to the input of a Set-Reset Flip-Flop circuit. During operation of the system, the two relays are placed at shoulder level, four metres apart on the walkway. When the subject enters the central four metre region of the walkway, he/she will interrupt the light beam of the first relay which causes the normally-open relay contact to close. Closure of the contact will set the Flip-Flop output. The output remains set until the subject interrupts the second light beam at the end of the four metre region. The output is then reset. By determining the duration that the output remained set, the time for the four metre excursion can be resolved.

To enable measurements to be taken when walking is initiated from either end of the walkway, the outlets of the relays are connected to a double-pole-double-throw switch, thus the same relay can set or reset the Flip-Flop circuit depending on the position of the switch. Two pushbutton switches are also included in the circuit to make manual set/reset of the circuit possible.

To collect, store and process the data from the walkway and relays, an APPLE II Plus micrcomputer is employed. The microcomputer has 48k of random access memory, an on-board analog-to-digital converter and an on-board real

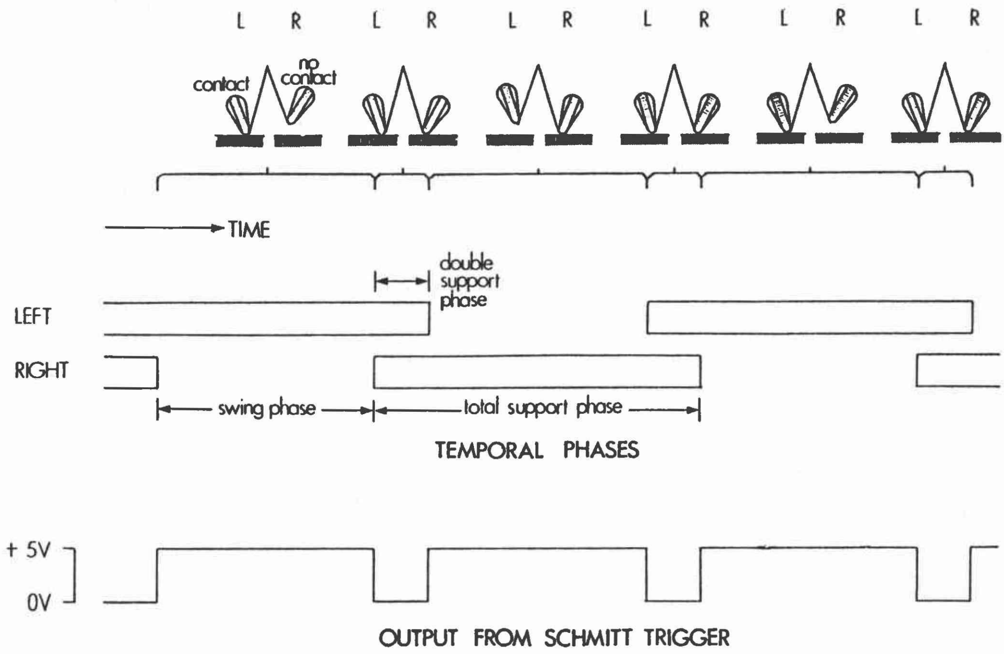

Fig. 3. Schematic representation of the level of the Schmitt trigger output at different phases of the gait cycle.

time clock. Other peripherals include a floppy disk drive, a thermal printer and a video monitor.

A control unit has been built to provide an interface between the microcomputer and the other hardware. It contains the Schmitt trigger and the Flip-Flop circuit. A 5v DC power supply is also built into the control unit to provide the voltage required by all the electronic components. LED and control switches are also mounted on the control unit. The unit also provides an interface for the output signals to the microcomputer and to any strip chart recorder. The output signals are fed into two separate channels of the analog-to-digital converter in the microcomputer for on-line measurement. A block diagram of the system is shown in Figure 4.

During a test session, the microcomputer uses a machine language routine to sample the incoming signals. This routine monitors the voltage level of the two signals alternately. When the signal is found to have changed state, the routine reads the time from the real time clock and stores the time readings in a buffer region set aside in the random-access memory. The routine also records the number of times that the Schmitt trigger signal changed state. This recording procedure will be terminated when the Flip-Flop is found to be reset (i.e. the subject has interrupted the second beam). Because the two signals are examined alternately, a delay may occur between the moment that a signal changes state and the detection of that change. The magnitude of this delay depends upon the execution time of the machine language instructions, the time required to digitize the signal, and the time required to access and record time readings from the clock. The maximum delay, however, is estimated to be 4 ms which is acceptable and well within the 10 ms resolution required.

Once the recording procedure is terminated, the main program retrieves the time readings from the buffer region and determines the various temporal factors and velocity. To determine the temporal factors, the operator has to indicate which foot, left or right, came into contact when the signal first changed state. This information is important in determining the proper sequence of foot contacts. Once the results are determined, the program then stores the results in a floppy disk file for future reference and prints the results.

The velocity is measured in the standard units of metres per second as well as in terms of relative speed. This method of normalizing walking speed to take into account differences in height, was suggested by Grieve and Gear (1966) and has been used in many studies since, including those by Charteris et al, 1981; Wall et al, 1980; Wall et al, 1981; and Taves et al, 1982. One of the reasons for the growing acceptance of this form of measurement is that the correlation between walking speed and the temporal measures such as stride time, is greater when speed is expressed in relative terms as opposed to the absolute terms of metres per second. (Rosenrot et al, 1980).

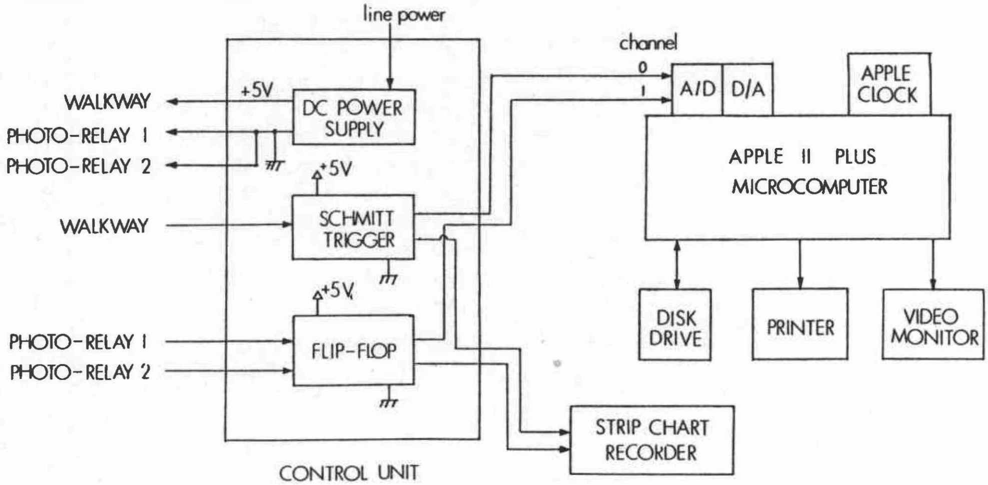

Fig. 4. Block diagram of the system.

The temporal parameters that can be determined from the measurement of the double support phases are shown in Figure 3. Single support time, which is not shown in this diagram, is equal to contralateral swing time. To distinguish the two double support phases that occur in a single stride the term "Double Braking Support" has been used. This term refers to the period of double support following heel strike. Thus left double braking support is the interval between left heel strike and right toe-off. This is the phase which Ducroquet et al, 1968 refer to as the "Double Anterior Support of Reception".

The result sheet is designed to present the temporal data both numerically and graphically in a from similar to that used by Wall et al, (1976). On the result sheet, the temporal factors for each stride cycle measured are given numerically in terms of raw time (seconds) and in percent of stride time. This permits a stride-to-stride comparison of the subject's walk. The mean values are also included. To aid in the interpretation of the data, two graphical plots are used. A real time factor graph is constructed from the temporal data as collected during the walk. It is used to indicate the times of contact of the subject's feet during the test, thus allowing a stride-to-stride comparison. A mean time factor graph is constructed by plotting the mean values of the temporal factors over a period of 5 seconds. This graph is designed to illustrate the average walking performance of the subject during one particular test, and to allow for easy comparison between different tests.

Subjects

The subjects who volunteered for this study were recent amputees undergoing a gait training programme. Included were two unilateral above-knee (AK) amputees, five unilateral below-knee (BK) amputees and one bilateral below-knee amputee. Table 2 outlines the statistics for each subject. It should be noted that Subject 1 had the big toe of the anatomic leg amputated and also wore an orthosis on that leg during the period of training. In addition, Subject 7 is blind. These factors may have influenced the results.

Table 2. Subject statistics

Subject No.	Sex	Age	Height (m)	Site of Amputation
1*	F	50	1.64	Right—AK
2	F	62	1.60	Right—AK
3	M	68	1.70	Left— BK
4	F	71	1.58	Right—BK
5	M	54	1.78	Right—BK
6	M	59	1.65	Right—BK
7**	M	49	1.67	Left— BK
8***	F	70	1.52	Left— BK Right—BK

* Subject 1 had left big toe amputated and also wore an orthosis on that leg.
** Subject 7 was blind.
*** Subject 8 had left leg amputated three years before the right leg amputated.

Each of the AK amputees wore a prosthesis which had a quadrilateral total contact socket, a single axis safety knee component and a solid-ankle-cushion-heel (SACH) foot. The prosthesis was suspended by a Silesian bandage. All BK amputees wore a prosthesis which was suspended by a pelvic band and had a patellar-tendon-bearing socket and a SACH foot.

These subjects were tested on different occasions during the course of their gait training. On each occasion, the subject was tested on four walks after two practice walks. Results from these four walks were used to determine the average walking performance of the subject on that day.

Results

Since the primary aim of the clinical study was to assess the clinical suitability of the walkway system, it was decided to treat the data by group as far as possible. It is well-documented that the temporal gait characteristics of AK amputees are significantly different from those of BK amputees. The following analysis is an attempt to compare the gait patterns of these two groups during the gait training period. To this end, the two AK amputees (Subjects 1 and 2) in the study were considered as one group, and four BK amputees (Subjects 3, 4, 5 and 6) were chosen as one group. Although Subject 7 is also a BK amputee, his gait was found to be significantly different from the other BK amputees, possibly because of his blindness. Therefore, it was decided to consider him individually. Furthermore, Subject 8 is also being considered individually because of her bilateral amputations.

For ease of comparison, the training period has been divided into three stages. The period of training for the subjects in the study was approximately six weeks, thus, it was decided to divide the training period into three two-week periods. For each subject, the results obtained

Table 3. A comparison of gait characteristics between selected subject groups in different periods of training.

Group	Training Period (weeks)	Speed (stat./s)	Stride Time (s)	Total Support Time (% stride time)			Double Braking Support Time (% stride time)		
Above-knee				Pros.	Anat.	Asym.	Pros.	Anat.	Asym.
Amputees	0-2	0.09	4.09	75.7	87.5	-11.8	39.8	23.4	16.4
(Subjects	2-4	0.14	2.69	74.2	82.4	-8.2	33.5	23.0	10.5
1 and 2)	4-6	0.14	2.47	69.4	79.3	-9.9	28.2	20.8	7.4
Below-knee				Pros.	Anat.	Asym.	Pros.	Anat.	Asym.
Amputees	0-2	0.19	2.23	74.3	80.0	-5.7	30.5	24.3	6.2
(Subjects	2-4	0.21	2.11	74.1	78.9	-4.8	29.6	23.2	6.4
3, 4, 5, 6)	4-6	0.27	1.92	71.7	75.2	-3.5	27.6	20.2	7.4
Subject 7				Pros.	Anat.	Asym.	Pros.	Anat.	Asym.
(Blind	0-2	0.15	2.42	66.0	80.5	-14.5	33.2	13.8	19.4
Below-knee	2-4	0.21	2.08	62.8	77.9	-15.1	30.0	11.4	18.6
Amputee)	4-6	0.20	2.09	66.4	77.4	-11.0	27.5	17.1	10.4
Subject 8				Right	Left	Asym.	Right	Left	Asym.
(Bilateral	0-2	0.11	2.88	82.0	85.5	-3.5	40.5	26.2	14.3
Below-knee	2-4	0.15	2.41	79.2	82.7	-3.5	35.9	26.2	9.7
Amputee)	4-6	0.17	2.28	81.2	83.9	-2.7	37.6	26.8	10.8

Note— Pros = prosthetic side; Anat = anatomic side: Asym = asymmetry (prosthetic–anatomic, except for Subject 8 where asymmetry = right–left.)

within a specific period were used to determine his/her average performance for that period of time. As a group, the average performance within each specific period was computed from the corresponding subjects' average performance in that period of time.

The results for the four groups of subjects are shown in Table 3. The graph (Fig. 5) illustrating the walking speeds for these groups showed an improvement during the gait training period. The walking speed of the BK amputee group, by the second two-week period, and even more noticeably in the last stage, revealed a marked improvement. The AK amputee group showed a significant improvement from the first stage to the second stage, but no change from the second to the last stage. In all periods of training, the BK amputees displayed a higher walking speed than the AK amputees. The speed of subject 7 also showed a marked improvement initially, and, although his speed decreased in the last stage, the change was only 0.01 statures/s. In general, he walked faster than the AK amputees, but slightly slower than the other BK amputees. The bilateral BK subject displayed improvement in walking speed over the training period. In addition, she exhibited a slightly higher walking speed than the AK amputees.

Figure 6 shows a decrease in stride time for all groups over the training period. The AK amputee group showed the most dramatic change in stride time, especially from the first stage to the second stage of training. The other groups displayed a more gradual change in stride time. A strong correspondence between the walking speed and stride time has been found. For example, the walking speed of the AK amputee group was shown to be slower than that of the BK subjects, whereas the stride time of the AK amputee group was found to be longer than that of the BK amputee group. Similar relationships can be found in the other groups.

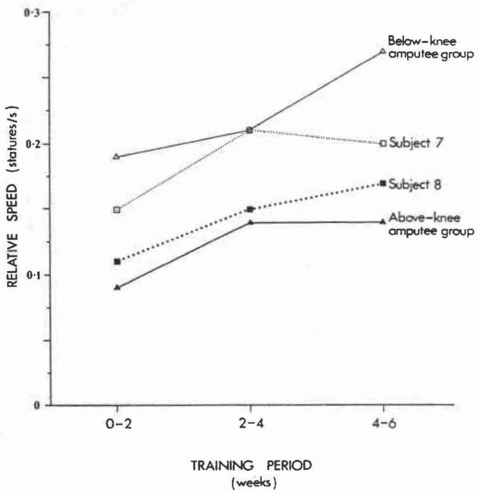

Fig. 5. Comparison of walking speeds of selected subject groups in different periods of training.

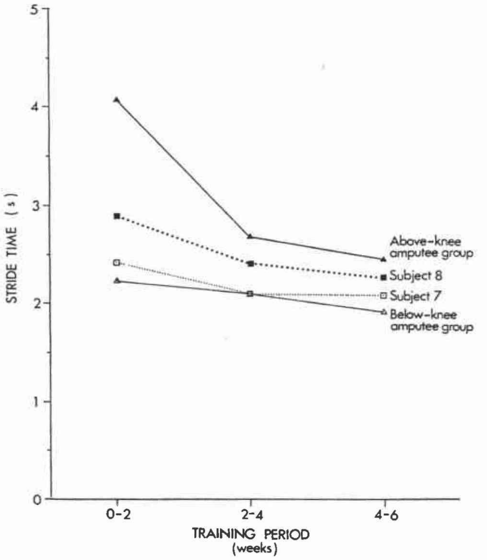

Fig 6. Comparison of stride times of selected subject groups in different periods of training.

For all groups, there are indications that the improved speed was achieved by decreasing stride time.

The quality of these subjects can be further demonstrated by considering the asymmetry in the temporal factors. Figure 7 illustrates the asymmetry in total support times and in double braking support times for all groups of subjects. Since the asymmetry in swing times is identical to that in total support times, it is not included in this comparison. Figure 7a indicates that for all subjects with unilateral amputation, the total support time of the anatomic side is longer than that of the prosthetic side. For the bilateral BK subject, the left total support time was found to be longer than the right total support time. The degree of asymmetry showed a reduction over the training period in all groups, and is an indication of an improvement in the quality of gait. Comparison of the performance of different groups showed that Subject 7 had the highest degree of asymmetry and Subject 8 had the lowest degree of asymmetry. In addition, the AK amputee group displayed a higher degree of asymmetry than the BK amputee group.

Figure 7b indicates that for all unilateral amputees, the double braking support time is longer on the prosthetic side than on the anatomic side. For the bilateral BK subject it was found that the left double braking support time was longer than that on the right side. The AK amputee group showed a marked reduction in the degree of asymmetry, especially from the first period to the second period of training. The BK amputee group showed a slight increase in the degree of asymmetry during the course of training, however the degree of asymmetry was smaller than that of the AK amputee group. Again, Subject 7's gait revealed the highest degree of asymmetry when compared to the other groups. However, his asymmetry was shown to be greatly reduced during the course of training, especially by the last training period. In the first and second periods of training, the degree of asymmetry in double braking support times of Subject 8 was comparable to that of the AK amputee group. Improvement was also noted here. However, in the last period of training, there was a slight increase in the magnitude of her asymmetry.

Marked differences in the gait of AK and BK amputees during the course of training have been demonstrated in the above comparisons. The gait patterns of the two special subjects were found to be characteristically different from

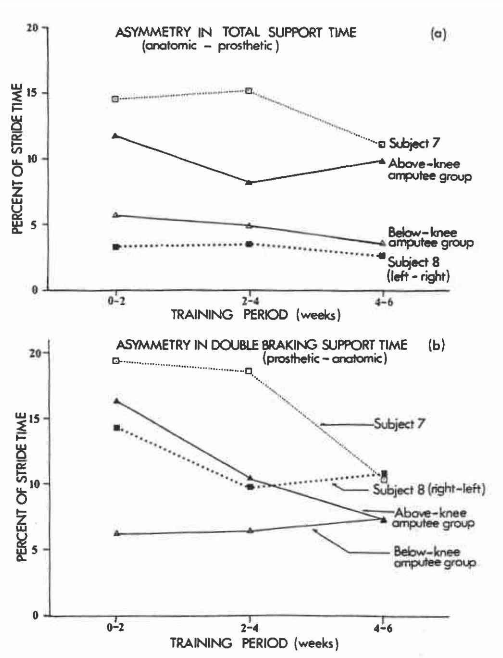

Fig 7. Comparison of (a) asymmetry in total support time and (b) asymmetry in double braking support time of selected subject groups in different periods of training.

those of the other groups. Subject 7, possibly because of his blindness, displayed a very asymmetrical gait. However, in terms of walking speed and stride time, his gait is comparable with the other BK amputee subjects. For the bilateral BK amputee subject, both her walking speed and stride time fall between those of the AK and BK amputee groups. She displayed a higher degree of asymmetry in the double braking support times than in the total support times.

Conclusion

Preliminary clinical assessment indicates that the system seems to be acceptable for clinical applications. The fact that the microcomputer is relatively small in size and the walkway is modular, allows the system to be set up in any standard physical therapy room. The walkway is flat and can easily be assembled and disassembled, allowing the system to be transported easily from one clinic to another. The speed and accuracy of the measurements provided by the system have been shown to be acceptable for the purposes intended. The technique used to collect the temporal data seems to be acceptable, from the clinician's viewpoint, because it produces a record of the patient's walking in a natural manner, unencumbered by apparatus and in the patient's normal shoes. The only attachment to the patient is a thin wire connecting the two strips of conducting tape which are placed on the soles of the patient's own shoes. A minor drawback of the system is that patients are required to walk with their feet on either side of the walkway's centre line. However, results from the clinical study seem to indicate this does not impose too great a constraint on the patients, particularly lower limb amputees who tend to have a wide base of support during walking.

Results from the clinical study have revealed the temporal gait patterns of eight amputee subjects during their gait training programme. As a group, the BK amputees displayed a higher walking speed than the AK amputees. Correspondingly, the stride time of the BK amputee group was shorter than that of the AK amputee group. In addition, the asymmetry in the temporal phase was found to be more pronounced in the AK amputee group than in the BK amputee group. The improvement shown in the AK amputees' gait over the training period, was more dramatic than that of the BK amputees, particularly in the early stages of training. The two special subjects in the study exhibited very different gait patterns from the others. The reason may be related to the physical characteristics of these subjects. It should be emphasized here that the results from the study were obtained from the subjects walking with the use of the parallel bars for support. This may be an important consideration when one wishes to compare these results with those from other studies.

Because of the small number of subjects and the significant differences between these subjects, the results from this study should be considered tentative. It is not the intention of this study to generalize the gait patterns of amputees during gait training. However, the results from the study can be used to illustrate the usefulness of the system in monitoring the progress of ability during gait training, and in allowing for comparison of a patient's walk with others of similar pathology.

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A field evaluation of arm prostheses for unilateral amputees

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Abstract

A post-clinical investigation has been carried out among 42 unilateral amputees who lost their hand due to an accident. The investigation was directed at two main topics of interest. Firstly the amputee, the problems he has to cope with, and the role the prosthesis plays in his life; and secondly the prosthesis, its use and its potential benefits and burdens. The group of amputees consisted of above-elbow and below-elbow amputees. Body powered as well as myoelectric prostheses were represented in the group. Most of the information was obtained during a two-day home visit where a semi-structured interview was conducted, and where a number of daily life activities were observed. The information thus obtained has led to a number of conclusions and recommendations with respect to the rehabilitation of this category of amputees, and with respect to the design criteria of protheses for unilateral amputees.

Introduction

In the Laboratory for Measurement and Control of the Delft University of Technology a research group is working on the design of prostheses and orthoses for the upper limb. Besides this design group another unit, the Man-Machine Systems Group, is involved, among other things, in evaluation studies and in the generation of design criteria in this field of rehabilitation. Both groups work in close co-operation with a number of rehabilitation centres.

In order to arrive at adequate design criteria, information should be available on the role the prothesis plays in the life of the amputee. Here it should be mentioned that the design activities in the laboratory are directed at provisions for unilaterally handicapped, because this is the largest group. Although much information about this category was obtained directly from the rehabilitation centres which co-operated in the design projects, the impression existed that the assumptions on which the choice of prostheses and the corresponding training programmes were based might not always reflect the actual role of the prosthesis in practice. A number of field studies on the use of myoelectric prostheses are known, such as those of Soerjanto (1971) and Pieper (1977). A comparative study between myoelectric and body powered prostheses with respect to their intensity of use was conducted by Becker (1979). Each of these studies, however, has a rather limited scope. A more extensive evaluation study has been conducted by Kay and Peizer (1958), who also took into account the psychological and social aspects in a comparative study between two different body powered prostheses. A comparative study with respect to presently available prosthesis types which takes into account all relevant factors is not known to the authors. Therefore it was decided to conduct a post-clinical study among a group of amputees who had been treated in two of the co-operating rehabilitation centres. Most of the data which will be reported here were obtained during the period 1977–1978.

Procedures and definitions

The question to be answered by this investigation can be formulated as follows: which conditions are necessary for adults with a

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unilateral, traumatic amputation, in order to function in the broadest sense with the aid of technical provisions? The investigation was directed at two main topics of interest, firstly the amputee, the problems he has to cope with, and the role the prosthesis plays in the life of an amputee, and secondly the prosthesis, its use, and its potential benefits and burdens. Five measurement methods were applied in the investigation. The following three were applied during a one day visit of the amputee to the rehabilitation centre:

a medical examination;
two psychological tests;
a questionnaire consisting of 92 multiple choice questions, mainly directed to the prosthesis and its use.

The following two methods were applied during a two-day visit of an occupational therapist at the amputee's home:

a semistructured interview based on 220 questions, covering the psychosocial aspects and the prosthesis;
observations of the actual use of the prosthesis for about 50 daily life activities.

The group of participants satisfied the following selection criteria:

Dutch nationality;
traumatic amputation;
unilateral amputation;
age 18 years or older;
amputation took place at least one year ago.

The participants were recruited from the records of two rehabilitation centres. From the original list of 101 amputees 42 persons finally took part in the project. The other 59 came into one of the following categories: address unknown (6), no reaction (25), negative reaction (6), not satisfying the selection criteria (20), withdrawal after initial consent (2). Before starting the investigation, the procedure was tested with 5 amputees from a third rehabilitation centre. The semi-structured interview initially consisted of a smaller number of items. Together, with the observations it took about one day. As a result of this tryout, where the interview had a more open character, the contents were enlarged to the present scope.

The data obtained could be divided into two groups, namely quantifiable data and purely qualitative data. The first group consisted of all answers which can be classified into a limited number of categories. To this group belong the medical data, the results of the pyschological tests, the multiple choice questionnaire, the activities of daily living (ADL), and also part of the data obtained in the interview. These data could be reduced to histograms, frequency tables in which variables are mutually related, correlation coefficient estimates, or outcomes of a factor analysis. The second group consisted of descriptions of events, thoughts and feelings, explanations of answers, etc. These data in the form of literal citations were sorted and filed according to subject matter. In general the operations just described will be clear from the results presented. Only the ADL-analysis requires a further explanation of the terms used. In order to characterize the way the prosthesis is used, a number of functions have been defined, Stassen et al, (1977) which can be classified as follows:

Mechanical or motor functions

Fixation in the prosthesis, or grasping.
Fixation between prosthesis and body.
Fixation between prothesis and environment.
Bilateral fixation, i.e. fixation between own hand and prosthesis.
Carrying.
Supporting.
Pushing or shoving.

For the grasping function a subdivision can be made in direct and indirect. Use of the *direct grasping* function means that an object is grasped directly by the prosthesis without interference of the amputee's own hand. The grasping function is called *indirect* when an object is put into the prosthesis by the amputee's own hand. A further distinction which can be made, is that between active and passive use. *Active* use of the grasping function refers to the opening and closing of the hand by means of a control action. *Passive* use refers to the situation that an object is forced into the prosthesis by the other hand. This is possible, for instance, with some types of cosmetic hands, which are provided with a spring loaded thumb.

Sensory functions

For the human hand two types of sensory function can be distinguished.

Exteroception, concerning the skin senses which give information about the exterior world like shape, roughness, hardness, temperature and wetness of objects touched by the hand. Although the terminology is not quite correct, in this study it will be briefly indicated as *touch.*

Proprioception, concerning the information from muscle spindless, tendon organs and joint receptors about positions and internal forces in hand and arm.

Cosmetic functions

The cosmetic functions refer to the natural appearance and thus to the degree of unobtrusiveness of the amputee with his prosthesis. In this study three types of cosmesis have been distinguished.

Passive cosmesis, this is the look of the prosthesis determined by its shape, size, texture and colour. This type of cosmesis is entirely prosthesis dependent.

Cosmesis of wearing, this is the naturalness of the way of moving of an amputee wearing a prosthesis, for instance when walking in a street. This type of cosmesis mainly depends on the person, particularly on the extent to which he has integrated the prosthesis in his body scheme.

Cosmesis of use, this is the naturalness of using the prosthesis in task execution. This type of cosmesis depends both on the possibilities of the prosthesis and on the proficiency of the wearer in using these possibilities.

Characteristics of the group considered

Before giving the results about the use of the prosthesis and about the way people cope with their handicap, a short description of the group will be given. Table 1 shows some general characteristics, whereas Table 2 refers to the types of prostheses worn and to some of the medical factors concerning the amputation. In general it can be stated that for the majority of the group the medical factors did not obstruct the use of the prosthesis.

The psychological tests, in particular the Amsterdam Biographical Questionnaire, made it possible to compare the group on a number of psychological characteristics with the Dutch population in general (Wilde, 1970). It was found that the group contained more extrovert people than might be expected if it had been a representative sample of the population. On the test attitude scale more self-defensive people were found. The other two scales namely neuroticism and psycho-somatic complaints did not show significant deviations.

Table 1. General characteristics of the group of 42 traumatic amputees who participated in the investigation.

Characteristic	Number	Classification
Sex	39	Male
	3	Female
Dominance	40	Right-handed
	2	Left-handed
Amputation side	26	Dominant
	16	Non-dominant
Amputation level	12	Above-elbow
	16	Fore-arm
	14	Wrist
Age at accident	11	8-20 years
	20	20-35 years
	11	35-60 years
Time between accident and investigation	11	1-5 years
	12	5-10 years
	19	10-35 years
Nature of accident	27	Industrial
	7	Traffic
	7	War
	1	Home

Table 2. Type of prosthesis worn and some of the medical factors concerning the amputation for the 42 participating amputees.

Characteristic	Number	Classification
Type of prosthesis	5	Cosmetic hand
	12	Body powered prosthesis
	19	Myoelectric hand
	2	Switch operated hand
	4	No prosthesis
Stump condition	36	Reasonable to very good
	6	Bad
Stump pain	37	Rarely or never
	2	Regularly
	3	Continuously
Frequency of phantom sensations	4	Never
	18	Sometimes
	8	Often
	12	Always
Nature of phantom sensations	27	Normal anatomy and position
	2	Normal anatomy, abnormal position
	9	Abnormal anatomy
Frequency of phantom pain	35	Rarely or never
	5	Regularly
	2	Continuously

The prosthesis and its use

The observations of the ADL performance showed that for many tasks which are executed two-handedly by non-amputees, a number of alternative ways exist for the amputee to cope with the task, with or without prosthesis. As an example, the handling of a purse will be considered. In the first manner, the purse is handed to the prosthesis by the amputees own hand, and opened with the own hand (use of the active indirect grasping function). In the second one, the purse is put down with the own hand, for instance on the counter in a shop, fixed by putting the prosthesis on it, and opened by the own hand (fixation with respect to the environment). In the third way, the purse is clasped to the body, and opened with the own hand (fixation with respect to the body). In the fourth one, the purse is placed on the prosthesis, and handled by the own hand (carrying function). In the fifth manner, the purse is placed on the counter, and handled with the own hand only (own hand only). In the sixth way, all money is carried in the trouser pocket (avoidance of purse handling). A seventh method, which was not applied for this activity, but which was noticed for a number of other activities, was asking for help.

The ADL analysis resulted in a number of tables which give the relations between individual user, type of activity and functional alternative. It was found that 26 activities out of the original list of 50 were executed by at least 4 participants (10%). Therefore this list of 26 activities was used for further processing. For each prosthesis type and amputation level, the average number of activities where the prosthesis was used was determined for each of the earlier defined motor functions, and also for the activities executed with aid. For the body powered prosthesis a distinction has been made in users who mainly used the hand, and those who mainly used the hook. Only one person with a body powered prosthesis used hand and hook about equally. Therefore, in the calculations of the average he is considered to count for half a person in each of the two categories. The results are presented in Table 3 as a percentage of the 26 activities considered. Before looking at the percentages in the table, it should be noticed that the number of persons in most of the groups is rather small (5 or less). Only the group of below-elbow amputees fitted with a myoelectric hand consists of 15 persons. Looking at the percentages, the table shows that the use of the grasping function (fixation with respect to the prosthesis) is highest for wearers of a myoelectric hand, followed by wearers of a body powered hook.

Below-elbow amputees use the grasping function more often than above-elbow amputees. The passive grasping function is sometimes used by wearers of a cosmetic hand. Furthermore, it should be mentioned that direct use of the grasping function is an exception; in general, active grasping is executed indirectly. Furthermore, the table shows that fixation with respect to the body or to the environment are frequently used alternatives for grasping. The bilateral fixation function does not occur in the table, because it is mainly used in activities outside the list of 26 items. In the interviews it was mentioned as a frequently used function. For the other fixation functions, however, the use over the 26 items can be considered as representative for use in general.

Table 3. The average percentage of activities out of a list of 26 items, where a certain function was used, or where the amputee was aided, distinguished according to prosthesis type and amputation level.

Prosthesis and amputation level (below- or above-elbow—b, a)		Number	Fixation with respect to			pushing	carrying	with aid
			prosthesis	environment	body			
Cosmetic hand	b	4	1	18	18	4	4	18
	a	1	—	—	4	4	—	23
Body powered hand	b	5.5	7	10	15	3	1	13
	a	1	—	—	8	—	—	—
Body powered hook	b	2.5	17	2	32	3	—	11
	a	3	3	9	5	3	—	9
Myoelectric hand	b	15	31	12	10	4	—	7
	a	4	12	10	7	3	3	8
Switch operated hand	a	2	4	2	—	—	—	27

When asked for what kind of activities they thought their prosthesis to be important, 28 people mentioned hobbies, 17 driving or cycling, 14 work, and 6 ADL. Table 4 gives a list of hobbies which were mentioned 3 or more times. Some people wore their prosthesis during sport, others did not. Some amputees wished to have a special cosmetic hand for sport, made of soft material. The role of the prosthesis in bicycle riding and car driving is indicated in Table 5. The table shows that there is a striking difference in use between above-elbow and below-elbow amputees.

On being asked what was liked and not liked about the prosthesis a number of positive and negative items were mentioned, which are categorized in Table 6. Complaints with respect to the cosmesis mainly refer to the vulnerability of the cosmetic glove with respect to dirt, discolouration and damage. It should be mentioned that criticism with respect to the cosmesis comes from the people who also mention the positive cosmetic properties. In the same way, the comments about the technical reliability mainly come from the people who appreciate the motor functions, and who have a user score above the group average. Complaints about the harness come from wearers of a body powered prosthesis. Complaints about perspiration are mentioned mainly by wearers of a myoelectric prosthesis. Physical and mental effort to operate the prosthesis are judged to be low, and are not considered to be important by the users.

Table 4. Hobbies mentioned by 3 or more amputees for which the prosthesis was considered useful.

Hobby	Times mentioned
Repair and maintenance jobs	18
Gardening	18
Card playing	8
Fishing	6
Soccer	5
Bird keeping	5
Tennis/badminton	3
Shooting	3
Billiards	3
Photography	3

Table 5. The role of the prosthesis in bicycle riding and car driving in relation to the amputation level.

	Amputation level with respect to elbow	
	above	below
Amputees	11	31
Bicycle riders	6	24
Wearers of prosthesis on bicycle	6	22
Users of prosthesis on bicycle	0	22
Car drivers	7	25
Drivers with a modified car	5	12
Wearers of prosthesis while driving	7	22
Users of prosthesis while driving	1	22

Table 6. Number of positive and negative comments concerning the properties of arm prostheses.

Comment	Times mentioned
POSITIVE	
Cosmesis	35
Motor functions	16
NEGATIVE	
Cosmesis	20
Technical reliabilty	13
Lack of touch	6
Hindrance due to harness	6
Hindrance due to socket and perspiration	9

Of the 42 participants, 22 still wear the type of prosthesis they first obtained. Table 7 shows the transfers which have taken place. With the introduction of the myoelectric prosthesis, 6 wearers of a body powered prosthesis changed to this type. An advantage of the myoelectric prosthesis which was often mentioned by below-elbow amputees is the lack of a harness, and thus of the hindrance it causes. The table also shows that 4 persons who originally had a cosmetic hand changed to a hand with a grasping function. On the other hand, 9 persons who originally had a prosthesis with a grasping function changed to a cosmetic hand or to no prosthesis at all. This group did not care much about having a grasping function. The 4 persons who do not wear a prosthesis any more felt especially hampered by the prosthesis because it took away their sense of touch. With their long fore-arm stumps they had a good motor function and they did not consider the passive cosmesis as very important, contrary to the other participants, who valued their prosthesis very highly and felt unhappy without it.

Based on the individual scores for intensity of use of the motor functions of the prosthesis, the group could be divided into 21 users with a total score higher than average and 21 users with a lower score. For each of the two groups the answers to a number of interview questions and

Table 7. Distribution of initial prosthesis and transfers of one type to another for 42 participants.

		Present type				
Original type	Total	Cosmetic	Body powered	Myoelectric	Switch operated	No prosthesis
Cosmetic hand	4	—	2	—	2	—
Body powered hand/hook	24	4	10	6	—	4
Myoelectric hand	13	1	—	12	—	—
Switch operated hand	1	—	—	1	—	—
Total	42	5	12	19	2	4

also the medical data and the results of the psychological tests were analysed. Thus, possible relations between a number of factors and the use of the prosthesis could be identified. Besides the use of the prosthesis as measured by the total score over all motor functions, the use of the gripping function only was also considered. In the latter case the analysis was based on the wearers of a body powered or myoelectric prosthesis because they had a reasonable gripping function at their disposal. By means of a chi-square test those factors were identified which showed a difference between the two groups of a 0.05 or lower significance level. The results are given in Table 8. The table shows that for use in general the amputation level is of influence. Much help from others goes with a low score both for use of the prosthesis in general and for use of the gripping function in particular. A short time between the amputation and provision with a prosthesis has a positive influence on the use of the gripping function. As could also be deduced from Table 3, wearers of a myoelectric prosthesis make more use of the gripping function than wearers of a body powered prosthesis.

As can be seen in Table 2, the number of people with a medical factor which might hamper the use of the prosthesis is too small to yield results in a significant test. This does not mean that it can be concluded that there is no influence. For instance, the fact that 7 out of 9

Table 8. Items which were found to be related to the intensity of use of the prosthesis over all motor functions for the whole group of amputees, and items which were related to the use of the gripping function only for the wearers of a body powered or myoelectric prosthesis. For each item the significance level according to a chi-square test for rejecting the nulhypothesis is given.

Use of prosthesis functions in general (42 persons)				
		user score		
Item	Category	high	low	sign. level
Amputation level	lower arm	18	12	0.05
	upper arm	3	9	
Help from the environment	not much	17	9	0.02
	much	4	12	
Use of gripping function (31 persons)				
Time between amputation and provision with a prosthesis	> 0.5 year	11	6	0.02
	⋭ 0.5 year	3	11	
Prosthesis type	myoelectric	12	7	0.02
	body powered	2	10	
Help from environment	not much	12	9	0.05
	much	2	8	

people, who have phantom sensations with an abnormal anatomy, have a low user score may be an indication. A number of factors could be identified, however, as having no influence on the intensity of use of the prosthesis in general and of the gripping function in particular. To mention a number of these factors: whether the dominant or the non-dominant hand was amputated; clinical or polyclinical rehabilitation; duration of the rehabilitation; number of treatment periods; whether the amputee was satisfied or not with the treatment; and the scores on the psychological tests.

Coping with the amputation

The purpose of rehabilitation is to enable the amputee to function again in his own environment. A very important step towards this goal is that the person learns to accept his state. For many people, though not for all, the prosthesis plays an important role in this process. There are however, a number of other important aspects which were brought out in the interviews. In many cases the cause of the amputation, often an industrial accident, is something which still keeps people occupied. Sometimes they have reasons to reproach themselves or others. In some cases people had been involved in a law-suit which was lengthy and sometimes yielded disappointing results. The positive or negative reaction of the environment to the accident can also be important. Especially during the period in the hospital, people have a need to talk with others about the accident and about their expectations for the future. The period between the hospital and the rehabilitation centre is a difficult one. They are no longer regarded as a patient and they discover the consequences of their handicap. Admittance to a rehabilitation centre is often mentioned as a positive turning point. Something is going to be done with their sitiuation. The amputee often discovers that there are people in a worse situation, which makes them feel less handicapped, although some people feel shocked and distressed at the sight of severely handicapped persons. An important help for coping with their amputation is the possibility of talking with other amputees. An important event is the provision of the first prosthesis. On the one hand there is a feeling of being complete again, on the other there is an alien object which has to be incorporated in their body scheme. Initially, the attention is mainly focussed on the cosmetic function of the prosthesis. The motor function comes secondly. Then, people first discover what they cannot do with the prosthesis, before they learn what they can do with it. People often mention that the training was not adjusted to their specific needs, so that they were left to find out things for themselves afterwards. For many amputees a difficult period begins again after rehabilitation. In the rehabilitation centre, where there are many handicapped, people do not mind showing their prosthesis or their stump; back in society they often do not dare to move freely. They feel uncertain also with respect to their expectations about the future. The question whether they can return to their old job or, if not, whether they can find another one is a worry from the beginning. Applying for a job is more difficult for an amputee, because most employers prefer a non-handicapped candidate. Confrontation with the outside world is often hard because people sometimes react rather tactlessly on seeing someone with an arm prosthesis. As a result, amputees are sometimes hard on themselves and on others. In small communities everbody is informed and things are less difficult. The attitude of the amputee's own family is very important. They can have a very positive influence by stimulating the amputee to do things himself, which increases his self-confidence. Hobbies which require a certain manual dexterity can also have a positive effect. In some cases the amputation was the cause for further study, resulting in a more attractive job. In general, it is very important to have an outlook for the future.

Of the 42 persons, 26 could be considered to have coped with their amputation, whereas 16 still had difficulties. By looking at the answers to some interview questions, a number of positive and negative factors could be identified. Table 9 gives a list of items on which the group with acceptation problems differs from the others on a significance level of 0.05 or less according to a chi-square test. As has been already mentioned the Amsterdam Biographical Questionnaire showed that the group of participants in the investigation as a whole contained more extrovert people than might be expected in a random sample from the Dutch population. It was found that the extrovert people were mainly found in the group who had learned to cope with

Table 9. Items in the semi-structured interview and in the Amsterdam Biographical Questionnaire which are related to problems in accepting the handicap, together with their significance level in a chi-square test.

Item	Sign. level
Trauma plays an important role in amputee's life	0.001
Difficulty in making contacts	0.002
Poor adaptability	0.01
Feeling a different person after accident	0.01
Feeling stared at by people	0.01
Often thinking back about accident	0.02
Feeling handicapped	0.02
Not extrovert according to ABQ-score	0.05
Sensitive to reactions of others	0.05

their amputation. Therefore, it could be deduced that the group as a whole was a positive selection with respect to the way they had coped with their handicap. People who still had difficulties should mainly be found in the group who had not participated in the investigation. Taking into account this effect, the number of amputees in general who satisfy the earlier mentioned selection criteria, and who still have difficulties in coping with their handicap, should amount to at least 60% instead of the 40% found in this particular group.

Conclusions

The prosthesis.

With respect to the value of the prosthesis and the way it is used the following conclusions could be drawn from the field study.

For the majority of the group, the cosmetic function of the prosthesis is very important.

Many people who value the cosmesis highly, pay much attention to the passive cosmesis of the prosthesis, but are less aware of the cosmesis of wearing and the cosmesis of using the prosthesis. As a result they often look conspicuous because of their tendency to hide the prosthesis.

Those amputees who have learned to move in a natural way, with or without prosthesis, taught themselves this ability. The cosmesis of wearing had not been taught in the rehabilitation centre.

Although not everyone is aware of the cosmesis of using, in general they avoid activities with their prothesis which require unnatural arm motions.

The motor functions are thought worthwhile for hobbies, transport, work, and activities of daily living; in that order of importance.

Use of the direct grasping function is an exception. If an object is picked up directly by the prosthesis, in most cases the orientation differs from the desired one. Therefore, in two-handed tasks the object is given to the prosthesis by the users own hand. It is easier and looks very natural.

The direct grasping function is used only for activities like picking up a suitcase or grasping the handlebars of a bicycle.

People are very willing to demonstrate the use of the direct grasping function in activities in which they have been trained, like picking up a glass. In practice, however, these activities are always executed with their own hand.

Frequently used alternatives for the grapsing function are fixation with respect to the body or fixation with respect to the environment.

In assessing the use of the prosthesis for task execution in general, it has to be borne in mind that the prosthesis has to compete with a number of alternative strategies such as:

- use of the stump;
- use of other body parts, for instance the remaining hand;
- asking for help from other people;
- avoidance of a certain activity.

An important disadvantage of a prosthesis in task execution is the lack of sensory feedback to the user, he is therefore very dependent on visual feedback.

Bearing in mind the previous points, the use of the grasping function or the use of the prosthesis at all should not be considered as a matter of course for unilateral amputees.

A mutual comparison shows that the wearers of a myoelectric prosthesis use their prosthesis more frequently than wearers of a body powered hook, who in turn use their prosthesis more than wearers of a body powered hand.

Body powered prostheses often require compensatory motions in order to operate the grasping function in different locations. These compensatory motions may look unnatural, and they are avoided if there is a less obtrusive alternative.

The body powered hook is especially advantageous for hobbies and jobs which require some manual skills because of the following properties:

It provides good sight of the grasped object.
It is not easily damaged.
It is easy to clean.

Whether or not a wearer of a body powered prosthesis will use his hand or his hook will also depend on the social context, which determines whether the wearer considers the passive cosmesis as important or not. For instance, for gardening some persons used the hook in the backyard, the hand in the front yard.

The myoelectric prosthesis is valued, because the wearers feel less hampered. In particular, below-elbow amputees do not need a harness. The latter point is also mentioned as cosmetically attractive.

Below-elbow amputees use their prosthesis more frequently than above-elbow amputees, which can be understood from the fact that in the first case the remaining body functions facilitate the positioning of the prosthesis.

Whether an amputee will wear and use a prosthesis or not depends on its potential benefits and burdens. Benefits are the cosmetic and motor functions; burdens can be divided into burdens inherent to wearing only, like the inconvenience caused by a harness if present and by the fitting, and in burdens related to the use of the prosthesis like the physical and mental effort to operate the prosthesis, the lack of touch, an obstructed view, the weight, and the susceptibility to dirt and damage.

For many users the burdens of wearing are the most annoying properties, due to their constant presence.
Unilateral amputees wearing a prosthesis with one active degree of freedom do not consider the mental load as important.

The cosmetic glove is considered very important for the passive cosmesis, but it is also the most vulnerable part of the prosthesis.

Some people with a long fore-arm stump who do not value the passive cosmesis very highly prefer not to wear a prosthesis thus avoiding its burdens. They often move very naturally and thus are less obtrusive than some wearers of a prosthesis.

Rehabilitation.

From the data concerning rehabilitation the following conclusions could be drawn.

No relationship was found between the duration of the rehabilitation process and the amputation level and the prosthesis type provided. Neither was a relationship found between the duration and the intensity of use of the prosthesis or the degree to which the amputee had learned to cope with his amputation.

Those who had learned to move in a natural way while wearing a prosthesis, had taught themselves this ability. The cosmesis of wearing had not been taught in the rehabilitation centre.

The personal contacts with other amputees and with the staff of the rehabilitation centre are highly valued. The contacts with the limb fitter are mentioned as especially positive and important.

There is a desire for prosthesis training which is more in accordance with the specific needs of the individual amputee.

In many cases, people were not prepared for the kind of problems generally encountered after returning to their own environment.

Coping with the amputation.

With respect to this subject the following conclusions could be drawn.

Accidents often result from human errors. Therefore the victims may reproach themselves or others. It was found that these feelings often keep people occupied even after many years.

The effects of an amputation are of many kinds. The loss of a limb may cause a feeling of incompleteness. Moreover, it also implies a loss of motor and sensory functions, which reduces the amputee's abilities. This reduction of abilities may change his life pattern and his professional career. Socially the amputee may feel stigmatized, sometimes being confronted with undesired attention.

The way the amputee will cope with these problems will partially depend on his personality structure and partially on social factors. Talking about the problems of an amputation to people with an understanding attitude is an important help in finding a state of acceptance of the amputation. In this respect, extrovert people have advantages over introvert people, as was found in this investigation.

The reduction of abilities brought about by amputation is something many people realize almost immediately after the accident. As a consequence their outlook for the future is often broken down. A restoration of their perspective for the future with respect to job and family life is often mentioned by amputees as a positive stimulus.

The prosthesis was found to play an important role in coping with the handicap. It can reduce the amputee's sense of incompleteness and obtrusiveness, and it thus helps to increase his self-reliance.

The results of the investigation indicate that a majority of all amputees who have lost a hand due to an accident, still have problems with the acceptance of their handicap after a number of years. This suggests that more attention should be paid to this aspect in the rehabilitation process.

Recommendations

The field evaluation described in this paper had a rather broad scope because the investigators were of the opinion that the prosthesis and its use could not be isolated from the total problem of the rehabilitation of amputees. It was also the intention to arrive at recommendations for all categories involved in this problem field, i.e. the amputees and their families, the members of the treatment teams in the rehabilitation centres, and the designers of arm prostheses. As a consequence the recommendations have been categorized according to those three target groups.

Amputees

For this group it is important to receive early information about the consequences of the amputation, the kind of help the rehabilitation centre can offer, and the problems to be expected after rehabilitation. Although people do get information at an early stage, it is often incomplete; moreover much of the information passes over their head at this time. The present investigation has yielded a lot of information about the experiences of other amputees. Therefore it is the intention to write a special booklet (in Dutch) with information for amputees. It will cover the following subjects: problems during the first period; treatment in the rehabilitation centre; information about the available prosthesis types, their benefits and burdens; problems which may be encountered after the rehabilitation period; and finally a list of institutions and societies which can be of use for the amputee. Here it should be noted that such a booklet is highly related to the social structure of a particular country.

Rehabilitation teams.

The purpose of amputee rehabilitation is to enable them to function again in their own environment as well as possible. Three global subgoals can be distinguished which, however, have a mutual interaction. The first is help to accept the amputation with its causes and effects. The second is to restore the functional possibilities as fully as possible, with or without a prosthesis. The third is to restore the previous life pattern or to achieve a new one within the limitations imposed by the handicap. In order to be able to accomplish these goals, it is necessary to have sufficient information about the life style of the amputee before the accident, his feelings about the amputation, the attitude of people in his direct environment, his expectations for the future and his expectations with respect to rehabilitation. The best way to obtain this information seems to be a home visit where much more insight can be gained into the particular circumstances of the amputee than during one or more talks in the rehabilitation centre. On the other hand, the representative of the rehabilitation centre can inform the amputee about the treatment programme and answer other questions he may have in relation to his situation.

The time between amputation and admission to the rehabilitation centre should be as short as possible. After admission to the rehabilitation centre, much time should be spent on discussing the benefits and burdens of the different prosthesis types in relation to his specific situation, so that a justified choice can be made. If a prosthesis will be provided, it is important to involve the amputee in the construction of the prosthesis. It should be realized that for most people the cosmetic function is of primary importance, certainly in the beginning. At this stage, much attention should be given to teaching the amputee to move in a natural way with and without the prosthesis. After the amputee has learned to operate the prosthesis, he should be given task training which is fitted to his needs. For each task, the different alternatives for execution, with or without the prosthesis, should be considered in order to arrive at the best individual solution. As soon as the amputee feels sufficiently proficient with his prosthesis, he should be confronted with the outside world in activities such as shopping, making use of public transport, etc. thus increasing his self-confidence by lowering a threshold which is often encountered after the period in the rehabilitation centre. Some of the participants in the evaluation study mentioned that they still felt embarrassed in public. Some activities, which are rather specific to the individual environment should preferably be taught at home. This may involve making special arrangements, however, it offers an opportunity to involve the family in the rehabilitation process. Opportunities should be created to talk about problems with other amputees and with staff members. One of the things people worry about is their return to work, therefore contacts should be made at an early stage in order to restore lost prospects in this field.

Designers of arm prostheses

For designers of arm prostheses it is important not only to consider the potential benefits of a prosthesis to be designed, but also the potential burdens. In the case of unilateral amputees, it has to be borne in mind that the prosthesis, if it is used, has the function of a non-dominant hand, and that it has to compete with a number of alternative ways of task execution. The functional benefits only play a role at the moments that they are used. Some of the potential burdens, however, like the hindrance due to fitting and sometimes a harness, are constantly present. For this reason, a reduction of these burdens may be of more importance to the amputee than an increase in functional possibilities. The cosmetic function of the prosthesis is valued very highly by most of the wearers. The need for a less vulnerable cosmetic glove, however, was often mentioned.

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Coping with the loss of a leg

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Abstract
This study sets out to examine the physical and psychological effects of amputation on marriage and family life; assess the extent to which the needs of the younger amputee are being met from current rehabilitation resources, and to ascertain how the non-disabled regard amputation and its consequences.

Interviews were conducted with a group of 19 amputees and a group of 40 non-disabled individuals within the same age range and the results are reported.

Introduction

How do people react to sudden misfortune? There is no simple answer, since individual reactions are sufficiently varied to limit the usefulness of general rules. Our knowledge of human variation is greater for some kinds of misfortune than for others—for example, bereavement (especially loss of a spouse) has attracted much more research than loss of a limb. Yet the latter is by no means a rare event, and we would like to report some findings from a small-scale but intensive study of amputees traced through a limb fitting centre in the United Kingdom.

About 5,000 lower limb amputations are performed annually in England and Wales. The reason for most of these operations is vascular or metabolic disease, injury accounts for only 10% of cases (perhaps surprisingly), and malignant disease for only 5%. Men outnumber women by a ratio of 2: 1, and 70% of patients are older than 60 (Department of Health and Social Security, 1981). We ourselves are particularly interested in the younger amputee, yet loss of a leg is typically a geriatric problem.

Level of amputation in the individual case is clearly a matter of clinical judgement, but the prospect of successful rehabilitation is much better when the knee joint has been conserved. The majority of amputees are given the opportunity to be fitted with an artificial limb at a specialized centre; and where a leg has been lost (much the most common form of amputation) they will usually receive training in the use of an artificial leg. The waiting period is dependent on the healing process, which is usually more complex after an accident (where there may be a delay of several months before the stump is considered sound enough to bear weight). In general, the sooner walking practice can begin the more favourable the outlook, although accident victims do at least tend to have youth on their side.

Beattie, a lecturer in psychology, has published (Beattie, 1979) a moving account of his wife's experience in losing an arm. He complained that personal factors, such as attitude to disablement and disfigurement, were virtually ignored by the attending physician in his excessive concern with mechanical factors. However, a psychologist can hardly be taken to represent the general public, least of all when married to another psychologist. Discussions with staff members soon made us aware that technical competence does not preclude sensitivity to the individual, yet equally it did not take long to find evidence of an unmet need for psychological guidance among both patients and staff. Our observations may help to put the Beatties' experience in perspective.

Interviews were conducted by one of us (LF) with 19 amputees who had responded to a postal questionnaire sent to a larger group of patients

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aged 20–60 who had lost a leg one to five years earlier but were otherwise in good health. All but four were married (or in one instance cohabiting), and their partners were also included in the home visit. None of those approached had refused to take part. Our aims were broadly threefold:

1. To look at the physical and psychological effects of amputation (which was mainly below the knee) and its impact on marriage and family life;
2. To assess how far the needs of the younger amputee were being met from current rehabilitation resources;
   and
3. To ascertain how the non-disabled "man in the street" (who might be the amputee of tomorrow) regarded amputation and its consequences for the individual.

For this last purpose we recruited a group of 40 married individuals within the same age range who were attending the casualty department of a teaching hospital with minor injuries. Again, all of those approached agreed to be interviewed after the nature of the project had been explained to them. Since this was an exploratory study, with few guidelines from the literature, we could not hope to rely on quantitative measures. Instead we made use of a brief structured interview but spent long enough with our subjects (usually at least two hours) to allow them to talk freely of their experience.

Knowledge of amputation

How much can we expect the layman to know? We had predicted, partly on the basis of our own previous ignorance, that he or she would be poorly informed as compared with the patient's spouse. However, we were surprised to find how little these two groups differed in their level of apparent knowledge. Only in their recognition of the importance of the knee joint were the spouses of amputees better informed. Annual incidence of leg amputation was underestimated by one in two of our informants when asked to choose between four alternatives (50, 500, 5,000 10,000). Again, four out of five thought of accidents as the main cause, and this even applied to five of the spouses of six patients with vascular disease. Similarly, the age of the average amputee was underestimated by around 40 years in each case. This was an unexpected misconception among the spouses, all of whom had at some time visited the Limb Fitting Centre where the elderly amputee is conspicuous (and most were able to acknowledge this when reminded). But perhaps we should not have expected too much sophistication from a group who on the whole were neither scholars nor scientists. After all, there are probably not too many relatives of sick or disabled people who are inspired to learn all they can about a condition merely through personal experience of it.

Functional impairment

Next, let us consider the functional limitations imposed by loss of a leg below the knee. One of us in his youth was hard put to match the skill of such a person on the tennis court, but most of our naive informants had never met an amputee. Our list of activities, mainly relating to mobility, self-care and use of transport, yielded a maximum score of 25. The mean score obtained by our amputees was 17·9, with only the more vigorous sporting pursuits reported as out of range. This fell to 12·5 when responses to the same questions were drawn from our naive informants, who were asked to imagine what the average amputee could do. Thus, as we had predicted, the naive group showed a marked tendency to exaggerate the physical handicap of losing a leg. Doubtless the public's horror of disablement springs partly from conceiving the consequences as even worse than they really are. The professional literature is of little help here since it relates primarily to the older patient whose difficulties are compounded by the ageing process if not also by concurrent illness. Loss of a limb or even part of a limb is a traumatic experience at any age, but up to the age of 60 most people in our experience seemed to have adapted to it well enough, at least from a physical standpoint.

What of the psychological effects? A good physical recovery is certainly no guarantee of a smooth personal adjustment, and we shall review the emotional aspects of amputation under the following headings: attitude to handicap, self-consciousness, and mourning of the absent limb.

Attitude to handicap

To estimate the amputee's sense of misfortune, we used two techniques. First, we followed Dembo et al (1956) in asking our subjects to place themselves (with reference to

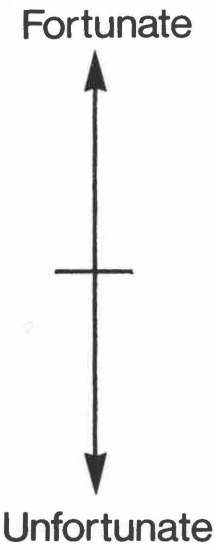

Fig. 1. Self rating scale.

the immediate present) on a vertical scale of 60mm, the top of which indicated the position of the most fortunate person in the world, while the bottom indicated the most unfortunate. The distance from the midpoint could be read off to the nearest millimetre, with scores ranging from +30 to −30 (Fig. 1). Our results are shown in the accompanying Table. Evidently the amputees thought that they would have rated themselves as only marginally more fortunate before the operation, and few saw themselves as unfortunate now.

Table 1.
Inter-group comparison of fortune scale ratings

Group	*Mean*
Amputees:	
Now	20·2
Before amputation	21·4
Naive subjects:	
Self-rating	14·4
Imagined state of amputee	−5·9
Spouses:	
Self-rating	16·8

The naive group could not quite match the amputees in level of self-rated good fortune, but the striking feature was the discrepancy (as measured by a gap of 26mm) between how the amputees saw themselves and how they were seen by their non-disabled peers. The spouses' self-rating was intermediate between the two other groups. In the absence of norms from the population at large one cannot attach too much weight to the comparison, but casual enquiry of relatives and friends suggests that most people are reluctant to declare themselves as unfortunate even in the most harrowing circumstances. Perhaps there are mechanisms of denial and self-protection that work to the disabled person's own advantage, up to a point anyway. Still, there was a statistical relationship between sense of misfortune and reported level of functional impairment.

Our second technique called for a ranking of six disabilities in order of severity: going blind, losing a leg, losing the preferred arm, becoming deaf, severe facial disfigurement, and paralysis (eg, polio). Again there was a major discrepancy between those with experience of amputation and those without it. Amputees and their spouses agreed in ranking it as the least severe handicap, whereas only blindness was rated as more severe by the naive group. Here the element of denial—or at least understatement—seems even more pronounced. But although some kinds of personal disaster may be almost too awful to contemplate, when actually faced with them many of us find that we can summon up the necessary coping strategies even without knowing how, and we may perceive others as even worse off than ourselves.

Self-consciousness

We tried to measure self-consciousness from a series of responses to questions on body image, anxiety about the partner's reaction, willingness to declare that one is an amputee where the fact might otherwise remain hidden, or to expose the stump in situations of varying intimacy. Where facial disfigurement was ranked first or second in severity of handicap another point was added to the score, which ranged from 0–8.

Not unexpectedly we found that heightened self-consciousness went with less belief in one's own good fortune. There was also a sex difference which carries conviction despite the small numbers. Six out of eight women but only three out of eleven men considered the change in body image as a more intrusive handicap than the impairment of function. Intuitively this makes good sense, and runs counter to the Limb Fitting Service's order of priorities—comfort, function, cosmesis. It also helps to explain the lingering dissatisfaction felt by Dr. Beattie (1979) and his wife.

That amputees may well expect to feel uneasy in their social relationships is suggested by a mismatching of attitudes expressed by amputees and naive informants. None of the latter would admit to feeling embarrassed if told by someone that he had an artificial leg, whereas a third of the amputees stated that they had met with such a reaction. In contrast, no amputee mentioned curiosity as a reaction they had ever met except from children, whereas over 80% of the naive informants said they would feel curious. Clearly there had been all too little communication between disabled and non-disabled people in this highly-charged area, and we wonder where the initiative should lie. Ought amputees to be more open about their private feelings, or should those who interact with them be more ready to overcome their own inhibitions?

The artificial limb was experienced as part of the body image by most amputees—as a friend affectionately given a pet name by at least two, but as something of a cross to bear all the same by the majority. Self-consciousness was again a major factor in certain contexts. A woman might refrain from wearing a skirt because she could not get an artificial leg to match her natural one. A student was constantly afraid that his leg would be noisy when walking through the college library or, worse still, that the foot might suddenly drop off in public. Fears of exposure and looking ridiculous had led in several instances to a restricted life style, geared to the avoidance of risk.

Mourning of the absent limb

It has been suggested that loss of a limb has something in common with loss of a loved one, and that the mourning process may follow a similar course. Anyone who has taken great care of his legs, only to have one of them removed without warning, is liable to feel cheated. Yet there was no hint of lasting depression as a response to amputation except where it happened to follow other disturbing events. The overall pattern was of initial sadness as an in-patient, giving way to optimism with physical improvement and increased confidence, though some experienced a temporary setback after discharge. Only two patients needed treatment for their depression, and both were divorced women living alone. In the same way relatively few bereaved people require anti-depressive medication, and prolonged grief reactions are more common in those with personality problems or other major stresses.

Sometimes a short delay between accident and amputation can help the individual and partner to adapt to the loss, possibly through a process of anticipatory mourning. This was shown in the contrast between two men who were involved in road traffic accidents during late middle age. In each case there was a month's delay before a leg was amputated; but whereas the first man had already accepted his loss in advance ("I didn't feel the leg belonged to me any more"), the second despite great pain had to wait longer than he wished because his wife pleaded with him and the doctors to persist in their efforts to save the leg. When the operation was finally performed she was so distressed that she cried for a week, a fact which three years later she found hard to understand. Here it may have been the partner whose grief was more troublesome, although she claimed that her sole concern was to protect her husband in case he might be unable to cope with the loss. Doctors needed to be aware of the dynamics of human relationships in their work with prospective amputees.

Factors promoting rehabilitation

There appears to be a genuine divergence between how members of the public visualize the consequences of amputation and how amputees themselves experience the reality of it. Our interviews convey a strong impression that persistent suffering or psychological disability was rare in this series, although individuality in coping styles was marked. We can still ask, therefore, what it is that enables one person to cope better than another? Whereas the amputees themselves were inclined to think that family support had been the crucial factor in coming to terms with their new situation, their partners were more likely to lay stress on the amputee's own personality. The extent to which loss of a leg could change the victim's whole life was apt to be underestimated by partners as well as by naive informants, yet the possibility of positive change (the familiar triumph over adversity) was more easily recognised by partners and perhaps others in daily contact.

Granted that the worst effects of disablement will be overcome by a robust personality almost regardless of rehabilitation facilities, a final question is what could be done to improve existing services at limb fitting centres. At this centre a consultant psychiatrist is available to see patients on request, eg, in the event of gross depression or other unmistakable psychopathology. We believe that a psychologist (not currently available) would also have much to contribute. Reactions to stress vary in intensity even when within the normal range; and the fact that most patients seem to get by without specialized psychological help is no argument against deploying it in selected cases.

The tendency of naive informants to overestimate the functional impairment of amputation is echoed in the finding that most of our amputees felt they had made better physical progress than they had expected. Experienced amputees may have a role in counselling recent patients and helping to promote realistic expectations, but care in their selection will need to be exercised. Thus a young woman in our series related how, two days after she had lost her leg from an accident, an unknown man "bounced" into her room and, without introducing himself, told her of all the things she would be able to do once fitted with an artificial limb. She was feeling low at the time and enquired irritably "How do you know?", to which he triumphantly retorted "Oh, I forgot to tell you, I'm an amputee too!" Any therapeutic effect had already been ruined by the total ineptitude of his unheralded approach. But, subject to certain safeguards, volunteer counsellors might be particularly welcome in hospitals where amputees are rare and nursing staff correspondingly ill-informed. A young man whose life revolves around cars does not like to be told that he will never drive again when there is no basis for such an assertion. Amputees who have achieved a good adjustment are well placed to offer sensible guidance in straightforward cases, always provided that the patient is receptive.

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Tubular orthoses

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Abstract

A method of constructing orthoses and other patient devices using nylon tubing and clip-together standard components is described. This permits the rapid assembly of custom orthoses that can be evaluated before prescription in a clinical setting. These orthoses have been successfully used for the control of thoracic spinal flexion, hip abduction, elbow extension, shoulder abduction, cervical spine stabilization and pressure sore relief. Advantages over existing orthoses include reduced weight, improved comfort and cosmesis, low cost and increased speed of provision. Examples of these orthoses are shown, together with details of their structure, function and clinical results.

Introduction

A new approach to the construction of orthoses has been developed. The basis of this construction is the interlinking of plastic tubes to provide a strong and lightweight framework. These tubes are linked to form structures to which pads, straps and other surfacing elements can be fastened. These form the interface of the orthosis with the body and so allow the framework to control the motions of the various body segments.

The orthoses have been successfully applied in the management of spinal injuries, arthritis, head injuries, burns and congenital disabilities. Examples of these applications will be discussed, including structural considerations, the current status of each orthosis and the areas of application. The management principles and plans for this new approach to orthotics will also be considered, together with the advantages offered to the patient and to the clinical community.

Structural considerations:

The structural principles common to all Tubular Orthoses include selected directional rigidity; use of tensile elements to increase the strength-to-weight ratio; three-point counter-loading where appropriate; and the use of contra-lateral body stabilization. The result is lightweight yet strong structures giving support in the directions needed and not restricting movement when not desired. Tubular Orthoses use the body to maximize support and stability of the device.

The use of plastic tubing for the construction of orthoses is advocated. High strength-to-weight ratio is achieved through this configuration and material. Rigid nylon bushing stock is used. Lengths are pre-cut in ½" (12·5mm) increments from 2" (50mm) to 2′ (600mm) in the sizes of ⅜" (9mm) O.D. ¼" (6mm) I.D.; ½" (12·5mm) O.D. ⅜" (9mm) I.D.; and ⅝" (15mm) O.D. ½" (12·5mm) I.D. These are interlinked by various components that function as T junctions, hinges, ball and socket joints, crossovers, C clips, rings, end plugs, cable ties and clamps. A selection of these is illustrated in Figure 1.

The result is a system of tubes and linkages that can be plugged together to permit rapid assembly and adjustment of a wide range of orthoses and patient devices. Six orthoses have entered the clinical trials stage using this system and these will now be described.

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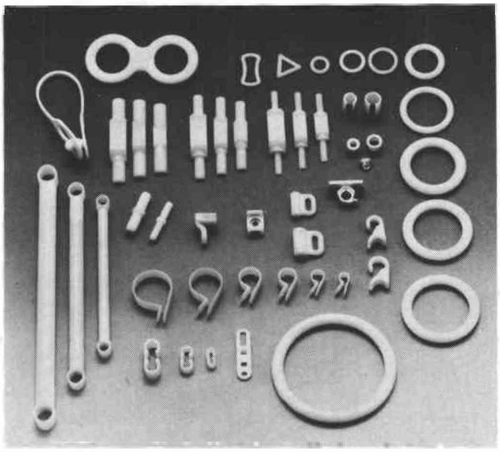

Fig. 1. An array of components is shown. The 3 sets of 3 linkages near the top of the figure are the T junctions, which are folded over and inserted into the tubes. A variety of additional components are presently being moulded, including ball and socket joints, lap hinge joints and cross-overs.

The orthoses

a) *The cervical orthosis*

(i) Structure and function

This orthosis is designed to provide control of flexion and extension of the cervical spine. This is achieved by support on the soft tissues under the mandible and over the upper portion of the chest; at the occiput and across the shoulders. Rigidity is controlled by the closeness of fit and by the position of the vertical tubes. The orthosis is constructed from short lengths of ⅜″ (9mm) nylon tube ranging in length from 4″ (100mm) posteriorly to 2″ (50mm) anteriorly. These are linked by T junctions to flexible clear PVC tubing at the superior and inferior perimeters of the orthosis. Closure anteriorly is achieved with ¼″ (6mm) nylon rod that plugs into the two anterior tubes. A breastplate ring and a chin support are heat formed in three sizes to accommodate a range of patients. A small chin cup is clipped to the chin support rod to complete the structure. Fabrication and fitting time is of the order of 30–45 minutes. The weight of the orthosis is 110 g. An example of the orthosis, without a chin cup, is shown in Figure 2.

ii) Clinical results and plans

Ten patients have been fitted in the preliminary clinical trials of this orthosis. These comprise 7 arthritis, 1 cerebral vascular accident, 1 spinal cord injury and 1 'whiplash' injury patient. Of these patients 8 continue to wear the device on a regular basis. One arthritis patient complained of soreness under the chin. The whiplash injury patient had tenderness at the occiput due to her injury, consequently she only wore it when riding in a car. However, the other 8 patients continue to wear their collars on a regular basis. For example, the spinal cord injury patient, (a chipped facet or slipped disc at C6 resulting from a skiing accident,) wore his collar at least 15 hours a day for two weeks immediately after his accident. The cerebral vascular accident patient had resulting muscle weakness on the right side. This was compounded by narcolepsy resulting in a postural problem of the head drooping to the right side. the collar was fitted primarily for posture control, enabling the patient to communicate more readily and to use a typewriter. The majority of patients had either rheumatoid or osteo-arthritis of long standing. Prime advantages cited by the patients over their existing Plastazote collars were coolness, reduced weight and increased rigidity. The preliminary trials of this device are now complete and extended clinical trials will now be conducted. These will include controlled studies

Fig. 2. The cervical orthosis showing the vertical ⅜″ (9mm) nylon tubes linked by T junctions to the superior and inferior lengths of PVC tubing. A curved chin piece of ¼″ (6mm) nylon rod is inserted into the top of the two anterior tubes and a chin cup is clipped onto this. A circular curving section of ¼″ (6mm) rod forms the breastplate.

on arthritis with radiological determination of atlanto-axial stabilization; provision of the collars for emergency care; and expansion of use in rehabilitation for posture control.

b) *The spinal extension orthosis*

i) Structure and function

This orthosis is designed to resist flexion of the thoracic spine. The orthosis also encourages extension which aids in resisting lateral and rotary motion of the spine. The resistance to flexion by the structure is achieved by three point application of forces. Sternal and pubic area pressures are counterbalanced by a lumbar pressure area. This is achieved by linking pressure surfaces at these three points with structural beams constructed from the plastic tubes. An outline of the forces involved is given in Figure 3. This three-point loading system is common to many orthoses. Immobilization of the thoracic spine is achieved by keeping the spine in extension. Additional support is given to the abdominal muscles by the ring network shown in the anterior view in Figure 4. This support in turn braces the spine in a similar manner to a corset.

The orthosis is constructed from plastic tubular rings; two large ones on the ventral surface and several small ones (2″ (50mm) diameter) on the dorsal surface. (The dorsal rings used are the same as those shown on the shoulder abduction orthosis in Figure 6). The two ventral rings are concentric and the smaller internal ring is distorted to press against the sternal and pubic areas at its upper and lower poles.

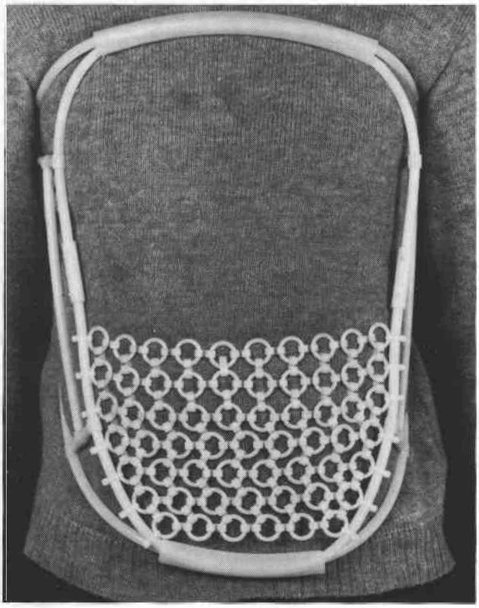

Fig. 4. This anterior view of the spinal orthosis shows the two concentric ventral rings joined at the top and bottom. A meshwork of fine nylon rings pulls the abdominal muscles up and in to aid in supporting the spine. Larger rings are used dorsally to enclose the lower back.

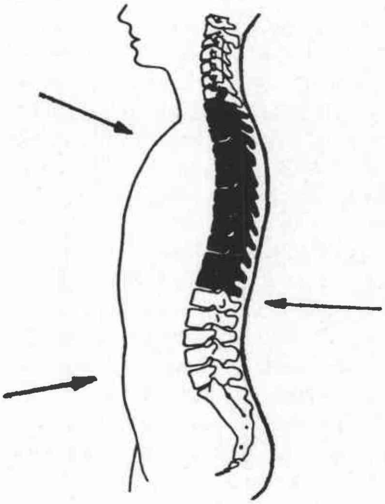

Fig. 3. The three-point force application of the spinal orthosis. The two anterior forces are balanced by the posterior force, with the objective of stabilizing the thoracic vertebra (shaded).

The small dorsal rings hook onto the larger ventral ring at each side of the body and they are detachable at these points for application and removal of the orthosis. When the cross-linked lateral sections of the ventral rings are pulled towards the body, they are pulled into the sagittal plane and so they are more able to aid in resisting flexion. The rings can be pulled away from the anterior superior iliac spines or be shaped around the breasts. The weight of the orthosis is 350 g.

(ii) Clinical results and plans

Forty-seven orthoses were fitted to patients in a clinical trial to obtain design information and to determine the correct prescription criteria for this orthosis. Consequently all the patients that were referred for fitting by physicians were fitted, regardless of the appropriateness of the orthosis. Even with this "take-all" approach, a 50% success rate was achieved. That is, 50% of all the patients referred accepted and continued to wear the orthosis until their spinal problem was resolved. The most successful users of the orthosis were those in the 15 to 40 age range who had suffered a spinal injury and needed an intermediate support after the removal of a plaster cast. The most unsuccessful cases were those patients suffering from arthritis of the spine, osteoporosis of the spine, or with intractable lower back pain.

The prescription criteria can thus be defined as: enhancement of stability of the spine and control of thoracic flexion for those patients having suffered recent trauma to the spine. Application will be most successful at the removal of a standard body cast when the patient is entering a more active stage of the rehabilitation process. The orthosis can reduce the time spent in a plaster cast and it can be used for pool therapy during rehabilitation. It will also provide support during showering and bathing. The orthosis is now ready for wide use and commercial availability will now be established.

Fig. 5. Lateral view of the abduction orthosis showing the anterior and posterior suspension loops. These are secured to the limb by Velcro straps to the thigh. The three-tube beam can be seen clearly maintaining the hips in abduction.

c) *The hip abduction orthosis*

(i) Structure and function

This orthosis is designed to maintain the hips in abduction and to permit the continuation of normal activities of daily living. Abduction of the hips is achieved by pushing the knees apart with a rigid tubular beam. This beam is held in place by loops of plastic tubing, anteriorly and posteriorly, that also suspend the orthosis from the waist. An example of the orthosis is shown in Figure 5.

The major functional part of the orthosis is the beam positioned between the distal medial surfaces of the thigh and resting just proximal to the superior medial aspect of the condyles of the knees. The function of the rest of the orthosis is to hold this beam in place, and so each part of the orthosis is constructed to different standards of rigidity. The beam is constructed of three ½″ (12·5mm) O.D. ⅜″ (9mm) I.D. longitudinal struts that are cross-linked with additional short struts. At the ends of this beam are pads that rest on the thighs. These pads are free-pivoting on the end cross-linking struts and therefore are self-aligning. The anterior and posterior tubes of the beam are open-ended to allow the long ⅜″ (9mm) suspension tubes to be plugged into them. The suspension tubes are continuous from the anterior beam tube, up the lateral aspect of the thigh, over the iliac crest and down the thigh again to plug into the anterior beam tube on the contralateral side. This arrangement can be seen clearly in Figure 5. The length of these tubes is adjustable where they plug into the cross-beam. These suspension tubes are held together with a waist strap and by additional straps around the proximal third of the thigh. The total weight of the abduction orthosis is 350 g.

iii) Clinical results and plans

Abduction tubular orthoses have been provided to two patients. The first patient was an eight year old child suffering from Legg-Perthes disease. This child has now used the orthosis for 24 months with continuing success.

The second patient was a four year old child who required hip stabilization following hip surgery. The orthosis was fitted shortly after surgery and it was used for two weeks post-operatively. This application was not a complete success, however, as the orthosis did not stabilize the hips adequately against rotation. Perineal care and toileting were facilitated by the orthosis for this patient and it was suggested by therapists that this could be a prime function of the orthosis for spastic adults.

Although the clinical trials of the abduction orthosis have been limited to two patients, it is felt that potential uses of the orthosis can be defined. They are: hip abduction management in Legg-Perthes whilst permitting ambulation and other activities of daily living for the child; perineal care management for the spastic child and adult; management of burn injuries; and post-operative stabilization of the hip. Preliminary clinical trials will be expanded to these areas in order to refine the design and prove the clinical viability of the device.

d) *The shoulder abduction orthosis*

i) Structure and function

The function of this orthosis is to maintain the shoulder in an abducted position whilst the patient is ambulatory or confined to bed. The orthosis is constructed using ½″ (12·5mm) O.D. ⅜″ (9mm) I.D. tubing. Two curved sections of tubing run up the lateral aspect slightly anterior and posterior to the pelvis, the shoulder and the distal portion of the arm. This curve is given by a heat gun and can be seen clearly in Figure 6.

The angle of abduction is determined by the length of the two straight supporting tubes running from the pelvis to the distal portion of the arm. A mesh work of small rings provides a comfortable and stable cushion over the lateral superior aspect of the pelvis and the supporting tubes are bridged at this point by a short curving tube. The wrist/hand is supported and cushioned by a thermoplastic resting splint and secured by straps. The main strapping support is anchored to a cross-bar mid-way along the arm. Two straps run anteriorly and posteriorly to the contra-lateral axilla and up over the shoulder. A meshwork of rings secures the orthosis comfortably using this contralateral stabilization. A waist band provides additional security. The weight of the orthosis is 620 g.

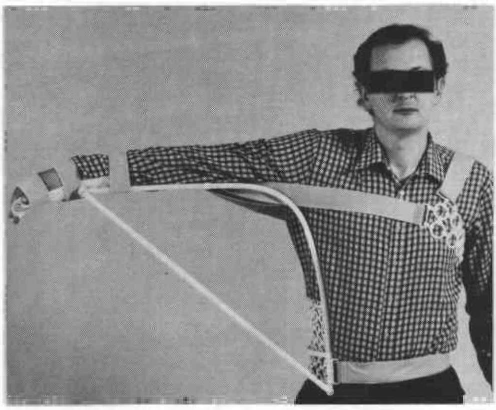

Fig. 6. The shoulder abduction ortnosis is shown here on an ambulatory subject. The meshwork of rings provide comfortable pressure distribution areas under which additional padding can be inserted if desired. The angle of shoulder abduction can be altered rapidly by use of differing lengths of the straight supporting tubes.

Fig. 7. The shoulder abduction orthosis is shown on a patient confined to bed shortly after skin graft surgery. This orthosis was used whilst the patient was both prone and lying on her side.

ii) Clinical results and plans

Two patients have been fitted with this orthosis. They both had severe burns to their back, axilla and lateral abdomen as well as elsewhere on the body. One patient was ambulatory and one patient was confined to bed (Fig. 7).

Acceptance by the ambulatory patient was not good, but this could be attributed to a widely fluctuating level of co-operation. The orthosis for the patient confined to bed was constructed by the leading author working from measurements supplied by the therapist, who then fitted the orthosis in the operating room after the patient had received a skin graft to the axilla. Adjustments to the angle of abduction were made quickly and easily in the recovery room with the use of shorter lengths of straight supporting tubes.

Wide application of this device is anticipated for burns cases, where the considerations of ease of sterilization, adjustment and access to the wounds are paramount. Clinical trials of this orthosis will be extended to post-surgical management of the shoulder as well as further burns cases.

e) *The elbow extension orthosis*

i) Structure and function

The function of this orthosis is to resist further flexion and reduce flexion contractures of the elbow. It is constructed of ⅜″ (9mm) O.D. ¼″ (6mm) I.D. nylon tubing and a mesh of rings at the elbow. A slight curve is imparted to the lower tubes with a heat gun and the correct length of cross-bracing tubes is selected to give the desired angle of elbow flexion (Fig. 8).

Straps at the proximal and distal ends of the orthosis hold the arm into it. Additional padding of artificial sheepskin can be used to protect the elbow, although this is omitted from the figure for clarity. Pronation/supination can be controlled by the addition of a thermoplastic wrist/hand splint if necessary.

ii) Clinical result and plans

Six elbow extension orthoses have been fitted to patients with various types of neurological damage. These comprise 3 head injury patients and 3 spinal cord injury patients. The head injury patients were tonic and they were fitted 8 to 10 months after injury. They had spastic flexion contractures of the order of 30–45 degrees. Regular methods of bracing had been tried and proven to be either of insufficient strength or to be otherwise inappropriate. For example, one patient had an intravenous block that prevented the use of plaster and another patient required a lightweight orthosis for daily use. The three spinal cord injury patients all had C5/C6 lesions with flexion deformities of the elbow ranging from 15 to 45 degrees. The orthoses in these cases were used on a 2 hours on, 2 hours off basis and one patient used the orthosis for sleeping in conjunction with a wrist pronation splint. The orthoses were used for an average of 2 weeks except for the patient who needed his for extended daily use.

The plans for this orthosis include an extension of the clinical trials to further cases of neurological damage and to other areas such as burns and serial casting of juvenile rheumatoid arthritis.

f) *Pressure sore relief frames*

i) Structure and function

The objective of this application was to explore non-standard orthotic uses of the Tubular Orthoses system in order to demonstrate the versatility of the system. Frames constructed of ½″ (12·5mm) and ⅝″

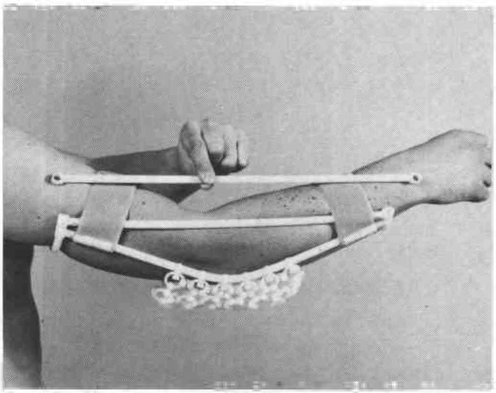

Fig. 8. The elbow flexion control orthosis is shown holding the elbow almost fully extended. The angle of flexion can be varied by using different lengths of straight tube from wrist to axilla, as shown. This tube can be pulled off and replaced quickly without any tools. The elbow is shown hanging free in the orthosis whereas a sheepskin pad is usually used.

Fig. 9. This pressure sore relief frame allowed the patient to sit in a wheelchair without weight being borne on the decubitus ulcers of his heels. The straps acting as slings were adjusted to provide correct clearance and positioning of his feet and legs. Gradual improvement in the condition of his heels has been observed over a period of 2 months.

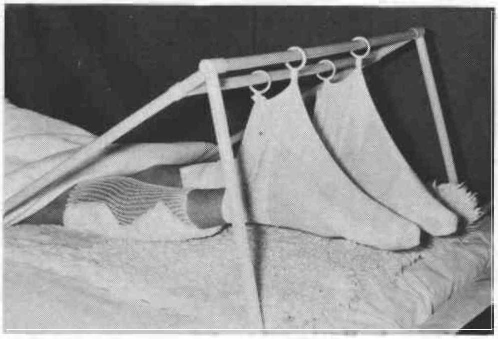

Fig. 10. Pressure sore relief frame used daily by this paraplegic patient in order to remove pressure from the anterior surface of the lower portions of his legs. He had an existing plantar flexion deformity and this did not worsen with extended use of this frame. Marked improvement of his pressure sores was achieved after alternative methods applied over a period of 8 months had failed.

(15mm) nylon tubing were used to manage cases of pressure sores in the lower limb. The function of the first orthosis was to relieve the weight of the legs from the heels of a wheelchair bound patient (Fig. 9).

The frame consists of vertical and horizontal supports to which straps are attached. These form slings for the calf and for the distal portion of the foot in conjunction with a Plastazote footplate. The heel hangs free and is unloaded. Additional protection for the toes is given by extension of the frame anteriorly.

The second patient fitted needed pressure relief to the anterior of his lower legs whilst lying prone. This was necessary as the patient, a paraplegic, also had severe pressure sores at the sacrum. A triangular based frame with cross-struts was constructed using ⅝″ (15mm) tubing (Fig. 10). A stainless steel rod was inserted inside the top cross-tube to give additional rigidity.

The patients feet were suspended using prosthetic stump sheaths attached by nylon clips to the tubes. This permitted selective positioning. The ankles appear to be more plantar-flexed than was the case due to the position of the feet within the sheaths. The anterior aspects of the lower portions of the legs were clear of the bed, although this does not show clearly in the figure.

ii) Clinical results and plans

Two patients have been fitted with these frames. The second patient with the anterior leg sores showed marked improvement of these sores after a 4 week period of use. The frame was used whilst the patient was prone for 2 hour intervals during the day with mobilization of the ankles at each time of application and removal. There was an initial plantar flexion deformity of 25 degrees and this did not show any worsening over the trial period.

The patient with the heel relief frames had decubitus ulcers of the heel due to peripheral vascular disease. He spent all of his time either in a wheelchair or in bed. Fitting of the frames resulted in a gradual improvement of his ulcers over a period of six weeks. For both of these patients alternative techniques over a period of 9 to 12 months had failed to resolve their problems. The pressure sore relief frames did give improvement of their pressure sores, they were rapid to construct (30–45 minutes) and easy to fit and adjust. Future plans include extension of the technique to other types of pressure sores, to burns cases and to post-surgical management of the lower limb.

Discussion

The construction techniques of Tubular Orthoses allow a diversity of orthoses to be constructed from the same basic components. Prototypes have been constructed of an upper limb orthosis to manage the MCP joints post-operatively, a resting frame for protection of the knee, and an ankle-foot orthosis for use as a dorsi-flexion assist. Although these devices have been tried on ourselves, they have not yet entered the clinical trial stage and no prescription criteria can be defined. However, it is anticipated that many diverse applications of the Tubular Orthotic approach will emerge as the technique is accepted.

The patients, the prescribing physicians, the orthotists and the therapists involved in fitting Tubular Orthoses have responded positively to these new devices. The patients who had had experience with other types of spinal and cervical orthoses remarked on the lightness of the orthoses, the coolness and the improved appearance. Some patients indicated that greater comfort was experienced than with their existing orthoses. Most frequently expressed was the coolness of the cervical orthosis, compared to existing all-enclosing orthoses. The orthotist participating in the trials of the spinal orthoses was very enthusiastic and supportive of this new device. The elbow and shoulder orthoses have been well-received by therapists, who appreciate the ease of making angle adjustments and the facilitation of access to the skin. Although the trials of the abduction orthosis have been limited, the appropriateness of the design was well demonstrated by the eight year old child. She was able to compete in her school sports day and to carry out other normal activities of a child her age. The pressure sore relief frames demonstrate that custom devices can be readily fabricated from standard tubular components and it is anticipated that a wide variety of these types of frames will emerge. Co-operating physicians gave a response that varied from enthusiasm and a willingness to continue prescribing the orthosis to that of a neutral opinion because of a lack of sufficient experience with the orthoses.

The advent of Tubular Orthoses presents an opportunity to develop a family of orthoses that will set new standards for orthotics. The management principles defined by Tubular Orthoses are those of speed of provision and adjustment of improved orthoses through the use of mass-produced interchangeable components. The adjustable nature of the orthoses permits them to be fitted in a clinical setting, so reducing the need for repeat visits at the initial fitting stage. In these ways the labour costs of supplying an orthosis are reduced. The material costs are reduced by the use of inexpensive standard nylon or polyethylene tubing readily available from plastics distributors. Additional inexpensive plastic junction components are being designed and moulded and these will be commercially available. These materials and techniques allow the orthoses to be quickly adjusted, thus allowing them to be used for evaluation purposes in the clinic before prescription. The exploitation of modern materials such as thermoplastics and modern techniques such as injection moulding can greatly enhance the field of orthotics to the benefit of patient and clinician alike.

Development and clinical trials of Tubular Orthoses are continuing and as the preliminary clinical trials are completed for each orthosis, instructional literature and journal articles will be prepared. This will include fabrication and fitting procedures, together with prescription criteria and biomechanical analyses of the function of each orthosis. In parallel to these activities will be the closer examination of the containment and interface requirements, resulting in a comprehensive modular exoskeletal system.

Acknowledgements

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Studies of dynamic ligamentous instability of the knee by electrogoniometric means

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Abstract

Ligamentous injuries to a knee joint increase the risk of post-traumatic degenerative changes. Successful early diagnosis and treatment of such injuries remains a challenging and controversial task.

There are a variety of clinical tests available and some of these are difficult to perform and interpret. These clinical tests are really static in nature and may not reveal the presence of what is essentially a dynamic event. A complete assessment would need to be "dynamic" and by its application during ambulation, incorporate the effects of ground-foot forces, joint motions and muscle activities.

At the Ontario Crippled Children's Centre (OCCC) a triaxial electrogoniometer system (extensively modified CARS-UBC) has been used, together with complementary gait laboratory instrumentation, in order to study the knees of 16 male subjects. Ten subjects had knees without evidence of injury and six had a variety of cruciate and menisceal tears.

The purpose of the study was to investigate if a subject's knee could be classified as "normal" or "unstable" by using just the data provided by the electrogoniometer during walking trials. These data are difficult to interpret in their time series form because they are multidimensional and in all subjects likely to exhibit subtle stride to stride variations. The method described allows the mapping of this data into an abstract two dimensional co-ordinate system, resulting in a set of trajectories which cluster together for data belonging to the "normal" group. Only two subjects, with grossly unstable knees, were judged different from normal using a level walking test protocol. Some potential reasons for this are discussed.

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Introduction

Knee joint function

The knee joint has received much attention over the years in almost all aspects of its function, components, replacement and repair. Discussion here will be restricted to studies pertinent to ligamentous knee injury.

Goodfellow and O'Connor (1978) gave a good functional description of the knee and pointed out that its important overall properties concern its mobility and stability and the interplay between them. Stability is the extent to which mobility is restricted by ligaments, joint surface geometry and active muscles and may be further considered as both a dynamic and a static property. Dynamic stability can only be fully assessed when a person is ambulatory and the forces of gravity and muscle activity are dominant features. Passive, or static, stability is the knee property most often judged by the popular clinical tests such as the "anterior-posterior drawer sign" or the "pivot shift sign". Ligamentous injuries which affect knee stability increase the risk of post-traumatic degenerative changes. The aim of treatment is to restore ligamentous stability and thereby reduce the likelihood of these changes occurring.

Classification of knee injury

A working classification of knee joint instability is mandatory, not only for the diagnosis of a specific injury, but also to apply treatment and to attach a meaningful prognosis.

Fowler (1980) reviewed those classification systems described in the past and pointed out their advantages and shortcomings. It is certain that a useful working classification will combine anatomical and pathological considerations. The type of instability experienced by a patient should ideally be correlated with the specific lesion. This is far from a simple task. There is a close interrelationship of all elements of the joint complex in contributing to the overall stability of the joint. There is not really such an entity as a "pure" lesion of a structure such as a cruciate ligament; some capsular involvement or other injury must invariably be found. A classification system must take into consideration all these factors. Often the extent of involvement of the various structures is the factor determining whether or not a knee can adequately compensate for an injury in the patient's usual range of activity.

Classification by passive assessment

The overall purpose of this type of classification has been to understand and correlate simple clinical stability tests with the various possibilities for internal derangement. The earliest detailed works used subjective observational methods (Brantigan and Voshell, 1941) which were repeated and refined by attempts at objective measurements. Many papers have been published in this area and are well described elsewhere. Recent work includes that by Butler et al, (1980) and Seering et al, (1980).

All of this work has had value in furthering understanding, but does not directly provide us with a classification of how a knee will behave under dynamic or ambulatory conditions. In fact, static clinical testing may be misleading. Butler et al, (1980) illustrated how, under the low forces of clinical testing, a partially torn ligament can deceive the clinician by blocking his attempt to recognise a positive sign.

Classification by dynamic assessment

In contrast to the numerous attempts to describe the role of the structures of the knee in passive testing, dynamic studies have received little attention in the clinical scene.

In general terms, when dynamic force actions are exerted on the limbs during walking they tend to produce dynamic turning effects (or moments) at joints. These turning effects are counterbalanced by the ensemble of reactions provided by muscle activity, ligament tensions and joint surfaces in contact. These internal forces usually cannot be directly measured using non-invasive methods and therefore must be estimated. Those situations where internal forces can be measured directly are few. Rydell (1966) made a direct determination of joint force at the hip using an Austin-Moore prosthesis with attached sensors. Others have implanted similar devices but few results have been reported.

A complete description of the dynamic behaviour of a joint must include information concerning forces, joint motion and muscle activity; all integrated with some concept of the interplay between them.

Attempts have been made to use optimization techniques to infer joint forces by criteria minimizing weighted sums of all lower limb muscle forces and residual unbalanced forces at all joints (Seireg and Arvikar, 1975). Justification for such criteria is still not established.

Generally accepted methods of estimating joint forces made use of anatomical and physiological constraint conditions together with force equilibrium equations. Techniques used by various researchers differ in the way constraint conditions have been applied to the equilibrium equations. One school of thought has used all unknowns in the equilibrium equations and then assumed that certain tendon forces are zero to produce a determinate system. All possible combinations of the unknowns are then tried and illogical solutions rejected to obtain joint forces (Chao et al, 1976).

The method of Paul (1967) for the hip, and Morrison (1967) and Harrington (1974) for the knee, was to identify the prime function of all the major structures and then simplify the equilibrium equations before attempting a solution. Correspondence between the results for Paul's approach and that of Rydell show that estimates obtained by manipulation of external measurements are realistically close.

All of these assessment efforts rely upon multiple signal acquisition of gait data which is combined with a generalized knowledge of functional anatomy to estimate internal states. The process by which this estimation is made is simplistic in comparison with the true situation. Whether or not this will matter depends upon the reasons for a particular investigation.

Whether the aim is clinical diagnosis of an injured knee or the refinement of basic investigative techniques the ability to identify and interpret "abnormal" joint motion would be of value.

Purpose of the study

The aim of this study was to apply a triaxial electrogoniometer to investigate the motion of the knees of subjects with normal and injured knees during level walking and determine whether a knee could be classified as normal or injured on the basis of such data.

Instrumentation

Choice of electrogoniometer

There are many systems intended for the collection of kinematic gait parameter measurements. Each of them has some advantages and disadvantages depending on the application.

The CARS-UBC system was chosen for our application because of:

i) Its availability.
ii) Its relative low cost.
iii) Its ability to detect valgus/varus and tibial rotation angles.
iv) Its ease of interfacing with our existing gait analysis systems.

Of particular importance was the reported ability to detect tibial rotation and valgus-varus angles because of the multifactorial nature of knee motion. These are particularly difficult to measure and attempts to use our existing optical processing methods were frustrating because of necessary increased data handling, operator fatigue and commensurate delays.

The availability of the CARS-UBC system and impressions of its use overrode the use of the systems described by Townsend et al, (1977) or Lamoreux (1971). There are some pitfalls in the use of a triaxial goniometer which have been described in the literature. Chao (1980) has explained some of the experimental limitations of this device.

The CARS-UBC electrogoniometer

The electrogoniometer has been well described by the designers (Hannah and Foort, 1979). Only brief details are given here.

The measurement module consists of a potentiometer/parallelogram cluster. Three potentiometers are arranged to be mutually orthogonal to give an angular measurement of the relative angular motions of the limb segments in three planes. At the knee these would be flexion-extension, internal-external rotation of the tibia with respect to the femur and valgus-varus as an angulation. The parallelogram chain is designed to absorb any translations due to bone movements or potentiometer—joint malalignments but to allow pure angular movements to pass through unchanged (Fig. 1). This makes the potentiometer cluster self-aligning with the anatomical centres of angular movement thus in theory eliminating any forces between the device and the joint which would affect the rotations being measured.

Each limb attachment consists of three parts; the thigh frame, the shank frame and the measuring module. The thigh frame has a lockable telescopic beam that is attached to the measurement module via a ball and socket connector. The manufacturers suggest that the thigh and shank frame be attached to the limb using adjustable plastic straps.

Anticipated problems

In the general area of measurement, no matter how simple the measurement system, several problems can be anticipated which to varying degrees will affect the signals obtained. These problems fall into the area of *quality* related and *application* related.

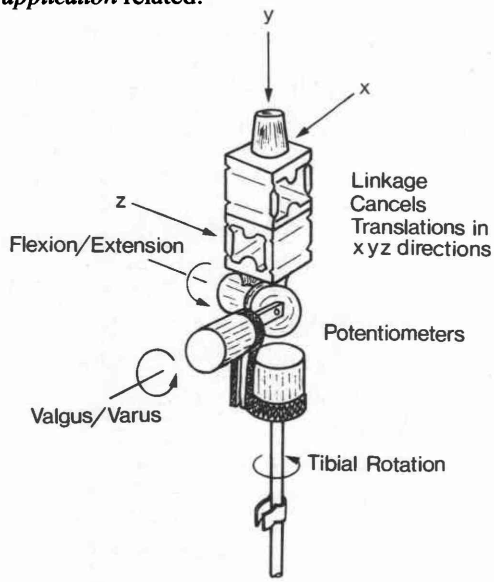

Fig. 1. Electrogoniometer measurement module.

Quality related problems concern all aspects of construction of the device, ie choice of materials, electrical wiring layout, ease of repair etc.

Application related problems are more subtle and fall into three categories. In this application they would be:

a) When the connection of the transducer to the leg affects the operation of the leg.
b) When the mere presence of the transducer changes the value of the measurand, although the operation of the leg is not directly impaired.
c) When the transducer is otherwise not suitable for the application.

In our initial assessment of the CARS-UBC system an attempt was made to identify and where possible, minimize these problems to an acceptable degree.

Results of electrogoniometer assessment

Mechanical changes

An initial evaluation by data collection from the knees of normal subjects gave grossly inconsistent signal patterns. The reasons for this were identified and changes were made to the following goniometer components (Fig. 2).

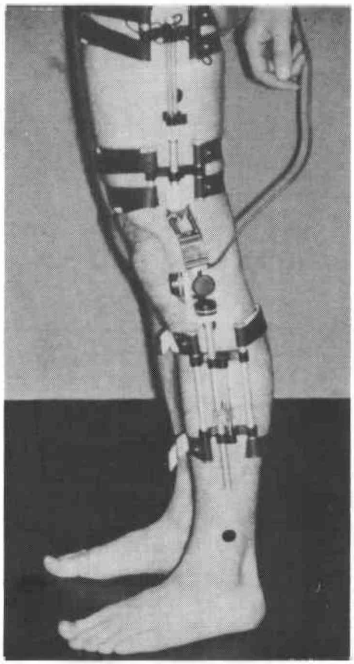

Fig. 2. CARS-UBC (modified) electrogoniometer.

1) The strapping arrangements.
2) The sliding mechanism.
3) The clip transmitting rotation to the tibial rotation shaft from the shank section.

The plastic straps provided had the advantage of easy adaptability to differing limb sizes. For our purposes this was not an important feature. The plastic straps were found to be unsuitable for comfort and attachment security. After short periods of use the heat of a subject's limbs would make the plastic more pliable, thereby loosening the straps. In addition, after several weeks the straps had to be replaced because of their increasing plasticity. These plastic straps were replaced with rubber straps covered with Velcro strips. The thigh unit is now held on by four rubber straps that extend from one side of the attachment to the other, secured by Velcro. The shank unit has two rubber straps attached in the same manner (Fig. 2).

The sliding mechanism and the tibial rotation clip were also changed. The rod extending from the tibial rotation potentiometer was provided in an acrylic material which had an uneven diameter along its length. This meant that in some phases of gait it would be sticking, whilst in others it would be lax; depending upon where the rod was in relation to the shank attachment section. Severe artifacts were introduced into the tibial rotation signals because of this. The rod was replaced with a polished aluminium tube which was light and smooth sliding. The original clip was replaced by a "Lexan" polycarbonate one which gripped the rod more securely than the original Derlin unit. The new clip was machined to eliminate any backlash in the transmission of rotation to the rod.

Effect of misalignment of goniometer parallel linkage

The three signals which are labelled flexion-extension, valgus-varus, and internal-external tibial rotation can only be so labelled because of a fairly arbitrary anatomical reference.

The angles detected by the electrogoniometer sensors are merely the orthogonal projections of the "true" knee angle vector (perceived outside the body). It is because of this that we examined the patterns of the three angle components provided by the goniometer under varying degrees of parallel linkage misalignment. Two protocols were selected.

The goniometer was applied "by eye" in the manner subjectively judged to be best by a group of applicators. The (normal) subject performed a level walk and data was collected. The goniometer was removed completely and then reapplied by the same applicator. Another walking trial was then conducted, data collected and then compared with that collected previously. It was found that each applicator could achieve subjectively consistent results although there were differences between the results of the applicators.

In the second protocol the goniometer was, as before, applied in the best "by eye" manner and data collected. The goniometer parallel linkage was then rotated about the tibial rotation axis by ± 30° and the test repeated. Marked differences in the tibial rotation curves were observed with the greatest variability being apparent in the swing phase of gait, demonstrating an interaction between the flexion/extension pattern and internal rotation pattern (Fig. 3).

This concern about the effect of goniometer placement upon the "tibial rotation" motion patterns affected our processing strategies.

To minimize problems caused by goniometer placement inconsistency the following steps were taken:

a) The goniometer was always applied by the same person.
b) Surface landmarks were identified in areas which could be subcutaneously palpated. The exoskeletal system was then applied according to the observations made.
c) The goniometer was placed as close to the limb segment as possible (without contacting the tissue) to minimize cross-effects. The linkage and sliding mechanisms were observed to ensure that no slipping or interference with the body could occur during testing.
d) The distal or tibial attachment was placed as far away from the joint centre as possible.

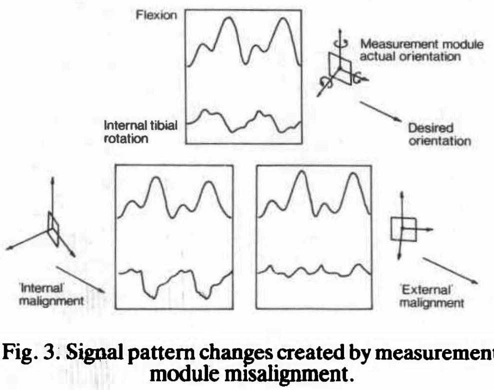

Fig. 3. Signal pattern changes created by measurement module misalignment.

Examination of normal and ligamentous injured knees

Methodology

In order to classify a knee electrogoniometrically as stable or unstable it appeared intuitively reasonable that the following steps be taken.

i) Examine the behaviour of the knees of a significant number of clinically normal individuals using electrogoniometric methods.
ii) Process the data collected in order to statistically represent the normal knee in a compact, non-redundant form.
iii) Examine a number of clinically unstable knees under identical testing circumstances and compare each with the statistical data base of normal knees.

Subject detail and test protocol

Ten volunteer subjects were examined using the electrogoniometer system applied bilaterally. Each of these subjects was judged by the absence of symptoms to be "normal".

The testing protocol of free, level walking in the gait laboratory (12m long) for multiple trials. Transient effects due to the subject speeding up and slowing down at the ends of the laboratory were eliminated by rejecting those strides. Sufficient trials were conducted to establish a record length of at least 40 strides for each subject. Average speed of walking was monitored over a 5m length of the walkway but no attempt was made to control the subjects' speed.

Six subjects with arthroscopically confirmed anterior cruciate injuries were examined using an identical protocol. All subjects had a clinically identified "pivot shift" and complained of episodes in which their knee "gave way" during some activities. None of these subjects had complaints of pain during testing.

Data acquisition

The electrogoniometer system was connected via an overhead cabling link to a DEC

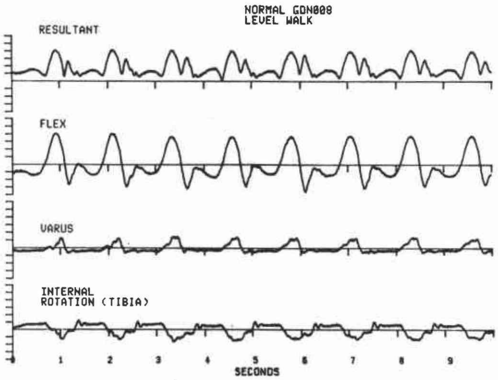

Fig. 4. Graphic display of unprocessed electrogoniometer signals.

PDP–11/34 computer which sampled each signal channel at a rate of 200 samples per second. A fourth order, digital equivalent, Butterworth filter was used to provide low-pass filtering to a cut-off frequency of 20 Hz. The laboratory graphic display terminal allowed immediate post-test display of the signal properties. An example of the signal display is shown in Figure 4.

Previously obtained "bench" calibration of the goniometer was used to scale the signals, to the correct units (10 degrees per vertical division on the axes shown). In addition, the mean values of the signals, calculated over the whole record lengths, were subtracted to form the signals for display.

Processing of data

Introduction

Having performed the level walking protocol with both normal and injured subjects the task of identifying the differences (and the significance of these differences) between these two groups remains. Examination of the unprocessed multiple angle signals "by eye" is difficult to perform objectively because of the volume of data involved. It would be possible to perform fairly straight forward reduction of the data into sets of numbers representing the local peak values of the signals and their times of occurrences. When this is done for all subjects it would be possible to test statistically whether the subjects could be separated into their normal and injured classes, purely on the basis of this data. However, intuitively this approach may sacrifice much of the information retained in the shapes of the signals and lead the investigator to a false conclusion. The methods popularized by Hershler and Milner (1980) which consider shape and magnitude in a so called angle-angle diagram are applicable when the interrelationship between two signals is to be investigated. When it is necessary to examine the interrelation between each of several signals then several angle-angle diagrams are needed. In the statistical literature there exist several methods which attempt to represent the variability in shape and magnitude of multiple signals in a single two dimensional plot. More specifically, the method of processing termed the Principal-Component expansion was thought appropriate and was used. This method consists of representing the multiple signals collected from the electrogoniometer in terms of two functions. These are formed by a transformation process designed to retain a large proportion of the variance, but in a more compact form. The idea behind this approach is that when all the records of all the normal subjects are mapped into a two dimensional display, the region bounded by the set of curves and shape of these curves will define the behaviour of the normal group. When any other individual person is then examined using the same methods and transformation parameters, and his or her data is mapped into the same diagram, it is possible to identify whether that data belongs to the class which represents "normal" (Fig. 5). The detailed method is beyond the scope of this paper but is briefly depicted in Figure 5. (Fukunaga, 1972).

Mapping method

The data collected from our subjects with clinically normal knees and obtained during level walking trials, was subjected to computer editing. All strides from the beginning or end of walking trials were rejected along with those close to turns by the subject. The three signals were adjusted to zero mean value, normalized and placed in an array 'C' (Fig. 5). The covariance matrix of C was determined and an eigenvalue analysis produced three eigenvalues representing the three dimensional property of the signals.

The 3×3 covariance matrix has elements which indicate the relative independence of each signal; with itself and the other two. The matrix is symmetric in form. The eigenvalues and their associated eigenvectors are the essential parameters of a linear system which is created

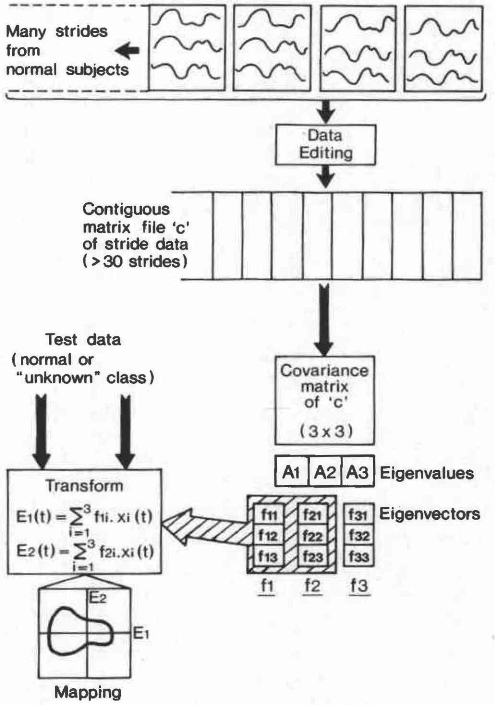

Fig. 5. Method of signal processing, mapping and comparison.

purely for the purpose of the mapping. If this plane is chosen by the linear system in Figure 5, using the eigenvectors corresponding to the two largest eigenvalues A_1 and A_2, then the maximum variance within the normal goniometer data will have been retained. The three goniometer signals are then combined and weighted by the normalized eigenvectors to produce a trajectory in the E_1–E_2 plane.

Computer programs were created to generate the eigenvectors and operate on the test data to produce the curves required on a computer graphics terminal.

Results of electrogoniometric comparison

The method of processing described above allows the representation of the data from the ten normal subjects as a set of trajectories in the E1–E2 plane. The set of curves in Figure 6 represent the data from one of these normal subjects. One individual stride trajectory is shown in Figure 7 and can be seen to represent a closed curve.

The three goniometer signals had a predictably high degree of interdependence. This fact is illustrated by the high percentage of

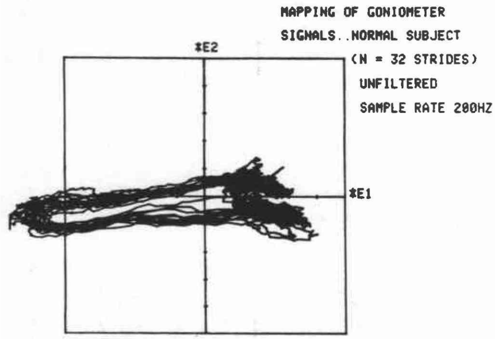

Fig. 6. Mapping of processed data for one subject.

variance retained in the mapping. For the ten normal subjects, computation of eigenvalues and eigenvectors for each revealed a mean variance of the signal retained to be 95·97% with a standard deviation of 3·13% for the ten subjects. The similarity of these data from normal subjects allowed all stride data to be combined and one set of eigenvalues and eigenvectors to be calculated. These eigenvectors were then used to map all the data from normal and injured subjects into the E1–E2 plane using the linear transformation shown in Figure 5.

Interpretation

The original data represents the three co-ordinate time history of knee motion for a set of subjects. For this three dimensional case, the process of mapping into the E1–E2 plane can be thought of firstly as transforming the data into a new co-ördinate system oriented such that the plane E1–E2 best illustrates the group variability of the data. The symmetry of the covariance matrix of the data ensures that the eigenvectors

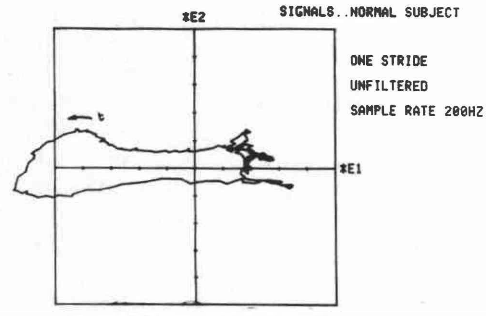

Fig. 7. Mapping of an individual stride.

are orthogonal and therefore that the transformation is orthogonal.

For example, for the whole normal group the raw eigenvalues and vectors were:

	A_1=2·591877	A_2=0·355032	A_3=0·053092
VECTOR 1	0·562171	−0·610671	−0·557714
VECTOR 2	0·691935	−0·022063	0·721622
VECTOR 3	0·452979	0·791577	−0·410142

% of variance retained 98·23 percent.
So that $(V_1,V_2), (V_1,V_3),(V_2,V_3)=0$

The result of the mapping is therefore an angle-angle diagram with the viewpoint chosen so that the inherent variability in the data is best visualized. For other applications, where the original data has a higher dimension, the mapping is abstract in form and may have no simple physical interpretation. This is because the map is constructed only for the mathematical convenience of classifying sets of data according to their similarities.

The representation of the zone of normal data in Figure 8 was used to then compare other individual subjects and classify them as normal or not normal. This comparison strongly depends upon the test data being collected under the same test conditions for the normal set of individuals and the individuals being investigated. The possible problems are indicated in Figure 8 which shows the first two strides, collected from a standing start of a normal subject, mapped togther with the "normal" zone. The result of this comparison indicates differences in both stance and swing phase patterns of the goniometer data due to differences in test conditions rather than any knee pathology.

Comparisons and discussion

Comparisons between the normal and injured groups were made from three points of view. The style and rate of trajectory plotting was observed interactively on a computer graphics terminal. The regions of each group of trajectories were defined on the diagram. Finally the methods of Hershler and Milner (1980) were used to compare the perimeter lengths and enclosed areas of trajectories.

As Figure 8 illustrates, radical differences can occur as a result of changing test conditions and this was reflected in the perimeter and area calculations as well as the region occupied by the trajectories. These differences were most clear during the swing phase portions of the data. The stance phase portions of the data appeared to be less sensitive to minor test variations. This is important because instability would manifest itself during stance phase load transmission, with swing phase changes most likely indicating compensatory behaviour by the subject.

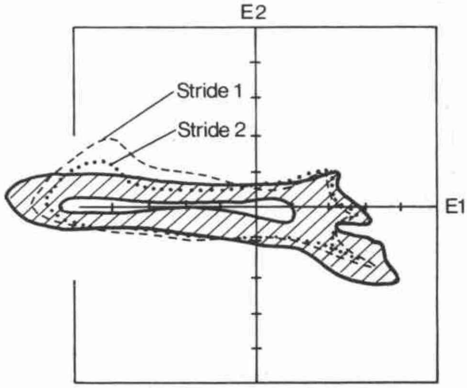

Fig. 8. Characteristics of normal data trajectories and the effect of test protocol changes.

Only two subjects could be classified as not exhibiting normal knee motion patterns and their trajectories are given in Figure 9. The first subject, age 36 had prior surgery to his left knee (meniscectomy) five years previously and presented for consultation with a torn anterior cruciate ligament. A positive pivot shift sign was demonstrated (Galway et al, 1972) to be gross on the left. The right knee had a greater than usual anterior-posterior laxity but negative pivot shift. The subject complained that his knee "gave way" on occasion but was mostly pain free. The second subject also had a long standing history of knee injury which had not been diagnosed or treated. Presentation was with a verified anterior

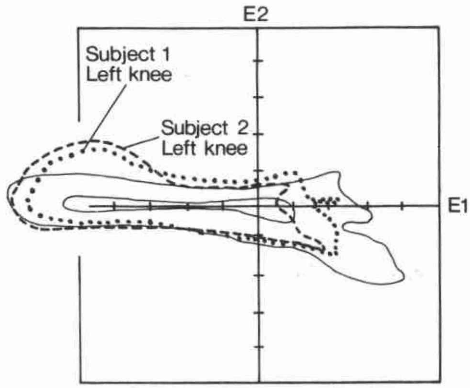

Fig. 9. Mapping of the two subjects judged to exhibit abnormal trajectories.

cruciate insufficiency and a grossly positive pivot shift. Neither subject participated in sport activities.

All the subjects had positive pivot shift signs but only the two above were inactive in sports and had *gross* clinical instability. It is perhaps initially surprising that all the clinically unstable knees could not be identified by motion detection. However, the level walking protocol which was utilized would allow the individual subject to compensate for ligament injury by muscular control (if such control were available). It is clear therefore that individuals who have good neuromuscular control will have stable knees during many activities, even though the commonly used clinical tests grade these knees as unstable. Noyes et al, (1980) have already reasoned that functional stability can be maintained in joints that appear to be unstable using routine clinical tests and this ability will depend upon the individual and his activity level. A need exists to develop dynamic tests for knee instability which consider each individual's capability to compensate under controlled activity conditions.

The triaxial electrogoniometer system does not provide sufficient information to classify knee instability to a clinically useful degree under level walking conditions. Further work will utilize a goniometer which identifies translational as well as angular modes of motion and a more vigorous test protocol which involves "cut" and "crossover" turns by the subject.

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Prosthetics and Orthotics International, 1983, 7, 174-175

Technical note— "Lawry" rotary attachment for paraplegics

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Abstract

Paraplegics usually transfer from wheelchair to water closet by side, rear or front approach. This necessitates removal of the arm support or back rest and sitting on the water closet in opposite to normal direction. The author has designed a rotary attachment which enables the patients to approach from the front and transfer easily so as to sit in the normal direction on the water closet without removal of the arm support or back rest. Further, this device enables the patient to move away from the water closet for washing purposes without having to get up from the water closet seat.

Introduction

Paraplegic patients normally attend to their toilet functions by the following methods:

Sitting in the wheelchair

Without transferring from wheelchair, moving the wheelchair over the water closet seat in the reverse direction and removing the special sliding seat under the buttocks.

Transfer from side

Bringing the wheelchair to the side of the water closet, removing one of the detachable arm supports and transferring themselves to water closet.

Transfer from front

Forward approach

Bringing the wheelchair in front of the water closet and transferring with the help of rail/ overhead support. In this case the patient sits on the water closet in a direction opposite to the normal.

Rear approach

By removing the back rest of the wheelchair and transferring with the help of hand support. In this case the patient sits on the water closet in the normal direction.

The disadvantage in the above toileting methods is that the patient must wash while sitting on the water closet seat. This is most inconvenient. There are many patients who would prefer to wash themselves away from the water closet. With this in mind, the author has designed a rotary attachment with a water closet seat attached; this facilitates washing and bathing away from the water closet without getting up from the water closet seat.

The rotary attachment

The rotary attachment consists of a "U" shaped seat held horizontally with the help of an "S" shaped cantilever system, which is grouted at a depth of 500mm from the floor level with a socket and two bearings, one ball and the other taper. The cantilever system has been designed to withstand a dynamic load of 200 kg. An 80mm diameter pipe is used as a female socket. The socket mounting is such that it projects 50mm above the floor level to prevent water seeping through. The "S" shaped cantilever is welded to a 40mm diameter mild steel rod, which goes into the socket and has a taper bearing at the bottom and ball bearing at the top. A foot rest is also incorporated in the device which also acts as a cover to the female socket to prevent water entering.

The height of the mobile "U" shaped seat is the same as that of a standard wheelchair seat. This facilitates the incorporation of a supporting clamp under the tip of the mobile seat. When the

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Fig. 1. Left, "Lawry" rotary attachment. Transfer is facilitated by use of the overhead support. Right, the rotary attachment is swung away from the water closet seat for washing. Note the water tap just below the back rest and separate shower hose.

wheelchair is brought in contact with this clamp, it prevents the wheelchair from toppling during transfer.

Salient features

1. Patients can tranfer to the "U" shaped seat from the wheelchair without help, by holding the circular overhead support (Fig. 1, left).
2. The rotary attachment can be adjusted to any desired angle, as it can be rotated through 360°. A locking arrangement has been provided to fix the rotary attachment seat at any desired angle.
3. The attachment can be fixed to any water closet of the pedestal type. Patients such as paraplegics, and above and below-knee bilateral amputees who retain strength in their upper limbs can use this independently.
4. Normal individuals may also use the water closet by swinging the seat of the rotary attachment out of the way.

Essential washing facilities are provided by a water tap with separate shower hose. A back support is fitted to the wall above the tap (Fig. 1, right).

Durability and maintenance

During the past year of use the device withstood both the static and dynamic loading of all patients without developing any defect. However, the locking arrangement for the rotary attachment has a tendency to slip. A change in design is in progress, and will be tried as soon as it is completed.

The mobile seat ring is supported underneath by a metal frame extension to the "S" shaped support. Hence the seat ring does not sag under any live load.

The bearing has to be lubricated as and when required. Painting of the device may be done once a year to prevent corrosion.

This attachment has been in use at the National Institute of Prosthetic and Orthotic Training, for the past year and patients have found it very convenient to use. The doctors of the Institute have also reviewed its performance and have accepted it as an excellent device for use by paraplegics. The Director of one of the leading Rehabilitation centres of the country has decided to install the device in his centre. Any suggestions for the improvement of the device would be welcomed by the author.

Acknowledgements

I am indebted to Maj. Gen. K. Raghunath (Retd.) who was Managing Director ALIMCO, for the encouragement given during the various stages of design, fabrication and installation and also for suggestions in improving the design. Maj. Gen. J. P. Bhalla VSM (Retd.) Director, NIPOT for giving permission to publish this article. Mr. A. Balakrishnan, B.E., F.I.S.P.O., Deputy Director (Trg) for his guidance in preparing this article. Mr. R. V. R. Naidu, Asst. Engineer for his encouragement and Mr. Sahadev Moharana, Plant Attendant for the excellent fabrication work.

Prosthetics and Orthotics International, 1983, 7, 176-177

Technical note— a patient propelled variable—inclination prone stander

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**RAAF Academy, University of Melbourne, Victoria, Australia.*

Abstract

A self-propelled mobile standing device is described with the facility of patient-operated inclination of the support platform, enabling objects on the floor to be reached. The device is provided with a removable tray at the level of the occupant's chest.

Introduction

Prone standers which can only be moved with the aid of an attendant are in common use. They are used mainly by children, except for some very specialized applications. The stander pictured here is believed to be unique in having both its mobility and its angle of inclination under the control of the patient using it. It was built for a four year old boy with cerebral palsy. He was able to operate it himself as soon as he was strapped into it (Fig. 1, left).

The advantage of a prone stander for a small child is that it places his head and arms at a higher level than does a wheelchair. For a child of four years, the capacity to play with objects on the floor is an advantage, and this variable-inclination device provides it (Fig. 1, right).

Fig. 1. Left, patient strapped into mobile prone stander. Right, mobile stander lowered to permit access to objects on the floor.

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Design details

The frame of the stander consists of hollow steel members of 19 mm (¾ in) square cross-section, with welded joints. It is mounted on two wheels of diameter 0.61 m (24 in), with hand rims, and has two Shepherd castor wheels of diameter 10 cm (4 in) at the rear. The patient can move the stander manually by rotating the main wheels.

The tray at the front is removable; it can also be swung to one side about a pivot point at the left rear corner (Fig. 2). Either operation permits the patient to turn a crank handle on the right side to reduce the angle of inclination of the support board continuously from its maximum value of 75°. The minimum angle of inclination achievable is −10°, in which position the patient can reach objects on the floor. During lowering of the board the centre of gravity of the patient moves forward of the main wheels, causing a pair of auxiliary castor wheels at the front of the stander frame to contact the floor. With the

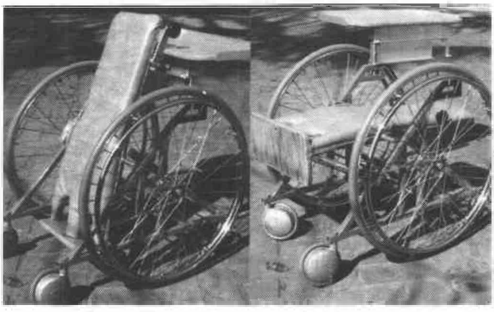

Fig. 2. Left, the mobile prone stander in the fully raised position with the tray in place, and right, fully lowered with tray swung aside.

board in the raised position these castor wheels are clear of the floor by 13 mm (½ in).

The inclination of the board may be adjusted by means of the crank handle to any desired angle between its two extreme values. A flexible cable transmits the rotation of the crank handle to a worm gear engaging a gear wheel fixed to the frame of the stander. This mechanism ensures that the board is firmly locked at all angles of inclination.

A tension spring connects the footing of the stander board to a fixed point of the frame. During lowering of the board the spring is stretched, and the energy thus stored in it assists the patient when raising his weight against gravity.

Further details of the design of the device may be obtained by applying to either of the authors of this paper.

Conclusion

This prone stander's dual capacities of mobility and variable inclination should make it useful for a large number of cases. Versions of it without either the self-propulsion or the variable inclination feature could easily be made.

Prosthetics and Orthotics International,1983, 7, 178-179

Reviews

The use of polypropylene ankle-foot orthoses in the management of the young cerebral-palsied child. C. B. Meadows, D. M. Anderson, L. M. Duncan and M. B. T. Sturrock.

This booklet is strongly recommended to both those involved in the care of Cerebral Palsy, and those interested in the rational approach to the use of orthoses and the development of research into this subject. At the same time it is a highly practical document. The theoretical concepts have been tested in the light of considerable experience of fifty children over five years, but it also covers many highly important details of manufacture and application. It is easy to read and well illustrated. The authors have defined their objective in different classes of the conditions, and good as this is, it is perhaps an area which will be expanded and deepened with further experience. Certainly it is a pointer to further but more controlled and quantified experiments.

There are, of course, matters for debate. Not everyone would agree that post-operatively after an Achilles tendon lengthening, maximum dorsi-flexion and inversion are always advisable. In fact, the disadvantages of persistent calcaneus may be considerable and permanent in relation to total gait efficiency and this is, to some extent, indicated in the illustrative examples of Locomotion Basics. Similarly the abolition of some degree of equinus may not be beneficial having regard to the situation in other joints and the type of palsy. What this means is that the text should be read with the same degree of questioning appraisal which the authors themselves have applied to their own work and this booklet is then used as a valuable tool and not a dogmatic programme. They are, in fact, quite emphatic that once produced, the orthosis must be "tuned", particularly in regard to the degree of dorsi- or plantar flexion. It is one advantage of this fixed ankle type of plastic orthosis that one cannot make adjustments easily and frequently, and in many centres neither patients nor resources would allow the repeated casting and production of orthoses which this may require. Perhaps there is a case for an articulated lockable plastic ankle joint.

One welcomes the attention to the shoe sole. This might well be regarded as an integral part of all these orthoses and this area enlarged upon, as it is not well understood in the average clinic.

The basic theory of locomotion biomechanics helps considerably to the understanding of this subject, but in the illustrative examples I think it would be an advantage to have the vector included in the diagrams, the variation of this during gait significantly affects the moment about various joints. This element seems to be rather concealed in the present diagrams.

These comments do not diminish the importance of the booklet to all disciplines engaged in the treatment of these cases, and indeed in the supply of plasic AFO's. One can only hope that it will be the forerunner of many others from this Unit.

G. Rose.
O.R.L.A.U.
Oswestry.

Editor's note

This booklet was originally published in a limited edition in 1980. Because of the demand it has now been reprinted and copies are available from Mr. B. Meadows, Tayside Rehabilitation Engineering Services, Dundee Limb Fitting Centre, 133 Queen Street, Broughty Ferry, Dundee, Scotland. The cost is £2 plus postage.

A manual for amputees. I. C. Narang

This 25 page booklet has been written by Brigadier Narang, formerly Commandant of the Armed Forces Artificial Limb Centre at Pune and concurrently Consultant in Prosthetics, Professor of Orthopaedics at Poona University. It provides information for the amputee including general advice, sections on stump bandaging, prosthetic maintenance and training and other matters such as advice for parents of limb deficient children.

Clearly it is orientated towards the problem in India and Eastern philosophy, but some of the thinking is more generally applicable. The approach to the subject is positive and humane. Technical advice is good with much accurate detail. Even minor matters are clearly recognised.

However, the range of prostheses referred to is limited and some of the components mentioned may not be in common usage. All levels are not covered but many of the general principles still apply. Mention is frequently made of return to work—in Western terms this would not be seen to be a common challenge.

Basically it is interesting, promoting thought, and must be welcomed as a very sincere attempt to produce a small publication of real value.

I. M. Troup.
Tayside Rehabilitation Engineering Services.
Dundee.

Editor's note

Copies of this booklet are available at a cost of $3(US) plus postage from Brig. I. C. Narang, L–32 Tara Apartments, Kalkaji, New Delhi–110019, India.

Prosthetics and Orthotics International, 1983, 7, 180-183

Calendar of events

National Centre for Training and Education in Prosthetics and Orthotics

Short-Term Courses and Seminars 1984

NC 705 Pediatric Footwear; 22 February, 1984.
NC 706 Wheelchairs; 27–28 March, 1984.

Courses for Physicians and Surgeons

NC 104 Amputation Surgery and Pre- and Post-Operative Care; 13–14 February, 1984.
NC 105 Amputation Surgery and Prosthetics for Vascular Surgeons; 21 March. 1984.

Courses for Physicians, Surgeons and Therapists

NC 505 Lower Limb Prosthetics; 16–20 January, 1984.
NC 502 Upper Limb Prosthetics and Orthotics; 23–27 January, 1984
NC 501 Functional Electrical Stimulation (Peroneal Brace); 12–15 March, 1984.
NC 506 Fracture Bracing; 2–4 April, 1984.

Course for Prosthetists

NC 205 Above Knee Prosthetics; 27 February–9 March 1984.

Course for Orthotists

NC 213 Ankle-Foot Orthotics (Conventional and Plastic); 30 January–10 February, 1984

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 0LS, Scotland. Tel: 041–552 4400 ext. 3298.

New York University Medical School

Short Term Courses

Courses for Physicians and Surgeons

754 A Foot Orthotics; 20 January, 1984.
741 C Lower-Limb Prosthetics; 27 February–2 March, 1984.
751 B Lower-Limb and Spinal Orthotics; 19–23 March, 1984.
741 D Lower-Limb Prosthetics; 23–27 April, 1984.
754 B Foot Orthotics; 4 May, 1984.
751 C Lower-Limb and Spinal Orthotics; 7–11 May, 1984.
744 B Upper-Limb Prosthetics and Orthotics; 21–25 May, 1984.

Courses for Therapists

759 A Prosthetics and Orthotics An Update; 9–10 January, 1984.
742 B Lower-Limb Prosthetics; 13–17 February, 1984.
742 C Lower-Limb Prosthetics; 9–13 April, 1984.
752 C Lower-Limb and Spinal Orthotics; 7–11 May, 1984.
758 B Foot Orthotics; 18 May, 1984.
759 B Prosthetics and Orthotics An Update; 31 May–1 June, 1984.
757 Upper-Limb Orthotics; 4–8 June, 1984.
745 Upper-Limb Prosthetics; 11–15 June, 1984.

Courses for Prosthetists

7431 A The Icelandic-Swedish-New York University (ISNY) Flexible Socket System; 4–6 January, 1984.

7431 B The Icelandic-Swedish-New York University (ISNY) Flexible Socket System; 11–13 January, 1984.

7431 C The Icelandic-Swedish-New York University (ISNY) Flexible Socket System; 18–20 January, 1984.

North Western University Medical School

Short-Term Courses

Courses for Physicians Surgeons and Therapists

602 C, 603 C Lower and Upper Limb Prosthetics; 5–9 March, 1984.
603 D Lower and Upper Limb Prosthetics; 2–6 April, 1984.
702 B, 703 B Spinal, Lower and Upper Limb Orthotics; 30 April–4 May, 1984.

Courses for Physicians and Surgeons

603 E Lower and Upper Limb Prosthetics; 23–27 April, 1984.
603 F Lower and Upper Limb Prosthetics; 7–11 May, 1984.

Course for Physicians, Surgeons, Therapists and Prosthetists

631, 632, 633 Management of the Juvenile Amputee; 4–8 June, 1984.

Courses for Physical Therapists

622 A Lower Limb Prosthetics; 23–27 January, 1984.

622 B Lower Limb Prosthetics; 14–18 May, 1984.

Course for Occupational Therapists

652 Upper Limb Prosthetics and Orthotics; 16–20 April, 1984.

Course for Rehabilitation Personnel

640 Orientation in Prosthetics and Orthotics; 26–28 March, 1984.

Course for Pedorthists and Orthotists

801 Pedorthic Management of the foot; 4–8 June, 1984.

1984

9th International Congress on Physical Therapy, Barcelona, Spain.
Information: Maison des Kinesitherapeutics, F-75010 Paris, France.

January, 1984

'Early Management of Spinal Cord Injuries', Giens, Hyeres, France.
Information: Dr. Eric J. J. Berard, Spinal Cord Injuries Unit, Hopital R. Gabran, F83406, Giens, France.

26–28 January, 1984

10th Annual Meeting of American Academy of Orthotists and Prosthetists, Florida, USA.
Information: Mr. Norman E. McKonly, AAOP, 717 Pendleton Street, Alexandria, VA 22314, USA.

23 February, 1984

Rehabilitation of the lower limb amputee (basic course) Manchester, England.
Information: Mrs. B. Hindley, Higher Clerical Officer, Rehabilitation Unit, Withington Hospital, Nell Lane, Manchester M20 8LR

March, 1984

3rd Israel-Scandinavian Rehabilitation Seminar, Eilat, Israel.
Information: Peltours, P.O. Box 394, Tel Aviv 6100 3, Israel.

1–4 April, 1984

Asian and Pacific Convocation on Rehabilitation.
Information: Accident Compensation Corporation, Private Bay, Wellington, New Zealand.

2 April, 1984

Canadian National Society for Prosthetics and Orthotics Seminar, Vancouver, British Columbia.
Information: Mrs. Gertrude Mensch, M.C.P.A., Henderson General Hospital, 711 Concession St., Hamilton, Ontario, Canada L8E 1C3.

3–5 April, 1984

Canadian Association of Prosthetics and Orthotists (CAPO) '84, Vancouver, British Columbia.
Information: Mrs. Gertrude Mensch, M.C.P.A., Henderson General Hospital, 711 Concession St., Hamilton, Ontario, Canada L8E 1C3.

11–13 April, 1984

British Orthopaedic Association—Spring Meeting 1984.
Information: Honorary Secretary, British Orthopaedic Association, Royal College of Surgeons, 35–43 Lincoln's Inn Fields, London WC2A 3PN.

19–24 April, 1984

1st International Meeting on Leisure, Recreation and Sports.
Information: Japan Sun Industries, Kamegawa, Beppu 874–01 Japan.

13–18 May, 1984

9th International Congress of Physical Medicine and Rehabilitation, Jerusalem, Israel.
Information: J. Chaco, M.D., P.O. Box 50006, Tel Aviv 61500, Israel.

30 May–1 June, 1984

Canadian Association of Occupational Therapists Annual Conference Saskatoon, Saskatchewan.
Information: Saskatoon 1984 CAOT Conference, c/o Shari Cherepaka, 343 Poth Crescent, Saskatoon, Saskatchewan, S7M 4T7.

4–8 June, 1984

15th World Congress of Rehabilitation International, Kishon, Portugal.
Information: Rehabilitation International, 432 Park Avenue, South, New York, N.Y. 10016, U.S.A. (other) Secretariado Nacional de Reabilitacao, International Fair of Lisbon, Praca das Industrias, 1399 Lisboa CODEX Portugal.

17–22 June, 1984

The Second International Conference on Rehabilitation Engineering combined with the 7th Annual Conference on Rehabilitation Engineering.
Information: Conference Services, National Research Council of Canada, Ottowa, Ontario, Canada K1A OR8.

19–22 June, 1984

Sixth International Conference, Analysis and Optimization of Systems.
Information: Service Des Relations Exterieures Domaine De Voluceau-Rocquencourt, B.P. 105–78153 Le Chesnay cedex, France.

24–29 June, 1984

Spinal Disorders 1984.
Information: Prof. Alf Nachemson, Dept. of Orthopaedic Surgery I. Sahlgren Hospital, S-41345 Gothenburg, Sweden.

29–31 August, 1984

Bi-annual Conference on Human Locomotion, Manitoba, Canada.
Information: CSB Human Locomotion III, Department of Mechanical Engineering, University of Manitoba, Winnipeg, Manitoba, Canada R3T 2N2.

12–14 September, 1984

The Fourth Annual Advanced Course in Lower Extremity Prosthetics.
Information: Lawrence W. Friedmann, M.D. Chairman, Department of physical Medicine and Rehabilitation. Nassau County Medical Center 2201 Hempstead Turnpike, East Meadow, N.Y.

18–23 November, 1984

2nd International Symposium on Design for Disabled Persons, Tel Aviv, Israel.
Information: P.O. Box 29784, Tel Aviv 61297, Israel.

7–12 July, 1985

14th International Conference on Medical and Biological Engineering and 7th International Conference on Medical Physics, Helsinki, Finland.
Information: Finnish Society for Medical Physics and Medical Engineering, P.O. Box 27 33 231, Tampere 23, Finland.

16–21 February, 1986

5th World Congress of the International Rehabilitation Medicine Association.
Information: Tyrone M. Reyes, M.D. Chairman, Organising Committee IRMAV c/o Philippine Congress Organising Center (PCOC) P.O. Box 4486 Manila, Philippines.

29 June–5 July, 1986

ISPO 5th World Congress, Copenhagen.
Information: ISPO Secretariat, Borgervaengt 5,2100 Copenhagen ø Denmark.

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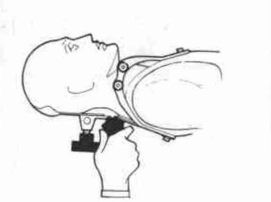

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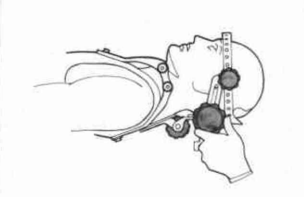

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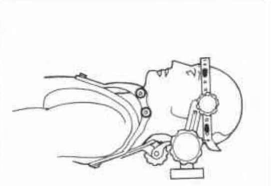

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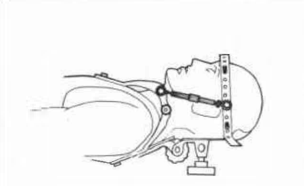

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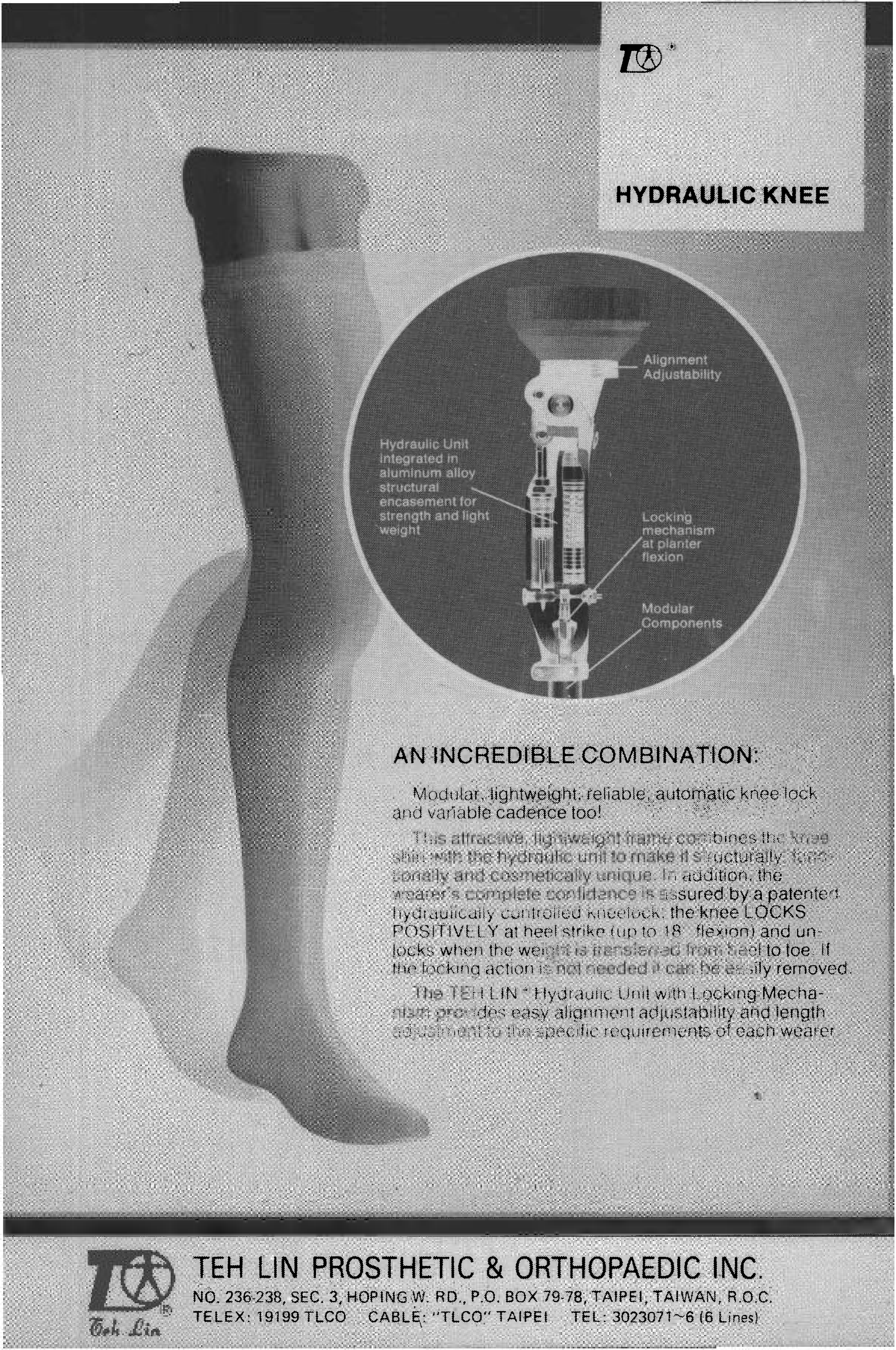
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