



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

Prosthetics and Orthotics International

August 1978, Vol. 2, No. 2



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Prosthetics and Orthotics International is published three times yearly by the International Society for Prosthetics and Orthotics (ISPO), PO Box 42, DK-2900, Hellerup, Denmark. Subscription rate is \$14 (U.S.) per annum, single numbers \$5 (U.S.). The journal is provided free to Members of ISPO. The subscription rate for Associate Members is \$7 (U.S.) per annum. Remittances should be made payable to ISPO.

Editorial correspondence, advertisement bookings and enquiries should be directed to Prosthetics and Orthotics International, National Centre for Training and Education in Prosthetics and Orthotics, University of Strathclyde, 73 Rottenrow, Glasgow G4 0NG, Scotland (Tel.: 041-552 4049).

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The Journal of the International Society for Prosthetics and Orthotics

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Editorial

A year has passed since our Second World Assembly and Congress in New York and we look forward to our next meeting in Holland in 1980. Our Society, however, does not exist solely to survive from one Conference to another but demands continuing efforts to fulfil our objectives in helping the disabled of the world. These efforts must be directed towards both short and long term needs. All our members are busy, dedicated people with a primary responsibility to their own work, yet by their membership of our Society they have demonstrated their commitment far and beyond that initial responsibility. It is perhaps fortunate that the human condition is such that the individual works best to a deadline and there is one deadline to which we, as a Society, must commit ourselves and that is the Year of the Disabled, 1981.

Your Executive Board will shortly be considering a number of suggestions for projects designed not only to meet our objectives, but to demonstrate to the world our value to society at large and its relevance to the Year of the Disabled. In due course the deliberations of the Executive Board will be exposed to the International Committee and to the Membership but in the meantime I am asking individual members to consider the importance of the Year of the Disabled 1981 and how, as individual members, they can best contribute. The ideal forum for the discussion of this subject is within the National Member Society structure and I hope that it will become the immediate concern of each National Member Society to develop ideas, suggestions and recommendations for the period from now until 1981. They should try to distill from their ideas concrete proposals or projects whether they are to be conducted at national or international level.

The membership is reminded that the International Society held a Workshop in Les Diablerets, Switzerland in 1974 to identify the needs and priorities in prosthetics/orthotics worldwide. The report of that Workshop was published and a copy sent to each member. It is suggested that this document will form the best basis for relevant discussion. A number of specific recommendations were made in that Report including a study of standards for education, the development of teaching material, development of our role as an advisory body both to individuals and organizations, the conduct of Workshops on relevant subjects, efforts to produce accurate epidemiological information, development of an information retrieval system and a number of recommendations regarding ventures in the field of publication. Many of these recommendations have already been taken up and reference has been made to them in previous editorials. Suggestions are needed to enhance these undertakings and to initiate work where we have not yet succeeded in making significant progress.

Our Society is unique in being multidisciplinary, international and composed entirely of individual professionals operating through the Constitution and structure of the Society. This does mean, however, that our financial resources are necessarily limited and this constraint is the primary reason why some of the recommendations of Les Diablerets have not been prosecuted. It is the present responsibility of your President and the Executive Board to improve our financial position if we are to make positive progress in improving our publication record and in establishing an international evaluation system. Initial moves have been made in this direction which, if successful, will ensure employment of a highly professional staff to service the Society and improve communications. In the interim, however, National Member Societies should use all their capacities to demonstrate need and persuade governments and agencies within their own nations to make contributions towards either National Member Society projects or those conducted on an international or regional basis.

The Year of the Disabled 1981 is exactly the right kind of stimulus required to promote the interests of our Society which is now beginning to make an impact on the world and its disabled but paradoxically is financially less well equipped to support its endeavours.

It is my earnest hope that all National Member Societies and individual members will respond quickly to my plea and report to the Secretariat about their meetings, outlining their ideas and recommendations.

George Murdoch

Trends in powered upper limb prostheses*

I. KATO

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Introduction

As Prof. Tomović pointed out at the 3rd ETAN Symposium in 1969, realization of multi-functional mechanisms and development of multilevel control methods were the main subjects areas of interest in the field of powered upper limb prostheses in the latter half of the 1960's. In addition, the use of myoelectric potential as the source of control signals and utilization of electric stimulation for sensory feedback became a common method in the 5th ETAN Symposium of 1975.

The utilization of myoelectric potential as the source of control signals was reported for the first time by Battye *et al.* in 1955 and the use of pulse electric stimulation as the feedback signal by Kato *et al.* in 1970¹. While these methods utilize a surface electrode, new attempts such as the direct insertion of an electrode into a nerve have been started. These will be described later.

Recently, a manipulator for the disabled was developed with multiple degrees of freedom. This can be placed on the working desk of an amputee requiring a prosthesis or placed on the table of a motorized wheelchair for patients with spinal cord injury requiring an orthosis. The patients can use the manipulator, which is driven by some signal, to accomplish their work.

Forearm prosthesis with one degree of freedom

The electric forearm prosthesis has already been introduced into practical use in many countries. The apparatus developed jointly by the Veterans Administration Prosthetic Centre (VAPC), and Northwestern University (NU) became commercially available as the Fidelity Hand (VA-NU) in 1973. The mechanical characteristics of this prosthesis are the variable

grasping force of the finger up to 5.5 kg, the spontaneous release of the grasp through dorsiflexion of the middle phalanx of the index and middle fingers in response to an overload above the pre-set value, and the packing of the battery within the wrist.

These mechanisms were recently employed in MYOMOT of Viennatone (Type MM4S). In MYOMOT, the conventional wrist band type battery was used in addition to the built-in type battery described above.



Fig. 1. Waseda hand-4P.

In Japan, the Waseda-Imasen-Myoelectric (WIME) hand-4P (Fig. 1) (Kato *et al.* 1970)² revised by Imasen Electric Industry Company Limited is undergoing field tests on about 25 amputees at the National Rehabilitation Centre for Handicapped, the Labour Accident Prosthetics and Orthotics Centre, the Tokyo Metro-

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*Based on a paper presented at the Second World Congress ISPO, New York, 1977.



Fig. 2. Waseda-Imasen-Myoelectric (WIME) hand.

politan Prosthetic and Orthotic Research Institute, and the Hyogo Rehabilitation Centre (Kato *et al.*, 1976,² 1978), (Fig. 2).

After more than two years of clinical testing sponsored by the Research Development Corporation of Japan, it is anticipated that it will be introduced into practical use within one year. The mechanism and control system of this apparatus are quite different from those of the forearm prostheses already commercially available from Europe and America. The mechanical part is provided with five fingers of adaptive type, each with basal and middle phalanges providing a grasp with 5 fingers and pinch with 3 fingers made possible by mechanical flip-flop. An ordinary electric forearm prosthesis measures the difference in myoelectric potentials of 2 channels and utilizes its polarity as the signal for opening and closing of the fingers. The WIME hand system utilizes the preferred method of generation of 2 channel signals, or the signal reaching the threshold determines the pattern. The Waseda University, the Mechanical Engineering Laboratory, and the Japan Bicycle Technical Centre are also co-operating in this project.

Forearm prosthesis with 3 degrees of freedom

Regarding the forearm prosthesis with 3 degrees of freedom, the final report of SVEN project-1 forearm prosthesis started in 1965

was submitted in 1973 (Hägg *et al.* 1973, Herberts *et al.* 1973, Almström 1977). Adaptive grasping, pronation and supination of the wrist, dorsiflexion of the hand, and lateral flexion of the wrist (manual movement) represented the available free movement. A similar mechanism was tentatively produced by Karas (1975) in Austria.

The National Defence Research Institute (FOA) took part in the production of the mechanical portion of the SVEN Hand. Its control system was developed in the Chalmers University of Technology. It is my understanding that a test of its application was conducted on several cases.



Fig. 3. Waseda hand-9H3.

In Japan, a hydraulic type hand prosthesis utilizing myoelectric potential (Fig. 3) is being developed by the WASEDA University, the Tokyo Metropolitan Prosthetic and Orthotic Research Institute, the Tokyo Metropolitan Institute of Gerontology, Mitsubishi Metal Corporation and Kayaba Industry Company Ltd. This model use a new type hydraulic actuator, the Rotary Servo Actuator (RSA) (Fig. 4), and has 3 degrees of freedom; opening-closing of fingers, dorsiflexion of the hand, and pronation-supination of the wrist. RSA is a torque amplifier with an internal mechanical feedback pathway, incorporating a rotary spool valve of a high degree of precision within the rotary actuator. The ultra-small hydraulic source (Fig. 5) for driving the device consists of a micropump, an electric motor, and an oil reservoir incorporated into one unit.



Fig. 4. Rotary Servo Actuator (RSA).



Fig. 5. Ultra-small-size hydraulic source.

A system is introduced in which the space distribution information of the multichannel EMG is utilized for pattern recognition for the co-ordinated control of pronation and supination, dorsiflexion of the hand and individual control of opening and closing of fingers. This control system is similar to the Chalmers system (Ichikawa *et al.*, 1975). Clinical testing of this system was recently started (Kato *et al.*, 1976).¹

Developments

The primary difficulty in the control of a powered hand prosthesis is how to obtain the control signal. This problem concerns the portion of peripheral nerve and the pulse transformation methods of EMG and its interpretation.

For this reason, attempts were made to obtain the control signal by the use of an implanted electrode. A new electrode was constructed and tested on laboratory rabbits for 244 days (Luka, 1975). The new electrode was sutured in association with the longitudinal axis of the neural sheath. This was connected with the extracorporeal amplifier via a carbon glass wire. For this new electrode, a high quality carbon (bio-carbon) developed by NASA was used and connected with the external wire via a SmCo magnet (REC, 1973). This is called Biosnap. Within the next three years, it is planned that control signals will be picked up from the musculocutaneous, radial, median and ulnar nerves by this neural electrode method.

The transmission of the state of control of the prosthesis to the user in a feedback mechanism remains another problem; that is, how to construct the portion equivalent to peripheral nerve. In the powered hand prosthesis in current use, the visual pathway is mainly utilized for such a feedback mechanism, as well as the change of sound in the driving unit and detection of the change of compression at the point of contact with the socket. The use of visual sensation involves the action of the central nervous system during the manipulation of the prosthesis, leading to enhanced work load on the side of the user. With the use of prostheses utilizing the internal power source, the state of loading is directly transmitted to the contralateral shoulder or the muscle subjected to cineplasty representing the power source. Thus, the magnitude of loading may be sensed unconsciously via the proprioceptors at these sites. For this reason, the amputee frequently prefers the system with internal power source to the system driven by a motor. For the propagation of powered prostheses, provision of the "peripheral neural pathway" is considered to be one of the requirements. Transmission of the feedback signals as pressure by a portion of the prosthesis to the skin of the user has been

attempted by electric or mechanical stimulation (Kato *et al.* 1970, Mann 1970).

In the new attempts by Reswick *et al.* (1975), the idea is further advanced by directly stimulating the remaining nerve in a neuro-electrode system. The information on the pressure and the position of the hand taken up from each sensor is transmitted percutaneously into the body as a pulsed electric stimulation via a Biosnap. A coil electrode was inserted about 10 mm into the remaining sensory nerve to transmit the information to the centre.

The insertion of this electrode was already attempted in amputees by attaching the sensor to a hook of the APRL type. Similar experiments have already been started using VA-NU myoelectric hand prosthesis.



Fig. 6. Télémechanique hand.

The author was invited to the 5th INTERBOR meeting in Paris in the spring of 1972 and had an opportunity of observing the exhibit of a hand prosthesis equipped with one mini-motor to each of the basal phalanges of 5 fingers. The prosthesis was designed by Barrachina *et al.* of the Rehabilitation Centre, French Veterans Administration. This hand prosthesis has been repeatedly revised by the group headed by Rabischong, and is known as a télémechanique hand. Hill *et al.* (1975) suggested a system of incorporating various kinds of action control circuit as modular cards, in order to select the desired action pattern by inserting the proper card.

Heer (1975) started a project of applying tele-operator techniques accumulated over many years at NASA to an instrument for the disabled in collaboration with VAPC. As the first step, a manipulator (Fig. 7) with 6 degrees

of freedom was placed on the table of an electrically driven chair and attempts were made to control this with a jaw-controlled bar and by voice through a minicomputer equipped to discriminate 35 words such as "up", "down", "right" and "left". This reached almost a practical stage. Though no especially new technique is used, this idea suggests a future direction in developing a prosthesis for the disabled.



Fig. 7. Voice controlled adaptive manipulator.

Method of evaluation

In the case of an ordinary industrial instrument, developmental research is conducted via basic research and exploratory research. Whenever it is necessary, instrument tests are conducted for practical use. In the rehabilitation instrument for the disabled, however, these processes are insufficient and a field test for practical use is indispensable after the developmental research.

Field testing is performed in 3 stages. Mechanical tests are not so different from those

for ordinary instruments. The focus of field testing rests in human-machine tests and psycho-sociological tests. The objective evaluation of this system on a human being is very difficult since it involves an evaluation of many facets of an individual.

As a method of human-machine testing, Activity in Daily Life (ADL) has already been adopted in the medical field. Since ADL indicates a series of repeated physical activities fundamental for independent living of an individual, this test alone gives insufficient data for the evaluation of adaptability to occupational life. In ADL testing, moreover, the subjective view of the evaluator considerably influences the results.

As an objective evaluation of human-machine testing, functional testing using M-series signals or abstract action testing has been suggested (Kato *et al.*, 1976). The former is the method of evaluation of human-machine systems using binary random signals in order to avoid ambiguous evaluation due to non-linearity and learning ability of human beings. The latter is the method of objective evaluation of function after abstracting and decomposing general action including occupational action into fundamental components.

In practice, these methods of evaluation are used in combination to carefully determine the suitability and occupational fitness of instruments.

Psycho-sociological testing evaluates the human-machine system described above with reference to living and occupational environment. Psychological aspects of the user are emphasized and items such as adaptation to society and changes of consciousness and behaviour are selected for survey.

As to the overall evaluation of these tests, the degree of mechanical restoration of the lost function becomes the starting point for the guidance, training, and selected introduction in occupation rehabilitation.

In Japan, this method of evaluation was applied to the field test for the WIME Hand and a summary of the results is in press (Kato *et al.*, 1978).

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An instrument for monitoring stump oedema and shrinkage in amputees*

G. R. FERNIE, P. J. HOLLIDAY and R. J. LOBB

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Abstract

A new system for measuring the cross-sectional area profiles of amputation stumps and whole limbs has been designed at the Amputee Research Centre. The instrument consists of a cylindrical tank supported on an elevator. The tank is raised to the height of the amputation stump and filled with water. A graph of the cross-sectional area profile of the amputation stump is generated by a mini-computer as the elevator descends. The cross-sectional area (A) is calculated from the expression:

$$A = \frac{dH_w}{d(H_w + H_e)} \times A_c$$

where H_w = height of water in the tank

H_e = height of the elevator

A_c = a constant, related to the size of the measuring tank.

This paper describes the instrument, which may find application in many other areas where there is a need to study shape.

Introduction

A new clinical system for measuring the cross-sectional area profiles of amputation stumps and whole limbs has been designed at the Amputee Research Centre. This instrument was developed in order to attempt to answer three questions:

- (1) Can the time taken for stump shrinkage to be completed be accurately predicted and delays or mistakes in definitive fitting minimized?
- (2) What is the optimum method to use to accelerate stump shrinkage?

- (3) To what extent does a mature amputation stump fluctuate in volume?

This instrument is based upon a novel concept and may find application in many other areas where there is a need to study body shape (Drillis *et al.* 1964). The results of the amputee study will follow in two years time. In the

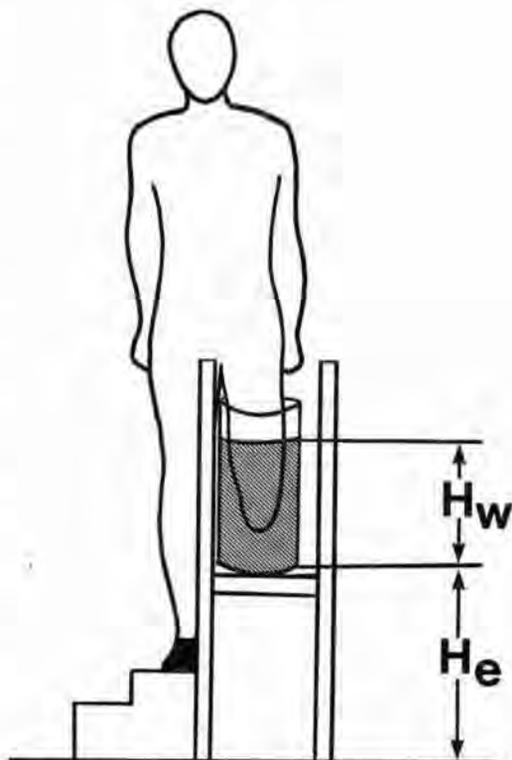


Fig. 1. Diagrammatic representation of the principles of the instrument, where H_w = height of the water in the tank, H_e = height of the elevator.

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*This project was funded by Health and Welfare Canada, Project 606-1317-41, National Sanitarium Association.

meantime it is felt that a paper describing the instrument and its use would be of value.

The instrument

A cylindrical tank is supported on an elevator (Fig. 1). The tank is raised on the elevator to fit the amputation stump and filled with water at a controlled temperature. As the tank is lowered so the water level in the tank is caused to decrease since the water surface is being withdrawn from the amputation stump. The rate at which the depth of water is decreasing at any moment in time is proportional to the cross-sectional area of the amputation stump that at that moment in time corresponds to the water surface. Evidently when the end of the stump is reached the rate of decrease in the depth of the water in the tank becomes zero. The depth of the water in the tank is H_w and the height of the elevator is H_e . The cross-sectional area at any moment in time during this measuring process can therefore be calculated according to this simple equation:

$$A = \frac{dH_w}{d(H_w + H_e)} \times A_c$$

where the constant A_c depends upon the cross-sectional area of the measuring tank used.

The instrument is shown in Figure 2. The elevator is in a rigid frame and is hydraulically



Fig. 2. The measuring system with a wooden shape in place for testing.

driven to provide a smooth, vibration free movement. The water filling and emptying is solenoid valve operated to increase the speed and ease of operation. Simple adjustable supporting pads and an adjustable arm rest are

used to steady the patient. An overhead safety harness is also fitted.

The height of the elevator is transduced by a potentiometric displacement transducer (R.I. Control Model 4040). The method of measuring the depth of the water is shown in Figure 3. A

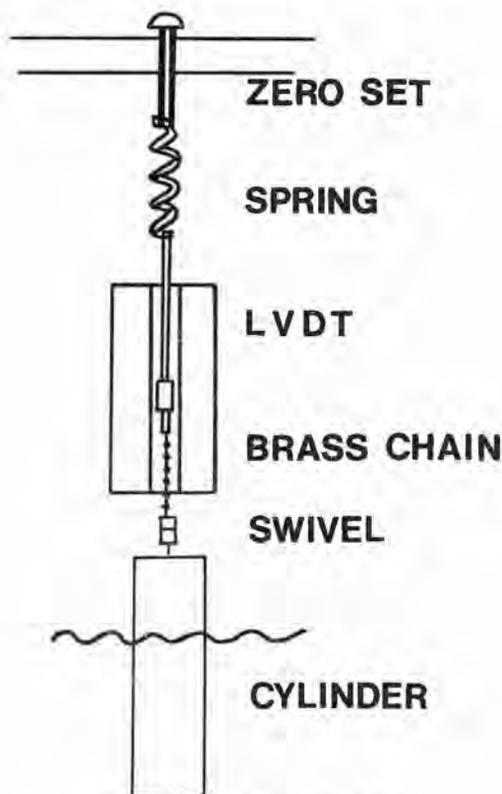


Fig. 3. Water depth transducer.

precisely machined cylinder is suspended in a manometer from an extension spring. Changes in the depth of the water in the measuring tank cause equal changes in the height of water in the manometer tube. The buoyancy force exerted upon the cylinder changes since it is proportional to its depth of immersion. The resulting change in length of the extension spring is transduced by means of a linear voltage displacement transducer.

The measurement process is controlled by a system based on the Tektronix 4051 mini-computer. The calculation involves a differentiating process. A "least squares" technique is employed to limit the noise sensitivity of this

process. A variety of different forms of graphical and numerical output have been employed. The results of each test are stored on magnetic tape so that they can be recovered for the sake of comparison at any time.

Instrument accuracy

A calibration shape made up of 4 cylinders of 5, 10, 15 and 20 cm in diameter was measured using the 25 cm diameter measuring tank on the instrument. This shape is shown in place in

Actual value (cm ²)	Mean measured value (cm ²)
19	19
77	76
176	174
311	310

Table 1. A comparison of the mean result of 12 measurements of a calibration shape with the actual cross-sectional area measured using a micrometer.

Figure 2. Table 1 shows a comparison of the mean result of 12 measurements with the actual cross-sectional area measured using a micrometer. Very close agreement was achieved.

A plexiglass model of an above-knee amputation stump has been used to test the reproducibility of the instrument. This shape was measured 20 times in each of 3 different sized measuring tanks. Surprisingly the repeatability was not found to be related to the size of the tank except for measurements over the distal 3 cm of the shape. An example of the superimposed 20 measurements obtained with the 25 cm diameter tank is shown in Figure 4.

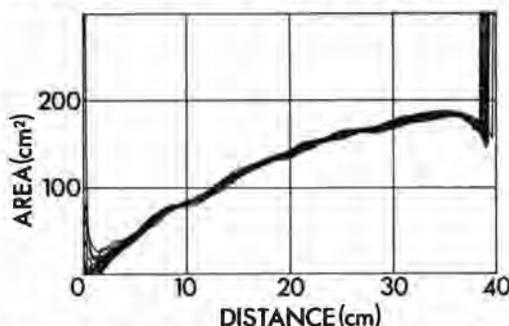


Fig. 4. Twenty superimposed measurements of a plexiglass above-knee amputation stump, measured in the 25 cm diameter measuring tank.

Sample result

Comparison of two cross-sectional area profiles of a 19 year old male above-knee amputee is shown in Figure 5. The curve

labelled A was made prior to applying an elastic tensor bandage for a duration of one and one-half hours. The measurement taken after the bandage was removed is labelled B. Very little difference between the two curves is demonstrated.

Discussion

Several techniques have been used for body shape determination including measuring tapes and calipers (Girling *et al.* 1972, Pritham 1974, Staats 1974), contour tracers (Newman 1966, Zuniga *et al.* 1977), photogrammetry (Herron 1970, 1972), and water immersion (Dempster 1955, Drillis *et al.* 1964, Contini 1970).

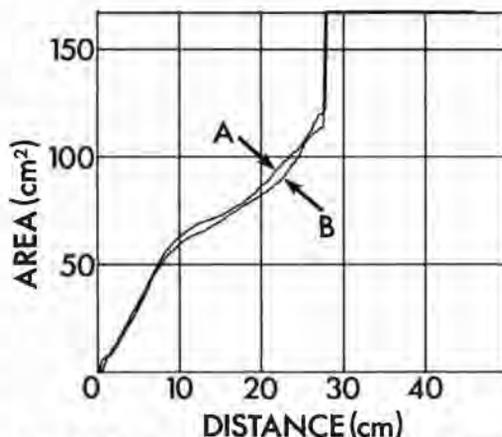


Fig. 5. Comparison of two cross-sectional area profiles of an above-knee stump. Curve A was the initial measurement, curve B was taken after application of an elastic tensor bandage. The horizontal axis represents the distance in centimetres from the distal-most point of the stump. This point is taken as the reference for all comparisons.

Previous immersion methods of measuring the volume changes in extremities have relied on one of two principles. In its simplest form volume displacement consists of placing an extremity into a tank full of water and measuring the overflow (Dempster 1955). This system has two disadvantages:

- (1) It is difficult to immerse the limb to the same depth on each measurement.
- (2) Only one figure is obtained representing a total change in volume.

Naturally a situation such as a proximal constriction leading to a distal swelling would

tend to produce a small change in total volume since one would tend to cancel the other.

An approach has been tried by other workers to remove this second deficiency (Contini *et al.* 1963). In this approach known quantities of water are added to the tank and the rise in water level is measured after each addition. That increase in water level is proportional to the volume of the particular section of the amputation stump that becomes immersed.

An alternative approach is to fit the tank with a syphon that is lowered by discrete intervals and the volume overflow is measured (Contini 1970). Both of these systems are very complex to operate and take a considerable amount of measurement time.

The use of the simple principle embodied in the design of this new instrument removes both of the major deficiencies of the previous systems.

The design of this new instrument eliminates the problem of marking the limb to facilitate comparison between measurements since the distal-most point of the limb automatically becomes the reference point. Some difficulties were encountered initially because of surface tension effect influencing the determination of the end of the stump. It was found desirable to incorporate a switch in the instrument by which means the operator signalled directly to the computer when the water surface was seen to detach from the skin.

It might be expected that geriatric patients may be apprehensive about being tested in such a complex instrument, however we have found this not to be a problem. The harness and supporting pads have proved to be adequate for holding the patients still. This firm support has provided the patients with a feeling of security which is reinforced by the operator's description of the testing process.

The effect of water immersion on limb shape due to hydrostatic pressure and buoyancy effects is unknown. However, it is assumed to be relatively constant for an individual. Similarly, alternative methods of measurement in air suffer from the unknown effect of gravity on dependent tissue.

Objections to immersing tissue that has not completely healed have been overcome by the use of self-adhesive surgical drape.

Summary

This paper has presented a description of a new system for measuring body shape by a water displacement technique. It is hoped that this development will be valuable to others interested in the measurement of shape and changes in shape.

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Measurement of prosthetic alignment

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Abstract

An essential part of alignment description is the position and orientation of the socket relative to the rest of the limb. Repeatable measurements of these parameters is hindered by the non-geometrical shape of the socket. A unique axis system has already been defined to enable such measurements to be carried out. The method however, employs an iterative technique and is time consuming. A simple device to facilitate these measurements has been developed and is reported.

Introduction

It is everyday prosthetic practice to align lower limb prostheses using bench and dynamic alignment procedures. Bench alignment is the initial setting up of the limb to a prescribed geometry, whereas dynamic alignment is the subsequent modifications made during walking trials. The prosthetist using his own judgement and the feedback from the patient aims to achieve the most suitable limb configuration for the function and the comfort of the patient. This limb configuration is known as the "optimum alignment", and it is generally believed that for a given patient and prosthesis this is unique.

The parameters involved in describing alignment are in everyday use and are referred to in the literature (Radcliffe 1955, 1961). The orientation and position of the socket relative to the rest of the limb is one of the most essential parts of this description. However, until recently the non-geometrical shape of the socket has prevented accurate alignment measurement. The first efforts in making repeatable measurements of socket alignment relate to a comparative study of various below knee (BK) modular assembly prostheses (Solomonidis, 1975). Re-

peatable was achieved by defining a unique axis system for the patellar tendon bearing (PTB) socket, and this definition was later extended to above knee (AK) level (Lawes *et al.*, 1975). The measurement technique however, utilized an iterative approach and was therefore time consuming. A simple device has been developed to facilitate alignment measurement and is reported here.

Reference axes

To specify the position and orientation of the components of a prosthesis in three dimensions it is necessary to have a frame of reference to which all measurements may be referred. The reference system used will be described briefly as it forms the basis for all measurements. It consists of a set of orthogonal axes with its origin at the "ankle joint" centre. The ankle centre is arbitrarily defined as the centre of the bolt hole on the top surface of the SACH foot. A similar origin can be also defined when uniaxial feet are used. However, as all legs measured had SACH feet no effort has been made in this direction. The top surface of the SACH foot is taken to form the $x-z$ plane, the y axis thus being normal to it.

The descriptions such as anteroposterior or mediolateral in relation to the lower limbs are generally rather loosely used. There is no universal agreement whether they relate to the direction of locomotion or the plane formed by the shank and thigh when the knee is flexed. This may not be critical for general descriptive purposes. However, when quantifying the geometry of a prosthesis forward and sideways directions must be defined. For AK prostheses the normal to the projection of the knee flexion/extension axis (i.e. the knee bolt axis) onto the $x-z$ plane is taken as the forward direction (x axis) and the z axis in turn is obtained to form a right handed orthogonal system. The forward direction for BK prostheses is defined using the socket reference axes.

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The socket axes definitions are detailed by Lawes *et al* (1975). Here only a brief description relating to below knee PTB and above knee quadrilateral sockets will be given.

PTB socket

Two parallel planes on levels contained within the socket are used, one located 25 mm from the distal end of the socket and the other 25 mm distal to the patellar bar (Fig. 1). Initially the patellar bar level was considered for the location of the top plane (Solomonidis, 1975). However this was later modified as the posterior brims of some sockets do not reach this level. In plan view the positive z axis is defined to be parallel to the posterior brim, lie in the top plane and be directed towards the patient's right. The y axis is located equidistant from the socket walls both anteroposteriorly and mediolaterally in the two planes (proximal direction as positive). The x axis is chosen to form a right handed orthogonal set.

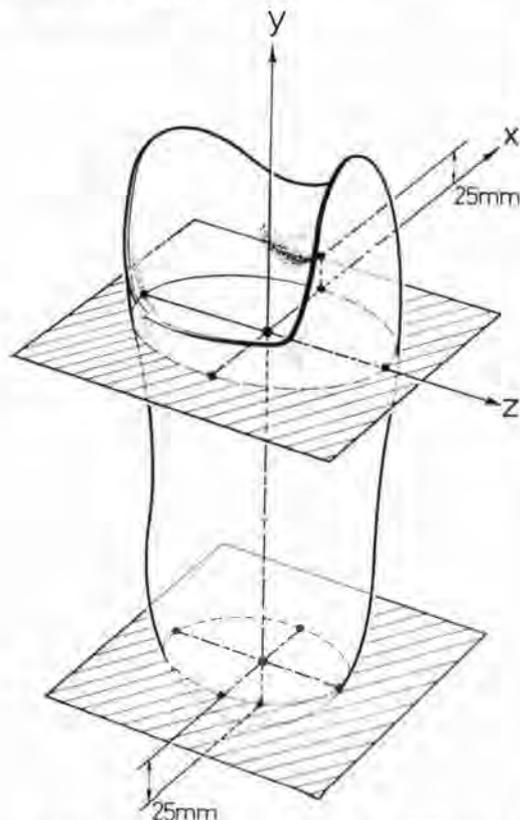


Fig. 1. Reference axes for a below-knee PTB socket (see text).

Quadrilateral socket

Again two parallel planar levels are established. One located 25 mm from the distal end of the socket and the other 25 mm distal to the ischial seat. Positive x axis is defined to be parallel to the flat medial brim in plan view and anteriorly directed. The y axis is established as in the case of PTB sockets and the z axis is chosen to form a right handed orthogonal set.

Both below and above-knee axes definitions provide a unique co-ordinate system for each particular socket.

Alignment measurement

The three axes for each system so defined can only be determined simultaneously. The orientation of the x-z plane can be established if the y axis is known, and in turn the y axis can not be located until the x-z plane is fixed. The initial measurement technique therefore, employed an iterative procedure as described by Lawes *et al* (1975). First the two planes and the x and z axes were estimated and then corrections were made depending on the calculated inclination between the y axis and the x-z plane. The procedure was repeated until an orthogonal set of co-ordinate axes were obtained. Although this procedure gave repeatable results it was very time-consuming, and therefore alternative measurement techniques were sought. As a result a socket axes locator, seen fitted to a socket in Figure 2, was designed and manufactured. This consists of a central rod upon which are mounted two sets of mutually perpendicular arms. One set is located 25 mm from one end of the rod. Its arms consist of chains of four bar linkages, where the central links have common members to keep the two arms and the rod mutually



Fig. 2. Socket axes locator seen fitted to an above-knee socket. The prosthesis is bolted by the foot-fastening bolt to the measuring table.

orthogonal. The rod forms the pivot point so that when each arm is extended to touch the inner socket wall the rod remains equidistant from the tips of the arm. The second set of arms are similarly constructed and mounted on a sliding carriage and a groove in the rod prevents the rotation of the carriage thus maintaining the two sets of arms parallel to each other. The carriage is clamped to the rod in the upper socket plane with a lock screw. Adjustment of the arms, which remain in position due to frictional resistance in the joints, causes the central rod to be aligned as the y axis of the socket.

The prosthesis to be measured is bolted by the foot fastening bolt, after the SACH foot is removed, to a vertical bracket at one end of the measuring table (Fig. 2). The table forms a surface parallel to the mediolateral plane (y-z reference plane) and a grid is inscribed on it for ease of measurement. A scribing block is used on the table top so that its pointer is adjusted to touch in turn the various reference points on the limb and the socket axis locator. By measuring the position of the scribing block on the grid and the height of the pointer above the surface of the table the three co-ordinate dimensions for each reference point can be obtained.

Experience to date using the socket axis locator has shown that the technique is satisfactory in establishing a socket reference axis system. Measurements of a pre-set alignment proved that any reference point can be repeatedly defined to an accuracy of ± 1 mm.

The system is presently being used in assessing the significance and repeatability of optimum alignment, and the effects of alignment variations on the load actions transmitted by prostheses.

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Experience in the treatment of femoral shaft fractures using a Vitratene cast brace*

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The concept of weight bearing in the treatment of lower limb fractures was described as early as 1791 by John Hunter. Boehler (1953) and Sarmiento (1967) applied this principle to the treatment of fractures of the tibia. Interest in bracing of femoral shaft fractures to allow weight bearing was recently revived by Mooney *et al.* (1970) and reported in detail by Connolly *et al.* (1973).

In 1973 a project of bracing the fractured femur was undertaken by the Department of Orthopaedic Surgery and Occupational Therapy at The London Hospital.

Method of treatment

After reduction of the femoral fracture, Hamilton Russell skeletal traction was applied until the fracture was sticky. An occupational therapist and occupational therapy technician measured and made the brace (Fig. 1) as follows; a long leg plaster cast incorporating an ischial shelf is made, from which a positive cast using dental grade plaster is prepared. Shapes of 4.5mm Vitratene and 6mm Plasta-zote are cut from patterns of the positive cast, heated together and moulded onto the positive cast and ischial shelf. The ischial shelf being added for comfort while wearing the brace. At this stage the Steinman pin is removed from the tibia and skin traction applied. The thigh and lower leg components are then fitted on the patient and necessary adjustments made. Knee joints consisting of stainless steel hinges and Duralumin struts are carefully aligned and riveted into place. Overlap tongues and Velcro straps are fitted and complete the brace.



Fig. 1. The Vitratene cast brace.

For upper and middle third fractures of the femur a pelvic band and hip joint are attached to prevent varus angulation with weight bearing.

Mobilization under occupational therapy and physiotherapy supervision is commenced and, when complete, patients are discharged to follow up in the fracture clinic and occupational therapy departments on an out-patient basis.

Clinical material and results

A total of 57 consecutive unselected patients were treated by femoral bracing. The age range was from 7 to 81 years with a mean of 37 (± 23)

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*Based on a paper presented at the Second World Congress, ISPO, New York, 1977.

years. There were 17 females and 40 males. The right side was involved in 36 patients, the left in 20 and in one patient the fracture was bilateral.

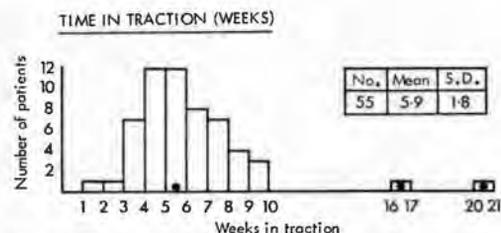


Fig. 2. Time in traction. Three cases (●) of non-union.

Figure 2 shows the time spent in traction, with a range of 2 to 10 weeks. Three patients were referred cases of established non-union and spent longer in traction, as did a fourth patient who required removal of an internal fixation device. For the remaining 53 patients, the average time spent in traction was 5.9 weeks.

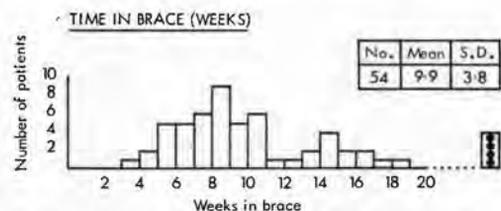


Fig. 3. Time in brace. Three patients (●) with previous non-union and one fractured tibia.

Figure 3 shows that the time spent in the cast brace ranged from 4 to 19 weeks. The 3 cases of non-union spent longer in the brace. A fourth patient was still in the brace at the time of writing because of an ipsilateral fracture of the tibia. The remaining 53 patients spent, on average, 9.9 weeks in the brace.

The hospital stay ranged from 5 to 12 weeks with an average of 8.1 (± 2.0) weeks. The total time from sustaining the fracture to removal of the brace was on average 15.9 (± 4.4) weeks, with a range 8 to 24 weeks, inclusive of the 3 cases of established non-union.

Figure 4 shows the site and type of fracture, 61 per cent being upper or middle third fractures. The average fracture angulation, as measured on both AP and lateral X-rays before bracing was 6 degrees (± 5 degrees) with a

SITE AND TYPE OF FRACTURE

	Upper third	Middle third	Lower third	
Transverse	3	9	3	15
Oblique	1	6	3	10
Spiral	1	2	3	6
Comminuted	4	9	13	26
	9	26	22	57

Fig. 4. Site and type of fracture.

range of 0 to 23 degrees. After bracing the average fracture angulation was again 6 degrees (± 6 degrees) with a range of 0 to 29 degrees. All the fractures united satisfactorily after bracing, including those cases of established non-union referred to us. The cases of non-



Fig. 5. A healed mid-shaft fracture.

union may require up to 8 months in the brace. An example of a healed mid-shaft fracture after bracing is seen in Figure 5.

Loss of position in the brace occurred in 8 per cent of all fractures. The resulting union was clinically and functionally acceptable, however, and loss of position was avoided in subsequent fractures by applying a pelvic band for upper and mid-third fractures. Some 24 weeks after the fracture average knee flexion obtained was 115 degrees (± 20 degrees). No shortening occurred in the brace.

A total of 49 patients were able to remove and re-apply the brace at an average of 2.6 weeks after the brace was first applied. Three of the younger patients required the help of a parent while 5 of the older patients needed additional help. At an average of 2.0 weeks after the brace was first applied 51 patients were able to manage stairs in a brace. We have records of 26 patients returning to work at an average of 5 months after the fracture. An additional 14 patients were of working age but their return to work date was not available for reasons of vagrancy or their being referred from outside our area.

Conclusion

Compared to conventional methods of treatment (Nichols, 1963, Dencker, 1965, Anderson, 1967) cast bracing after traction reduced time in hospital and knee stiffness without shortening, non-union or infection.

In upper or middle third fractures, alignment was sometimes lost, this may be prevented by adding a pelvic band in abduction.

In all, 57 patients were treated by femoral bracing. On average they were hospitalized for 8.1 weeks, spent 5.9 weeks in traction, a further 9.9 weeks in a brace and attained 115 degrees of knee flexion.

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A mechanically-actuated wave mattress

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Abstract

A polio victim who has been in a negative pressure ventilator ("iron lung") since 1950 was in need of an activated mattress to combat the hallucinatory effects of complete immobilization and to assist with body pressure distribution. A mechanical method was used to give the patient's mattress a moving wave form of vertical amplitude 50mm with a period variable from 50 seconds to infinity. His arms rested on separate supports which oscillated 180 degrees out of phase with the trunk support. The device is powered by a 12 volt electric motor operating through two mechanical reduction gear units. It differs significantly in design and purpose from pneumatic ripple mattresses.

Details of bed design

The bed consisted of a T-foam mattress of basic thickness 75mm laid on a base made of eight 5-ply wooden planks 12mm thick. The plan view of the planks is shown in Figure 1. The width of each plank (other than 1) is 216mm. Adjacent planks were hinged together by stapling 50mm wide seatbelt webbing to their upper faces along their common edges.

Beneath the planks a long carriage (Fig. 2) was made to oscillate horizontally with an

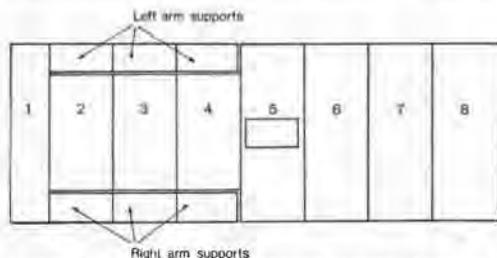


Fig. 1. Plan view of planks forming mattress support.



Fig. 2. Oscillating carriage.

amplitude of 216mm in the direction of the long axis of the bed. The carriage was supported on six polyurethane wheels with ball bearings (skateboard type wheels) which ran in two aluminium channels that served also as the main frame of the system. The carriage was provided with an array of similar free wheels on its upper face, and these supported formers or cams attached to the under sides of the bed planks (Fig. 3).

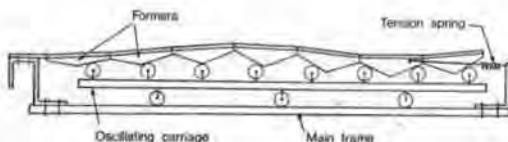


Fig. 3. Side elevation of the bed, showing formers and carriage wheels.

As the carriage moved back and forth the formers rode over the free wheels. The shape of the formers and the spacing of the wheels caused the planks to oscillate vertically with different phases. The effect was to make the wave form in Figure 3 travel to and fro at the same frequency as the carriage. The out-of-phase movement of the arm planks was achieved by providing these planks with their own

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formers and shaping them appropriately. For clarity the arm planks and their formers and wheels are omitted from Figure 3.

By reducing the depth of the formers towards the head of the bed the vertical amplitude was gradually reduced from 50mm at the foot and centre to zero at the shoulder line. This was necessary because the patient's neck must remain centred in the diaphragm covering the iron lung aperture.

Plank 1 at the head end of the bed was bolted to brackets (Fig. 3) which could be moved up and down by the usual vertical control mechanism of an iron lung bed. Lateral movement of the foot of the bed was prevented by a fixed vertical plate which fitted snugly between two parallel plates mounted on the under side of plank 8. To ensure smooth operation the system of planks was kept under tension by a strong spring pulling plank 7 towards the foot of the fixed supporting frame (Fig. 3).

Driving mechanism

A 12 volt, 1800 RPM "pancake" electric motor was mounted on the frame of the carriage. Power was provided by a lead-acid battery located outside the lung.

Two reduction gear boxes were also mounted near the foot of the carriage, the first being an infinitely-variable-speed unit and the second a 53:1 reduction unit.

A crank of 108mm throw was mounted on the output shaft of the second drive unit. A connecting rod linked the free end of the crank to the foot of the main supporting frame. Rotation of the crank caused the carriage to oscillate longitudinally with the required amplitude of 216mm.

By moving a lever attached to the first gear box its reduction gear ratio could be varied. The lever was accessible to an attendant through a porthole in the side of the lung. Its use enabled the period of oscillation of the wave mattress to be varied from 50 seconds to infinity.

Upholstery and finish

At the patient's request the thickness of the T-foam was increased beneath his knees, and was reduced beneath his sacrum to relieve pressure. A cut-out was made in the T-foam to accommodate a urinary bottle which was

given an upward tilt by allowing its lower end to drop through a cut-out in plank 5 (Fig. 1).

The T-foam on the arm planks was separated from that supporting the torso to permit independent movement of these areas. A deep channel was formed in the T-foam of each arm support to ensure that the arms did not fall off the edges of the bed. The various pieces of T-foam were glued to the tops of the bed planks and upholstered with waterproof "60-40" cloth (60 per cent cotton, 40 per cent nylon).

The sides of the wave mattress were provided with shields of 20-gauge galvanized steel sheet along the whole length of the bed. A Terry cloth covering the upper surface of the mattress was attached by Velcro strips along its edges to similar strips riveted to the shields on both sides of the bed. This arrangement encased the mechanism and ensured that the patient's clothing and bedding could not become caught in it. Figure 4 shows the completed unit.



Fig. 4. General view of the completed wave mattress, with Terry cloth cover lifted to reveal mechanism.

Conclusion

The system described differs significantly from pneumatic ripple mattresses in common use. It is a reliable method of providing a bed with a moving wave profile of variable period. It would be applicable to standard hospital beds, where the absence of the severe space restrictions of an iron lung would make it a relatively simple matter to design.

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Rehabilitation engineering as the crow flies*

PART IV—CRITERIA AND CONSTRAINTS

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In Parts I and II of this series we discussed the way in which a biomechanics clinic team can be formed and the kind of information the rehabilitation engineer should seek as an aid to defining problems and solving them. In Part III we offered a "framework" for problem-solving which can be used to pace development of solutions and help facilitate communications between team members and various teams. We will discuss now the *criteria* and *constraints* which determine the nature of the "products" of rehabilitation engineering.

Criteria = factors used in evaluating various designs which are proposed.

Constraints = factors which form boundaries or limits to possible designs.

The criteria define the *goals* or ideals you have in mind and the constraints *limit* the degree to which the goals can be achieved. If your goal is to go to London, the methods of transportation possible place limits on your plans. The constraints will never allow for the perfection desired, but when the criteria are broken down into parts and valued, the optimum possibilities will emerge and necessary compromises be anticipated.

As an example, let us consider a real patient for whom we developed a set of statements on criteria and constraints. She is a person who spends most of her time lying on a plinth, and who is lifted many times a day for the performance of various functions. The biomechanics clinic team suggested that her life could be improved through rehabilitation engineering on the basis of information provided

by various team members and others associated with the patient.

For this person, the problem was stated as *to increase her comfort*.

This was the most *general* statement we could think of. It was our intention to leave this statement in as open a form as possible so that the direction of enquiry or the solution selected would not be inhibited by the initial statement. Starting at this point, we developed the following set of statements on criteria and constraints (Table 1).

Note that we see the objective *in terms of the patient* rather than in terms of some mechanical contrivance! And this will be the point of entry to all problem-solving which is related to a particular patient's well-being. (If the solution sought were to benefit an institution or a professional group for example, then the focus would be on that.) The aim now is to build up a mental image or environment within team members as they act and interact around the problem in such a way that criteria which are increasingly explicit and which encompass the original general statement are developed. Thus, *to improve comfort becomes to improve:*

Functional comfort = comforts essential for life

Physical comfort = comforts which make life easier

Psychological comfort = comforts related to the quality of life

We are seeing comfort (almost feeling it!) in terms of what is *essential*, what is *facilitating*, and what adds *quality* to the person's life. Consider the first sort of comfort. For the

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*Parts I-III of this series were published in the last issue of Prosthetics and Orthotics International (Vol. 2 No. 1).

TABLE 1

Problem: To improve the comfort of the disabled person Ms.....

CRITERIA AND CONSTRAINTS

Criteria (relevant factors used for evaluating the design)

Types of comfort: *Functional comfort* = Comforts essential for life

Physical comfort = Comforts which make life easier

Psychological comfort = Comforts related to the quality of life

Functional comfort criteria

1. Protection from environment—safety
2. Optimum feeding capacity
3. Optimum body-product management
4. Optimum capacity to communicate
5. Psychological factors optimally handled
6. Dependent factors optimally handled
7. Optimum management of sleeping

Physical comfort criteria

1. Ability to shift position
2. Ability to assume most comfortable position
3. Access to physical environment
4. Protection from environment
5. Optimum control of movement, location
6. Optimum use of senses (vision, hearing, etc.)
7. Optimum pressure distribution
8. Optimum use of body power
9. Ability to control heat flow
10. Optimum capacity for hygiene
11. Optimum garment design
12. Dependent functions optimally handled

Psychological comfort criteria

1. Ability to be private
2. Psychological protection
3. Access to dynamic sensations
4. Ability to influence design
5. Optimized cosmesis (colour, shape, etc.)
6. Optimized capacity to communicate
7. Access to communication devices
8. Creativity facilitated
9. Access to information
10. Opportunity to contribute
11. Access to psychological environment
12. Dependent functions optimally handled

Constraints (limitations on design)

Types of constraints: *Patient*

Physical environment = Those essential for survival

Social environment = The material world

Technological = The community and its institutions

= Skills, facilities, techniques, materials, etc.

Patient

1. VITAL FUNCTIONS
 - (a) Pulmonary function
 - (b) Cardiac status
 - (c) Vascular status
 - (d) Neurological status
 - (e) Metabolism
 - (f) Elimination—bowels, bladder, etc.
 - (g) Susceptibility to disease
2. FEEDING
 - (a) Frequency
 - (b) Quantity
 - (c) Quality
 - (d) Duration
 - (e) Periodicity
 - (f) Aids
3. SLEEPING
 - (a) When

Physical environment

1. HEAT TRANSFER
 - (a) Heat transfer coefficients
 - (b) Thermal resistance
 - (c) Environmental temperature & humidity
2. SPACIAL FACTORS
 - (a) Door sizes
 - (b) Hall widths
 - (c) Floor plans
 - (d) Transport system used
 - i car doors
 - ii trunk size
 - iii seating arrangements
 - iv access arrangements
 - (e) Stairs, steps, curbs
 - (f) Elevators
 - (g) Bathroom arrangements
 - (h) Boundaries, inside, outside
 - (i) Ground surface characteristics

Social environment

1. STAFF LIMITS
 - (a) Times available
 - (b) Number
 - (c) Location
 - (d) Strength
 - (e) Skills
 - (f) Acceptance
 - (g) Turnover rate
 - (h) Shift changes
 - (i) Frequency of contact
2. OTHER PERSONS
 - (a) Who
 - (b) Frequency of contact
 - (c) Where
 - (d) Skills
 - (e) Duration of contact
3. RESPONSIBLE AGENTS
 - (a) Medical

Technological

1. TIME
 - (a) For design
 - (b) For fact-finding
 - (c) For fabrication
 - (d) For prototype testing
 - (e) For experimenting
 - (f) For follow-up
 - (g) For maintenance (long term)
2. COSTS
 - (a) Time
 - (b) Materials, components
 - (c) Environmental changes
 - (d) Operators
3. SAFETY
 - (a) Chemical stability
 - (b) Fire resistance
 - (c) Structural safety factor
 - (d) Electrical safety

- (b) Parental
 - (c) Community (legal, financial)
 - (d) Others, family, etc.
4. COSMESIS
- (a) Institution, community acceptance
 - i position
 - ii shape
 - iii odour
 - (b) Acceptance by her
5. COMMUNICATIONS
- (a) Where
 - (b) When
 - (c) Methods
 - (d) Ability to get information
 - (e) Limits of speed, quality, quantity
 - (f) With whom
6. SAFETY
- (a) Impacts
 - (b) Psychological
 - (c) Other
- (i) Furniture dimensions
 - i home
 - ii institutional
 - iii community
3. SAFETY
- (a) Protection from weather
 - (b) Protection from impacts
- (b) How well she sleeps
- (c) Duration
 - (d) Where
 - (e) Positions during
4. SENSORY FACTORS
- (a) Range of vision
 - (b) hearing
 - (c) touch
 - (d) kinesthesia
 - (e) taste
 - (f) smell
 - (g) balance
 - (h) Rate of response
 - (i) Intensity of response
 - (j) Appropriateness of response
5. HEAT TRANSFER
- (a) Body area
 - (b) Temperature distribution on her body
 - (c) Variations with time
6. HYGIENE
- (a) Frequency of cleaning
 - (b) Method of cleaning
 - (c) Her response to it
 - (d) Who assists
 - (e) Where it is done
 - (f) When it is done
7. PSYCHOLOGICAL
- (a) Cosmesis, body image
 - (b) Self-help capacity
 - (c) Self-help inclination
 - (d) Frustration tolerance
 - (e) Fears
 - (f) Desires
8. BIOMECHANICAL FACTORS
- (a) Weight distribution
 - (b) Body dimensions
 - (c) Ranges of movements
 - (d) Forces generated
 - (e) Power developed
 - (f) Rate of movements
 - (g) Reaction time
 - (h) Duration of actions
 - (i) Intensity of actions
 - (j) Appropriateness of actions
- (c) Mechanical safety—pinch, stability
- (f) Locking of wheels
4. SIZE
- (a) Maximums of
 - i surfaces
 - ii lengths
 - iii volumes
 - (b) Minimums of
 - i surfaces
 - ii lengths
 - iii volumes
 - (c) Dimensional ratios
5. WEIGHT
- (a) Maximum operating force
 - (b) Portability
 - (c) Upper weight limits
 - (d) Lower weight limits
6. MANUFACTURING
- (a) Degree of complexity allowable
 - (b) Maintenance limits
 - (c) Life expectancy of device
 - (d) Market
 - (e) Distribution system

person to be functionally comfortable she needs to be able to do a number of things. For example, she must be able to *communicate*. She must be able to *regulate or adjust* to the environment. She must be able to *participate* favourably in her social environment.

Imagine the impact on engineers who start to focus this closely on the individuals who will be the recipients of their services. How much better it is to *investigate* in this way than to plunge in, plaster already dripping wet and tools ready. If we continue to investigate only a single facet of comfort, such as functional comfort, a number of criteria emerge.

- (1) The patient is to be protected from the environment—*indoors? outdoors? fair weather or foul? in public places? etc.* (Remember, if psychological comforts are a serious consideration, you may expand her environment, facing her with new hazards.)
- (2) Optimum feeding of the patient—*design anticipates health-promoting foods, foods that are attractive, and not just easy to feed.*
- (3) Optimum handling of body wastes—saliva, urine, faeces, sweat.
- (4) Optimum organization of communication to ensure improved capacity to survive. (Risks are sometimes taken which are unwarranted unless such risks are off-set by important gains.)
- (5) Optimum handling of psychological factors—the patient should not be so disturbed by the process of living as to expose her to the risks which are life-threatening, for example, suicide.
- (6) Optimum approach to dependent functions—the patient will not face risks such as being dropped, gouged, etc.
- (7) Optimum management of rest, sleep and relaxation—avoidance of hazards such as smothering or falling.

You might be able to add criteria to the lists provided in the table developed for the example case. A good technique is to imagine yourself

in comparable circumstances. Imagine the sort of environment you would choose to be in, or require for optimum survival from the functional, physical and psychological view-points. Such criteria as "the ability to shift position" lead to quite different views of how devices such as orthoses should be designed. We see "back braces" which are such *straight jackets* that the motions needed or desirable are inhibited—even after "cure" is complete. For the case in question, you will see that we identified over 30 "comfort" criteria. You will also notice that the qualifying words "optimized" or "access to" are governed by limits. Thus, such criteria as "optimized cosmesis" (the feel, sound, shape, colour, and motions which harmonize with the recipient and environment) or the "ability to be private" (meaning the capacity to *choose* private conditions) are bound by essential realities. These constitute the *constraints*.

In generating the lists of constraints, we identified four main groups which would affect the degree to which we could reach toward any ideal goal established by the assembled criteria. We saw some which related strictly to the *patient*. Others related to the *physical environment*, the *social environment*, and finally, the *technological limits*.

Considering the conditions within which the patient now lives, one can be committed at least to *improving the conditions* for this patient. The gap between the ideal and the end result constitutes the compromise necessary or *accepted*. That there will be compromise for the example patient is clearly indicated by the extent of the constraints generated. Some are more important than others, some permit little or no compromise. To live at all means that *vital functions* must continue—breathing, circulation, sensing, digesting food, eliminating wastes, conquering infection. These are *inside-the-body* operations which can be affected by design. Other constraints are imposed by the *need* to live—eating, sleeping, sensing, heat transfer, hygiene, psychological factors, bio-mechanical factors—such as skin resistance to force-motion. These constraints are of high importance.

As soon as you start considering such constraints as the patient imposes, others which relate to the *physical environment* come into focus. A support surface imposes forces, allows

movements, restricts circulation, inhibits heat flow, collects moisture, etc. The size of a door, an elevator, a curb, the presence of steps confine you in your design approach. The wheels of a dune buggy are not the same as the wheels of a baby carriage.

When the person ventures out, the *social environment* impinges; whether "out" is into the corridor or onto the street. Such factors as how strong or willing a helper is; the degree to which people around contribute to the psychological well-being of the patient; who the person is, family, friend, volunteer, assistant; how well informed these people are; the speed, extent and quality of communications; community acceptance; her acceptance of those in the community; the safety of the person in the social environment, all affect design. An old person's balance requires consideration from the bus driver and fellow passengers or even assurance of a seat. A dribbling person is better served with a paper napkin than embarrassing stares. A humane social environment is one in which the *means* are made available by which the imbalance between the able and the disabled can be redressed. How nearly this is optimal affects design.

Even when there is ample good will and money is available, there can be limits of skills, limits of other means. The *technological constraints* are a final hurdle imposing compromise. Fact-finding, designing, fabricating and testing take time. Maintenance is required no matter how well you design, especially initially. An operator may be needed. Would it be better to by-pass the machine and use a person directly? Will there be enough demand to make design worthwhile? Can it, will it be made, by whom, where, in what sort of facility?

Finally, all the information must be sought, sifted and ordered into useful form constituted as criteria and constraints. The information will be based on the observations, expert opinion, recorded information and personal preferences of those involved (patient, family, doctor, helpers). This takes time. In this case we interviewed therapists, nurses, the dietitian, other engineers, doctors, the social workers, the parent, the teachers and a psychologist. Such an extravagant enquiry may not be needed often, but in this case, exposure to the various opinions and pieces of information led us to a radical change of view as we assembled the

constraints and criteria. We came to understand the problem in terms not only of *lifting*, but also in terms of *mobility* and *communications within the context of a changed environment*. This experience raised regrets for previous impulsive enterprises which could have been better prepared and which might never have been attempted at all had the criteria and constraints been laid out. Alternatively, definition of the criteria and constraints centred on this person has led to worthwhile solutions to problems of mobility, and developments are underway to design a lifting system—so designed as to form modules for an environment more suitable to this sort of patient. We recommend that people working to apply engineering to rehabilitation problems make up such criteria lists. The criteria can be rated with respect to particular designs so that they can be "scored", perhaps on a 0–10 scale. The total score of a particular design can be used to rate it in relative terms with other designs or compare it to the ideal which the criteria represent.

Summary

When engineers function in a biomechanics clinic team, collecting information for the definition and solution of problems, and developing solutions in a logical pattern, then establishment of criteria by which to judge actions and results at various stages are essential. In our procedures, we make the most general statement we can which will indicate the goal we have for the patient or the type of patient being considered. Based on this, we proceed with a breakdown of the goal into increasingly explicit statements keeping the objective in focus. Eventually, with the criteria we need in order to decide "yes or no" to any aspect of the solution developing, we consider the constraints. These we see as imposed by the life-requirements of the patient, the effects of the physical environment, the limitations imposed by the social environment, and the limits of available technology, including the skills of the designers, the manufacturing capabilities and the distribution system with which the designers must cope. When a "checklist" of requirements and limits has been established, the "critical eye" watches over the rehabilitation engineer as he in effect watches over himself!

The value of flexor hinge hand splints*

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Abstract

Functional hand splints have been in use in a number of spinal injury units in the USA since the early 1950s. The splints are designed to provide a pinch-grip either by harnessing wrist dorsiflexion or by external power. Such devices are little used in the United Kingdom.

This paper describes the results of late provision of 62 such splints in a Disabled Living Unit. A proportion of tetraplegic patients found such splints of considerable functional value.

It is estimated that some 30-60 patients each year would benefit from them if appropriate facilities for early fitting were available.

Introduction

Injuries to the cervical region with spinal cord damage and consequent tetraplegia are a not infrequent cause of chronic disability in young people. With efficient initial management many survive and have a reasonable life expectancy. Such people have a varying degree of upper limb involvement depending upon the level and the completeness of the lesion. Their residual function ranges from very high lesions, with limited shoulder movement only to lower cervical lesions where only intrinsic hand function is impaired. In order to carry out the basic functions of eating, toilet and communication, and simple additional functions such as writing, washing and shaving, it is necessary to have some sort of prehension and movement of the elbow. These movements can be provided or simulated by;

help from an attendant
splints, gadgets and aids
surgical reconstruction.

Surgical reconstruction

There are varying estimates as to the number of tetraplegics who would benefit from reconstructive hand surgery, from 5 per cent (Guttman, 1973) or 22 per cent (Lamb and Landry, 1972) to 60 per cent (Moberg, 1975). In the absence of a major surgical programme of reconstruction most spinal paralysis units rely upon simple cuff-like splints and a bimanual grip (Fig. 1) and use of the mouth for general activities of living for the majority of tetraplegics, backed up by a comprehensive social support system of care.



Fig. 1. Bimanual grip—patient with C5 lesion extracting a cigarette.

Functional hand splints

Since the early 1950s many spinal injury units in the USA have had a programme of functional splinting based upon a splint which harnesses

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*Based on a paper presented at the 6th Scientific Meeting of the United Kingdom National Member Society, I.S.P.O. Guildford, April 1978.



Fig. 2. Three point pinch. Top, demonstrated by patient with C5 lesion. Bottom, in use for his hobby, model making.

remaining power of wrist extension (dorsiflexion) and by means of the splint transferring that power to a pinch grip, the pinch deriving from a three-point chuck made up of the thumb, index and middle finger (Fig. 2).

For those patients who do not have sufficient power to drive the splint by wrist extension the movements of the shoulder can be harnessed or external power (compressed CO₂ or electrical motors) can be used (Fig. 3). The earliest description of the appliances designed to convert wrist extension to pinch seems to be that of Bisgrove (1954). During the following decade the concept was developed and publicised from Los Angeles (Anderson and Sellars, 1958; Anderson and Snelson, 1962; and Nickel *et al*, 1963).

Modification

There have been several variations on the theme and a number of modifications (Bennet, 1957; Sabine *et al*, 1965; Engel *et al*, 1967; Goodman *et al*, 1970; McKenzie, 1973). The variations were to materials, the design of the linkages and finger cages, and the use of power



Fig. 3. Use of powered flexor hinge hand splint—patient with C5/6 lesion showing Top, bimanual writing technique. Bottom, writing using a powered splint. *Reproduced by kind permission of the Director, Butterworths (Legal Medical and Scientific Publishers).*

(Long and Masciarelli, 1963; Barber and Nickel, 1969; Kelly and Hartman, 1971).

A number of centres have published the results of follow up studies of patients fitted with flexor hinge splints:

Rancho los Amigos Hospital, Downey, California (Runge, 1966)

Houston, Texas (Newson *et al*, 1969)

Yunker Centre, Des Moines, Iowa (Spieker and Lethcoe, 1971)

Highview Hospital, Cleveland, Ohio (Allen, 1971)

Wisconsin Rehabilitation Center, Madison (Knox *et al*, 1971).

Most of these follow up reviews cover experience extending over about a decade and report in each instance on about 50–100 patients fitted with the splints.

Rehabilitation

Although the presentation and the treatment programmes differ there are many similarities:

- (a) The splints are usually fitted as part of the initial hospitalization and subsequent rehabilitation programme.
- (b) The acceptance rate for the wrist-driven splints is about one half of those fitted, ranging from 43 per cent (Allen, 1971) to 90 per cent (Knox *et al*, 1971).
- (c) The acceptance rate for wrist driven splints is higher than for powered splints.
- (d) Acceptance and continual use appear to be related to many factors. The particular design of the splint, its efficiency and reliability; the amount of training and indoctrination in splint usage; "motivation" and ultimate resettlement of the patient are the important factors.

In the United Kingdom, although two descriptive reviews have appeared in the rehabilitation literature (Parrish, 1963; and Shah, 1974) there has been little enthusiasm for the splint. Even though Sir Ludwig Guttman concedes that both surgical reconstruction and flexor hinge hand splints have their place in the management of the tetraplegic hand (Guttman, 1973), his philosophy "if you cannot use one hand—use both hands" dominates most rehabilitation programmes.

Only one rehabilitation unit seems to be fitting these splints regularly and we have previously described our experience with a very limited follow up (Goble and Nichols, 1971 and Nichols, 1971).

This paper is a report of a follow up of 62 patients admitted to Mary Marlborough Lodge between 1964 and 1975 who were fitted with flexor hinge hand splints.

Material and method

Patients

Between 1964 and 1975 sixty-two patients admitted to Mary Marlborough Lodge disabled living research unit, for functional assessment and rehabilitation, were fitted with flexor hinge hand splints. All had completed major periods of hospitalization and rehabilitation in other units and the injury or illness had occurred many months and often years previously. Many of the patients were readmitted several times but a postal follow-up survey was carried out on all during 1976. Only 52 of the 62 patients were traceable. It is probable that the main reason for inability to trace was death.

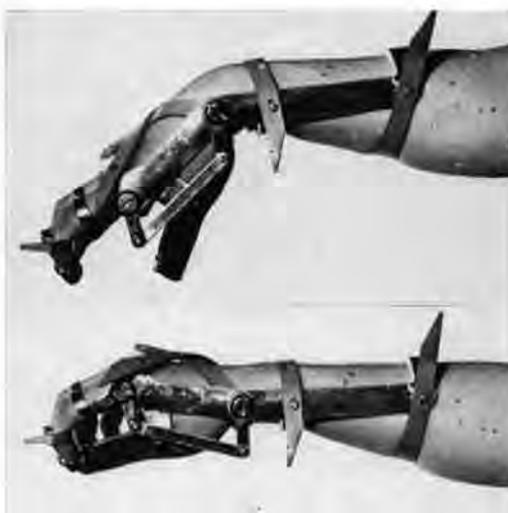


Fig. 4. Standard flexor hinge hand splint showing Top, wrist flexion and open grip. Bottom, dorsiflexion and pinch grip.

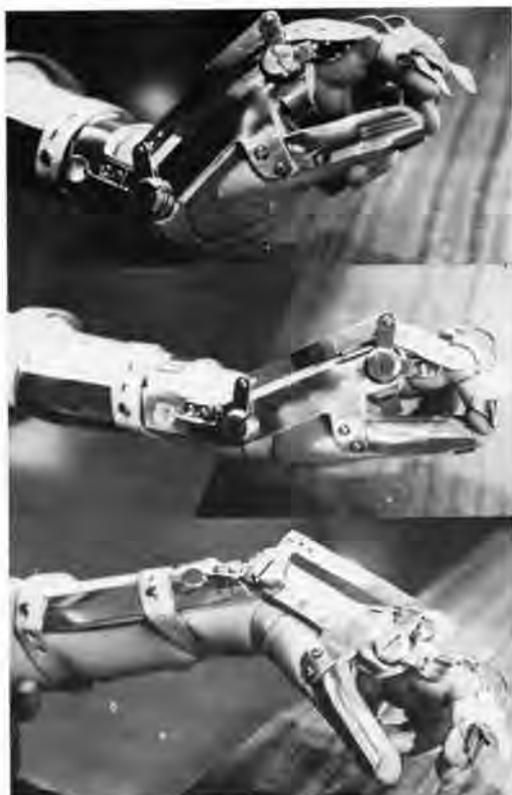


Fig. 5. Ratchet modification—patient with C5 lesion showing range of wrist position with 3 of the 5 ratchet positions. Top, position 1, centre, position 2, bottom, position 3.

Splints

Of the 62 splints manufactured and fitted, 44 were wrist-driven, 12 were gas (CO₂) powered, and 6 were spring assisted. The splints were constructed from kits of parts obtained from the USA of the type developed at Rancho los Amigos Hospital. Each splint was individually made and modified as necessary. The time for construction ranged from 38 to 80 hours depending upon the difficulties encountered (for example contractures or spasticity) and the modifications needed. Knox *et al* (1971) noted that the average time for manufacture in their unit was 40 hours.

Modification to standard splint

The standard Rancho los Amigos splint (Fig. 4) with metal finger cages has been the basis of our splint programme. The commonest modification carried out has been the insertion of a radial deviation hinge (8 patients). In recent years we have changed from the "parallelogram" to the "ratchet" type of moving linkage (Fig. 5). Minor adaptations to cater for holding specific tools and devices for eating, writing, or leisure activities were provided for 9 patients.

Questionnaire

Much of the information required was already available in the medical notes and workshops records and these were used to complete the main questionnaire. However a personal questionnaire was sent out to each patient and completed either by the patient or a relative or attendant.

Of the 52 traceable patients, 44 completed and returned this second questionnaire, a return rate of 85 per cent.

Results

Patients

The details of the patients reviewed and the types of splints fitted are given in Tables 1, 2 and 3.

The ages of the patients at time of fitting is shown in Table 4. The time between onset of injury or disease and fitting of the splint is shown in Table 5.

Table 1
Diagnostic categories of patients fitted with flexor hinge hand splints

Tetraplegia from spinal cord lesion	41
Poliomyelitis	2
Brachial plexus lesion	5
Others	4
TOTAL	52

Table 2
Patients' age at time of injury or disability

0-19 years	17
20-29 years	24
Over 30 years	11
TOTAL	52

Table 3
Types of splint fitted

Wrist driven	38
Spring assisted	5
Gas powered	9
TOTAL	52

Table 4
Age of patient at time of fitting

	0-19	20-29	30+	TOTAL	Youngest	Oldest
Users	4	10	5	19	9 yrs	46 yrs
Non-users	2	18	13	33	11 yrs	64 yrs
TOTAL	6	28	18	52		

Table 5
Time between onset of injury or disability and fitting of flexor hinge hand splints

Splint type	1 yr	1-2 yrs	3-4 yrs	5-9 yrs	10+ yrs	TOTAL
Spring assisted	1	3	-	1	-	5
Powered	1	3	-	2	3	9
Wrist-driven	-	18	11	6	3	38
TOTAL	2	24	11	9	6	52

Table 6
Use of wrist driven splint by patient with tetraplegia

LEVEL	COMPLETE LESIONS			INCOMPLETE LESIONS			ALL LESIONS		
	Users	Non-Users	Total	Users	Non-Users	Total	Users	Non-Users	Total
C 3/4	-	-	-	-	1	1	-	1	1
C 4	-	1	1	-	1	1	-	2	2
C 4/5	1	2	3	1	-	1	2	2	4
C 5	-	2	2	-	-	-	-	2	2
C 5/6	4	4	8	1	3	4	5	7	12
C 6	1	2	3	-	2	2	1	4	5
C 6/7	1	1	2	2	-	2	3	1	4
C 5/6/7	-	1	1	1	-	1	1	1	2
C 7	1	1	2	1	1	2	2	2	4
TOTALS	8	14	22	6	8	14	14	22	36

Wrist driven splints

The wrist driven splints were of the type originally designed for C5/6 spinal cord lesions. In our series 36 patients with spinal cord lesion were fitted with these splints. At follow-up 14 patients with tetraplegia due to spinal cord lesions were still using their splints.

Table 6 gives the details of the level of the lesion and the use of the splints at follow-up.

Table 7 indicates the activity for which the splints are used.

Some patients who have remained functional users of wrist driven splints tend to use them for many hours a day but other patients use them for specific activities, for example writing or feeding, for short periods only. This group of patients have become dependent upon their splint for one or more activity. The length of

Table 7
Activities for which wrist driven splint is most used
by tetraplegics

Patient's activities	EMPLOYED				SCHOOL OR UNIVERSITY						HOMEBOUND			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Job	•	•		•										
Full or part time study		•			•									
Hobbies		•	•	•	•	•	•	•	•	•	•	•		•
Writing	•	•		•	•		•			•		•	•	
Feeding		•			•		•							•
Toilette	•					•		•	•	•	•		•	

Table 8
Time between fitting of wrist driven splints and survey for patients with tetraplegia known to have used splint until death

Years after fitting	NUMBER OF PATIENTS		
	Using splint	Not using splint	All patients
0-2	6	1	7
3-4	2	6	8
5-6	1	3	4
7-8	1	2	3
9-10	2	7	9
11-12	0	2	2
12+	1	0	1
Dead at time survey	1*	1	2
TOTAL	14	22	36

*known to have used splint until death

Table 9
Other wrist driven splints issued

Diagnosis	Sex	Age at fitting	User	Non-user
Anterior poliomyelitis	M	36	●	
Post radiation peripheral neuritis	F	64		●

time between fitting the splints and the follow up is shown in Table 8.

Two patients with other lesions were also fitted with wrist driven splints and the details are given in Table 9.

Spring assisted splints

Detailed records and follow up questionnaires were completed on 5 of the 6 patients fitted with spring-assisted splints. Their details are given in Table 10. All these patients were ambulant and 4 had normal use of the non-

Table 10
Patients fitted with "spring assisted" flexor hinge hand splints

Diagnosis	Sex	Age at fitting	User	Non-User
Polyarteritis nodosa	M	52		●
Brachial plexus lesion	M	24		●
Brachial plexus lesion with Volkmann's ischaemic contracture of forearm	M	21	●	
Brachial plexus lesion (bilateral)	M	19	●	
Brain injury	F	11		●

involved hand. The brachial plexus lesions fitted with splints in the year prior to this survey are still using the appliance.

Powered splints

Details are available on 9 of the 12 patients who were fitted with gas-powered splints (Table 11). Of these, 5 were high cervical cord lesions. Two patients regained sufficient strength in the hands to discard the splints. Three patients discarded the splint because they could not put it on and take it off themselves; 2 of these have learnt to write with their pen held in their mouth and one uses a simple cuff splint with attachments for pen, fork, spoon, toothbrush and paintbrush. One tetraplegic patient uses a gas-powered splint "occasionally" for writing and had used it when taking examinations. His main complaint is that he cannot put it on and take it off himself, and this is the factor which prevents him continuing to use it.

Two patients with brachial plexus lesions found that the powered splint in conjunction with the flail arm splint was too cumbersome (Nichols, *et al*, 1975). One patient has a bilateral congenital abnormality and a low IQ but he wears a gas powered flexor hinge splint continuously; however he is frustrated by repeated breakdowns as the device is not robust enough for the activities which he attempts to achieve.

Table 11
Details of patients fitted with gas powered splints

Diagnosis	Sex	Age at fitting	User	Non-User
Tetraplegia	M	29	●	
Tetraplegia	M	29		●
Tetraplegia	M	21		●
Tetraplegia	M	25		●
Tetraplegia	M	29		●
Bilateral brachial birth palsy	M	18	●	
Brachial plexus lesion	M	31		●
Brachial plexus lesion	F	51		●
Anterior poliomyelitis	F	35		●

Bilateral wrist-driven splints

Six patients were issued with bilateral wrist-driven splints (Table 12). Three patients found they could only use one splint at a time because the sensory difficulties of tetraplegics necessitates

Table 12
Patients issued with bilateral wrist driven splints

Diagnosis	Sex	Age	Using both splints	Using one splint	Using neither splint
Tetraplegia	M	30			•
Tetraplegia	M	20	•		
Tetraplegia	F	25	•		
Tetraplegia	M	21		•	
Tetraplegia	M	28		•	
Tetraplegia	M	45		•	

careful vigilance and patients found it difficult to watch both hands at once. One of the three, who uses one splint for 15 hours a day, commented that persistent use of one hand has resulted in gross under-development of the other side of his body. Two of the 6 patients were fitted with a second splint at their own request during the period of the study and are still using both splints; one for his clerical job, and the other patient—a housewife—for certain tasks in the kitchen and for rug-making. The sixth patient used one splint only for eighteen months but then found that the quality of writing ability which the splint provided was inadequate for the demands of his job and further education.

These findings support the views of others (Engel *et al*, 1967; Sabine *et al*, 1965), that the advantages of one unsplinted hand outweigh those of the bilateral pinch grip using two splints, except for specific tasks.

Maintenance problems

For a disabled person dependent for functional activities upon aids or appliances, mechanical reliability and efficient maintenance services are of the utmost importance. In our experience there are two main problems in the maintenance of flexor hinge hand splints, the finger cage tends to get knocked out of alignment during strenuous use and during handling, occasionally a finger cage has been broken off. The moving parts of the splint tend to wear out and this has been a factor which has determined some of the later developments and adaptations to the original design.

As a generalization it is our experience that once fitted and found to be comfortable and satisfactory during the post-fitting training period, the splints are remarkably reliable and robust. Minor repairs and replacements are carried out on a postal basis for all our patients.

It is only when a splint has to be completely renewed or a major adaptation carried out because of altered requirements, changing activities, or altered clinical status, that re-admission becomes necessary.

In our survey of 52 patients only 7 recorded serious breakdown of non-powered splints.

Powered splints are a different problem in so much that the connecting tubing and controls of the gas power tend to wear and then they require more frequent maintenance than the non-powered splint, but only one patient recorded breakdown problems.

Independence for application

One major problem which often led to rejection of the splint was the patient's inability to put it on and take it off himself. When another person is necessary to put the appliance on, or to set up the activity for which the device is necessary, acceptance is more dependent upon that person's interest and enthusiasm rather than that of the user. Many patients commented on this difficulty but in our series the analysis of answers did not show a statistically significant difference (Table 13).

Table 13
Use of splint in relation to ability of patient to put it on him/herself

	Yes	No	No response	TOTAL
Users	16	3	0	19
Non-users	16	11	6	33
TOTAL	32	14	6	52

Self propelling wheelchairs

Another major factor which caused some of our earlier patients to discard the splint were the difficulties experienced in propelling wheelchairs while wearing the splint. The modification from the "palmar" linkage to the "dorsal" linkage, plus the inclusion of a "ratchet" has eased this problem but it still remains a difficulty for some.

Splint acceptance

It is part of our rehabilitation philosophy to actively encourage severely disabled people to take up specific non-vocational activity (Nichols, 1971) an approach strongly emphasized in

relation to the rehabilitation of tetraplegics by Runge (1966).

We are convinced that early fitting of the flexor hinge hand splint is probably the most important factor in achieving long-term acceptance and usage. The splint making programmes are usually closely integrated with the early hospital care, indeed, in some units the splints are routinely fitted while patients are still confined to bed in the early phase of management (Meyer, 1974). In Mary Marlborough Lodge we are only involved in the *late* rehabilitation of tetraplegics but even so, the acceptance rate is nearly 40 per cent for wrist-driven splints. Of the 23 tetraplegic non-users, 12 were fitted more than three years after the injury whereas only 1 of 14 users was fitted after that length of delay. These figures may not be related solely to the time factor. Other factors, such as length of training period, encouragement of friends and family, and the patient's interest in achieving a specific goal are also involved.

Need for flexor hinge hand splints in the UK

Accurate statistics about the incidence of

spinal cord lesions in the UK are not readily available. Extrapolating from the figures quoted by Guttman (1973) from the various spinal units in the UK it would appear that about 500-600 new cases are admitted every year. Of these about 100-200 will be tetraplegic. At minimum therefore about 30-60 patients each year are likely to derive considerable functional benefit from a flexor hinge hand splint and a further 30-60 would benefit from reconstructive surgery.

Discussion

It is often more instructive to analyse our failures than our successes. In general, the immediate acceptance of an aid or orthotic device depends upon the skills of the technician making the device, whether it is comfortable and whether it is aesthetically acceptable. But above all, it probably depends upon the enthusiasm of the therapist for the use of the device and her belief in its therapeutic value or its functional value. In the long term it depends on whether the device enables the patient to achieve some activity which he really wants to do (Table 14).

Table 14
Use of hand splints at time of follow up

Diagnosis	Type of Splint	Sex	Age at fitting	Job/school	Writing	Toilet/selfcare	Hobbies	Total no. activities
Tetraplegia	wrist-driven	M	9	●	●	●	●	3
Tetraplegia	wrist-driven	M	20	●	●		●	2
Tetraplegia	wrist-driven	M	21				●	1
Tetraplegia	wrist-driven	M	21			●	●	2
Tetraplegia	wrist-driven	M	21	●	●			1
Tetraplegia	wrist-driven	M	24		●		●	2
Tetraplegia	wrist-driven	M	28	●	●	●	●	3
Tetraplegia	wrist-driven	M	30			●		1
Tetraplegia	wrist-driven	M	45	●	●	●		2
Tetraplegia	wrist-driven	M	46		●			1
Tetraplegia	wrist-driven	F	14			●	●	2
Tetraplegia	wrist-driven	F	25			●	●	2
Tetraplegia	wrist-driven	F	25		●	●	●	3
Tetraplegia	wrist-driven	F	30		●		●	2
Tetraplegia	powered	M	29	●	●			1
TETRAPLEGIC TOTAL				6	10	8	10	
Brachial plexus lesion	spring-assisted	M	19			●		1
Brachial plexus lesion	spring-assisted	M	20				●	1
Anterior poliomyelitis	wrist-driven	M	4				●	1
OVERALL TOTAL				6	10	9	12	

The flexor hinge hand splint has a functional value for a proportion of patients with tetraplegia. In our series 6 patients used their splint for work, 8 used it for toilet activities, and 4 specified that they were unable to manage their own incontinence devices without the aid of the splint. Ten patients write with the aid of the splint and 10 use it for a variety of hobbies and leisure activities. One patient wears the splint all day while at work as a school-teacher, and 1 child was enabled to remain at normal school because of the splint, without it he would have gone to a school for the physically handicapped. Thus, for some patients, the splint becomes an essential key to independence.

Conclusion

The establishment of a number of spinal injury units for the early care and rehabilitation needs of spinal paralysis patients has been proposed (DHSS, 1972).

This paper is in part an appeal for the inclusion of comprehensive rehabilitation facilities with appropriate orthotic skills to be available to such units. It also indicates that such units might benefit from a more comprehensive rehabilitation programme where the skills of orthopaedic surgeons, orthotists and remedial therapists, which have been derived from the care of a variety of different clinical problems, can be harnessed and applied to the needs of the tetraplegic patient.

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Hand orthosis for various finger impairments— the K U finger splint*

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Introduction

The dynamic hand orthosis which has so far been in use varies in structure, function and material. Commonly it takes too long to manufacture, it is difficult to adjust and there



Fig. 1. 40-year-old male. Right radial nerve palsy (deep branch) secondary to fracture of the head of the radius. The K U finger splint, W type, was applied for two months after surgery. The post-operative course was uneventful and the palsy recovered satisfactorily.

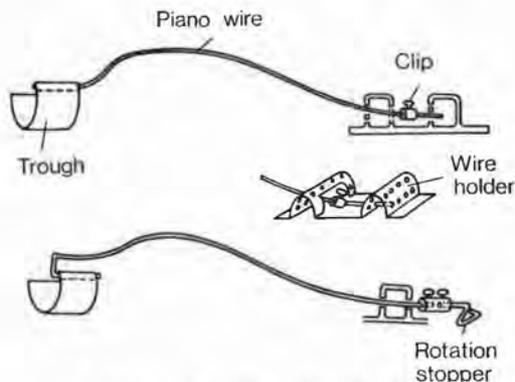


Fig. 2. K U finger splint, W type.

are many types that are unsatisfactory in durability, comfort and cosmesis.

Hence a new kind of hand orthosis that can be easily manufactured from simple parts and common materials is needed. It should be cheap, easy to adjust, improve the activities of daily living and both cosmesis and comfort should be acceptable.

Kumamoto University has developed the K U finger splint which attempts to meet these aims as closely as possible. It has been in use since 1971.

Description

The K U finger splint can be divided into two types; the W type in which piano wire is chiefly used, and the S type that makes use of fishing line (string).

W Type (Figs. 1 & 2)

Piano wire is connected to U-shaped metal or plastic troughs, the other end of the wire is

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*Based on a paper presented at the Second World Congress ISPO, New York, 1977.

inserted in the wire holder(s) attached to a wrist cuff. The wire holder is made of two metal half-cylinders fixed to the cuff. The wire can be positioned as required through the holes in the half-cylinders. A clip is fitted between the wire



Fig. 3. 36-year-old male. Right posterior interosseous-nerve syndrome due to soft tissue tumour of the forearm. The K U finger splint, S type, was applied in order to assist the thumb and finger extensor muscles. The paralysis recovered three months after surgery.

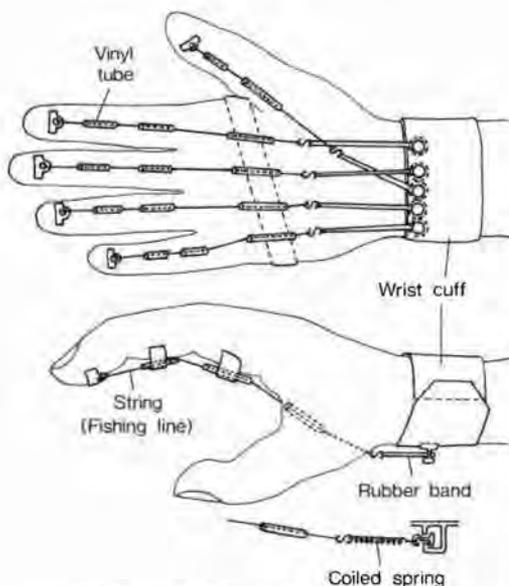


Fig. 4. K U finger splint, S type.

holders to retain the wire and permit some degree of excursion. Rotation of the wire may be prevented by fitting a triangular wire at the end, in which case only one wire holder is required. The metal trough is shaped from aluminium which is plastic coated for comfort and water resistance.

The most convenient sizes of wire are 0.8 mm, 1.0 mm and 1.2 mm in diameter which can assist or resist finger movements in the power ranges 1-70 gm, 4-180 gm and 7-300 gm respectively.

The direction and range of power of the W splint can be adjusted easily depending upon the diameter of wire used, the manner in which it is bent and the positioning in the wire holder.

S type (Figs. 3 & 4)

A thin, well fitting glove is put on the patient, tiny vinyl tubes are arranged along the tendon which requires support and fishing line is run through the tubes. The end of the fishing line is attached to an S-shaped ring which is fixed to the wrist cuff by a rubber band or coiled spring.

The vinyl tube should avoid the area of the finger joint so that smooth joint movement can be achieved. The tube can be attached to the

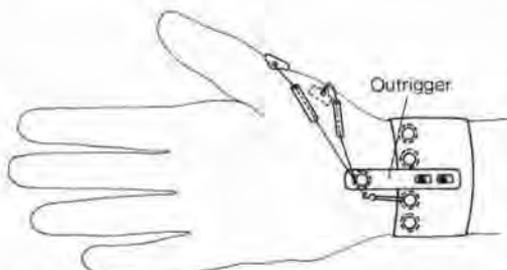


Fig. 5. S type splint with outrigger to assist apposition of the thumb.

glove by glue, adhesive tape or it can be sewn on.

When using the S orthosis to assist finger flexion the fishing line is set along the line of action of the flexor digitorum profundus tendon; for assisting flexion of the thumb the line is adjusted along the line of action of tendon flexor pollicis longus. When assisting apposition

of the thumb a simple outrigger is used to pull the line in the same direction as the action of opponens pollicis tendon (Fig. 5).

The S orthosis can be used not only to assist finger flexion but also for extension, in which case another type of outrigger is helpful to extend the finger and thumb in the desired direction (Fig. 6).

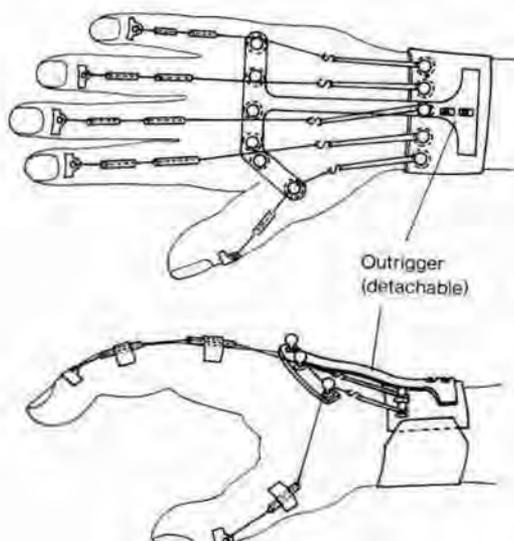


Fig. 6. S type for extension assist of the thumb and the fingers.

Indications and use

Radial nerve palsy at the wrist level

When the W type orthosis is used, the trough should be placed over the proximal phalanx of each finger and the metacarpo-phalangeal (MCP) joint should be pulled towards extension, and when the thumb cannot give adequate extension or abduction either, the piano wire should be fixed to the wire holder so that the power can work in that direction (Fig. 1).

When the S type orthosis is used, small vinyl tubes should be placed along the long axis at the centre of the dorsal side of each finger and the fishing lines led through them (Figs. 3 & 6). The T-shaped outrigger should be set at the cuff on the wrist joint and by careful choice of the 4 or 5 truss studs which are fixed on this outrigger, in order to fit the line of finger

extensors, extensor pollicis longus, extensor pollicis brevis, abductor pollicis longus tendon and so forth, the movement of tendons can be fairly assisted. The fishing lines should be fixed to the proper truss stud at the wrist joint by means of the S-shaped ring and rubber bands of the correct tension.

In case of the S type orthosis, a finger cuff made of vinyl or leather instead of vinyl tubes can be fixed to the proximal phalanx and the MCP joint can be given extension with fishing line (Fig. 7). In this case there is no need to wear a glove.

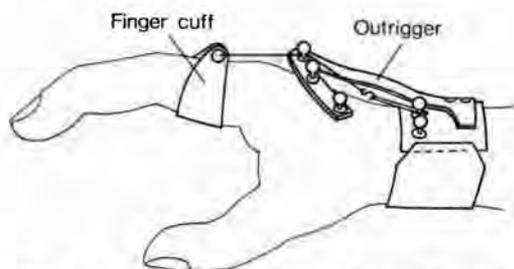


Fig. 7. MCP joint extension assist without wearing a glove.

Median nerve palsy at the wrist level

The main symptom in this case is the disability of apposition of the thumb generally called "ape hand". When using the W type orthosis for this palsy, the trough is put on the proximal phalanx of thumb and the piano wire is placed to pull the thumb into apposition.

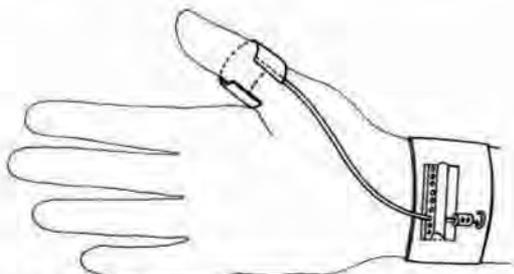


Fig. 8. W type to assist apposition of the thumb.

In this case the wire holder should be set at the palm side on the wrist joint (Fig. 8). The piano wire can also be connected to the block of the

opponens bar and C-bar, and set to the wire holder in the direction of apposition (Fig. 9).

In the case of using the S type orthosis, extend the fishing line so as to reach the first metacarpal head through the small outrigger that is attached to the wrist cuff. The fishing line should be pulled with a rubber band, so assisting the movement of the thumb towards



Fig. 9. 37-year-old male with rheumatoid arthritis. The patient showed disability of right thumb apposition due to carpal tunnel syndrome. The K U finger splint, W type, was prescribed. Because the patient also had weakness of extensor digitorum communis muscle, the finger extension assist mechanism was also included in the orthosis. The orthosis improved the activities of daily living and he continued wearing it for two months.

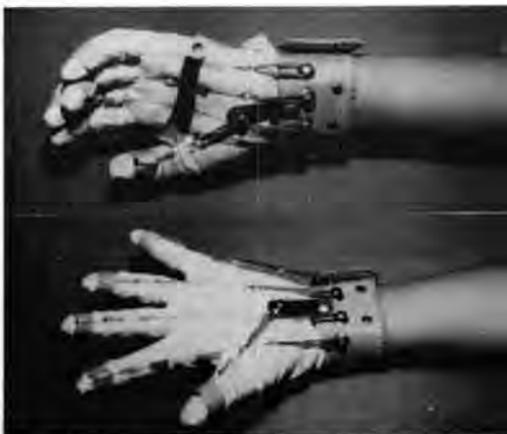


Fig. 10. 34-year-old male. Left median nerve paresis due to pronator syndrome. The K U finger splint, S type, was prescribed for him to assist the thumb and finger flexion. The grasping function was improved by it.

apposition (Fig. 5). If there is weakness of thumb flexor or finger flexor muscles, place vinyl tubes along the tendon of flexor pollicis longus and flexor digitorum profundus, and then let the fishing line run through them (Fig. 10).

Ulnar nerve palsy

Mostly in case of isolated ulnar nerve palsy, the ring finger and the little finger will present claw finger deformity, and flexion of the MCP joints and extension of the I P joints will become difficult. The S type orthosis can be used for this condition. The fishing line can be pulled round from the dorsum of the proximal phalanx toward the palm, choosing the proper truss stud, and fixed to the cuff of the wrist joint on the palm side with a rubber band to assist flexion of the MCP joint. On the other hand, the W type orthosis is used for extension of the I P joints. In this case the trough may be placed at the middle or the distal phalanx of the fingers (Fig. 11).

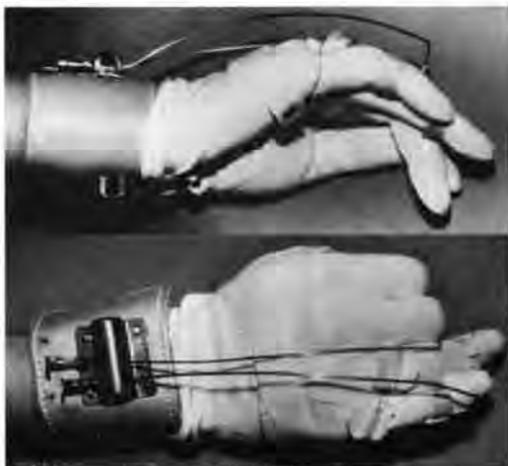


Fig. 11. 46-year-old male. Right tardy ulnar-nerve palsy secondary to the fracture of lateral condyle of the humerus. The patient showed typical clawing deformity of the ring and little fingers. The K U finger splint, W type and S type combination, was applied after nerve surgery. The palsy was partially improved.

Other pathological conditions of the fingers

The W type and S type orthoses can be used as a dynamic orthosis before and after surgical operation for tendon rupture of the finger and for the maintenance of correction of ulnar drift

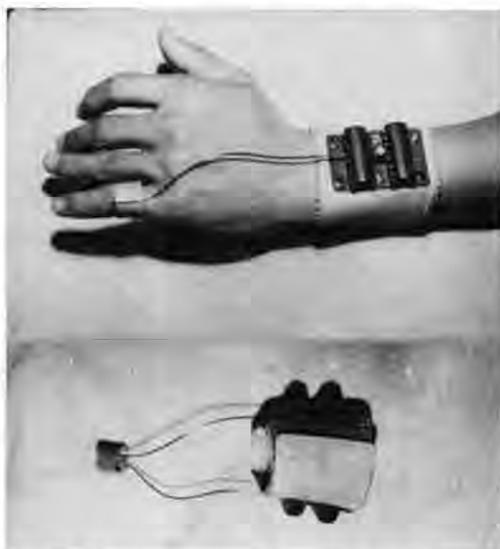


Fig. 12. For correction of ulnar deviation, W type.

(Fig. 12) after finger arthroplasty. They can also be used for the purpose of static splinting to hold the correction of finger contracture. These orthoses can give help to each tendon in its assisted active movement and resisted movement according to its own muscle power.

Discussion

Various kinds of hand orthoses have been made to date, but most of them have not been good enough to give satisfaction to the patients. Of course, Swanson's splint (1971) leads others in function but it is rather poor in its cosmesis and it is not light in weight, so it is not easy to wear it for a long period. Bunnell (Boyes, Ed. 1970) invented several wire splints such as the knuckle bender splint, reverse knuckle bender splint, finger-bender splint etc. These wire splints are excellent from the functional view point, but there is some degree of limitation in hand and finger activities because of the protruding wire frame and rubber bands. The Thomas suspension splint and Oppenheimer splint have no provision for adjustability of the individual fingers.

Four kinds of finger orthoses have been produced by the Steeper Company (Hugh Steeper Limited, 237-239, Roehampton Lane, London SW15 4LB), the main one among them being the spider splint. These are superior to the

others in their external appearance, being light in weight, excellent in adjustment and also have the feature of not hindering the action of holding things in the palm of the hand. But structurally the power to push the finger towards the ulnar side is strong, and so, in case of a rheumatic patient, there is the risk of making ulnar drift worse. In addition the indications for these orthoses is quite limited; they are suitable only in the case of low radial nerve palsy.

The first trials of the K U finger splint were based for the most part on the W type, followed by trials made based primarily on the S type (Watanabe, 1973). These two orthoses are made of several simple materials (Fig. 13) and are able to be applied to various cases of finger troubles. By adjusting the piano wire and fishing



Fig. 13. Components and materials of the K U finger splint.

line, it is quite convenient to change the power of the orthosis according to the progress of the disease. If the materials are stored as a kit or in a half-made form, a doctor or occupational therapist can at once put them together

according to the need and let the patients use them. If the patient understands the purpose of splinting, he himself can in some degree adjust the orthosis. This hand orthosis can freely regulate the direction, the range, the distance that the power works, and is also light in weight, easy to put on, and its cosmesis is not bad. In case of using the S type orthosis at the palm side, it does not cause any disturbance when holding things as the former orthoses did, and it is convenient in activities of daily living, too.

The problem of the K U finger splint is that the orthosis reaches the wrist joint and so it may cause limitation in the movement of the wrist joint. However in the cases in which this orthosis has been used there have been no troubles at the wrist joint. In case of the S type orthosis, the simplest way of applying it is to fix the parts and materials to the glove, the wearing of which may sometimes give a patient trouble. When the patient does not like to wear a glove, it is possible to use a thin sack-like vinyl instead (Fig. 14).

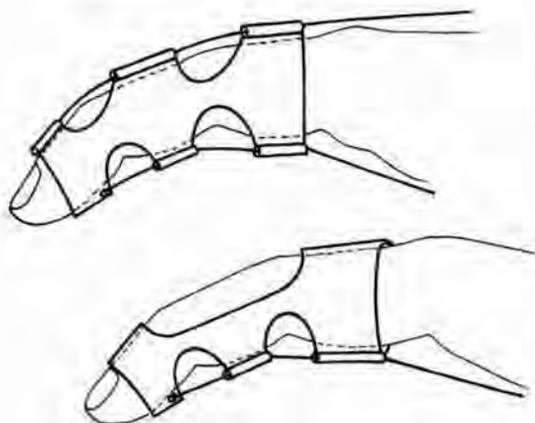


Fig. 14. Thin vinyl finger cuff for flexion and extension without wearing a glove.

The indications of the K U finger splint are (1) radial nerve palsy (low level), (2) median nerve palsy (low level), (3) ulnar nerve palsy, (4) injuries of flexor or extensor tendons of thumb and/or fingers, (5) contracture of thumb or fingers, (6) ulnar deviation of the fingers at M P joint, (7) pre- and post-operative conditions of various finger impairments.

Summary

The K U (Kumamoto University) finger splint has been manufactured for the purpose of developing an effective hand orthosis for various finger impairments using simple parts and materials. By combining the W type orthosis for which piano wire is mostly used, and the S type for which fishing line is mainly used, it has been used to good effect on patients with several kinds of finger impairments. The fabrication and adjustment of the orthosis is simple and if the material is in kit form, a doctor or an occupational therapist can at once construct one and give it to a patient. For this reason, the patient will not lose the chance of timely treatment.

Work is continuing to find a way to simplify and widen the use of the K U finger splint.

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The use of lumbosacral corsets prescribed for low back pain

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Introduction

Low back pain is a common complaint, often requiring sick leave, (Horal, 1969; Westrin, 1970; Helander, 1973) for which a lumbosacral corset is frequently prescribed. According to Perry (1970) only 14 out of 3410 American orthopaedic surgeons had never prescribed some kind of support for low back problems. The situation in Sweden is presumably very similar. In Sweden, with a population of 8.2 million inhabitants, as many as 61,000 corsets were supplied to patients because of low back pain in 1976. These corsets cost about 22 million Swedish crowns. It was therefore thought worthwhile to assess to what extent such corsets are really used.

Material and method

The archives of the orthopaedic workshop affiliated with the orthopaedic clinic of a central county hospital covering a district with 260,000 inhabitants was searched for patients who had their first corset prescribed in 1972. The staff of the clinic then consisted of five orthopaedic surgeons and of these three had more than ten years experience of orthopaedic surgery. Prescriptions for corsets made by other doctors than the abovementioned five were not accepted by the workshop. Of the cases collected from the archives 260 patients who had been fitted with their first corset were randomly selected. Their hospital records were collected and certain clinical data were noted in a special form. In the summer of 1976, i.e. 3.5-4.5 years after they had received their corset, the patients were interviewed by telephone according to a specially designed questionnaire. A total of 201 of the patients were successfully contacted all of whom confirmed that they had been fitted with a corset for the first time in 1972. The sample thus consisted of 201 patients. The first inter-

views were conducted by a doctor, but later by a secretary who had assisted at the first interviews and gained the necessary experience.

Results

In total 109 women and 92 men were interviewed. The sex distribution tallied well with the fact that 55 per cent of all corsets supplied by the County National Purchasing Centre were for women. This suggests that the sample was representative. It is clear from the age distribution (Table 1) that about two-thirds of the corsets were supplied to persons between the ages of 41 to 70 inclusive. There was no difference between the men and the women in this respect.

Table 1
Age distribution of patients when fitted with corset

Age	Men	Women	Total
-25	4	1	5
26-40	19	19	38
41-55	33	37	70
56-70	28	40	68
71-	8	12	20
	92	109	201

The diagnoses are given in Table 2. The term chronic lumbago is used to denote back pain radiating down the thigh(s), but not further than to the knee(s). Chronic lumbago-sciatica designates low back pain radiating down the thigh and below the knee(s). Acute lumbago-

Table 2
Diagnosis at time of prescription

Chronic lumbago	108
Chronic lumbago-sciatica	39
Acute lumbago-sciatica	26
Vertebral body fracture	11
Miscellaneous	17
	201

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sciatica is to be understood as low back pain of less than six months duration radiating to below the knee(s) in association with a positive Lasègue's sign and neurological deficit. Cases of acute herniation of the intervertebral disc should be found under this diagnosis. The group with vertebral fractures comprises both recent and old fractures and the miscellaneous group embraces, among other things, spondylitis, scoliosis, spondylolysis, spondylolisthesis, osteoporosis as well as six cases of acute lumbago. In the first three diagnostic groups based on clinical findings the roentgenologist's report contained no notes about any changes in the lumbar spine other than disc degeneration and/or spondylosis. Sometimes the roentgen examination revealed nothing remarkable.

The vast majority (90 per cent) of the patients were examined roentgenographically in association with the prescription for a corset and in none of them had the examination unexpectedly revealed infection or a malignant process. Examination of the hospital records of the remaining 10 per cent contained no notes about any infection or malignant process later discovered.

The border between chronic lumbago and chronic lumbago-sciatica is neither sharp nor natural. These two groups were therefore pooled and then constituted about three-quarters (73.1 per cent) of the total material.

Table 3 shows the age and sex distribution of the use of corsets by the patients 3.5 to 4.5 years after they had been supplied. Of the original 201 patients, 105 still wore a corset. In addition, 38 patients (19 men and 19 women) had worn a corset until they had become symptom-free. Two of these 38 had worn a corset for about

a week, 5 for one week to one month, 11 for one to three months, 12 for three months to one year and 2 for more than a year. Six patients reported "for some time" or "in the beginning".

In 143 (71 per cent) cases, then, it was known that the patients had made some use of their corset. That is almost three-quarters used it for some time after the prescription and 3.5 to 4.5 years later half of the original patients still used a corset. After this period 163 still had symptoms and 105 of them were still using a corset, i.e. 64.8 per cent or roughly two-thirds.

In the lower age classes the women tended to use a corset less often than the men, but in the highest age class it was the women who used the corset more often.

Table 4 shows the distribution of the diagnoses at the time of prescription of the corset and the frequency of the use of the corset at the time of the interview. In the pooled group of chronic lumbago and chronic lumbago-sciatica the frequency with which the corset was used corresponded roughly to that in the sample as a whole, i.e. half of the original sample used the corset and the other half did not.

The other diagnostic groups were small, yet the following tendencies could be discerned. The frequency in the fracture group was slightly lower, probably because this group included fresh fractures requiring the use of a corset for only some months. The frequency in the group of acute lumbago-sciatica was higher than in any of the other groups, probably because the symptoms in this group are mainly physical. The large pooled group may comprise some patients with social and/or psychosomatic problems which cannot be solved by use of a corset.

Table 3
Age distribution of users and non-users with symptoms at time of interview.
(Thirty-eight patients had become symptom-free and stopped using the corset by the time of the interview and are excluded.)

Age at prescription	Men		Women		Total	
	Users	Non-users	Users	Non-users	Users	Non-users
-25	1	3	0	1	1	4
26-40	9	4	3	14	12	18
41-55	22	12	15	9	37	21
56-70	15	2	28	6	43	8
71-	2	5	10	2	12	7
	49	26	56	32	105	58

Table 4

Distribution of users and non-users at time of interview among diagnostic groups. (Diagnosis made at time of prescription.)

	Users	Non-users
Chronic lumbago	58	50
Chronic lumbago-sciatica	17	22
Acute lumbago-sciatica	17	9
Vertebral body fracture	4	7
Miscellaneous	9	8
	105	96

In Table 5 the site of pain at interview is related to the frequency of the use of the corset at the time of the interview. The frequency was largely the same whether the pain was confined to the lumbar region or radiated down to below the knee. It was interesting to note that the number of patients with pain radiating to below the knee had diminished during follow up time (cf. Table 4).

Table 5

Use of corset relative to symptoms at time of interview

	Users	Non-users	Total
Pain in low back only	89	46	135
Pain radiating past knee(s)	9	4	13
Other pain or no answer	7	8	15
Symptom-free	—	38	38
	105	96	201

The frequency with which the corset was used is given in Table 6. If groups 1, 2 and 3 be pooled, it would mean that about half (48.6 per cent) still used their corset at least once a week.

Table 6

Use of corset by the 105 users

1	Always, day and night	1
2	Always during the daytime	35
3	At least once a week	15
4	At least once a month	25
5	At least once a year	25
6	Irregularly	4
		105

If groups 1 and 2, 3 and 4 be taken together and groups 5 and 6, it would mean that a third wore the corset daily, a good third at least once a week or month, and barely one-third at least once a year or irregularly.

Table 7

Distribution of users and non-users by occupation

Occupation	Men		Women	
	Users	Non-users	Users	Non-users
Light work	12	10	16	25
Heavy work	26	22	22	24
Pensioners	11	11	18	4
	49	43	56	53

In Table 7 the use of the corset is related to occupation. The 201 patients represented 64 occupations, which were distributed among three groups: light work (office workers, housewives in town, inspectors, executives or the like), heavy work (farm labourers, workers in heavy industry or workshop, farmer's wives and the like) and pensioners.

The men used a corset equally often whether their work was heavy or light. But women with heavy work seemed to use their corset more often than the other women. Female pensioners seemed to use their corset more often than men of corresponding age.

Table 8

Reasons for using corset

Relieves pain	5
Supports back	56
Relieves pain and supports back	38
Other reasons	2
No answer	4
	105

Table 8 gives the reasons why the patients used their corsets. It was astonishing that though the questions were by no means leading, the patients fell into two large groups. Support of the back with or without relief from pain was the reason given by 89 per cent. Only 5 per cent reported alleviation of pain as the only reason.

Table 9
Reasons for not using corset

Symptoms ceased	38
Corset does not help	7
Corset does not fit	37
Other reasons or no answer	14
	96

During the period in question the corsets used were of 6 types, but the frequency with which they were used did not vary with type.

As for the 96 non-users who stopped using corsets (Table 9) the 38 who became symptom-free have been accounted for earlier. That 37 of 96 reported that the corset did not fit properly suggests that the standard of work at the corset workshop had been unsatisfactory but when questioned the workers there reported that patients were always requested to return if they were not satisfied with the fit of the corset. It was interesting to note that only 7 said that the corset had not helped at all. The figure is astonishingly low and might be explained by the unwillingness of patients to say anything unfavourable about the treatment they had been given.

Table 10
Patient opinion of corset. Main complaint only.

Extends too far up or down	17
Too stiff or hard	30
Too tight or too loose	12
Presses or chafes	16
Too warm	6
Too short	5
No comments	115
	201

The patients opinions of the main defect of the corset are given in Table 10. Caution must of course, be exercised in the evaluation of these opinions. If a corset had really been too long or too short, it could surely have been adjusted when the patient was being fitted with it. The other defects reported may have been due to a poor fit, but the true cause of complaint may be that the patients had not worn their corsets long enough to get used to them.

More information when a patient is being fitted with a corset and possibly also follow-up would certainly increase the frequency of the use of the corset to the advantage of the patients, remembering that only 7 patients stated that the corset was of no help.

Summary

Two hundred and one randomly selected patients (109 women and 92 men) fitted with their first lumbosacral corset because of low back pain were interviewed 3.5-4.5 years later.

Two-thirds of the patients were 41-70 years when fitted with the corset. Barely three-quarters of them wore the corset regularly immediately after prescription. One-fifth became symptom-free within the period covered by the study. Of those who still had symptoms at the time of the interview, two-thirds (about half of the original material) were still wearing a corset. Of these two-thirds, about half wore the corset at least once a week. The women doing heavy work and female pensioners tended to use their corsets more frequently. The frequency with which the corsets were used was not influenced by the clinical diagnosis or the type of corset used. As many as 89 per cent of the patients reported that they used the corset because it supported their back or because it not only gave such support, but also relief from the pain. Thirty-seven of 96 non-users reported that the corset did not fit well but only 7 that they did not benefit from the use of the corset.

A better follow-up of users would surely increase the frequency with which such corsets are used to the advantage of the patients.

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Technical aids*

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Introduction

The "disabled" represent a population with a wide variety of functional losses. The VA are in complete accord with the idea that each individual has a right to all the help technology can offer at a given time. The range of disability and therefore the needs are enormous; few centres, even in developed countries, have the time or the means to develop technical aids in sufficient quality and quantity to meet all these needs. It is essential to link all centres in the field to avoid costly duplication and repetition of error, to advance development, and improve treatment as rapidly as possible. Some links in this chain of co-operation have already been forged; information about development and evaluations are now being disseminated through such organizations as VA, ISPO and ICTA (ISO).

Technical aids, by which are meant all rehabilitative devices except artificial limbs, are quite different now from what they were perhaps 5 years ago; there are available today an enormous number of devices for the handicapped. Most of the newer ones fall into four major areas:

- Mobility aids
- Communication devices
- Manipulation and control of the environment
- Patient handling devices.

Mobility aids

Mobility is one of the fundamental characteristics of the animal kingdom and its loss can be devastating for human beings in modern society. Apart from conventional crutches, canes, walkers, artificial limbs or orthotic devices, there are wheelchairs, licensed vehicles and other mobility aids which are not clearly wheelchairs or licensed vehicles.

Wheelchairs

Until recently relegation to a wheelchair was an admission of medical failure and so only the most general features of the chair were of concern. Now the wheelchair is looked upon as a rehabilitation tool to replace functional loss. As such, there must be judicious prescription of the most appropriate components from a vast number of options.

Figure 1 (left) shows a manually-propelled wheelchair which represents an archetype of a variety of such devices. Wheelchairs are specially designated as standard, heavy duty, lightweight, amputee chairs, indoor chairs and, more recently, outdoor chairs. Nevertheless all are simply variations on this basic type with special applications based on moderate design changes and a great deal of imagination. The Veterans Administration have developed standards, specifications, and test procedures for manual wheelchairs. These may serve some day as the basis for international standards.

Not too long ago, American medical rehabilitation specialists considered powered wheelchairs too dangerous for use by quadriplegics in hospitals. Today an opposite point of view prevails; their fear of accidents was not well founded. Another philosophical change is the view that a wheelchair is a means of transportation and not principally an exercise device. The basic model upon which most powered wheelchairs have been designed is the joystick controlled type chair.

Many variations of this basic model have been developed for special applications; they feature light weight, foldability, or portability of components. The other end of the scale perhaps is represented in Figure 1 (right), a heavy, expensive "wheelchair" which provides many more functions than the basic type first shown; breath control, joystick control, body

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*Based on a paper presented at the Second World Congress, ISPO, New York, 1977.



Fig. 1. Left, typical manually propelled wheelchair. Right, an example of a heavy, multi-purpose wheelchair.

attitude alteration, uneven terrain capability, and a variety of accessories. There is even an increasing demand for wheelchairs capable of travelling at 8 to 11 kilometres per hour. Several such chairs have been designed including a VA version featuring an automatic transmission to achieve high speeds at low power and high power at low speeds.

Perhaps more than anywhere else, standards, specifications, and appropriate test procedures are required to control the safety and quality of electric wheelchairs. Powering conventionally designed wheelchairs may unduly stress them, causing premature structural failure. The most effective types of control systems need to be determined from a range that includes joysticks, breath controls and even eye motion sensors, voice controls and acoustic controls. The VA are developing standards and specifications for these devices and intend to reconcile them with others in the world community.

Multi-purpose mobility aids

Between the wheelchair as a mobility aid and a licensed vehicle such as an automobile or a van, there is yet a third class. These are the devices which provide a number of other functions in addition to the basic one of mobility. Thus we have seen wheelchairs that perform as stretchers and therapeutic aids in enabling a patient to stand erect. Others double as shower chairs and commode seats.

Included in this group are some that are in effect wheelchair transporters. Their underlying use is to enable a wheelchair user to cover distances and speeds beyond the normal ranges and speeds of wheelchairs but short of the ranges and speeds of licensed vehicles. The safety and practicality of these devices must be carefully considered.

Of great significance in this group is a device which enables a wheelchair user to move about in a wheelchair and to stand up independently for activities of daily living, school, or work. Examples of this type are shown in Figure 2. Others enable a patient to move about in a wheelchair, to stand erect independently, and to move about in the erect position independently of the wheelchair.

Licensed vehicles

"Add-on" automotive hand control systems are used by lower limb amputees and those without sufficient upper-extremity strength and range of motion to operate standard motor vehicles. With the exception of mechanical advantage, no form of power augmentation is provided for these systems. The VA have developed standards, specifications and test procedures to govern their quality and safety, which are being adopted by other U.S. agencies. We hope they will also provide some basis for international standards. A new generation of automotive control systems has been developed



Fig. 2. Left, stand-up wheelchair. Right, powered stand-up mobility system.

to provide alternatives for handicapped drivers unable to use mechanical "add-on" hand controls. Several servo-operated control systems are now being evaluated. One example is the Scott Van; another example is the Lunar Rover (Fig. 3), an adaptation of the joystick controlled vehicle used on the moon. Others are the Sevier Van and a French vehicle controlled by a "fly-by-wire" joystick originally designed for the Mirage jet aircraft.

As persons with increasingly severe disabilities are enabled to drive by means of improved technology, additional problems arise. Among them are designing proper lifts (Fig. 4) to enable wheelchair users to enter and leave a van safely. Another highly important area is the securing of a wheelchair within a van or automobile when used by either driver or passenger in a wheelchair.



Fig. 3. Adaptation of the joystick controlled vehicle used on the moon.



Fig. 4. Automatic wheelchair lift system for a passenger vehicle.

Communication devices

Information transmission

Man alone is characterized by the ability to communicate by speech although he also employs a variety of other means of communication. Inability to communicate by speaking or writing is a catastrophic loss for which little has been done to date. Fundamental research on language disorders due to cerebral dysfunction has not yet led to technological solutions. However, speech disorders not due to cerebral involvement are being helped to some extent by improvement of technical aids. The simplest one presents a picture or symbol to carry a message. A more advanced alphanumeric system and others with a voice output have been developed.

Another communication problem is the inability to read, not because of blindness, but because of paralysis and the inability to handle the material to be read. Figure 5 shows a device to enable such persons to turn the pages of a book. Also available are machines that utilize 35 mm slides to display reading material. Other systems use microfilm and microfiche.



Fig. 5. Page-turning device.

Sensory aids

Apart from long and/or white canes and apart from sound amplifiers for telephones, other devices have been developed to aid both the blind and the deaf.

The Lindsay Russell Pathsounder, a sensory aid for the blind, uses ultrasonic pulses to probe the surroundings. It signals the user by tactile or audible feedback. It must be used with a cane or dog guide.

The C-5 Laser Cane is a VA sponsored mobility aid for the blind. The complete system is self contained. It directs three infra-red beams from a gallium arsenide laser, one upward and ahead, one ahead, and one downward to the ground. Audible indications warn of overhanging obstructions, while objects ahead, discontinuities in the terrain, e.g. curb, are indicated tactiley.

The Sonicguide is an ultrasonic mobility aid for the blind. It should be used with a primary mobility means such as a cane or a guide dog. If objects are present, the user is warned by an auditory signal to an ear-piece (vented to allow transmission of ambient sounds).

The Braille-Output Calculator for the blind was developed by the American Foundation for the Blind. The output is a printout in Braille.

The Speech Plus (Speech+) is a speech output calculator for the blind (Fig. 6). It was developed by Telesensory Systems, Inc.



Fig. 6. Talking output calculator for the blind.

Control of the environment and manipulation

Environmental controls

Amputees and paralytics have lost their ability to grasp, transport, and release objects, the dexterity considered a fundamental human trait such as the large brain, binocular vision, and the apposable thumb. Prosthetic hands or hooks are used as replacements in the case of amputation; splints or other orthotic devices for certain paralytics. The functional loss of limbs compounded by inability to maintain trunk posture and exacerbated by the inability to speak, tragically closes the door to a life limited only by the imagination. New technical



Fig. 7. VAPC Hospital Environmental Control System.

aids may help to replace some of these lost capabilities.

A bed-ridden or wheelchair-bound person still needs to use many common household appliances. The VAPC Environmental Control System, shown in Figure 7, is operated by an actuator which is sensitive to both positive and negative pressures developed in the mouth. The actuator can also be operated by two push-button switches. A monitor, which consists of indicator lamps, displays the appliance under control by the patient. The power and control section completes the system. One model for the home has 20 channels while the one for hospital use has 12 channels. With certain variations there are approximately eight or nine similar systems, some using solid state components. All, however, are grandchildren of the early Possum system.

The state of the art in environmental control systems has been advanced with the recent development of the VAPC Remote Station Environmental Control. It permits a person to move about freely by means of a wireless arrangement.

Patients able to speak may find value in the Voice Operated Typewriter and Environmental Control, developed for VAPC by Scope Electronics, Inc. The system incorporates six interconnected sections or units which permit voice activation of an environmental control and electric typewriter.

Medical manipulators

Remote manipulators were originally developed for handling materials in hostile

environments; in nuclear reactors, under the sea or in space. Rehabilitation of the high level quadriplegic person, for example, does not yet include provision for voluntary control of the upper extremities. Orthotic devices are not sufficiently advanced to provide a wide range of useful activities. The most obvious step at the moment is to provide the quadriplegic with a teleoperator or manipulator, e.g. a third arm controllable by whatever residual mechanical motions he can produce such as tongue movement, intra-oral breath pressure or movements of the head. Voice recognition devices are also being used to control the manipulator without physically linking the user to it. Among those developed to date is the VAPC Manipulator (Fig. 8). The basic unit is a telescopic arm which can reach objects within a sphere with a diameter of 2.5 metres while lifting 2 kilogrammes; it is now being modified for control by speech.

As shown, the device is controlled principally by movement of the head or chin. Up to 9 degrees of freedom can be achieved by utilizing a phase shifting lever mounted next to the chin control. The most ingenious element of this system is that the log of input position is proportional to the velocity of the movement of the manipulator terminal device.

The Applied Physics Laboratory of Johns Hopkins University, and the Research Centre for Rehabilitation of Heidelberg, Germany have



Fig. 8. The VAPC Manipulator.



Fig. 9. Left, the Royalair Fluidized Bed. Right, the Sevier Mobile Bed.

also developed medical manipulators for the seriously disabled person. They are different from the telescoping VAPC design in that both resemble prosthetic arms with jointed segments controlled in a variety of ways.

Patient handling devices

Beds

Several special beds have been developed to prevent decubitus ulcer, improve circulation, and provide mobility.

The Royal Air Fluidized Bed (Fig. 9, left), developed at the University of South Carolina, pumps air through a medium of silicon ceramic beads 74 to 105 millimicrons in diameter, in which the patient is suspended. The whole system is covered by a polyester sheet in which the orifices are smaller than the smallest ceramic bead. Provision is made for temperature and humidity control. A patient sinks in about 100 mm, reducing the maximum pressure on his skin to approximately 10 mm of mercury.

The Egerton Stoke-Mandeville electrically operated Tilt and Turning Bed with Gutman Head Traction Unit permits one attendant to turn a patient on his side, approximately 70 degrees, and to tilt him head or feet down, approximately 15 degrees. Both tilting and turning systems are independent and can be operated at the same time or separately.

The Hess Rotary Bed No. 387, or the Hess "Sandwich" Bed, is a turning frame which simplifies patient care. One person can turn a patient. In addition, the patient can be tilted head or feet down.

The Rancho Flotation Bed is designed to distribute the body weight of an occupant so that it is in effect weightless. The bed contains a mixture of barium and petroleum with a specific gravity twice that of the body which, therefore, floats immersed halfway.

Others of this class are the Steeper CO-RO and the Roto Rest Bed developed in Ireland.

The Sevier Mobile Bed (Fig. 9, right), is designed as a standard hospital or home bed for spinal cord injured and similar patients. It has two other functions: (1) the occupant can adjust it to raise the back and lower the legs while at the same time the sides raise to prevent him from rolling out and narrowing the bed, and (2) the occupant can then drive the bed away as though it were a wheelchair passing through doorways in its narrowed mode. It is not designed to replace a wheelchair but rather for short excursions indoors and outdoors to avoid the need for frequent transfer in and out of a wheelchair with the aid of attendants.

The Mobilizer is an ingenious device which permits one nurse or attendant in the hospital or home to lift patients weighing well over 90 kg out of bed, on to the Mobilizer, and then to transport them to a bath, X-ray, gymnasium and then back to bed. It is designed with a roller system which places the platform under the patient with no danger of pinching the skin.

Our principal needs now are for objective evaluation, standardization, dissemination of information concerning applications throughout the world, and the development of methods for deploying, servicing and replacing the products of this technological surge.

Rehabilitation engineering— a growing part of the rehabilitation services*

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The first objective in creating a better supply of technical aids is to know about the needs of the consumers. This is a sophisticated matter, not least for the handicapped consumers.

Specification of these needs is thus always a complicated process. Interviews with such consumers and systematic observation of their problems in daily life appear to be the best means, but few such investigations have been made, and these often lack necessary details. The statistics about frequency of handicapped groups give only limited guidance.

On the international level, ICTA¹ has done some work in this area, as for example in its publication on need analyses concerning dwelling requirements for different disability groups and requirements of the visually impaired in the environment.

However, the classification of different groups of disabled consumers, based for example, on anthropometric studies, is at present only in a very early stage of development. This is one reason why it is so difficult to quantify the various consumer groups within the handicapped population.

One of the principles for our work at least if we look at the greater perspective, is to integrate the handicapped groups' demands in the relevant goods offered for sale on the market for the ordinary consumer. We have, however, also to face the fact that even among these items there must, of necessity, be some special applications for handicapped persons such as grips for severely rheumatic hands, beds for people with limited ability to move, adapted dwellings for severely handicapped persons. In

these cases it is not enough to create an output of items on the market for the general public, where also the demands of handicapped have been taken into consideration. It is therefore natural to work in parallel with all the other items constructed, tested and produced just for the handicapped consumers. Let us first look at research and development.

Research and development (R & D)—where are the resources?

The R & D concerning technical aids and environmental facilities for handicapped is, as is most R & D, very expensive. The willingness to pay the appropriate costs is limited, especially if the consumer group is very small. One way, perhaps the only one, is through international co-operation.

To develop new aids for deaf-blind persons and other multihandicapped is very expensive especially compared to the number of consumers. But also when the number of consumers is higher, for example hand amputees, there is a need for closer international co-operation. Too much money is spent in isolated places with too little result.

For such co-operation there is a need for some fundamental knowledge. ISPO has a good idea of the resources which are at the disposal of its members through their institutions such as staff, scientific facilities, etc. The source is a register of members meant to be used for identifying specialists and teams for research, evaluation and teaching purposes.

ICTA has a continuous—but not quite systematic and far from complete—registration of institutions involved, showing that these institutions are mostly situated in highly

*Based on a paper presented at the Second World Congress, ISPO, New York, 1977.

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¹International Commission on Technical Aids, Housing and Transportation, a branch of Rehabilitation International.

NORTH AMERICA		
Canada	23	
USA	244	267
SOUTH AMERICA		0
EUROPE		
West Germany	36	
Great Britain	75	
France	12	
The Netherlands	17	
Scandinavia	38	
Others	55	233
AFRICA		4
ASIA		
India	14	
Indonesia	1	
Japan	21	36
AUSTRALASIA		
Australia	16	
New Zealand	5	21

Fig. 1. Distribution of Research and Development institutions—from the ICTA register.

industrialized areas in North America and Europe (Fig. 1). Needless to say all investigations of this type can only give a rough idea of the situation. They are also highly influenced by the location of the investigator. It is supposed that the result would be different if the investigation was made in Moscow or Peking instead of Stockholm.

Attempts to make inventories of planned and ongoing projects are being made by the Smithsonian Science Information Exchange, Inc., Washington, D.C. However, the input of R & D projects in this field to the Smithsonian data base seems to be rather poor.

Other attempts by ICTA are to stimulate different countries to achieve or promote projects of international value. Here may be mentioned as examples a study of airlines and disabled travellers sponsored by the Society and Home for Disabled, Copenhagen, and a study made by the Netherlands Society for Rehabilitation concerning architectural facilities. Simple inventories concerning a certain group of aids on the market are sometimes of value. Such inventories have in the framework of ICTA been made, for example, concerning technical aids for children and on behalf of ICTA by the Department of Health and Social Security, London, concerning electronic environment control systems.

Testing and specifications—a key to better technical aids

Rehabilitation International (RI) and its branch ICTA have been aware of the fact that testing and standardization of aids are to some extent of great value.

Testing or evaluation can ensure that the need specifications (standards) are fulfilled. They can give the specifications for producers and others to promote security, reliability and comfort. They can also positively influence the production costs. There are already some national specifications worked out for electric wheelchairs and lifts. On the international level there are standards for hearing aids through IEC (International Electrotechnical Commission).

International standardization is handled by IEC and ISO (International Organization for Standardization). ISO has certain committees where the needs of the handicapped are specially observed. ISO/TC 59 on "Building construction" deals with all questions concerning building. One of the tasks of this committee is to standardize lifts—an extremely important target for ICTA's efforts. ISO/TC 59 has also a special working group, WG 1, which has to take care of the interests of different handicap groups in this connection. ISO/TC 159 "Ergonomics" has the following subcommittees: SC 1 ergonomic guiding principles, SC 2 ergonomic requirements to be met in standards, SC 3 anthropometry and biomechanics, SC 4 signals and controls, SC 5 ergonomics of the physical environments.

RI and ICTA have close co-operation with these technical committees and their branches and have also proposed ISO to take care of standards for wheelchairs, which is planned to be handled in TC 136 on "Furniture" and specially in its subcommittee SC 8 on "Hospital Furniture".

Other ISO committees of interest to the handicapped are, the technical committee TC 145 on "Graphic Symbols" which will handle the symbol of access, TC 22 on "Road Vehicles" and TC 29 on "Small Tools". There are also plans for a TC on Prosthetics and Orthotics in which ISPO will be closely involved.

Information — the beginning and end of rehabilitation technology

In this survey the necessity of prompt and adequate world-wide information has been stressed in order to ensure that R & D and testing is not carried out in vain. The result of these activities as well as information on new products, new arrangements and new ideas must also be widely disseminated as soon as possible. International congresses like the World Congresses of ISPO and RI are obvious meeting places where these problems are discussed.

Printed publications, conferences and seminars are the means for this part of the programme of both these and other international organizations.

Courses concerning prosthetics and orthotics are continuously being arranged by ISPO and World Rehabilitation Fund. Interbor (International Association of Orthotists) through its

congresses is spreading information in the same field.

Publications which may be mentioned are Excerpta Medica Section 19 Rehabilitation and Physical Medicine and Section 27 Biophysics, Bioengineering and Medical Instrumentation, which give a short presentation of most reports and articles printed. This information covers the world literature in this field but unfortunately not until about a year and a half after publication. The list of literature published periodically in the bulletin *Biomedical Engineering*, London, is faster, but does not so completely cover the field and does not give any summary of the contents.

Conclusions

With these facts as a background we have to develop a programme for a better structure of world resources in this field. That means that we must;

- (a) build models for projects for international co-operation
- (b) create instruments for mutual information about planned and ongoing projects and about available resources for R & D and testing
- (c) promote international evaluation, testing and standardization

and

- (d) structure the international work achieved by different international organizations—such as ISPO, RI/ICTA and others—to the benefit of best use of limited resources everywhere.

Calendar of events

COURSES

New York University Medical School

Short Term Courses for Prosthetists-Orthotists 1978-1979

740 Below Knee Prosthetics; August 28-September 15, 1978.

746 Upper Limb Prosthetics; January 2-12, 1979.

753 Lower Limb Orthotics; January 15-February 2, 1979.

758 Upper Limb Orthotics; May 29-June 8, 1979.

743 Above Knee Prosthetics; June 11-29, 1979.

756 Spinal Orthotics; July 9-20, 1979.

In view of the very heavy demand, early registration is encouraged. Further information may be obtained by contacting Ms. Sandy Kern, Registrar, Prosthetics and Orthotics, New York University Post-Graduate Medical School, 317 East 34th Street, New York, NY 10016. (212) 679-3200, extension 3707.

National Centre for Training and Education in Prosthetics and Orthotics

Short Term Courses 1978-1979

NC 201 Ankle-Foot Orthotics for Orthotists (I); 2-6 October, 1978.

NC 204 Patellar-Tendon-Bearing Prosthetics for Prosthetists; 9-20 October, 1978.

NC 101 Lower Limb Prosthetics for Physicians and Surgeons; 13-17 November, 1978.

NC 202 Ankle-Foot Orthotics for Orthotists (II); 20-24 November, 1978.

NC 205 Above-Knee Prosthetics for Prosthetists; 27 November-8 December, 1978.

NC 301 Lower Limb Orthotics for Therapists; 11-15 December, 1978.

NC 203 Knee-Ankle-Foot and Hip-Knee-Ankle-Foot Orthotics for Orthotists; 15-26 January, 1979.

NC 302 Lower Limb Prosthetics for Therapists; 29 January-2 February, 1979.

NC 206 Upper Limb Orthotics for Orthotists; 12-16 February, 1979.

NC 102 Lower Limb Orthotics for Physicians and Surgeons; 19-23 February, 1979.

NC 208 Patellar-Tendon-Bearing Prosthetics (supra-condylar suspension) for Prosthetists; 5-16 March, 1979.

NC 207 Spinal Orthotics for Orthotists; 19-30 March, 1979.

Further information may be obtained by contacting Mr. J. Hughes, Director, National Centre for Training and Education in Prosthetics and Orthotics, University of Strathclyde, 73 Rottenrow, Glasgow G4 0NG, Scotland. Tel.: 041-552 4400, extension 3298.

13-15 September, 1978

Third Conference on Materials for use in Medicine and Biology—Mechanical Properties of Biomaterials, Keele University, and Bioceramics Symposium (16 September).

Information: Dr. G. W. Hastings, Bio-medical Engineering Unit, Medical Institute, Hartshill, Stoke-on-Trent, Staffordshire ST4 7NY, U.K.

Bioceramics Symposium information: Dr. G. J. Gittens, Department of Ceramic Technology, North Staffs Polytechnic, College Road, Stoke-on-Trent, Staffordshire, U.K.

13-15 September, 1978

4th International Seminar of the Rehabilitation International Medical Commission, Southampton, England.

Information: Rehabilitation Department, Tremona Road, Wessex Rehabilitation Association, Southampton General Hospital, Southampton SO9 4XY, England.

17-21 September, 1978

IVth International Congress on Neuromuscular Diseases, Montreal, Canada.

Information: Secretariat, IVth International Congress on Neuromuscular Diseases, 3587 University Street, Montreal H3A 2BI, Canada.

18-21 September, 1978

Third European Conference of Rehabilitation International and Naidex '78 "The Disabled Person in the Family", Brighton, England.

Information: Royal Association for Disability and Rehabilitation, 25 Mortimer Street, London W1N 8AB, England.

20-22 September, 1978

Autumn Meeting, British Orthopaedic Association, London (combined with Spanish Orthopaedic Association).

Information: Miss M. Bennett, Honorary Secretary, B.O.A., Royal College of Surgeons, Lincolns Inn Fields, London WC2A 3PN, England.

24-28 September, 1978

American Academy for Cerebral Palsy and Developmental Medicine, Toronto, Canada.

Information: American Academy for Cerebral Palsy and Developmental Medicine, 1255 New Hampshire Avenue N.W., Washington, D.C. 20036.

25-28 September, 1978

International Conference on the Media and the Handicapped, Paris, France.

Information: World Veterans Federation, 16 rue Hamelin, Paris 16e, France.

25-30 September, 1978

International Congress on Occupational Health, Dubrovnik, Yugoslavia.

Information: Dr. R. Mundy, Quality House, Quality Court, Chandry Lane, London WC2A 1HP, England.

September, 1978

Conference of the International Federation of Multiple Sclerosis Societies, Hanover, Federal Republic of Germany.

Information: International Federation of Multiple Sclerosis Societies, Stubenring, 6/4/9A, 1010 Vienna, Austria.

4-7 October, 1978

VIII International Congress INTERBOR, National Congress and Exhibition Hall, Madrid.

Information: D. Oriol Cobi, General Secretary, Enrique Granados 131, Barcelona-8, Spain.

5-7 October, 1978

Annual Congress of Physiotherapists.

Information: Mrs. Turner, Chartered Society of Physiotherapy, 14 Bedford Row, London WC1R 4ED, England.

5-8 October, 1978

Sixth Panhellenic Congress of Rheumatology with International Participation, Athens, Greece.

Information: Dr. Basil Thomas, General Secretary, Sixth Panhellenic Congress of Rheumatology, c/o Hellenic Society of Rheumatology, 4 Papadiamandopolou Street, Athens 612, Greece.

9-12 October, 1978

Third Latin and Portuguese Congress of Rheumatology, Lisbon, Portugal.

Information: Third Latin and Portuguese Congress of Rheumatology, c/o Portuguese Society of Rheumatology, Rua D. Estefania 187-189, Lisbon, Portugal.

16-20 October, 1978

14th Congress of the International Society for Orthopaedic Surgery and Traumatology, Kyoto, Japan.

Information: XIV World Congress SICOT, Crescent Plaza 103, 4-6 Minami-Aoyama, 2-chome, Minatoku, Tokyo 107, Japan.

25-26 October, 1978

Course on Joint replacement in Rheumatoid Arthritis and Other Joint Diseases, Nuffield Orthopaedic Centre, Mary Marlborough Lodge, Oxford, England.

Information: The Secretary, Demonstration Centre, Nuffield Orthopaedic Centre, Headington, Oxford OX3 7LD, England.

October, 1978

Rheumatoid Arthritis Surgical Society, Overseas Meeting, Japan.

Information: A. Benjamin, Hon. Secretary, Rheumatoid Arthritis Surgical Society, Fosse House, Brownlow Road, Birkhamsted, Herts, England.

5-11 November, 1978

ISPO International Course on Above-Knee Prosthetics, Rungsted, Denmark.

Information: ISPO Secretariat, PO Box 42, DK 2900, Hellerup, Denmark.

10 November, 1978

British Orthopaedic Research Society, Autumn Meeting, Leeds, England.

Information: Prof. D. L. Hamblen, British Orthopaedic Research Society, c/o Dept. of Orthopaedics, Western Infirmary, Glasgow G11 6NT, Scotland.

12-14 November, 1978

First Iranian Biomedical Engineering Congress, Jundi Shapur University, Ahvaz. The Congress will be held under the auspices of the World Health Organization. Authors interested in presenting papers are requested to send abstracts before August 20 1978.

Information: A. Fathipour, Secretary, Biomedical Engineering Congress, PO Box 67, Ahvaz, Iran.

12-17 November, 1978

American Academy of Physical Medicine and Rehabilitation and American Congress of Rehabilitation, New Orleans, Louisiana.

Information: C. C. Herold, American Academy of Physical Medicine and Rehabilitation, 30 North Michigan Avenue, Suite 922, Chicago, IL 60602.

13-18 November, 1978

32nd World Medical Assembly, Manila, Philippines.

Information: World Medical Association, 13 Chemin du Levant, 01210 Ferney-Voltaite, France.

16-18 November, 1978

Course in Orthotics and Prosthetics for Consultants, Senior Registrars and Registrars (in Orthopaedics, Rheumatology, Physical Medicine) and Senior Orthotists. To be held at the Robert Jones and Agnes Hunt Orthopaedic Hospital, Oswestry.

Information: Mr. G. K. Rose, Director, Orthotic Research and Locomotor Assessment Unit, The Robert Jones and Agnes Hunt Orthopaedic Hospital, Oswestry, Salop SY10 7AG, England.

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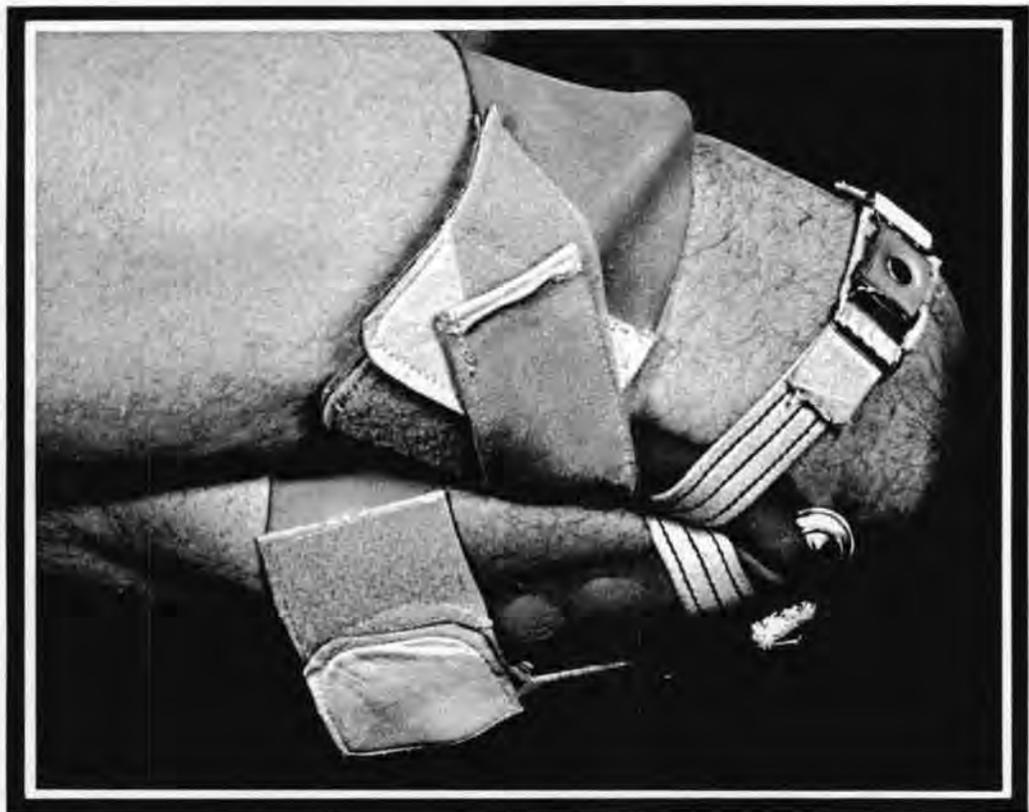
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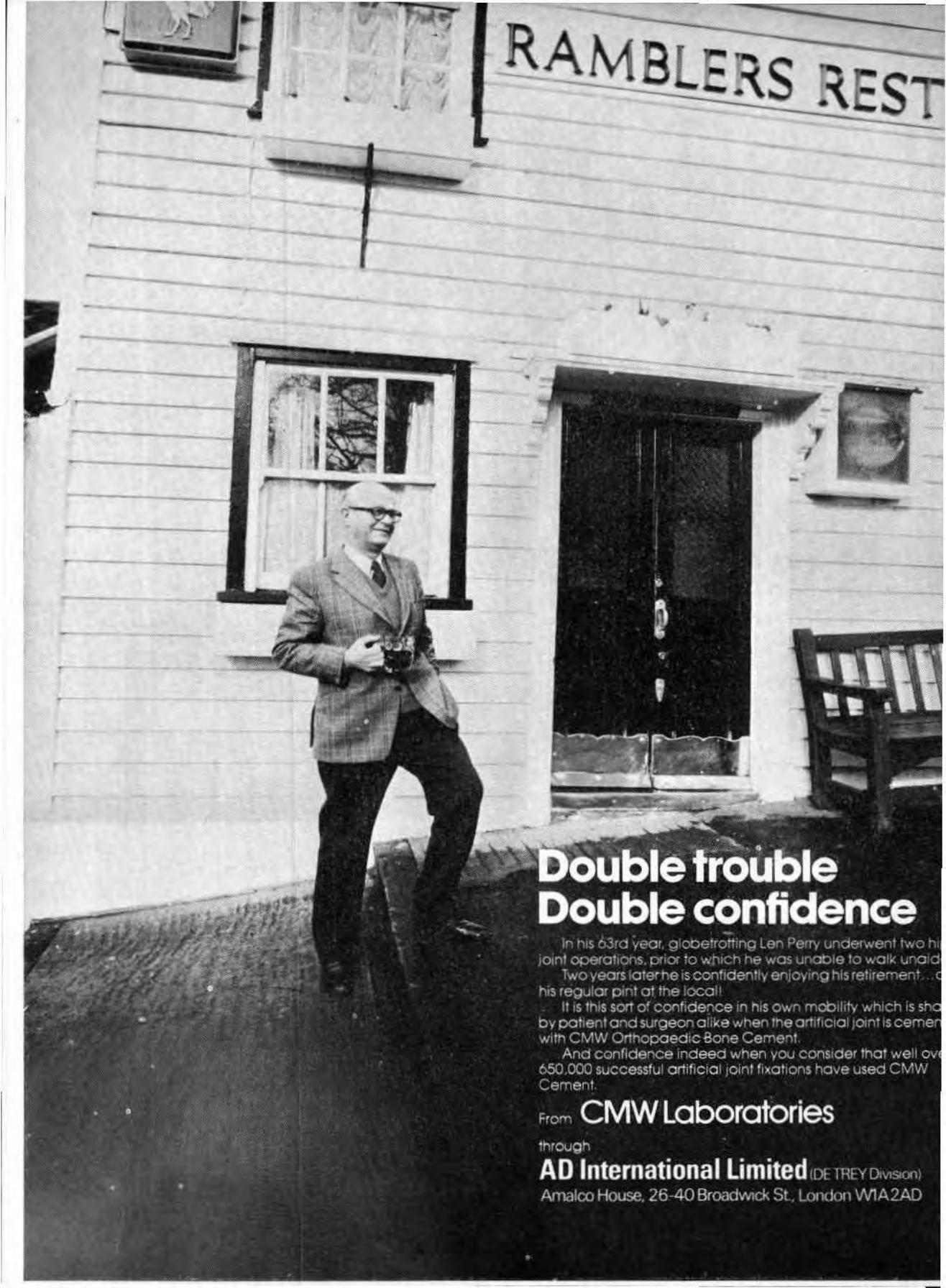
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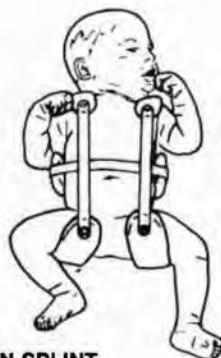
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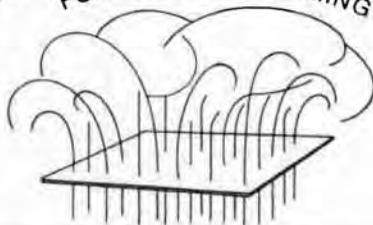
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References to articles in books should include author, year of publication, article title, book title, edition, editor (if different from author), first and last pages, publisher and place of publication. For example, Hughes, J. (1975). Recent developments in prosthetics and orthotics. *Recent Advances in Orthopaedics* (2) Ed. McKibbin, B., 196–216, Churchill Livingstone, Edinburgh.

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