Prosthetics and Orthotics International

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Prosthetics and Orthotics International

The Journal of the International Society for Prosthetics and Orthotics

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Contents

Executive board of ISPO

Editorial

On the occasion of our World Assembly in New York the International Committee selected Netherlands as the site for the next World Assembly in 1980 after considering various proposals. This was warmly welcomed by the membership especially after the considerable work that had gone into the preparation of the proposal. It was also welcomed because of the strength of the Netherlands National Member Society and their active programme of scientific meetings. It became apparent however, at the time of the meeting of the ISPO Conference Committee with the Netherlands Congress Committee, that there were major difficulties primarily financial in nature and related to the high cost of living in the Netherlands. Both ISPO and the Netherlands Congress Committee worked hard to resolve these difficulties but by the summer of 1978 it was clear that we could not go forward on our original plans. Dr. Hazelaar, Secretary of the Netherlands National Member Society has written and his letter is reported here in full:

"From the Editorial column of Prosthetics and Orthotics International, 1978–2, ISPO Members were informed about possible difficulties in the siting of the World Assembly, 1980. ISPO Netherlands indeed saw no other possibility than to return the invitation to organize the 1980 Assembly as budgetary problems could not be solved in an acceptable way.

It is with sad feelings that we write this letter. One does not throw away easily 1½ years of hard work by a Congress Committee derived from all levels of medical and paramedical groups and dedicated to its task. One does not play with the trust ISPO Netherlands members gave their Board to act as the situation required. One does not think lightly about the deep commitment of members of the ISPO Netherlands Board. One does not assume low the amount of time and co-operation given by members of the ISPO Board.

Let it be known that we do really thank everyone.

As to the 1980 Assembly we hope the ISPO Board will find another location and the Congress will be a successful one. One of the very clear points in the preliminary discussion of the Dutch Congress Committee was the fact that we have to face a changing attitude towards larger Congresses. People come not only to hear, they want to *do* something. Maybe ISPO can contribute to this general change in course and as a follow up to the New York morning sessions enlarge the active participation of Congress participants in the exchange of knowledge.

We certainly hope so.

Hazelaar."

We very much regret that we have been unable to proceed with our plans in the Netherlands and we commend the Netherlands Member Society for their dedication to the task in the preliminary organization and join with them in what must be a deep disappointment in our inability to reach a satisfactory and sensible arrangement.

Once the decision regarding the Netherlands was reached proposals were sought from four nations and at a meeting of the Conference Committee and the full Executive Board in Rungsted in November 1978 Bologna, Italy was selected as the site for our 1980 World Assembly and Congress. I am glad to say that due to the dedicated work and organizing ability of Professor Hannes Schmidl we have now concluded arrangements following visits to Bologna and its excellent Conference Centre with our friends and collaborators from INTERBOR.

The Conference Committee met with the Mayor of Bologna and his colleagues and with those others who are essential to a successful outcome including, of course, the officials of the Conference Centre, Tourist Bureau, etc. We are confident now that we can fully regain the lost time ensuring a successful outcome.

The 1980 World Assembly and Congress will be held in Bologna 28th September–4th October and it is my hope that you will all begin to make arrangements to come. The pattern used originally in Montreux and expanded and improved in New York will, we hope, again provide the basis for our activities. Thus you can expect lead papers from the world's authorities, special interest sections for

submitted presentations, and most important, an array of instructional courses. We are particularly fortunate that the simultaneous translation arrangements provide for interpretation in four languages in four places simultaneously. The Conference Centre itself is a beautiful building, functionally designed and providing an ideal environment for our Congress. There is ample exhibition space in an attractively structured building immediately adjacent.

We can expect to be received with great warmth by the citizens of Bologna. The city has a long tradition of orthopaedic surgery and technical orthopaedics; it is also renowned for its food and wine and we will have the opportunity of indulging ourselves. Bologna is centrally situated for easy access to Venice, Florence and other famous historical cities and, while the Congress will take place after the main tourist season, this part of Italy will still be blessed with warm, beautiful weather.

The first announcement and call for papers will soon be on its way and we look forward to a large and early response.

George Murdoch

President

International Course on Above-knee Prosthetics

RUNGSTED, 6th–10th November, 1978

This course, reminiscent of previous events held throughout the years in Denmark by the Society and previously by our forerunner, ICPO, was a great success. The theme included all aspects of above-knee amputation surgery, prosthetic fitting and supply, and patient treatment. In addition to being an instructional course this was an opportunity for the foremost practitioners in the world to compare techniques and experiences and distil improved practices for the benefit of their patients.

Associated with the course was an exhibition displaying the latest mechanisms and supply systems available and in the course itself the exhibitors had the opportunity to make presentations highlighting their own recent advances. The companies who took part and who also generously sponsored the course were:

Otto Bock

Camp Scandinavia

Een and Holmgren

J. E. Hanger & Co. Ltd.

IPOS KG

United States Manufacturing

All told 126 participants and lecturers from 22 different countries took part.

Erik Lyquist, the course director, ably assisted by the staff of the Orthopaedic Hospital, Copenhagen, and our Secretary Aase Larsson,

ensured the smooth running of the organization. Patients from the Orthopaedic Hospital also gave generously of their time in a series of most interesting demonstrations.

It was perhaps fitting that the course should take place in the beautiful course centre at Rungsted where almost exactly eight years ago to the day the International Society was inaugurated. The beauty of the surroundings and the excellence of the catering and domestic arrangements did much to enhance the event.

The social highlight of the course was undoubtedly the course dinner which was presided over in firm but genial fashion by Wilfred Kragstrup. The delightful meal was supplemented by interesting diversions performed by representatives of each of the National groups. This demonstrated in a most enjoyable way not only the truly international nature of our Society, but also the wealth of talent which has been lost to the entertainment industry!

The organizers are intent that the membership as a whole and not only those privileged to attend should gain from the course. To achieve this we intend to publish many of the papers and reports presented in the next several issues of the Journal starting with the current one. We hope in this way to achieve our goal of benefitting patients throughout the world.

The course dinner—the United Kingdom Pelvic Band. Received no offers of engagements, but plenty of suggestions.

The course dinner—the United States contribution. 'Thanks for the memory'.

Normal human locomotion*

J. HUGHES and N. JACOBS

National Centre for Training and Education in Prosthetics and Orthotics, Glasgow.

Abstract

A study of normal locomotion requires an understanding of both the movements and the force actions involved. This is equally true in appreciating the problems of pathological gait.

The gait cycle is described in terms of the significant events which occur during both the stance and swing phases.

The basic principles underlying the analysis of force actions in walking are briefly described. A simple example of force actions in the elbow joint is considered and the analysis extrapolated to provide a general statement regarding locomotion. This relates to the muscle actions required to resist turning actions at joints due to the force effects in walking and the corresponding forces in the joints themselves.

The conventional display of information relating to joint actions is considered and compared, with the actual situation. "Stick diagrams" of motion in the sagittal plane are used to identify and discuss the actions at the joints of the leg in walking. Comparisons are made between this and pathological gait—in particular that of the above-knee amputee.

Introduction

Normal human locomotion is the rather grand term given to the description of walking by individuals who fall within the range considered as "normal". It is a highly individual and variable activity influenced by age, sex, body build, physical condition, temperament, fatigue and many other less obvious factors. Despite this enormous variability there are characteristic actions which are common to all forms of "normal human locomotion". An understanding of these will facilitate not only a study of normal locomotion itself, but also the analysis of the problems of pathological gait.

As this paper is one of a series concerned with the problems of the above-knee amputee, it will be appropriate to identify any factors which are particularly useful in improving our understanding of above-knee amputee gait. It will also be the intention to consider the interpretation of information which is conventionally displayed in describing locomotion.

Locomotion is often described in terms of movement alone. Of equal importance, however, are force effects and it is only by combining considerations of motion and force that a complete understanding may be achieved.

The gait cycle

The act of locomotion is typified by a number of events which occur in a rhythmic, repetitive pattern. Figure 1 provides a visual display of the events in the "gait cycle", i.e. the period which starts the instant one foot contacts the ground and proceeds through the process of walking until the instant the same foot again contacts the ground. The gait cycle is composed

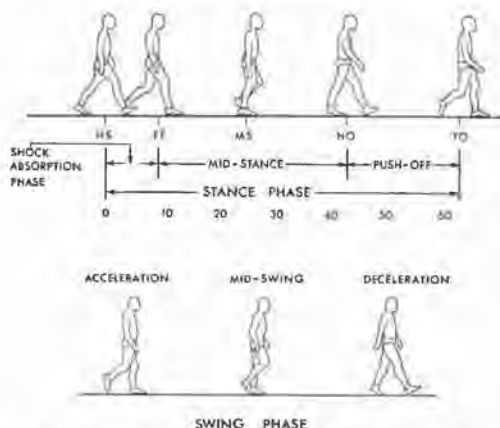Fig. 1. The gait cycle showing events in stance and swing phase.

All correspondence to be addressed to Mr. J. Hughes, Director, National Centre for Training and Education in Prosthetics and Orthotics, University of Strathclyde, 73 Rottenrow East, Glasgow G4 0NG.

of two separate sections—the stance phase, when the foot is in contact with the ground and the swing phase, when the foot and leg are swinging forward to be placed in front of the body to begin another cycle. The stance phase accounts for about 60% of the cycle at normal walking speed, reducing as the walking speed is increased.

The stance phase is itself subdivided by a number of events—heel strike, when the heel contacts the floor; foot flat as the sole of the foot comes into contact with the ground; mid-stance when both ankles are in apposition; heel-off, when the heel leaves the ground; toe-off when the foot loses ground contact. The period between heel-off and toe-off is known as push-off, when the ankle is very actively plantar flexed.

The swing phase is typified by three events—acceleration, which is the period of acceleration of the foot forward in space; mid-swing, when both ankles are in apposition and coinciding with mid-stance on the other foot; deceleration, when the foot is being slowed down preparatory to placing on the ground to begin another stance phase.

Double support periods occur when two feet are in contact with the ground at the same time. There are two such periods in every gait cycle—between heel-off and toe-off on one side and heel strike and foot flat on the other. The faster the speed of walking, the less time is spent in double support. Indeed, in athletic terms, the definition of walking is that double support is maintained, otherwise the subject is running.

Force effects

Some basic understanding of force effects is essential to the study of locomotion. Force can have two effects—translation and rotation. If a force system is in equilibrium, all of the translational and rotational effects must balance.

In human body terms, the significance of this may be appreciated with reference to Figure 2, which shows a static situation in which a subject holds a 10 kg mass in his hand. It is of interest to identify the force actions produced at the elbow joint.

The rotational effect of a force is known as the moment of the force and is equal to the magnitude of the force multiplied by the perpendicular distance from the line of action
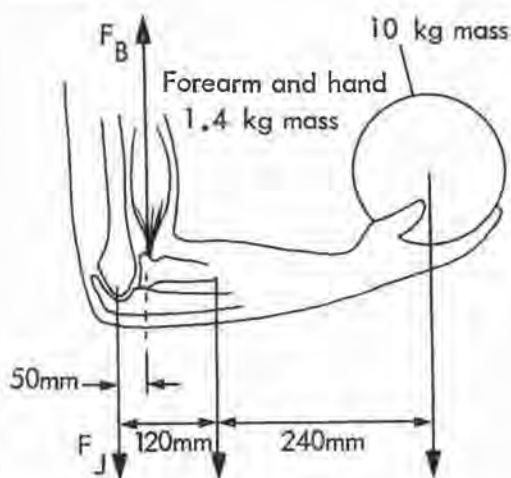
Fig. 2. Force effects produced at the elbow joint when holding a 10 kg mass.

of the force to the point of rotation. In the example, if rotational effects about the elbow joint are considered, the mass of the forearm and hand (which is assumed to be 1,4 kg) and the mass held in the hand (10 kg) are producing moments tending to extend the elbow. If the arm is in equilibrium, the biceps must produce a flexion moment which is equal to this. Noting that:

F_B = Force in the biceps

F_J = Force in elbow joint

A mass of 1 kg exerts a force of 9·81 Newtons due to gravity.

Then:
$F_B \times 50 = 9\cdot81 \times 1\cdot4 \times 120 + 9\cdot81 \times 10 \times 360$
$\therefore F_B = 739$ Newtons

Considering then the translational effects, it is seen that the forearm and hand and the mass held in the hand exert downward forces of (1.4+10) 9·81 Newtons. Biceps exerts a force upward of 739 Newtons. For equilibrium there must be a force in the joint acting downward on the radius and ulna,

$F_J = 739 - (11\cdot4 \times 9\cdot81) = 627$ Newtons.

In general when force actions are exerted on the body, they tend to produce turning effects or moments at joints. These turning effects are counterbalanced by turning effects produced by pull in appropriately placed muscles. The muscle forces are often much larger than the externally applied forces because lines of action

of the muscles are frequently much closer to the joint centres than the external actions. These large muscle forces produce correspondingly large joint forces.

This general statement is fundamental to an understanding of normal or pathological gait. The joints of the lower limbs are subjected to external force actions in the process of walking. These force actions tend to cause moments at the joints which are resisted or controlled by muscle action. Normal walking is characterized by an ability to exert and control the appropriate muscle groups in accordance with the external force actions. Pathological gait arises from an inability to exert or control the muscle forces or the resulting joint forces.

In the lower limb the relevant external forces are due to the force between the foot and the ground; the force due to the mass of the segments of the limb; the forces due to inertia effects, i.e. due to the accelerations and decelerations of the limb segments. For most of the stance phase, by far the largest contribution is by the external force action between the foot and the ground.

Analysis of motion in the sagittal plane

Conventionally information on locomotion has been presented in the form of graphs of variation with time of angle and moment at the joints of the leg, such as in Figure 3, which displays this information for the knee joint. It is interesting to compare this clearly defined presentation with a composite graph of knee moments (Fig. 4) measured by Bresler, Frankel and Morrison (Paul, 1974). This demonstrates that although Figure 3 displays a characteristic pattern, wide variations do exist as might be expected. Conventional locomotion data is useful, but must be treated with an understanding that it presents a distillate of a widely varying reality.

A useful approach to presenting a composite picture of the force actions and muscle activities at the joints of the leg utilizes "stick diagrams" and identifies the situation at significant points throughout the gait cycle as shown in Figures 5 to 13, inclusive. Only the force action between ground and foot is considered during stance as this is the major action—the mass of the leg and inertia effects are neglected.
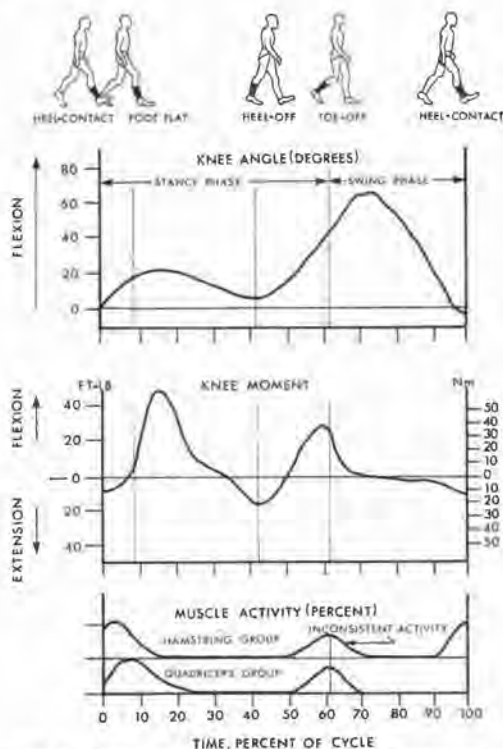
Fig. 3. Variation with time of angle and moment at the knee joint.
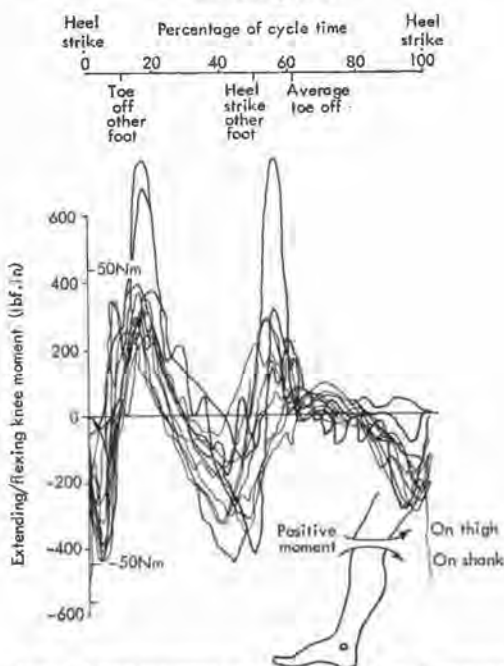
Fig. 4. Knee moment variation with time. Summary curves from Bresler and Frankel (4 subjects) and Morrison (10 subjects) from Paul (1974).

Fig 5. Heel strike
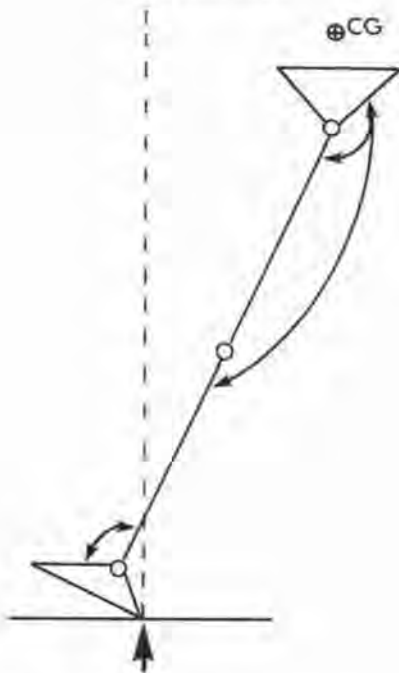
Reaction:

Anterior to hip causing flexion moment. Anterior to knee causing extension moment. Posterior to ankle causing plantarflexion moment.

Hip is flexed to 25°. The gluteus maximus and hamstrings are active in preventing further flexion.

Knee is in full extension at heel strike. The extension moment is overcome by action of the hamstrings which controls knee extension and initiates flexion.

Ankle is in neutral position then begins to plantarflex. This plantarflexion is controlled by action of the pretibial muscles.

Fig. 6. Shortly after heel strike

Reaction:

Anterior to hip causing flexion moment. Posterior to knee causing flexion moment. Posterior to ankle causing plantarflexion moment.

Hip is held in 25° of flexion by action of gluteus maximus and the hamstrings.

Knee is in 5° of flexion and continues to flex. The rate of flexion is controlled by action of the quadriceps.

Ankle is in 5° of plantarflexion and continues to plantarflex under the control of the pretibial muscles.

Fig. 7. Foot flat

Reaction:

Anterior to hip causing flexion moment. Posterior to knee causing flexion moment. Posterior to ankle causing plantarflexion moment.

Hip is in 25° of flexion then begins to extend by action of gluteus maximus and the hamstrings.

Knee reaches 15° of flexion and continues to flex until it reaches 20° shortly after foot flat. It then begins to extend. The quadriceps are active in controlling the angle of flexion.
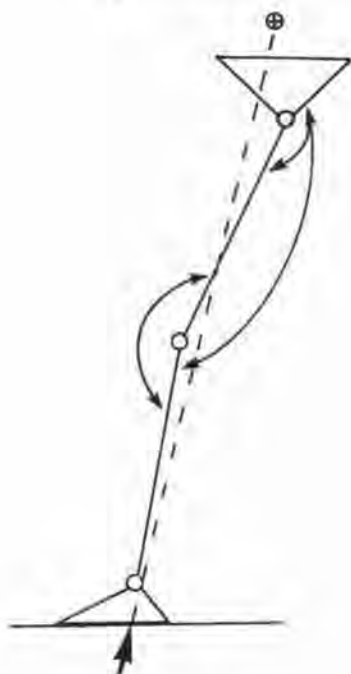
Ankle is in 10° of plantarflexion. The plantarflexion moments reduce as the reaction moves along the foot and the pretibial muscle activity falls off. As the ground reaction passes anterior to the ankle joint the segments of the supporting limb begin to rotate over the fixed foot.

Fig 8. Mid stance
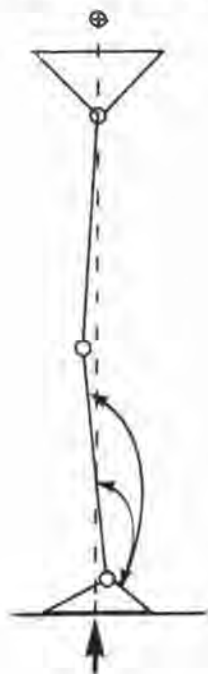
Reaction:

Passes through hip joint, no moment. Posterior to knee causing a flexion moment. Anterior to ankle causing dorsiflexion moment.

Hip is in 10° of flexion and continues to extend as the ground reaction moves posterior to the hip joint shortly after mid stance.

Knee reaches 10° of flexion and continues to extend. Quadriceps action has fallen off and it is suspected that the soleus is active in controlling knee flexion.

Ankle 5° of dorsiflexion and continues to dorsiflex due to ground reaction. The dorsiflexion is controlled by the calf group of muscles which begins to display activity.

Fig. 9. *Heel off*

Reaction:

Posterior to hip causing extension moment.
Anterior to knee causing extension moment.
Anterior to ankle causing dorsiflexion moment.

Hip reaches about 13° of extension then begins
to flex. The iliacus and psoas major are active
in controlling extension and initiating flexion.

Knee is flexed to about 2°, which is the
maximum extension reached at this point in
the gait cycle. The gastrocnemius may be active
in preventing further extension.

Ankle reaches 15° of dorsiflexion after which
it plantarflexes due to a powerful contraction
of the calf muscles which counteracts the dorsi-
flexion moment and assists in propelling the
body forward.

Fig. 10. *Toe-off*

Reaction:

By toe-off the reaction has lost most of its
significance as the majority of weight is borne
by the other foot.

Hip is in 10° of extension and continues to
flex due to the plantarflexion of the foot and
activity of the rectus femoris.

Knee is flexed to about 40° and continues to
flex under the small ground reaction moment
and plantarflexion of the foot.

Ankle has reached 20° of plantarflexion due
to contraction of the calf muscles. These muscles
become inactive directly after toe off.

Fig. 11. Acceleration

Hip is in 10° of extension and flexes as the hip flexors accelerate the limb forward.

Knee is in 40° of flexion and continues to flex under pendulum action as the limb accelerates.

Ankle is in 20° of plantarflexion directly after toe off. It then begins to dorsiflex under action of the pretibial group of muscles.

Fig. 12. Mid swing
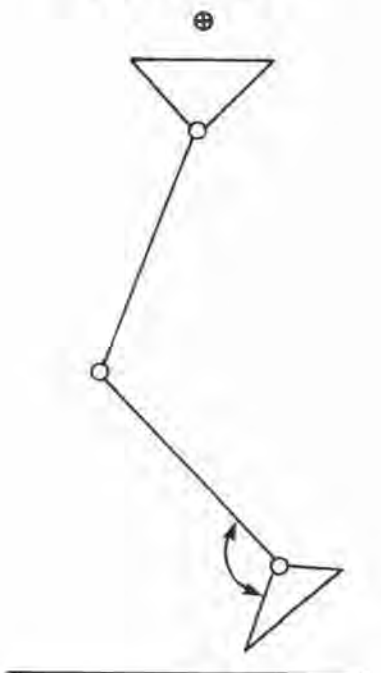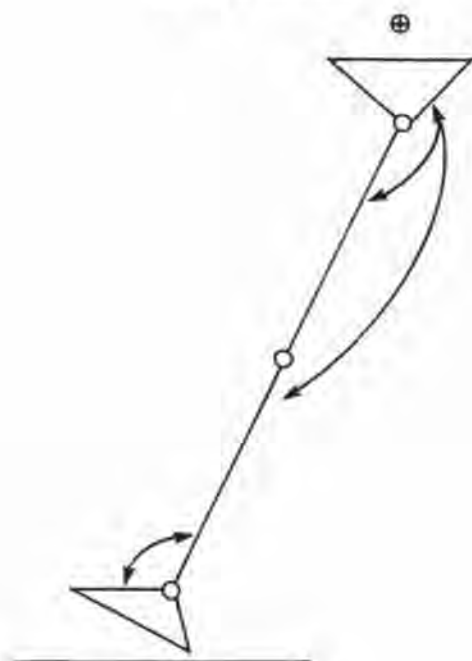

Hip is flexed to about 20° and continues to flex.

Knee reaches about 65° of flexion then begins to extend under pendulum action.

Ankle has reached its neutral position and is held there by slight activity of the pretibial muscles.

Fig. 13. Deceleration

Hip reaches 25° of flexion and is restrained by gluteus maximus and the hamstrings.

Knee is in full extension and restrained by the hamstrings.

Ankle is still held in the neutral position by action of the pretibial muscles.

The hip, knee and ankle are now positioned for the following heel strike. All the muscle groups that are necessary to counteract the ground reaction force are now active.

The importance of combining motion *and* force studies may be appreciated by considering Figure 6 which displays the situation shortly after heel strike. In this situation the ankle is plantar flexing; however, the pretibial muscles are active *not* the plantar flexors. This is because the force action exerted on the foot in this position is tending to plantar flex the foot and consequently the pretibial group must act to produce a resisting dorsiflexion moment, thus controlling the movement. Note that absence of the ability to exert this controlling moment, as in hemiplaegia would produce a pathological gait observed as "foot slap". Similarly at the knee, although the knee is flexing, it is the knee extensors which are active because the external force is tending to produce flexion. It can be seen then that movement studies alone provide insufficient information from which to infer the required muscle actions and this is essential to an understanding of normal or pathological gait.

Amputee gait

Similar considerations govern all aspects of above-knee amputee gait. The moment action at prosthetic joints will determine the resisting moment which must be applied by that joint. In the example cited above at Figure 6, the plantar flexion moment at the ankle would be resisted by the plantar flexion rubber or "bumper". The moment action at the knee, however, in the case of a single axis knee without a stance phase stability mechanism would lead to flexion of the knee with consequent collapse of the amputee as there are no knee muscles to exert an extension moment. In this situation it would be necessary to ensure that the force actions were tending to extend the knee, a force effect which could be resisted by the extension limiter. This could be achieved, for example, by placing the knee centre posteriorly behind the line of action of the external force, thus changing the moment action from that of flexion to extension. Such consideration and the other alternatives will be presented in a subsequent paper on the biomechanical considerations related to the above-knee amputee and his prosthesis.

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Above-knee amputation — an 'ideal' situation*

G. MURDOCH

Department of Orthopaedic Surgery and Traumatology, University of Dundee.

The author's contribution to the course in Rungsted was intended to establish a foundation on which further discussions could be based. By agreement with the organizers it was decided that an ideal situation should be presented where thigh amputation would be discussed in the context of normal tissues.

Accordingly, this is simply a summary and reference can be made to Amputation Surgery in the Lower Extremity, Parts I and II (Murdoch 1977). In the presentation nothing about causal conditions, level and limiting factors, stump environment, pre and post-operative care or prosthetic rehabilitation was included.

The author emphasized first that the amputation should be done at as low a level as possible compatible with prosthetic fitting and, in particular, the type of knee mechanisms available. To accommodate the majority of knee mechanisms and to preserve neuro-vascular bundles so far as possible a distance of some 120–130 mm above the knee joint provides the longest possible stump. It was emphasized clearly that the anatomy at different levels in the thigh alters considerably, particularly in relation to the adductors.

In an ideal situation equal anterior and posterior flaps should be employed and the general rule is that the ratio of the base of the flap to its length should be as great as possible. In planning flaps one must ensure that there is adequate skin to permit suture without undue tension. The author cautioned the inexperienced to retain a sufficiency of skin in the flaps, tailoring the skin to fit the needs of the all but completed amputation at the end of the operation.

Attention was then directed to the management of the individual tissues encountered,

skin, fascia, muscle, nerve, blood vessels and bone.

Skin

Further to the need to ensure a sufficiency of skin it is essential that the skin edges are handled gently and that they are closely abutted to ensure primary wound healing and a thin, strong scar.

Fascia

In general, minimal dissection between skin and deep fascia should be used.

Muscle

Management of muscle has been a matter of controversy for a very long time. The early German workers stressed the importance of attaching the divided muscle to the end of the stump securely and it would seem that their objective was to produce a muscle "pad". More recently, Dederich (1967), Burgess (1968) and Weiss (1969) have emphasized this requirement. Many benefits have been attributed to this approach, namely that it is more physiological, provides a more stable shape with less muscle wasting, better proprioception with preservation of existing neuromuscular mechanisms, more efficient vascular dynamics, etc. but few studies exist to support these contentions which all seem to be eminently sensible.

Dederich (1967) demonstrated improved vascular supply to the stump end after myo-plastic revision and Hansen-Leth and Reimann (1972) demonstrated, in the laboratory rabbit, a better blood supply to the stump end when muscle stabilization is used. Condie (1973) suggested that muscle stabilization provides for better aphasic muscle activity in amputations at below-knee level on the basis of e.m.g. recordings. The author firmly believes in the secure

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All correspondence to be addressed to Prof. G. Murdoch, Department of Orthopaedic Surgery and Traumatology, Caird Block, Royal Infirmary, Dundee.

attachment of severed muscle to the end of the stump.

Experience has demonstrated, certainly in the young adult, that simple muscle to muscle suture over the bone end is insufficient and suture of the lateral and medial hamstrings and any adductors of bulk to the bone via drill holes is advocated. These muscles are then cut flush with the bone end and the quadriceps, which has been left longer, is then drawn over the stump end to be sutured to the posterior muscles. If secure fixation is not achieved then the major muscle units work with less efficiency, causing earlier fatigue, significant distortion of the shape of the stump, and permitting lateral migration of the bone end.

Nerve

Management of the divided nerve has been a subject of controversy over many years. There now seems general acceptance of the view that a high clean cut of the nerve will ensure that the inevitable neuroma is located in such a situation that it will not become involved in distal scar tissue and thus does not interfere with prosthetic fitting or produce significant symptoms.

Bone

There is some evidence that the medulla of the bone should be closed by a periosteal flap to retain normal intramedullary pressures (Askalanov and Aronov, 1959).

In the healthy young adult the periosteum is thick and is easily formed into a flap sufficient to close the medulla. It is said that this retains the normal intramedullary pressures with improved drainage into the general circulation. Emphasis is placed on the fact that simple transection of the bone is not sufficient and that the anterior presenting edge of the cut end of the bone must be sculptured and smoothed to ease the task of the prosthetist and prevent the occurrence, albeit rare, of unwelcome bursae.

The presentation concluded with the view that in normal tissue a tourniquet should be employed, haemostasis ensured, and that closed suction drainage was highly desirable.

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Knee disarticulation versus above-knee amputation*

R. F. BAUMGARTNER

Balgrist Orthopaedic Hospital, University of Zurich.

Abstract

If below-knee amputation is impossible, knee disarticulation should be considered before above-knee amputation, regardless of age and etiology. Knee disarticulation which leaves the femur and patella untouched offers many advantages. The surgical technique is simple and non-traumatic since no bone or muscle tissue is to be dissected. The thigh muscles are completely preserved and thus there is no muscular imbalance. The stump permits total end bearing and its bulbous shape permits easy and firm attachment of the prosthesis. A specially designed double-wall socket and various types of knee joints are presented. Modern prostheses are superior to above-knee prostheses with regard to function, comfort and cosmesis. Results of 72 patients of all age groups are presented and discussed.

Introduction

If it is impossible to obtain a short below-knee amputation, *knee disarticulation* should be considered before above-knee amputation regardless of etiology and patient's age. There is no level of amputation between the ankle and the hip joint where one can perform an amputation which does not require separation of bone or muscle tissues. At knee disarticulation level the surface of the wound is the smallest possible which minimizes the danger of haemorrhage or infection. In children, the distal epiphyseal line of growth is fully preserved. In contrast to above-knee amputation the stump resulting from knee disarticulation permits full endbearing. All the muscles of the thigh are entirely preserved.

Despite all these advantages, knee disarticulation is still unpopular compared with above-knee amputation. The main objection comes from the prosthetists who complain that there is not enough space for the prosthetic knee

joint and have difficulties in fitting the bulbous shape of the stump into a regular socket. For this reason many surgical techniques of through-knee amputation indicate the removal of parts or all of the femoral condyles and the patella to facilitate prosthetic fitting (Fig. 1).

However, knee disarticulation leaving the femur and patella untouched offers many advantages, particularly with regard to surgical technique, stump qualities and finally even prosthetic fitting. The following technique (Kjolbye, 1970; Vitali et al, 1978) is recommended.

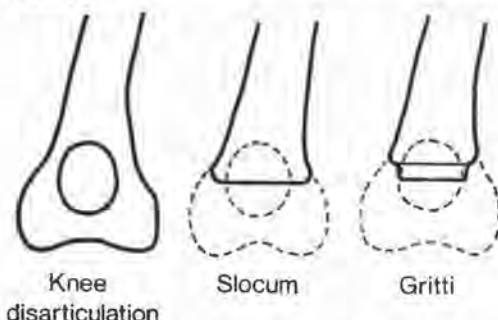Knee   Slocum   Gritti
disarticulation

Fig. 1. Some of the most common through-knee amputations. Except for knee disarticulation they involve resection of part or all of the femoral condyles and the patella.

Operative technique

It is preferable to have the patient in a supine position which gives easy access to the knee joint and also permits an above-knee amputation to be done if necessary, without changing the patient's position. Furthermore, the supine position does not give any particular problems to the anaesthetist which is of great importance in poor risk cases, such as geriatric patients. A tourniquet may be used except for vascular patients. However, as there are only a few easily identified vessels a tourniquet is not an absolute necessity.

All correspondence to be addressed to: Dr. R. F. Baumgartner, Orthopädische Universitätsklinik Balgrist, Forchstr. 340, CH–8008 Zürich, Switzerland.

The knee joint is flexed to a right angle. A skin incision is made with respect to the condition of the particular patient. If possible, an attempt should be made to obtain two lateral flaps with the scar placed longitudinally at the dorsal side of the femur between the two condyles. This scar is placed far from the end bearing area of the stump and permits a high resection of the sciatic nerve. This procedure necessitates a circular incision at about 50 mm distally from the tibial plateau (Fig. 2). However, previous operative scars and the viability of the tissue might require other types of skin flaps, such as a long anterior flap. It is important to include existing scars into the new skin incision and not to create additional scars whenever possible.
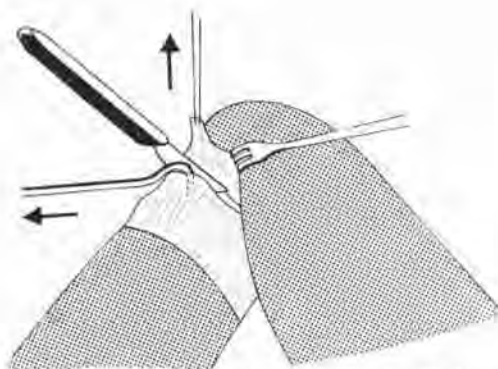
Fig. 2. A circular skin incision 50 mm distally from the tibial plateau is necessary to obtain two lateral flaps with a longitudinal skin closure at the dorsal side of the femur. The patellar ligament is disinserted at the tibial tuberosity which gives free access to the tibial plateau.

Disarticulation of the joint begins by removing the patellar ligament from the tibial tuberosity which gives free access to the tibial plateau (Fig. 3). In the anterior-posterior direction, the tibial plateau is separated from the meniscal cartilages, the cruciate and lateral ligaments and the joint capsule. Finally the tibial plateau is completely dislocated anteriorly. It is then easy to identify popliteal vessels and nerves, the latter being cut at least 70 mm proximally from the end of the stump. The procedure is completed with sectioning of the hamstrings and the complete removal of the gastrocnemius muscles. In vascular cases, it might be safer to remove the meniscal cartilages as well, otherwise they can be left in place and act as an additional cover
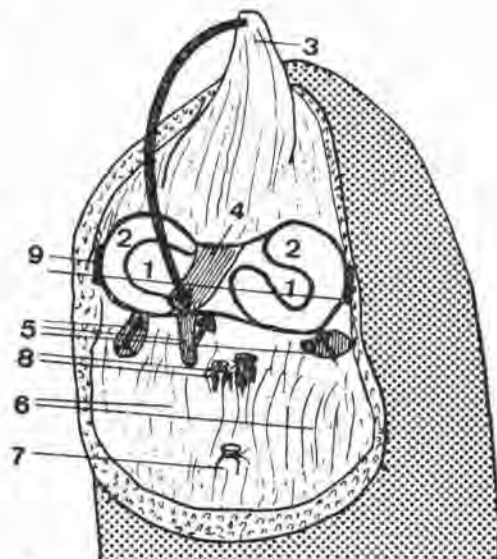
Fig. 3. Knee disarticulation. Distal-dorsal view of the stump. 1: femoral condyles, 2: meniscal cartilages, 3: patellar ligament to be sutured to the posterior cruciate ligament (4), 5: tendons of the hamstrings which might be connected with the posterior joint capsule or a cruciate ligament, 6: the gastrocnemius muscles, 7: sciatic nerve, 8: popliteal artery and vein, 9: collateral ligaments.

for the end bearing femoral condyles. Before closure, the patellar tendon is sutured to the cruciate ligaments or to the anterior knee capsule and the hamstrings to the posterior knee capsule. To avoid granulomas, it is preferable to use resorbable material for suturing. In vascular cases, the author has started not to suture any ligament at all and there is surprisingly little retraction of the patella even if its ligament is not anchored. Haemostasis and drainage are most important at any amputation level, but particularly so in the knee disarticulation. There is no space for a haematoma and if one leads to necrosis and infection, the result might be an above-knee amputation. The skin flaps are carefully shaped and closed with only a skin suture. Due to the considerable retraction of the skin in the area of the knee joint, the size of the flaps must be large enough to guarantee a skin closure without any tension (Fig. 4).

Stump qualities

Knee disarticulation preserves all the muscles of the thigh. Therefore, there will be no retraction of muscles and no muscular imbalance

Fig. 4. Eighteen year old male patient. Knee disarticulation following trauma. Anteroposterior flap with large scar formation at the thigh. The patient is now fitted with a total end bearing prosthesis, four bar linkage with hydraulic knee and swing phase control.

which is unavoidable in above-knee amputation even using myoplastic techniques. In above-knee amputations parts of the adductors always have to be sacrificed whilst the abductors between the iliac bone and the greater trochanter always remain intact. Bony outgrowth

which often compromises a good above-knee stump is impossible in the knee disarticulation. One of the main advantages of the knee disarticulation stump is its total end bearing quality. Therefore, the ischial seat, which causes so many problems in above-knee amputees, becomes superfluous. The range of motion of the hip joint remains completely free, including flexion and rotation movements and thus permits a more natural, less energy consuming gait (Table 1).

Post-operative management

There will be considerable shrinking of the stump, even if all the muscles of the thigh are intact. The distal part which is not covered by muscles is extremely sensitive to pressure, especially the patella and the dorsal sides of the condyles. Therefore, care must be taken to avoid pressure sores due to bandaging, bed rest, plaster casts or poor prosthetic fitting. For gait training immediately after surgery, it is therefore preferable to fit an inflatable plastic splint. When the patient lies in bed, the femoral condyles must be relieved by padding similar to the well known procedures that prevent pressure sores at the heel (Fig. 5).
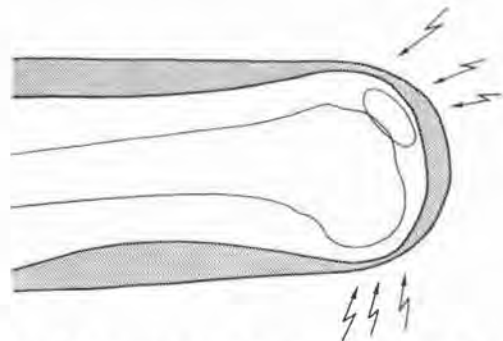
Fig. 5. The dorsal sides of the femoral condyles and the patella are most sensitive to pressure.

Table 1

Stump	Knee disarticulation	Above-knee amputation
Thigh muscles	**preserved**	partially preserved
Bony outgrowth	**impossible**	possible
Lever	long	short
Shape	bulbous	conic
End bearing	total	none (or partial)
Ischial bearing	**none**	total
Hip joint range of motion	**free**	limited

Fig. 6. Twenty-two year-old male patient. Knee disarticulation after motorcycle accident. Local infection at the medial condyle. Stump revision with partial resection of the femoral condyles. Healing occurred within four weeks.

Post-operative complications

As at any other amputation level, problems in wound healing might also occur in knee disarticulation. As long as there is only superficial necrosis of soft tissues on a rather small surface, healing can be achieved by conservative treatment within a reasonable time. However, larger necrosis including ligaments, cartilage and bone requires operative treatment. In this case, the modified techniques removing the patella and the condyles totally or partially are most suitable as a second line of defence (Fig. 6).

Prosthetic fitting

The objections from the prosthetists against the shape and the length of the stump in knee disarticulation have almost completely disappeared during the past years. New designs of prostheses are now available which are superior to the best above-knee prostheses with regard to function, comfort and cosmesis. This has led to prosthetists advocating knee disarticulation even more than the surgeons do.

The two major features are the socket and the knee joint.

The type of socket used at Balgrist has been developed by Botta and uses the double-wall technique. There is an inner soft socket made from polyethylene foam. Its purpose is to provide total contact and at the same time to transform the bulbous stump into a conic one. The patient puts on this socket first and then he can don the outer socket which is made from laminated plastic. The bearing surface at the distal end must exactly fit the shape of the femoral condyles and avoid pressure on the patella otherwise pressure sores are the inevitable consequence (Fig. 7). The rigidity of the socket decreases gradually distally to proximally. Thus a semi-flexible socket is obtained which gives more comfort particularly in sitting, donning and doffing the prosthesis. The upper border of the socket follows a line which is approximately 50 mm below the inguinal ligament. This fact is particularly appreciated by female patients and by double amputees. Donning and doffing the pros-
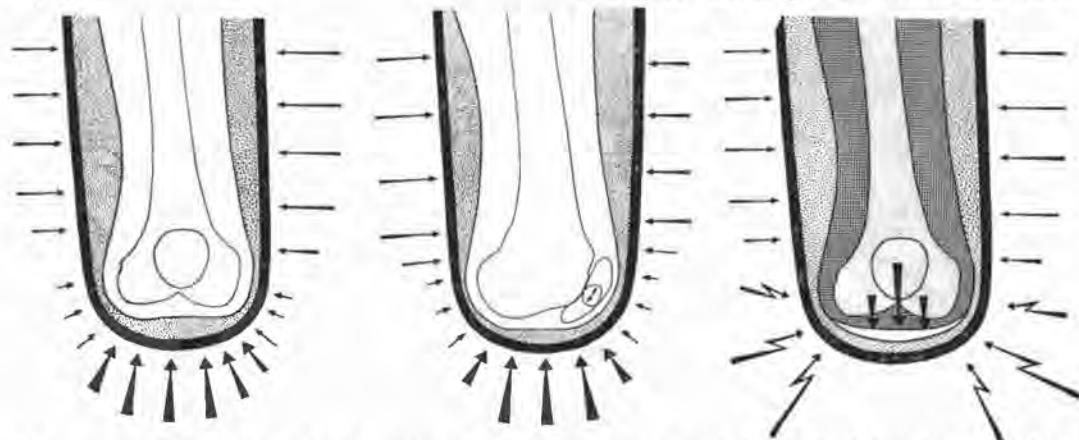
Fig. 7. Double wall socket for knee disarticulation. The inner socket, made from polyethylene foam, transforms the bulbous stump into a conic one. The outer shell is made from laminated plastic. Total contact is most important especially in the weight bearing areas, left and centre. Otherwise pressure sores at both femoral condyles are inevitable, right.

Fig. 8. Donning and doffing the prosthesis presents no problems even to geriatric patients.

thesis is very simple since it does not require any particular effort or skill which again is especially appreciated by double amputees and by geriatric patients (Fig. 8).

Knee joints as they are commonly used in above-knee prostheses are of no use with knee disarticulations. Joints especially designed for knee disarticulation are now available, the first one being developed by Lyquist at the Orthopaedic Hospital in Copenhagen. Other types of knee joints have since been developed, most of them using four bar linkage mechanisms and permitting knee flexion far in excess of 90°. They are available with or without swing phase control. Further research is being done with regard to improving the solidity of the knee mechanism. Prostheses for knee disarticulation and above-knee amputation are compared in Table 2.

Results

From 1968—1978, the author has performed 72 knee disarticulations, mainly for peripheral vascular occlusion. Four patients presenting congential deformities corresponding to knee disarticulation also have been fitted with the new type of prosthesis. Re-amputation at an above-knee level was necessary in 7 cases, all of them being vascular patients. They all had to be amputated at a high above-knee level due to advanced tissue necrosis. Local complications in wound healing occured in 16 cases.

Table 2

Prosthesis	Knee disarticulation	Above-knee amputation
Socket contact	total	partial to total
Socket quality	soft	rigid
Belt suspension	none	frequent
Ischial seat	none	compulsory
Skin hygiene	good	poor

Knee design:
  friction unit
  swing phase control }
  lock
	available	available

Modular prosthesis	available	available
Cosmesis	satisfactory	satisfactory

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Revascularization or amputation*

A. H. BOONTJE

University Hospital, Groningen

Introduction

The choice between revascularization and amputation is of great practical significance for patients with threatening ischaemia of a limb. Medical and surgical efforts should focus primarily on prevention of loss of the limb by various conservative measures and by revascularization, either by direct arterial reconstruction (disobliteration or a bypass procedure) or by indirect lumbar sympathectomy.

In spite of progress that may have been made in the technique of amputation and in prosthetics, a natural leg is in principle to be preferred to a prosthesis. Moreover, an amputee runs a fair risk of losing the other leg as well: 17% of our amputees between 1972 and 1977 had a bilateral amputation. On the other hand, efforts to save the limb should not excessively prolong the time spent in hospital. When limb salvage seems impossible, one has to opt for the less lengthy procedure of amputation followed by rehabilitation. To determine the indication for primary amputation or revascularization, numerous factors have to be taken into account (Table 1). Fixed rules about indications cannot be given, but the various considerations which play an important role in the choice between revascularization and amputation are presented and discussed.

Table 1
Factors determining the choice-revascularization or amputation

1) Extent of the gangrene.
2) Progression or regression of the ischaemia.
3) General condition of the patient.
4) Angiography.
5) Skill and judgment of the vascular surgeon.
6) Effect of revascularization.
7) Motivation of the patient.
8) Life expectancy.
9) Economic factors.
10) Quality of the limb-fitting centre.

All correspondence to be addressed to: Dr. A. H. Boontje, Department of Vascular Surgery, University Hospital, Groningen, The Netherlands.

Fig. 1. Cases for amputation. Top, severe ischaemia with marked discolouration. Bottom, extensive gangrene.

Extent of gangrene

If there is severe irreversible ischaemia with marked discolouration of the foot and lower leg and complete loss of sensory and motion functions, it is evident that primary amputation is the only choice (Fig. 1, top). The same applies to a patient with marked and extensive gangrene (Fig. 1, bottom). In such extreme cases, the choice of amputation is not difficult.

Progression or regression of the ischaemia

Revascularization is generally unsuccessful when the gangrene extends far on the plantar or dorsal aspect of the foot, but the choice can be difficult in patients with limited gangrene

Fig. 2. Top, multiple defects and marked discolouration. Bottom, following conservative treatment, no amputation was necessary.

Fig. 3. Top, severe ischaemia of lower leg and foot. Above-knee amputation indicated. Bottom, following conservative treatment, below-knee amputation possible.

because it is often difficult to evaluate and predict the severity and course of ischaemia of the leg in patients with rest pains (stage III in the usual Fontaine classification of arteriosclerosis obliterans) or with limited gangrene (stage IV). It is generally advisable to continue observations on such endangered limbs for at least a few days before deciding whether revascularization can be attempted or amputation is the only choice. Figure 2, top, shows a patient with multiple defects and marked discolouration. Conservative measures were taken and the result indicates that amputation is quite unnecessary (Fig. 2, bottom).

As regards these conservative measures: elevation of the head of the bed is sometimes helpful when a patient has rest pains although analgesics are usually necessary. To improve the circulation, patients with rest pains and limited gangrene should be given Dextran by intravenous drip. The effect of a Dextran drip is often striking and dramatic. Local treatment of the gangrene is required as well. Efforts should be made to change a wet gangrene into a dry necrosis. Ointments are to be avoided in favour of a dry sterile dressing, perhaps with

some neutral powder. Local surgical interventions such as incision and drainage may be required, particularly when there is infection. The infectious component of the gangrene may be as prominent as the ischaemic features especially in patients with diabetes mellitus. But in all these cases one should be very reluctant to amputate one or several toes. Physiotherapy is likewise important, to prevent and control flexion contractures. Finally one must bear in mind that, in many patients with severe ischaemia of the leg, these conservative measures can reduce the manifestations of the ischaemia (discolouration or cyanosis, oedema or lymphangitis) to a more distal level. Not infrequently it is thus possible to perform a below-knee amputation on a patient who initially seemed to require an above-knee amputation. Figure 3, top gives an example, the circulation of the lower leg is seriously impaired with violent rest pains, but after conservative treatment a below-knee amputation would appear to be suitable (Fig. 3, bottom).

General condition of the patient

The general condition of the patient also has to be evaluated and, often, improved. Ninety

per cent of all major leg amputations are performed as a result of circulatory disorders resulting from arteriosclerosis obliterans. Most of these patients are in fact of more advanced age, suffer from generalized atherosclerosis, and usually show multiple disorders. Cardiovascular and cerebrovascular disorders are common, and many patients suffer from diabetes mellitus. Operative morbidity and mortality are therefore by no means negligible. Disorders of cardiac and pulmonary function must be controlled. Dehydration, found in many older patients, must be dealt with. Diabetic patients have to be stabilized.

All in all, the operative risk must be estimated and the vascular surgeon, aided by advice from the internist or neurologist, must decide whether a patient is a suitable candidate for reconstructive vascular surgery. The risk entailed by such a vascular operation is generally not too grave (Table 2), the mortality does not exceed a few percent, and lumbar sympathectomy also carries a very low risk. The operative mortality after a major amputation is significantly higher. In some cases with a markedly increased operative risk, conventional arterial reconstruction can be replaced by an alternative procedure with a reduced operative risk (femoro-femoral bypass or axillo-bifemoral bypass).

Table 2
Operative Mortality

Arterial reconstruction	
aorto-iliac	3%
femoropopliteal	1%
Lumbar sympathectomy	1%
Amputation (BK and AK)	19%

Acceptance of a given operative risk depends not only on the severity of the ischaemia of a leg but also on the skill, philosophy and experience of a given vascular surgeon. The decision can therefore never be entirely objective, but must of necessity encompass some subjective factors.

Angiography

Angiography is used to determine technical operability in a patient considered for vascular surgery. This angiography, preferably translumbar aortography, is necessary to determine the localization and extent of the arterial obstruction, so that an operation can be properly planned. Its results determine whether a patient requires a more or a less extensive reconstructive operation. With regard to the technical operability of an arterial obstruction, moreover, two criteria have to be fulfilled. To begin with, there should be no inflow obstruction caused by a more cranially localized obstruction, if so, latter must first be dealt with. Secondly, there should be no marked outflow obstruction, which would destroy the

Fig. 4. Translumbar aortography showing occlusion of left superficial femoral artery with a good outflow tract.

result of an arterial reconstruction by early thrombosis.

In the presence of an aorto-iliac obstruction, revascularization to the deep femoral artery is often successful even when there are more distal obstuctions. But, particularly when there is a femoro-popliteal obstruction, occlusions of several lower leg arteries may be such that circulation-improving reconstruction is impossible.

Figure 4 shows an angiogram with an occlusion of the left superficial femoral artery, but with a good popliteal artery and three lower leg arteries. In this case with a good outflow tract reconstruction is feasible. However, a superficial femoral arterial occlusion with no outflow at all is inoperable. There are only a few collaterals, but no lower leg arteries.

Skill and judgement of the vascular surgeon

Determination of technical operability in each case considered for arterial reconstruction

Fig. 5. Angiogram showing an occlusion of the superficial femoral artery, stenosis of the popliteal artery with only the distal part of the anterior tibial artery patent.

depends also on the experience, skill and surgical judgement of the vascular surgeon. An example of a common surgical technical problem can illustrate this. On the angiogram shown in Figure 5, there is an occlusion of the superficial femoral artery, an irregular popliteal artery and complete occlusion of two of the three lower leg arteries, only the distal segment of the anterior tibial artery still being patent. One might be ready to declare such a patient inoperable, but in this case a bypass procedure was successfully carried out, the bypass extending from the common femoral artery in the groin subfascially along the knee to the ankle, there to anastomose with the anterior tibial artery. The limb was salvaged.

The effect of revascularization

After opting in favour of a circulation-improving procedure, be it direct arterial reconstruction or a palliative lumbar sympathectomy, its effect must of course be awaited. One should bear in mind that the effect is not always immediately visible or discernible. After successful revascularization, rest pains disappear fairly quickly but necrosis cannot immediately be abolished. One must wait and see whether the necrosis is progressive or not and whether spontaneous demarcation and healing will occur. If the gangrene is progressive after a reconstruction then amputation is after all unavoidable. In all other cases however, the necessity of waiting for spontaneous demarcation of the necrosis must be emphasized. Amputation of one or several toes is in principle contraindicated in this situation. If one waits sufficiently long (and in some cases this may mean several months), then such a mummified toe is shed spontaneously leaving no defect. A toe amputation is required only in some cases of a purely diabetic angiopathy, where there is no obstruction of the arteries of the leg and when the infection has been controlled, or after successful arterial reconstruction or effective lumbar sympathectomy when intra-articular involvement is noticed.

A few examples can illustrate the effects of revascularizing procedures. The livid discolouration of a big toe (Fig. 6, top) disappeared completely fairly soon after lumbar sympathectomy (Fig. 6, bottom). A patient with severe ischaemia of the toes and the anterior part of the foot (Fig. 7, feft) had a marked improvement of

Fig. 6. Top, livid discolouration of the left big toe. Bottom, improvement following lumbar sympathectomy.

Fig. 7. Left, severe ischaemia of the toes and foot. Right, two months after femoro-popliteal arterial reconstruction. Marked improvement of circulation with necrosis confined to two toes. The limb was salvaged.

the circulation after femoro-popliteal arterial reconstruction. Necrosis was only confined to two toes and the limb was salvaged (Fig. 7, right).

Motivation of the patient

It should be realized that a limb-saving policy after arterial reconstruction or lumbar sympathectomy cannot be continued indefinitely. A patient with limited necrosis cannot be confined to bed for an unlimited period. A time may come when protracted conservative postoperative treatment will have to be abandoned in favour of amputation with less time-consuming rehabilitation. The prospect of a long confinement in bed after successful arterial reconstruction for necrosis is accepted by some patients, but totally rejected by others. There are also patients who reject an arterial reconstruction with a risk of failure and rather opt in favour of an amputation with a relatively certain prognosis of rehabilitation. This also depends, of course, on the need of the patient for normal use of his leg which is determined not only by his previous confinement to bed (if any), but also by his age (particularly physiological age) and by his occupation and hobbies. Another important factor is the patient's willingness and ability to contribute to quick rehabilitation and limb-fitting, which is dependent on his mental attitude and the presence or absence of mental disorders. The physical capabilities of the patient also determine whether rehabilitation will be successful. Poor cardiac function or severe arthrosis can interfere with limb-fitting. And of course the patient's family plays an important role; the family can contribute to successful rehabilitation and give the patient proper support in his own environment.

Life expectancy

If severe ischamia exists in a patient whose life expectancy is extremely short, for example due to metastatic carcinoma, then arterial reconstruction is in principle not indicated. In such cases one may decide to do a primary amputation or even no amputation at all.

Economic factors

Economic factors may also play a role in the selection of patients for revascularization or amputation. What is less expensive: arterial reconstruction followed by a fairly prolonged confinement to bed until demarcation of the necrosis occurs, or amputation followed by rehabilitation and limb-fitting? Should we, and may we in fact, take these economic aspects into account when we consider indications?

Quality of the limb-fitting centre

Finally, the patient's fate, or rather, that of his ischaemic limb, depends not only on the vascular surgeon who evaluates his case but also on the facilities available at the limb-fitting centre and the results obtained there.

Conclusion

The factors which determine the choice, revascularization or amputation of an ischaemic leg are very numerous, variable and sometimes also related. They are concerned with the extent and course of the gangrene, the general condition of the patient and the risk of operation, the technical operability in terms of arterial reconstruction, the skill and judgment of the vascular surgeon, the motivation and life expectancy of the patient, as well as the facilities at the limb-fitting centre.

In principle, arterial reconstruction should be the primary consideration in all patients with severe ischaemia of a leg, and threatened with loss of the limb. This implies the need for evaluation by a vascular surgeon. If arterial reconstruction is impossible or undesirable and if lumbar sympathectomy is not indicated either, then if amputation is necessary it must be decided, when is it necessary, and whether a below-knee or an above-knee amputation is possible.

The patient with severe arterial circulatory disorders is best served when the vascular surgeon who is responsible for the arterial reconstruction, also assumes responsibility for determining the timing and the level of an amputation, and in some hospitals even for doing the amputation.

In other words, the same doctor, preferably the vascular surgeon, has to be responsible for the selection of the patients and the judgement whether the patient is a candidate for revascularization or amputation.

Above-knee amputation in children*

R. F. BAUMGARTNER

Balgrist Orthopaedic Hospital, University of Zurich.

Etiology

Five to 10 per cent of all amputees treated at Balgrist were amputated before the end of growth. In this group, the etiology is very different from that in adults. Arterial occlusion which is the cause of leg amputation in 80–90 per cent of adults is very unusual in children: haemorrhagic infarction due to meningococcal sepsis or anaphylactic reaction to drugs with necrosis of peripheral tissues are fortunately rare.

The major cause of amputation in children is *trauma*, which accounts for 75–80 per cent of cases. It is $2\frac{1}{2}$ times more frequent in boys than in girls and 3–4 times more frequent in the lower than in the upper limb. The distribution between above-knee and below-knee amputation is about even. There is a uniform age distribution in traumatic amputation in children from 2–16 years. The major causes of traumatic amputation in children are traffic accidents (40%) and agricultural machinery (30%). Railroad and traffic accidents often cause bilateral lower limb amputations.

Ten per cent of children are amputated due to *malignancy*. Progress in diagnosis however permits a more differentiated treatment, particularly local resection instead of amputation. Amputations due to malignancy are ten times more frequent in the lower than in the upper limb.

Osteomyelitis and *tuberculosis* used to be one of the major causes of amputation in children before the advent of antibiotics. They have now almost completely disappeared in countries with a high standard of living.

Growth problems

As in any other cortical bone, the proximal and distal epiphyseal growth plates are

responsible for growth which takes place mainly at one end of the bone. In the femur, the

Fig. 1. Amputation between the middle and distal third at the age of 2 years. Radiograph 16 years after operation shows shortening of the stump and dysplasia of the entire left side of the pelvis. Excellent stump qualities. The patient is fitted with a total contact prosthesis without additional suspension.

contribution of the distal growth plate is about 70 per cent whilst only 30 per cent is provided by the proximal plate at the femoral head and the greater trochanter (Blount, 1954). The loss of the distal epiphyseal plate therefore greatly retards the growth in length of the femur. The younger the child at the time of amputation, the greater will be the disproportion between the length of the remaining femur compared with the amputated side. For example, an amputation between the middle and distal third at the age of 2 years will become a very short stump once the patient has reached maturity (Fig. 1).

However, a difference in length will also occur even where the distal growth plate can be preserved (Fig. 2). As in poliomyelitis, one of the consequences of amputation is a diminished blood supply since there are fewer cells to be served and there is less activity of the muscle tissues. The result is a significant slowing of overall growth not only in length but also in the other two dimensions. Not only the hip joint,

but the entire pelvis becomes hypoplastic. This effect is the more marked the higher the level of amputation and the younger the child at the time of amputation. In one case of a bilateral high above-knee amputation at 2 years, the child developed after 13 years a subluxation of both hips which were perfectly normal before amputation (Fig. 3).

Stump revision due to overgrowth is unknown in the femur, however the end of the bone can become very sharp because of the lack of growth and it may be necessary to round this edge with a minimum of further shortening.

The question of improving the qualities of the femoral diaphysis by lengthening or enlarging is very delicate. The few bone grafts at the end of the femur seen at Balgrist were all resorbed leaving another scar at the site where the graft was extracted. More modern techniques of intradiaphyseal lengthening using the Wagner (1972) technique are worth considering but have not yet been attempted.

Soft tissue growth is not retarded as much as bone growth. There is, therefore, often an abundance of soft tissue around the hypoplastic femur. This may cause difficulties in fitting with a total contact prosthesis. However, resection of superfluous soft tissues should not be done as a routine since it always causes a further shortening of the stump. With modern prosthetic fitting using a total contact socket, this operation should only be performed in exceptional cases, for example when the skin flaps are in poor condition.

In some cases however, there might be a lack of soft tissues or formation of keloid scars.

Fig. 2. Disarticulation of the knee at 3 years. Eight years later, the femur of the amputated side is 75 mm shorter than the opposite side where the patient is amputated at a below-knee level.

Fig. 3. Thirteen year-old girl with bilateral high above-knee amputation performed at 2 years of age. Dysplasia of both hips with tendency towards subluxation. Both hips were perfectly normal at the time of the amputation.

Fig. 4. Knee disarticulation after a peripheral tissue necrosis due to anaphylactic reaction to penicillin Large areas of the stump are covered by skin grafts. Keloid scars have been eliminated by plastic surgery. The patient is fitted with a knee disarticulation prosthesis with double walls taking advantage of the full end bearing quality of the stump despite its poor soft tissue coverage.

Plastic surgery with excision of the scar tissues and covering with Z-flaps is indicated. If possible, further skin transplants in children should be avoided. The regenerative power of the soft tissues in children is considerably higher than in adults; even extended skin defects close spontaneously within a few weeks providing a scar with excellent qualities.

Through-knee amputation

Wherever possible, this level of amputation should be performed in children because the distal growth line of the femur can be preserved. It should be done even if the quality of the soft tissues is poor and the patella has to be removed. Also, this level provides a stump with full end bearing qualities which permits prosthetic fitting without an ischial seat (Fig. 4).

The short above-knee stump

The shorter the stump, the more important becomes the disproportion between the re-

maining muscle groups. In the frontal plane, the abductors between the pelvis and the greater trochanter always remain intact whilst the adductors always have to be partially removed. In the sagittal plane, the same discrepancy occurs between the flexor and extensor muscle groups. The shorter the stump, the more it will assume an abducted and flexed position. The question arises, whether a very short femoral stump is of any use and should not be completely removed. An even more conservative attitude is advocated to children than to adults. Even if the short femur goes into an abducted position of 60° or more, it can be actively moved and is most useful in sitting. In addition, if the soft tissue cover is sufficient, it can be fitted with an above-knee prosthesis instead of the Canadian hip disarticulation prosthesis (Fig. 5) which also accelerates the disproportion between the muscle groups of the femur.

Fig. 5. The shorter the above-knee stump, the more severe the disequilibrium between the different muscle groups. The result is an abducted and flexed position. Nevertheless this stump should not be amputated because it still has many functional qualities.

Congenital limb deficiencies

At the above-knee level, even grossly deformed stumps from congenital limb deficiency can be superior to an amputation stump with regard to function. There is no scar formation and sensitivity and blood circulation are intact. A phocomelic foot should never be amputated but actively included in a prosthesis. Even if the bone and soft tissues between the pelvis and the foot look poor the stimulation of these tissues when using a prosthesis might give surprising results (Fig. 6).

Prosthetic fitting

The basic design of above-knee prostheses for children is not different from adults. Patients are fitted, as a rule, with total contact sockets

Fig. 6. Left, phocomelia. Centre, first prosthetic fitting with Canadian disarticulation prosthesis. Right, two years later patient fitted with an above-knee prosthesis incorporating the foot which performs as an above-knee stump.

with partial or full end bearing depending on the stump. End bearing in children is particularly important because it stimulates growth and acts against osteoporosis. It furthermore prevents chronic oedema of the end of the stump which often causes serious troubles in the years to come. In bulbous stumps or congenital deformities the double wall technique referred to in the paper on knee disarticulation is used (Fig. 7).

Above-knee Amputation in Children

In small children, a prosthetic knee joint is superfluous. A lockable joint is fitted at the age of about 4–5 to facilitate sitting. A single axis knee is usually fitted when the child enters school. It is sometimes difficult to find components small enough for children. The knee joints available are usually simple hinges and do not offer the comfort of a brake or swing phase control commonly used in adults. While the difficulties in miniaturizing knee joints and the relatively small need for them are realised, perhaps more could be done in this field by the manufacturers of prosthetic components.

Fig. 7. Congenital limb deficiency with absence of the femur. Functional and cosmetic result with the double wall technique. At the left, plaster cast indicating the position of the stump in the socket (prosthetist: P. Botta, Biel, Switzerland).

R. F. Baumgartner

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The interface between the body and the above-knee prosthesis*

G. HOLMGREN

Een-Holmgren Orthopaedic Inc, Uppsala

Introduction

When fitting a prosthesis to an amputee, the primary task is to try to compensate as much as possible for his functional loss, although sometimes only a cosmetic compensation is possible.

A functional compensation is possible only if the remaining forces and the movements of the hip and the stump can be transmitted to the prosthesis.

Transmission of forces and movements

Functionally the leg prosthesis is a mechanical extension of the amputated leg and it serves as a component in the locomotion system. When standing and walking, considerable forces are involved. The prosthesis therefore has to be designed and aligned to be able to accept these forces and to stabilize and respond to the needs of the amputee.

The normal leg is connected to the rest of the locomotion system by the skeleton. As it is not possible to fit a prosthesis in a similar way, the prosthesis has to be connected to the skeleton via the soft tissues of the stump. These soft tissues can be deformed and displaced due to external forces. This decreases the stability and rigidity of the fixation of the prosthesis. The result is loss of energy, discomfort and distortion of the gait pattern.

It is therefore not possible to utilize the qualities of the prosthesis and its alignment if the fixation to the stump is not optimized.

The prosthesis is fitted to the stump by means of a rigid socket, or rather to the deformable and mobile soft tissues covering the remaining skeleton (Fig. 1).

The stability of the transmission of forces and movements therefore depends on how successfully the soft tissues can be utilized to reduce relative movements between the femur and the socket.

Fig. 1. Left, above-knee socket fitted. Right, above-knee stump with prominent soft tissues.

The prognosis for a good result is improved if the stump is well prepared and firm. If myoplastic or osteoplastic techniques have been used, i.e. the distal ends of the cut muscles have been anchored to the distal end of the stump, the result is usually much better than if this has not been done.

The stability of the fixation of the prosthesis also greatly depends on how the prosthesis is suspended.

The most efficient suspension and fixation is achieved by means of total contact sockets utilizing suction (suction sockets).

When fitting such a prosthesis, the stump is purposely deformed in order to achieve a pretension of the surrounding skin. This pretension increases the stability and reduces relative movements between the stump and the socket.

This technique, however, demands that the amputee is able to put the prosthesis on properly which may sometimes be difficult for elderly patients.

All correspondence to be addressed to Gunnar Holmgren, Een-Holmgren Ortopediska AB, Bergsbrunnagatan 1, S-753 23 Uppsala, Sweden.

Mediolateral stabilization of pelvis

The negative consequence of instability is most obvious as far as the mediolateral stabilization of the pelvis is concerned.

Due to the forces from the abductors, the femur, which lacks rigid skeleton connection to the foot and ground, tends to move in the lateral direction. If the socket is not in proper contact with the ischial tuberosity, it also tends to move in the vertical direction.

The absence of a rigid skeleton connection also results in the fact that the floor reaction between the prosthesis and the ground cannot efficiently be transmitted to the femur. Consequently the physiological hip joint is unable to serve, in a strict sense, as an origin and a support for the stabilization of the pelvis when the prosthesis is weightbearing.

This can be reasonably compensated for by connecting the socket to the ischial tuberosity. If this has been successfully achieved, the ischial tuberosity serves as a support-point during the latter portion of the stance phase, allowing the amputee to utilize his hip muscles for balancing the pelvis mediolaterally.

The result of the abductor forces depends on how much the relative movements between femur and the socket can be restricted. It has already been mentioned that the flexibility of the soft tissues of the stump limits the stabilizing of the femur in the socket and consequently the stabilization of the pelvis. There are, however, other limiting factors.

When stabilizing the pelvis, the femur tends to rotate in the socket due to the forces from the abductors. The reaction forces against this turning effect occur in the lateral-distal and the medio-proximal positions of the stump (Fig. 2). If the tissues in those areas are less able to accept the resulting pressures, this reduces the possibility to stabilize the pelvis in a proper manner.

From elementary mechanics it is also known that the shorter the stump the higher will be the reaction forces due to the stabilizing moment. The pressure on the lateral contact surface also increases as the surface area itself decreases when the stump is shorter. Amputees who have short AK stumps consequently tend to tilt their bodies towards the amputated side to reduce the pressure on the stump surfaces involved.

In spite of all the various theories and methods used to fit an AK prosthesis to the body
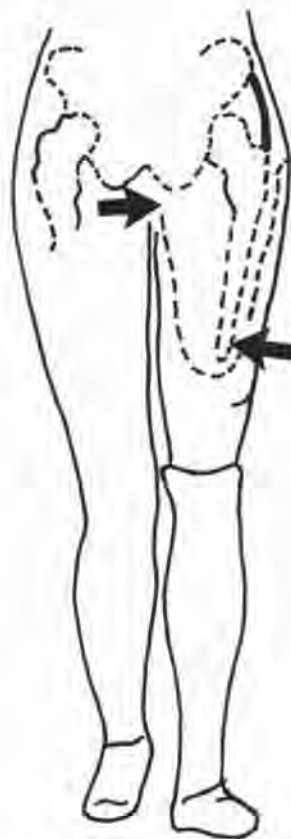
Fig. 2. Pressure points at the stump during pelvis stabilization.

there is no disagreement that a proper configuration and "matching" of the socket to the stump is of utmost importance in each individual case.

It is also agreed that it is not possible to correct for an improperly fitted socket by means of any advanced knee and foot mechanisms. If the socket is functionally well fitted and comfortable, the rest of the leg could very well be a simple pylon.

During weightbearing, when the opposite leg swings, a prosthesis with mobile knee and ankle joints works as a stick. It is only in the latter portion of the weightbearing phase that the limitation against dorsiflexion of prosthetic foot and the characteristics of polycentric knee joints provide a different function.

Functionally, therefore, knee and foot joints mainly contribute to the possibilities of improving the gait pattern.
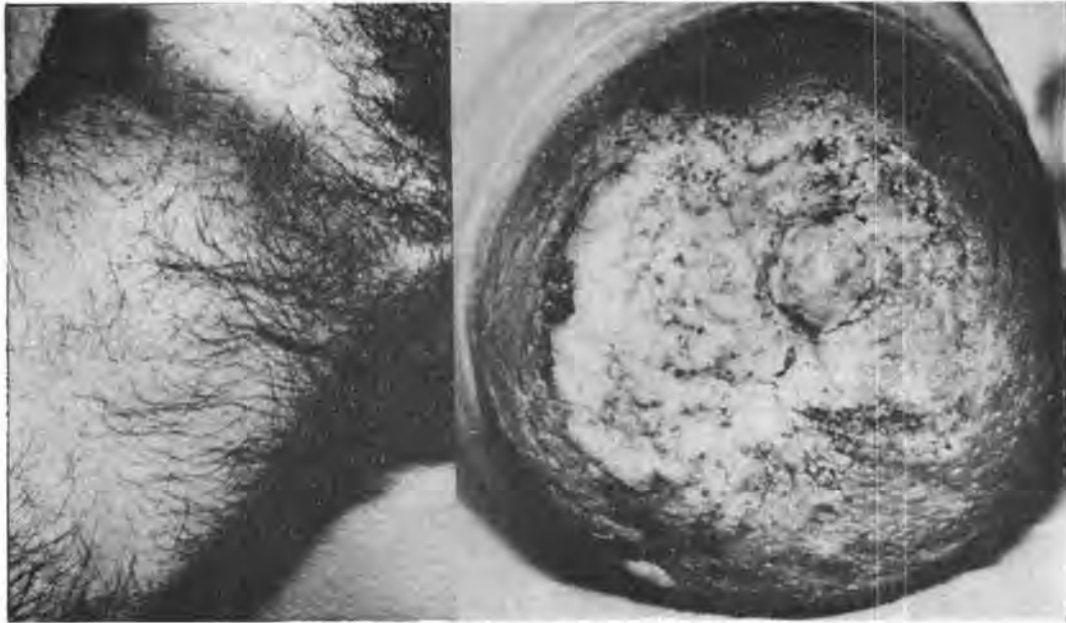
Fig. 3. Stump damage caused by too narrow sockets.

Experience and investigations also indicate that most of the daily problems, when using the prosthesis, are related to the fitting of the prosthesis to the body.

Practical considerations on suction sockets

If the volume of the socket is smaller than the volume of the stump, there will frequently be oedema, fatigue sensation, impaired sensibility, and tissue damage (Fig. 3). If the socket is too narrow, it may also be difficult to provide necessary contact between the socket and the ischial tuberosity.

As the suction effect contributes to the suspension of the socket, it is required, for the purpose of sealing, that the skin is sufficiently stretched when the stump is moved into the socket. Therefore there has to be such a pressure between the skin and the socket walls that sufficient friction and sealing is established.

The increased stability should not only be looked at as a result of the suction effect itself but of its capability to maintain the pre-tension of the soft tissues, which is developed when the stump is pulled into the socket. This pre-tension of the stump tissues contracts the compression force of the tissues at the weightbearing areas.

If the socket is not sufficiently sealed to the stump the suction will be lost. In an effort to

Fig. 4. Stump showing deformable and mobile soft tissue.

make sure of sufficient sealing, the socket volume is sometimes made too small, which creates stumps problems and also impairs the function.

The elastic properties of the soft tissues vary, which calls for individual analysis of each case (Fig. 4). Thus the flexibility of the soft tissues may affect the final circumference at different levels and the depth of the socket.

The dynamic requirements put certain demands upon the proximal configuration of the socket. The quadrilateral socket shape is determined by considering the function of the four major hip muscle groups.

The proximal shape also considers the

relationship of the socket to the ischial tuberosity and the inferior ramus of the pubis.

As the physiological hip joint is situated proximally and laterally to the inferior ramus of the pubis and the ischial tuberosity, the stump must be properly mediolaterally aligned when casting. The basic consideration in this respect is that the distance between the distal end of the stump and inferior ramus of the pubis decreases, and also to some extent the distance to the ischial tuberosity, as the stump adducts.

The above is an attempt to focus on the main factors that have to be considered when constructing the interface between the body and the prosthesis. Of course, any aid that improves the control of volumes and pressures and can simulate the functionally necessary deformations of the soft tissues is of great value.

For the past decade we have applied the following techniques in producing the socket for the AK amputee:

The casting procedure is illustrated in Figures 5—8.

1. A reproducable control of volume, compression and simulation of soft tissue deformation is achieved by using the elastic bag, developed at the BRADU under the supervision of Dr. Redhead (1973), although the application of the plaster of Paris and some important steps of the procedure have been modified.

2. The proximal configuration of the socket is based on the basic work by Radcliffe (1955).

3. The quadrilateral shape of the socket and the alignment to the ischial tuberosity is achieved through palpation by the hands and not by using standardized brims. It is our view that by doing this we improve the conditions for individual considerations of differences in muscle prominence and soft tissue conditions. Working this way we have found that the angle between the anterior and the posterior wall is frequently different from case to case.

Fig. 5. Left, inner nylon sock applied to stump—used in a later stage to achieve pre-tension of the stump tissues. Right, specially prepared Tubigrip casting sock with applicator, being applied over entire pelvis area and stump.
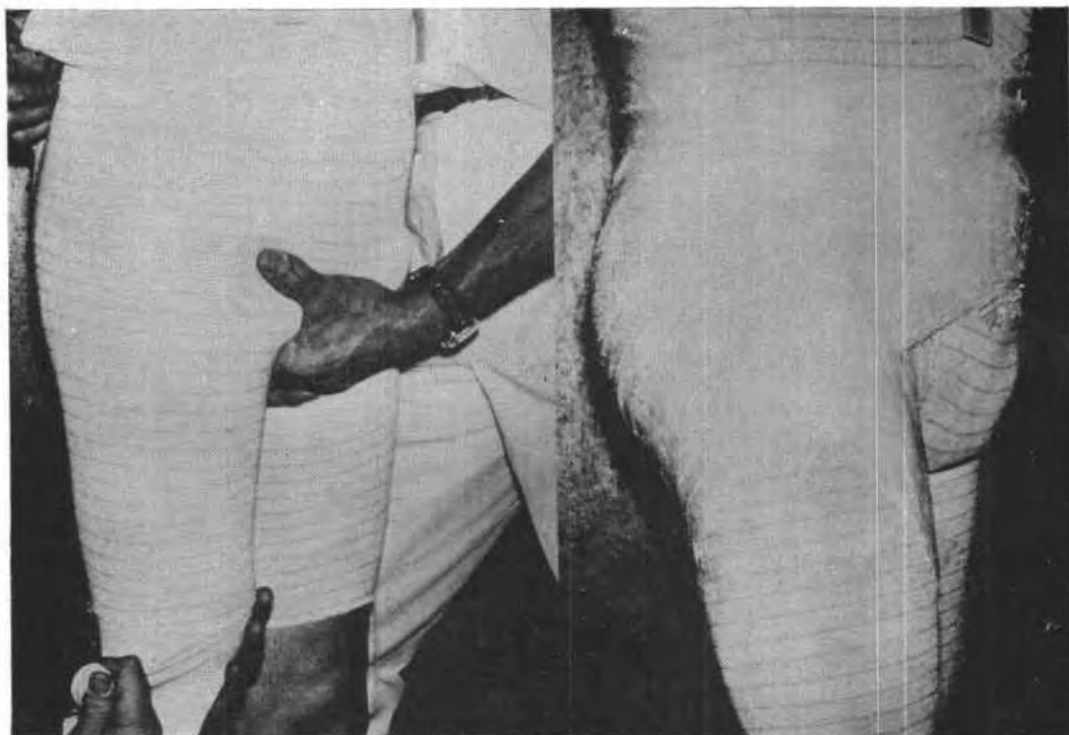
Fig. 6. Left, Tubigrip cast sock being held in position while second operator withdraws nylon stockinette to achieve pre-tension of the stump tissues. Right, first stage of plaster of Paris wrap encasing the pelvic girdle and proximal stump area.
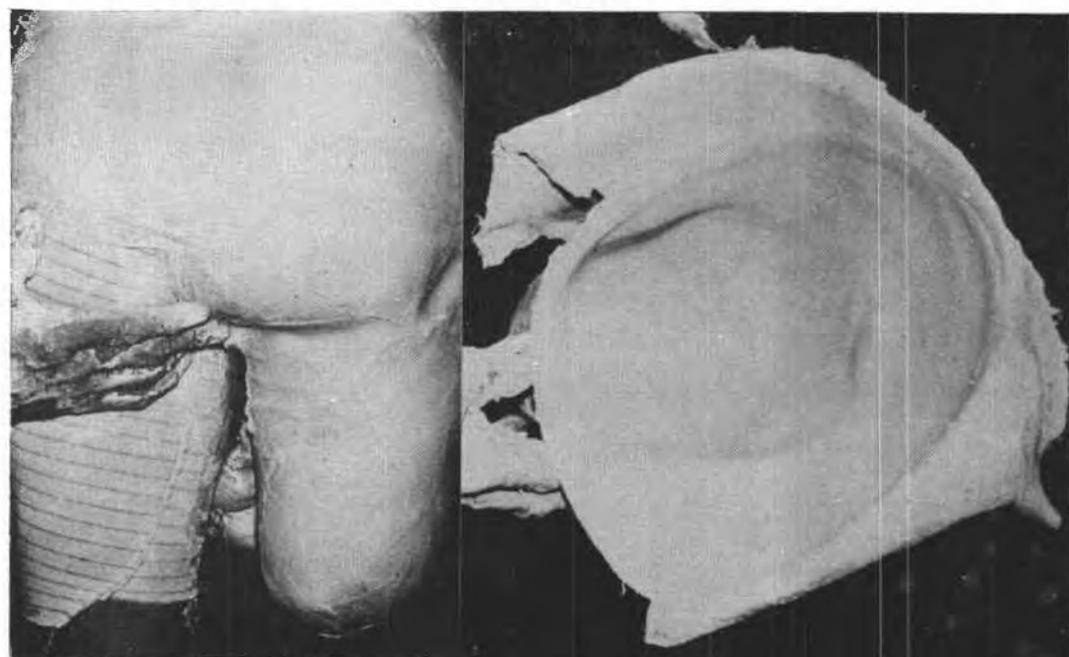
Fig. 7. Left, wrap cast complete showing deformation for ischial seating area. Right, completed wrap cast after removal showing the deformation to a quadrilateral shape, the ischial seat and bulge into the femoral triangle.
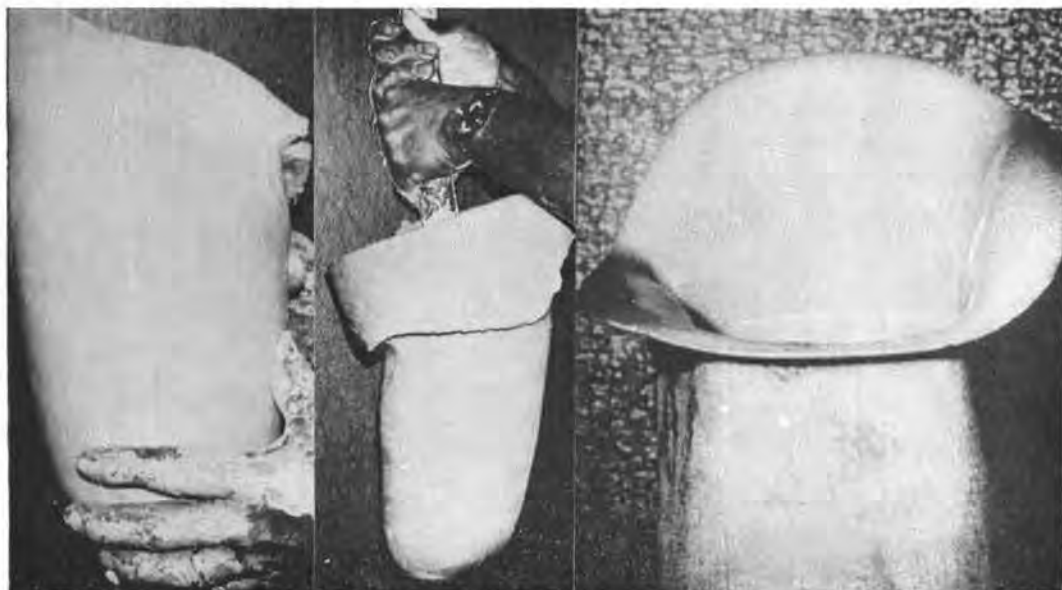
Fig. 8. Left, negative cast trimmed and modified at proximal trim line. Centre, resultant positive cast. Right, the end product of the casting procedure illustrating the plastic laminate socket—quadrilateral shape—ischial seating area—high anterior and lateral walls, and the generous flare of the anterior proximal brim.

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The principles and practice of hip guidance articulations*

G. K. ROSE

*The Orthotic Research and Locomotor Assessment Unit,
The Robert Jones and Agnes Hunt Orthopaedic Hospital, Oswestry*

Introduction

Many complete paraplegic patients, ranging from adults with traumatic lesions to children with spina bifida cystica, are given a variety of orthoses in an attempt to produce locomotion on an empirical basis with little or no understanding of the mechanical principles involved. Not surprisingly large numbers fail to achieve this and even greater numbers abandon the exhausting, slow ambulation produced after long rehabilitation, in favour of the wheelchair.

Swivel walking devices (Motloch and Elliot, 1966) were used for the first time for this type of patient in Shrewsbury in 1967 (Edbrooke, 1970). The fundamental mechanics had been worked out by Spielrein in 1963 for an amelic case and were confirmed for these patients by Rose and Henshaw (1972). Despite the undoubted advantages of this type of apparatus and in particular the fact that it can be used in time coincident with normal developmental stages and leaves the hands free, the dynamic cosmesis is not always accepted by the patients or parents.

To provide rational, reciprocal ambulation the basic question, "how could a patient paralyzed in both legs ambulate?" was partially answered in 1974 (Rose). With the knees and ankles stabilized in KAFO's (long leg braces) the following criteria were identified:—

1. That the hip must be placed ahead of the foot. This can be achieved either in hip hyperextension or in flexion (Fig. 1).
2. One foot must be raised from the ground by a combination of:—
   2.1 Downward pressure by the ipsilateral arm and crutch.
   2.2 Body sway to the contralateral side.
   2.3 Provision of a dihedral wedge under the sole of the contralateral shoe.

All correspondence to be addressed to: Mr. G. K. Rose, Director, The Orthotic Research and Locomotor Assessment Unit, The Robert Jones and Agnes Hunt Orthopaedic Hospital, Oswestry, Salop SY10 7AG, U.K.
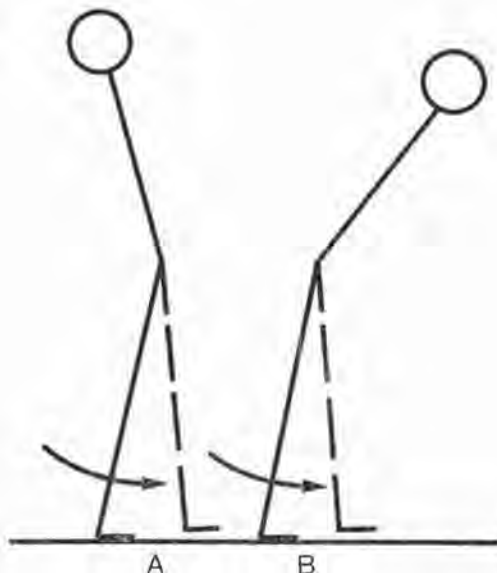
Fig. 1. With the patient hyperextended (A) or flexed (B) at swing leg/hip, the geometry of the leg is the same, and when lifted from the ground it will swing forward under the influence of gravity.

In these circumstances, under the influence of gravity, the lifted leg will then swing forward and can be grounded. The process is now repeated for the other foot. It is then that problems arise. Due to the geometry of the whole system the back foot is likely to strike the front or even become trapped behind it. The second, even more inhibiting, complication, is "wind swept" fall out, that is to say the patient falling laterally with abduction of one hip and adduction of the other and it is very difficult for the patient to control this.

It became apparent, therefore, that guidance of the hip joint path was imperative. From a mechanical point of view maintenance of the legs in abduction could be achieved most satisfactorily by some form of strut, or struts,

placed between the long leg braces, which would be in compression (Fig. 2A). To provide forward motion other than the swivel mode this strut could then be articulated at each end (Fig. 2B), however, it would then produce a highly variable and unpredictable curved track which is useless for guidance. To produce a predictable path, also curved and therefore of short step length, the advancing leg must rotate about the longitudinal axis of the other and this requires a complex mechanical tracking device, (Fig. 2C) which is difficult to produce and maintain (Glory, 1972). For a pathway nearer to normal reciprocal gait a compression strut which allows elongation would be necessary (Fig. 2D) and the problems of providing this seem insuperable. In addition such struts as have been tried produced considerable problems with clothing and "doff and don".
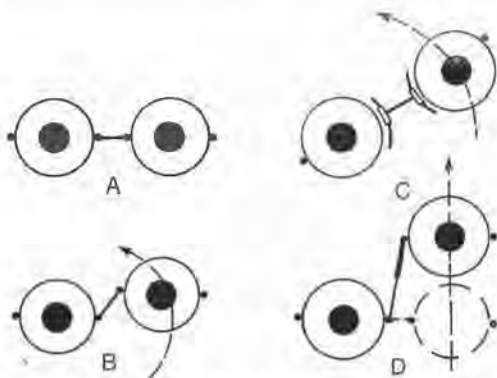
Fig. 2. Guidance of hip joint path. (A) A simple strut at some point between long leg braces, articulated at each end, seems the best mechanical solution to prevent impedance of one brace by the other. (B) Shows one of the variants of track so produced, but because this is not predictable, guidance is inefficient. (C) Shows a complex tracking device producing a curved, short step pathway. (D) To produce a fore and aft reciprocation requires a strut which elongates whilst under compression.

It was necessary, therefore, to adopt an open structural device with no compression element between the legs. It consisted of a very rigid body brace articulating through ball bearings to the leg braces, providing planar leg movement and resistance to adduction. With this the problem of foot collision and wind swept fall out were eliminated.

Horizontal rotation about each hip was also incidentally eliminated.

Such patients still suffered from an incapacitating disadvantage, namely posterior fall out. It is not possible for them to prevent this with crutches, and it was necessary, therefore, to limit flexion of the hip by means of a stop. It was not necessary to limit extension because this was done naturally by the hip joint itself.

The next problem was to discover the optimum degree of permitted flexion. The greater this is, the greater the potential stride length. Yet there is an absolute limit to this range, and this derives from the relationship of the centre of gravity of the patient plus walking device to the supporting foot. Considering a patient in the double stance phase, when, by the process described, the back leg is raised the situation may be as shown with the centre of gravity behind the support leg (Fig. 3A). In such circumstances the patient will inevitably fall backwards and there is no reaction between crutch tip and floor which will permit effective function of the arm muscles. On the other hand, if the situation is as in Figure 3B when the arm muscles can contract effectively and draw the patient's body forward rotating over the support leg. The critical nature of this flexion range was well demonstrated by patients who could walk vigorously with the apparatus initially, but would remain either immobile or fall backwards if the flexion was increased a few degrees only due to wear of the joint.

It is customary for patients using this apparatus to start with a rollator as this has mechanical advantages. It may enable the centre of gravity to be placed just ahead of the line of the back feet and this certainly occurs in some patients (Fig. 3C). On the other hand, because a rollator is heavier than a pair of crutches, the centre of gravity of the whole system is affected advantageously. This situation was established in a patient who walked confidently with a rollator but diffidently with crutches. When a two pound weight was attached to the end of each crutch just proximal to the rubber the patient was equally confident as with a rollator.

As the swing leg goes forward the centre of gravity of the whole system advances. Provided that it does so rapidly, the disadvantages of a centre of gravity just behind the support foot may be overcome inertially by a sharp jerk forward of the pelvis and backwards of the shoulder prior to the moment the swing leg leaves the ground. Two practical points therefore arise:—

A   B   C
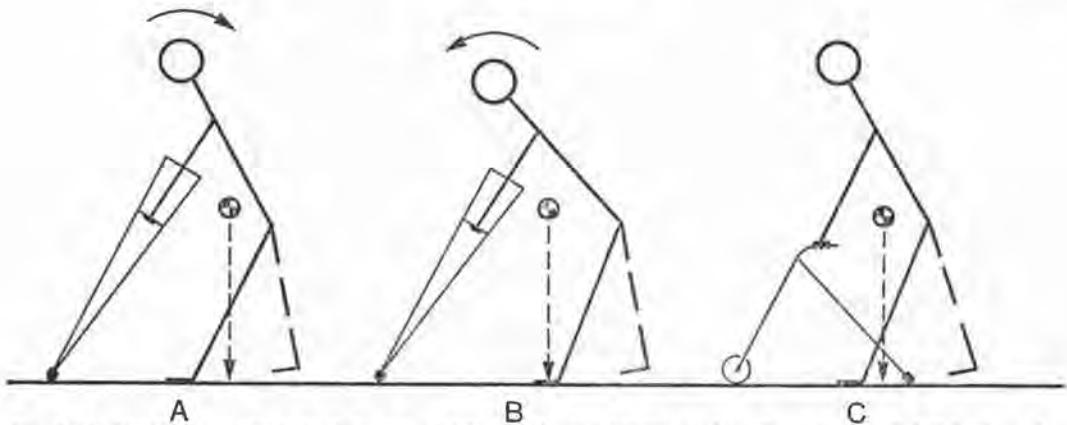
Fig. 3. (A) Centre of gravity behind the support leg produces a situation where the patient will fall backwards. (B) Centre of gravity ahead of the stance leg enables satisfactory action of arm-trunk muscles to pull the body forward. (C) Situation (A) can be changed by use of a rollator to put the centre of gravity in front of the most posterior support edge.

1. That greater initial gravitational moment on the KAFO segment, when posterior to the hip, in order to overcome inherent frictional constraints of the orthosis may be achieved by the addition of relatively small, empirically determined, distally placed weights on the KAFO segments.

2. Where the patient has some difficulty in clearing the swing leg from the ground the rate of forward movement may be improved by the addition of a spring anteriorly to the articulation, the so called Assisted Hip Guidance Orthosis. The spring is loaded during that phase of walking when the hip is extended, without necessarily going into extension, and rapidly unloaded at the beginning of the swing phase. The results of such a spring in terms of heart rate and speed are shown in Figure 4.

The problem of clearing one foot has several components. An abduction hinge placed at the hip level has been used for several years (Herzoz and Sharrard, 1966) but it has the disadvantage compared with angulation at the sole/floor interface (Fig. 5) that, for the same clearance, the centre of gravity of the system in the second case moves further laterally towards or over the support area, whereas with the abduction hinge the movement is less. This means, therefore, that with angulation at the sole/floor interface greater downward pressure by the ipsilateral arm and crutch is necessary. In practice it is often the fatigue and discomfort of the arms which limits this type
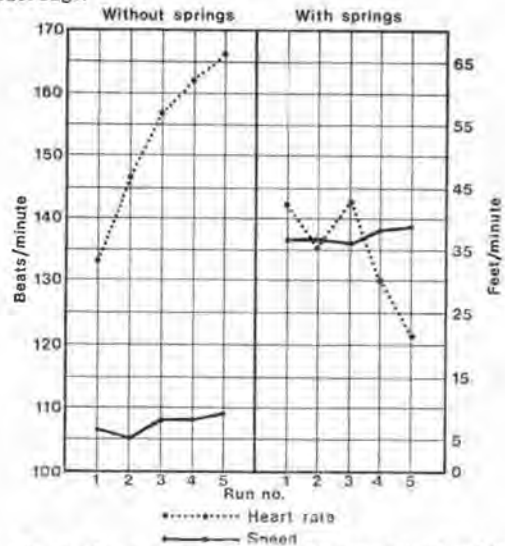
Fig. 4. Comparison of hip guidance orthosis with and without springs using speed and heart rate over 5 × 10 ft. runs.

Abduction hip   Lateral rocker
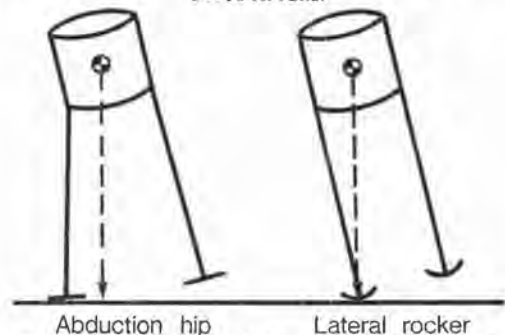
Fig. 5. Left, abduction hinge at hip level. Right, lateral rocker at sole level. Comparison shows the difference in movement of the centre of gravity toward the support areas for the same angular deviation.
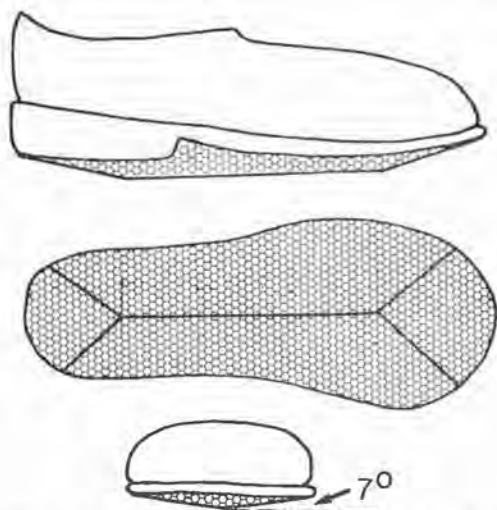
Fig. 6. Undersurface of the foot showing dihedral provided; this should be about 7 degrees.

of walking. Angulation at the sole/floor interface is facilitated by a sole dihedral (Fig. 6).

Another adverse factor is any flexibility of the device. To achieve rigidity it has been necessary not only to make the body brace of rigid material but in the larger child to reinforce it and to re-design the sacral band to provide not only pressure against the sacrum but also rigid spacing of the articulations (Fig. 7). It is possible that in the future with the development of better materials, for example a combination of metal and carbon fibre, that equally rigid, lighter body braces may be produced.

The disadvantages of the open structure method of securing hip guidance have been indicated and the stresses on and around the articulations required very considerable strengthening of the design.

Consideration has to be given also to the optimum degree of adduction of the legs. Clearly if the swing phase is to be unimpeded there must be no contact during this time between one leg brace and the other.

Considering the geometry involved and the fact that the objective of a patient using two crutches is to raise one foot from the ground just sufficient to allow it to swing forward, significant differences with different degrees of abduction can be demonstrated (Fig. 8). In the particular configuration chosen, where the leg length is twice the hip width, and the legs parallel, Figure 8A shows that to raise the foot

Fig. 7. Re-designed sacral band which provides one area of three point pressure over the sacrum and separates and stiffens the articulations.

a standard amount an angulation of 6.5 degrees occurs and that this was found to put an adduction moment on the hip articulation generated by the ground reaction force at the supporting foot. In Figure 8B with 10 degrees abduction the angulation required to produce the same lift of the foot is 4.0 degrees and this was found to put an abduction moment on the articulation. For 20 degrees abduction (Fig. 8C) the angulation is 2.5 degrees with an increased abduction moment. From the point of view of minimizing stress on the articulations, optimum abduction would be that which puts the stance leg at right angles to the support surface and this is 5 degrees for this example (Fig. 8D).

This is not, however, the only factor to be considered. It will be noted that in all the examples the rise in the centre of gravity is the same but that the lateral shift of the centre of gravity diminishes with increased leg abduction as does the angulation of the trunk (if it is considered as a rigid body). This means that the moment about the support leg increases with the abduction and implies that in these circumstances the contralateral crutch load has to be increased to produce the elevation. The design of the apparatus keeps the lumbar spine
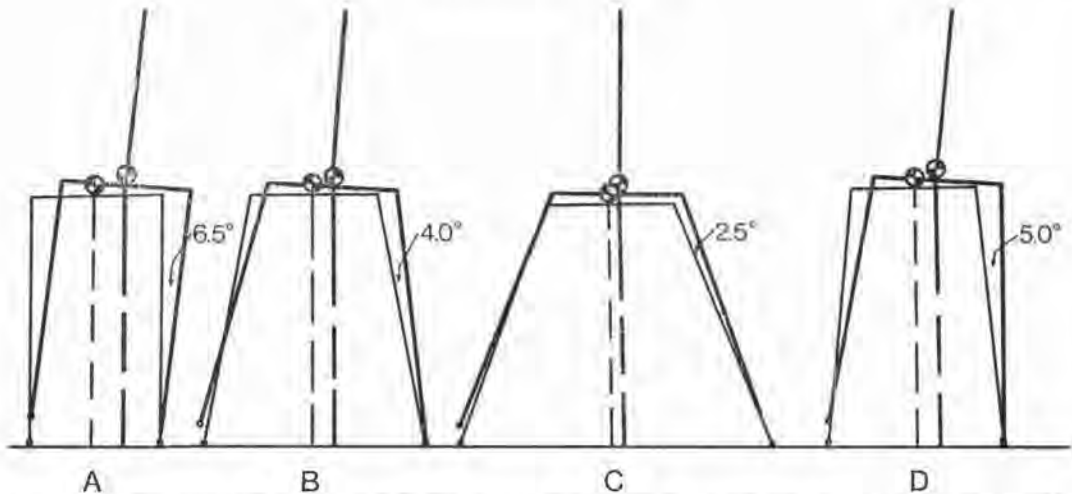
Fig. 8. Shows the various angular deviations for the same amount of foot raise with different degrees of abduction. See text.

relatively rigid but movement of the trunk above this, including head and arms, can produce a small beneficial shift of the centre of gravity towards the stance leg reducing this moment. Probably small differences in shift of the centre of gravity are of no significance, having regard to the leverage advantage of the crutch in elevating the leg (Fig. 9A).

These geometric principles, whilst precise, cannot be precisely applied in practice. It is, however, necessary that the maximum rigidity should exist at all levels of the orthosis and indeed it is common with problem cases that one finds some flexing occurring at several

Fig. 9. (A) Shows the geometry of the optimum abducted stance leg in relation to the position of the centre of gravity and force required by the crutch to elevate the swing leg return to the ground i.e. a safe situation. (B) Shows that one crutch must be used to elevate the swing leg and then the other to prevent the patient falling and to return the swing leg to the ground, i.e. an unsafe broken rhythm form of gait.

levels, in, above and below the articulation. If such flexibility exists, it affects both the stance and swing leg. The swing leg tends to fall inwards requiring greater lateral deviation of the body to elevate it from the ground and this in turn increases the stresses on the stance leg with increasing adduction there and again further lateral deviation of the whole patient. It is here that the relationship of the centre of gravity to the support area may become quite critical. In such circumstances it can pass lateral to the support area (Fig. 9B). Whilst this is not a disaster, as falling is prevented by the use of the ipsilateral crutch and the leverage advantage may be as good as on the other side, it does have an inhibiting disturbance of rhythm. It seems that the ideal situation is, as in normal walking, that the centre of gravity moves towards a position vertically above the support foot but does not reach it, i.e. stable equilibrium.

In these circumstances almost all the energy used in lifting is returned, whereas if the centre of gravity passes beyond the support, extra energy has to be injected by the ipsilateral arm before stability is restored. At this time the energy situation has not been quantified and it is probably the rhythmic one which is the more important. Observing patients with this device there is no doubt as to the superior progression achieved by those who never reach the unstable situation.

The problem of the relationship of the axes

Fig. 10. Optimum relationship of articulations through body and leg brace.

Fig. 11. Variation of swing leg track related to articulation abduction/adduction.

of the articulation to the ground has a number of conflicting considerations and some compromise must be made:—

(i) From the point of view of maintaining the axes parallel to the ground when in swing phase a configuration as shown in Figure 10 is necessary. This should apply the least constraint to forward motion.

(ii) Having regard to the options of setting the axes of the articulations together with the pathway of the swing leg (Fig. 11), the pathway produced by the adduction setting is the least attractive.

For these reasons, and for engineering practicalities, 5 degrees of abduction below the articulations has been chosen.

The question of in-toeing or out-toeing has to be considered: in general we have set the articulations parallel. They do not remain so, where there is an added rotational element to progression, but this seems to represent the best compromise.

The geometry here is of course highly simplistic and pays regard to few of the many dynamic factors which must be present. Where some assessment has been made of the dynamic stresses within orthoses these have been found to be very considerably greater than those calculated from the static conditions and there is no reason to suppose that this situation is not

the same. Clearly it will be important in the near future to quantify these.

As had been indicated mobility of the spine above the body brace can affect the situation and clearly it is affected by abnormalities of the spine, particularly where the curvature has caused "decompensation", that is to say that the centre of gravity of the trunk and arm segments have shifted laterally in regard to the pelvis and hip joints. In such circumstances it will be easier for the patient to lift one leg than the other. Commonly patients when first put into this apparatus may find that they can clear one foot with ease and the other with difficulty which is usually the left. When all other factors have been checked and if necessary corrected for example asymmetry, flexibility of the orthosis, spinal decompensation or shortening of one leg etc., this difficulty may still remain. In such circumstances a week or two of training, concentrating on swaying from one foot to the other may be sufficient to put the matter right, but in other cases use of a spring assist will be necessary. At this time we have not been able to define precisely those factors which make a spring assist imperative. In general it is our custom to make the orthosis without the spring assist but if success is not achieved with a very short period of training, the spring is added and in such circumstances it has been found that the situation improves rapidly. Almost certainly one factor is the degree of tolerance of rhythmic angulation of the individual patient consequent upon the cerebral element of the lesion.

To date twenty-eight patients have been supplied with this device and of these six were fitted with spring assist.

The apparatus permits independent transfer, assumption and removal, ambulation at a reasonable speed in the region of 50 feet per minute over a variety of surfaces including for example a grass field.

As in all orthoses it is important that when supplied a check should be carried out so that time is not wasted on abortive training which cannot succeed because of mechanical or geometric deficiencies in the device. It is simple, therefore, with the patient standing to rock him in turn on to each side until the foot clears the ground. It soon becomes apparent whether the apparatus is sufficiently rigid and whether the angle of deviation can be tolerated by the patient. As regards the permitted flexion range, 5 degrees

of this is supplied initially. Once the patient is used to the apparatus then the possibility of increasing the range can be estimated by leaning the patient backwards whilst holding crutches until the balance point is found and this corresponds to the permitted flexion (Fig. 12).

Acknowledgements

Fig. 12. Method of determining optimum flexion range at hips.

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Standards for lower limb prostheses

A. BENNETT WILSON Jr.

Ever since it was established in 1970, ISPO has been responsible for a series of conferences designed to result in the development of functional standards for lower limb prostheses. The first conference in this series was convened by the Committee on Prosthetics Research and Development of the U.S. National Academy of Sciences, and was held in San Francisco in March 1971 to discuss problems with the so-called modular prostheses that were available or being developed at that time. One of the many recommendations from this conference was that international standards for lower limb prostheses should be developed. An effort was also started to encourage manufacturers to use standard sizes so that components could be interchanged among systems.

To follow up on this conference, the Department of Health and Social Security of the United Kingdom convened a conference at Ascot, England, in 1972 where methods of physical testing and the collection of data were presented and agreed upon. At this time laboratories in various countries volunteered to participate in the programme by collecting data in such forms that they could be pooled so as to present the most reliable results possible with a minimum of costs.

A small working group was assembled in Dundee, Scotland, in 1973 by the ISPO Committee on Research to review the work up to that point.

The next major conference was convened by the DHSS at Heathrow, England, in 1974 where data accumulated to that point were reviewed and analyzed. It was the unanimous decision that the approach being used was correct but data on more subjects were needed. The groups concerned agreed to continue to collect the data needed.

The data were accumulated by the summer of 1976 and a conference was convened in Philadelphia, U.S.A. in 1977 by ISPO, primarily with funds supplied by the Rehabilitation

Values for Standards for Lower Limb Prostheses as Developed at Workshops
Sponsored by ISPO and held in Heathrow (1974) and Philadelphia (1977)

	Axial Load Newtons		Torque Newton Metres		Knee AP Bending Newton Metres		Knee ML Bending Newton Metres		Ankle AP Bending Newton Metres		Ankle ML Bending Newton Metres	
	Static	Cyclic	Static	Cyclic	Static	Cyclic	Static	Cyclic	Static	Cyclic	Static	Cyclic
Heathrow 80 Kg	2120 b/k	1060 a/k	26·7 a/k	12·5 a/k	165 b/k	90 a/k	125b,k 90a/k	80 a/k	210 b/k	110 b/k	45 b/k	30 ak/bk
Heathrow 105 Kg	2780	1390	35	17	220	120	165b/k 115a/k	105	280	145	60	45
PHP 1	2783	1391	34·8	16·4	250	118	164	85	276	144	100	50
PHP 2 All categories	2250	1300	35	20	230	120	150	80	230	140	70	60
PHP 2 Light duty	1120	980	15	—	80	70	45	40	100	95	35	40
PHP 3 as Heathrow at 105 Kg except where a figure is entered		1340		21					static thought too high			
PHP 4 Static loads as Heathrow		1333		20		100 could be higher		80		160		±40
Consensus Figures reached in Plenary Session	2500	1350	35	20	230	120	150	80	250	140	±70	±50

Services Administration, U.S.A., where a final set of physical standards were agreed upon. The values for standards for lower limb prostheses as developed at the workshops held in Heathrow and Philadelphia are shown in the Table.

The proceedings of the Philadelphia Conference have been published as a report which should be useful to designers, manufacturers, and government agencies that have responsibility for the provision of artificial legs, it is not apt to be of much value to the vast majority of practitioners.

Copies are available from Mr. J. Hughes, Hon. Secretary JSPO, National Centre for Training and Education in Prosthetics and Orthotics, University of Strathclyde, 73 Rottenrow, Glasgow G4 0NG, Scotland. The cost is $10 (U.S.) per copy plus postage.

Workshop on classification and measurement of lower limb amputation stumps

The Standing Committee on Research of ISPO is especially concerned with promoting research in areas which are identified as being of international significance, but which are receiving inadequate attention. The President, George Murdoch, and myself as Chairman of the Research Committee, believe that one such area where fundamental knowledge is required is that of the classification and measurement of stumps. As a basis for the development of an international standard and protocol it is proposed to collect information on national and local practices and to collate this for consideration in a workshop to be held in Bologna at the time of the next World Congress in 1980. The development of such a standard system would be invaluable in the reporting and comparison of results.

If you are using a system of classification and measurement, or if you have ideas on how one might be developed, you are invited to send details to the address given below. You are also asked to indicate, without obligation, whether you would be interested in taking part in the workshop.

BJÖRN M. PERSSON, M.D.,
Associate Professor of Orthopaedic Surgery,
Department of Orthopaedic Surgery,
Lund University Hospital,
S-221 85 Lund, Sweden.

Third World Congress

Bologna—28 September–4 October 1980—Prelude to 1981 Year of the Disabled

ISPO in collaboration with INTERBOR (the International Society of Orthotists and Prosthetists) will organize the Third World Congress in Bologna, Italy, on 28 September–4 October, 1980. The programme will provide substantial coverage of technical, scientific and administrative topics associated with amputation surgery, prosthetics, orthotics and related areas of orthopaedics and rehabilitation engineering.

We believe the programme, by its review of recent advances, scientific content and comprehensive reporting of experience, will truly honour the spirit of the Decade of the Disabled and provide an ideal prelude to 1981, the United Nations Year of the Disabled Person. A very interesting and informative array of *instructional courses* is planned, such as those presented at the 1977 New York Congress. This will offer physicians, surgeons, prosthetists, orthotists, therapists and rehabilitation engineers information which is immediately useful in a clinical setting. *Scientific sessions* will be structured as forums for exchanges of information on recent and current research and development. *Workshops* and symposia are to be organized so that smaller groups can treat very special and sometimes controversial subjects in detail. Featured will be *plenary sessions* in which recognized world leaders will present triennial reviews of practice in the major aspects of orthopaedic rehabilitation.

This opportunity to communicate with one's peers is enhanced by the excellent facilities available in the attractive, modern conference centre in Bologna. Simultaneous translation will be available in four different sites at the same time. Languages offered will include English, French, German and Italian. Translation into Spanish and Japanese is also being considered.

Bologna, one of the most ancient and outstanding Italian cities, is well known for its arts and its culture. The University of Bologna, one of the oldest in the world, was founded in the 11th century and had such students as Dante, Petrarch, Copernicus, Bocaccio and Erasmus. The anatomist, Marcello Malpighi, the physicist Luigi Galvani and the naturalist, Ulisse Aldrovandi, were some of its most famous professors. Bologna is also the centre of orthotics and prosthetics in Italy. Indeed in Bologna we find the Instituto Ortopedico Rizzoli, as well as two outstanding prosthetic/orthotic facilities—one located in the Rizzoli Institute and the second at the prosthetics centre of INAIL.

In addition to its history of scholarship, especially in the medium of orthopaedics and anatomy, Bologna is renowned for its art, culture and gastronomic excellence. There is much to be enjoyed in this ancient and beautiful city where costs are among the lowest in Europe.

ISPO and INTERBOR members are eligible for a reduced registration fee. The first announcement and preliminary registration form will be posted to the membership shortly.

Bert R. Titus, CPO.

It is with deep regret that we inform the membership of the death of Bert Titus, Treasurer of the U.S. National Committee of I.S.P.O.

For upwards of 25 years, Bert was Director of prosthetic-orthotic services at Duke University in Durham, North Carolina. Under Bert's guidance and direction this facility developed international renown as a foremost centre of clinical practice and research in prosthetics and orthotics.

Bert's service to the profession included a term as President of the American Board for Certification and several terms as a member of the American Academy of Orthotists and Prosthetists. He was the current president of the North Carolina Society of Orthotists and Prosthetists and a Fellow of ISPO.

Since the inauguration of our Society, Bert Titus has been one of its most active members and supporters, serving on the Executive Board of the U.S. Committee, as well as Treasurer. Few prosthetists-orthotists in the United States have displayed the leadership and the international interest exhibited by Bert. His personal and professional presence, which inspired us all, will be sorely missed in ISPO activities.

Book review

Amputations and Prostheses, Vitali M., Robinson K. P., Andrews B. G. and Harris E. E., Bailliere Tindall, London, 1978, 241p. £10.50p.

In 1948 Queen Mary's Hospital, Roehampton, became the major United Kingdom Centre for amputation services and at present cares for some 15,000 amputees. From this large experience the authors give a condensed report on the present state of the art of techniques in surgery, prosthetic fitting and rehabilitation problems of the amputee.

After brief surveys on history, statistics, and trends, the first third of the book is dedicated to general problems of rehabilitation, bio-mechanics and prosthetics. Special attention is given to patients with congenital deformities, and vascular and neoplastic disease but not to problems of trauma and growth. The main part of the book deals with the specific problems associated with each level of amputation and covers all aspects of surgery, prosthetic fitting and training. After a general chapter on post-operative physical and psychological changes, rather too little attention is given to future developments.

The book is written by and dedicated to practitioners. It puts emphasis on methods which are based upon the authors' experience over many years with a great number of patients. Most of these techniques are well known all over the world, some of them are rather specific to British practice. For example, emphasis is put on Syme's amputation. Other techniques which leave the calcaneus intact and thus give even better end bearing qualities to the stump are considered as being useful only in developing communities where modern prostheses are not available. Thus the continental surgeon may gain the impression that rather little attention was paid to literature from outside the United Kingdom.

The illustrations are excellent as far as the drawings related to anatomy and surgical technique are concerned. Unfortunately the photographs do not all meet the same standard.

The book nevertheless is of outstanding value to every colleague who has to deal with amputees. It therefore should be available in every orthopaedic library.

R. Baumgartner
Zurich, Switzerland

Calendar of events

New York University Medical School

Short Term Courses

Courses for Physicians and Surgeons
741D Lower Limb Prosthetics, 30 April–4 May, 1979.
751C Lower Limb and Spinal Orthotics, 7–12 May, 1979.

Courses for Therapists
742D Lower Limb Prosthetics, 16–27 April, 1979.
752C Lower Limb and Spinal Orthotics, 7–12 May, 1979.
757B Upper Limb Orthotics, 21–25 May, 1979.
745B Upper Limb Prosthetics, 4–8 June, 1979.

Courses for Orthotists
758 Upper Limb Orthotics, 29 May–8 June, 1979.
756 Spinal Orthotics, 9–20 July, 1979.

Course for Prosthetists
743 Above Knee Prosthetics, 11–29 June, 1979.

Course for Rehabilitation Counsellors
750B Prosthetics and Orthotics, 14–18 May, 1979.

Requests for further information should be addressed to Professor S. Fishman, Prosthetics and Orthotics, New York University Post-Graduate Medical School, 550 First Avenue, New York, NY 10016, U.S.A.

18–21 April 1979
British Orthopaedic Association—Spring Meeting, Exeter, U.K.
Information: Hon. Secretary, British Orthopaedic Association, Royal College of Surgeons, 35–43 Lincolns Inn Fields, London WC2A 3PN, U.K.

22–27 April, 1979
American Occupational Therapy Association 1979 Conference, Detroit, Michigan.
Information: Mrs. M. Hicks, Conference Co-ordinator, American Occupational Therapy Association, 6000 Executive Boulevard, Suite 2000, Rockville, Maryland, 20852, U.S.A.

22–27 April, 1979
6th Pan-Pacific Conference of Rehabilitation International, Seoul, Korea.
Information: Dr. Jung Soon Shin, Secretary, 6th Pan-Pacific Conference of Rehabilitation International, 15-san, Sinchon-dong, Sudaemoon-ku, Seoul, Korea.

25–27 April, 1979
Symposium sur l'Intégration au Travail des Handicapés Physiques, Quebec, Canada.
Information: Jocelyne Bédard, Comité des Communications, Le Centre de Réadaptation du Quebec, 525 Boul. Hamel, Quebec, Que. GIM 258.

26–28 April, 1979
Annual Child Prosthetics-Orthotics Clinic Meeting, University of Tennessee, Memphis, Tennessee.
Information: Sidney Fishman, Ph.D., Prosthetics and Orthotics, NYU Post-Graduate Medical School, 317 East 34th Street, New York, NY 10016, U.S.A.

30 April–4 May, 1979
Toward the Eighties—a Seminar on Children's Prosthetics in conjunction with the International Year of the Child, Hosted by the Saskatchewan Council for Crippled Children and Adults and sponsored by War Amputations of Canada.
Information: Mr Tony Vanderwaarde, 1410 Kilburn Avenue, Sasketoon, Saskatchewan, Canada, S7M OJ8

2–4 May, 1979.
Annual meeting, President's Committee on Employment of the Handicapped, Washington DC.
Information: R. H. Ruffner, PCEH, Director of Communications, Washington, DC 20210, U.S.A.

11 May, 1979
Problems of Fracture Fixation, Stoke-on-Trent.
Information: BES, K. Copeland, University College, Gower Street, London WC1, U.K.

17 May, 1979
One day course. Hoists: Their Role in the Prevention of the Occupational Hazard of Back Pain, Newcastle-upon-Tyne.
Information: The Secretary, Newcastle Council for the Disabled, Aids Centre, Mea House, Ellison Place, Newcastle NE1 8XS, U.K.

17–18 May, 1979
3rd Annual International Rehabilitation Film Festival, New York City.
Information: International Rehabilitation Film Review Library, 20 West 40th Street, New York, NY 10018, U.S.A.

22–26 May, 1979
Orthopädie-Technik '79 International — Congress and Exhibition.
Congress information: Congress Bureau, Wilhelm Syborg, COC-Kongreß organisation, Kongreß-Zentrale, Klingsorstr. 21, D-1000 Berlin 41, Germany.
Exhibition information: Bundesinnungsverband für Orthopädie-Technik, Hern Dipl.-Kfm. F. Scl ütte, Kettwiger Straße 27, D-4300 Essen 1, Germany

6–8 June, 1979
Canadian Association of Therapists, Ottawa.
Information: M/s. D. Campbell, 67 Nanook Crescent, Kanata, Ontario, Canada K2L 2B2.

7–8 June, 1979
Course on Children's Equipment, London.
Information: The Secretary, Disabled Living Foundation, 346 Kensington High Street, London W14 8NS, U.K.

16 June, 1979
One day course. Swivel Walking for Paraplegic Adults and Children, Salford.
Information: Mr. J. Howarth, Regional Education and Training Officer, Gateway House, Piccadilly, Manchester, U.K.

17–21 June, 1979
International Congress on Electromyography, Stockholm.
Information: Dr. A. Persson, Huddinge Syjukhus, S–141 86 Huddinge, Sweden.

21–22 June, 1979
The Plastics and Rubber Institute—Third International Conference on Plastics in Medicine and Surgery, Twente University, The Netherlands.
Information: Mr. J. N. Ratcliffe, Sec. Gen., The Plastics and Rubber Institute, 11 Hobart Place London SW1W 0HL, U.K.

22–29 June, 1979
23rd Annual Meeting American Association for Rehabilitation Therapy/Association of Medical Rehabilitation Directors and Co-ordinators.
Information: M. Abelson, Box 218, Yonkers, New York, 10705, U.S.A.

July, 1979
American Association for Rehabilitation Therapy Conference, New York, U.S.A.
Information: E. A. Cavalier, Box 6412, Gulfport, Miss. 39501, U.S.A.

July, 1979
Japan Society of Medical Electronics and Biological Engineering, 18th Annual Conference, Tokyo, Japan.
Information: K. Ikeda, JSMEBE, Kikaishninko Building, 5–8, 3-Chome, Shiba-Koen, Tokyo 105, Japan.

10–13 July, 1979
International Conference on Emotional and Sexual Needs of Handicapped People, University of Sussex, Brighton, England.
Information: Committee on Sexual Problems of Disabled People, 49 Victoria Street, London SW1H 0EU, U.K.

19–21 July, 1979
Bioengineering and the skin—International symposium, Cardiff, Wales.
Information: Dr. P. A. Payne, Bioengineering Unit, University Hospital of Wales, Heath Park, Cardiff, U.K.

4–8 August, 1979
3rd International Conference of European Association of Special Education on theme "Communication and Handicap", Helsinki, Finland.
Information: Secretary of International Affairs, Remo Harjunkoski, Lintuparvenie 19, 02660 Espoo 66, Finland.

19–24 August, 1979
Medical and Biological Engineering Conference, Jerusalem.
Information: P.O. Box 16271, Tel Aviv, Israel.

23–25 August, 1979
Course on Aspects of Lower Limb Amputee Rehabilitation for Physicians and Surgeons, Prosthetists and Therapists. To be held at Nordeland Sentralsykehus, 8000 Bodø, Norway.
Information: M/s. Inger-Lise Sverdrup, Co-ordinator for teaching services, Nordland Sentralsykehus, 8000 Bodø, Norway.

26–31 August, 1979
2nd Annual Interagency Conference on Rehabilitation Engineering, Atlanta, Georgia, U.S.A.
Information: Convention Management Consultants (CMC), 5401 Kirkman Road, Suite 550, Orlando, Florida 32805, U.S.A.

27–31 August, 1979
7th International Congress on Ergonomics.
Information: Organizing Committee, 7th. I.C.E., ul Gornoslgska, 20, C0–848, Warsaw, Poland.

2–9 September, 1979
Ninth European Rheumatology Congress, Weisbaden, West Germany.
Information: Dr. (Med.) G. Josenhans, IX European Rheumatology Congress, c/o Deutsche Gesel-eschaft für Rheumatologie E.V., 2357 Bad Braunstedt, Falkenweg 7, West Germany.

9–14 September, 1979
International Diabetes Federation 10th Congress, Vienna.
Information: J. G. L. Jackson, Secretary, International Diabetes Federation, 3/6 Alfred Place, London WC1E 7EE, U.K.

17–21 September, 1979
ISPO International Instructional Course on Lower Limb Orthotics, Washingtonian Motel, Gaithers-burg, Maryland, U.S.A.
Information: CMC, Inc., 5401 Kirkman Road, Suite 550, Orlando, Florida 32805, U.S.A.

18–22 September, 1979
7th International Congress of Biomechanics (Biomechanics 79) Warsaw, Poland.
Information: Organizing Committee, Inst Sportu, Ceglowska, 68/70, 01–809, Warszawa, Poland.

24–25 September, 1979
International Society for Prosthetics and Orthotics, United Kingdom 7th Scientific Meeting, University of Sheffield.
Information: Mrs. Kerion Meusel, Secretary, U.K. National Member Society, ISPO, Orthotic Research and Locomotor Assessment Unit, The Robert Jones and Agnes Hunt Orthopaedic Hospital, Oswestry, Salop SY10 7AG, U.K.

24–27 September, 1979
International Conference on Riding for the Disabled, Warwickshire, U.K.
Information: Riding for the Disabled Association, Avenue "R", National Agricultural Centre, Kenilworth, Warwickshire CV8 2LY, U.K.

26–30 September, 1979
American Orthotic and Prosthetic Association National Assembly.
Information: M/s. S. I. McCamley, AOPA, 1444 N. Street, NW, Washington DC 20005, U.S.A.

6–10 October, 1979
32nd Annual Conference on Engineering in Medicine and Biology, Denver, Colorado.
Information: Mrs. P. I. Horner, Administrative Director, Alliance for Engineering in Medicine and Biology, 4405 East-West Highway, Suite 404, Bethesda, Maryland 20014, U.S.A.

22–23 October, 1979
3rd Annual Conference of the American Society of Biomechanics, The Pennsylvania State University, State College, PA, U.S.A.
Authors interested in presenting papers are requested to send abstracts before 1 May, 1979 to Doris I. Miller, Hutchinson Hall DX–10, University of Washington, Seattle, WA 98195.
Information: Mr. Ron Avillon, Conference Co-ordinator, Keller Building, Pennsylvania State University, University Park, PA 16802.

November, 1979
Third International Congress on "Improving the Quality of Life of the Handicapped with Assistive Devices", U.S.A.
Information: World Veterans Federation, 16 rue Hamelin, Paris 16e, France.

1980
4th World Congress of the International Rehabilitation Medicine Association, Stockholm.
Information: International Rehabilitation Medicine Association, CH–7310 Bad Ragaz, Switzerland.

Spring 1980
8th Annual New England Bioengineering Conference, Cambridge, Massachusetts.
Information: Institution of Electrical and Electronics Engineers, Conference Services, 345 East 47th Street, New York, NY 10017, U.S.A.

23–29 March, 1980
Bio Engineering 80, London.
Information: BES, K. Copeland, University College, Gower Street, London WC1, U.K.

24–28 March, 1980
Aids for the Disabled, Dusseldorf.
Information: International Trade Fairs Ltd., 2 Old Bond Street, London W1, U.K.

8–12 April, 1980
1st World Congress on Biomaterials, Vienna.
Information: K. Copeland, University College, Gower Street, London WC1, U.K.

27 April–2 May, 1980
3rd International Congress on Physically Handicapped Individuals who use Assistive Devices Houston, Texas, U.S.A.
Information: William A. Spencer, M.D., President, Scientific Program Committee, T.I.R.R., Texas Medical Centre, P.O. Box 20095, Houston, Texas 77025, U.S.A.

7–9 May, 1980
Engineering Aspects of the Spine, London.
Information: Institution of Mechanical Engineers, 1 Birdcage Walk, London, SW1, U.K.

26–30 May, 1980
8th International Congress of Physical Medicine and Rehabilitation on "Disability—Prevention and Management by Rehabilitation Medicine", Stockholm, Sweden.
Information: Secretary, Dr. I. Swedborg, Ávd. for Fys. Med. och Rehab., Karolinska Sjukhuset S–104 01, Stockholm, Sweden.

June, 1980
24th Annual National Rehabilitation Conference, Arlington, Texas.
Information: D. Hall, 912 Rosevale Drive, Hewitt, Texas, U.S.A.

20–27 June, 1980
International Conference on Rehabilitation Engineering, Sheraton Centre, Toronto, Canada.
Information: CMC, Inc., 5401 Kirkman Road, Suite 550, Orlando, Florida 32805, U.S.A.

22–27 June, 1980
Rehabilitation International 14th World Congress, Winnipeg, Canada.
Information: Mr. Jack Sarney, Canadian Rehabilitation Council for the Disabled, Suite 2110, Yonge Street, Toronto, Ontario M5E 1E8, Canada.

August, 1980
National Multiple Sclerosis Society Conference, Denver, Colorado, U.S.A.
Information: Sylvia Lawrie, 205 East 42nd Street, New York, NY 10017, U.S.A.

September, 1980
Mediterranean Conference on Medical and Biological Engineering, Marseilles, France.
Information: Prof. G. Kapham, Faculté de Médecine (Nord), Boulevard P-Drummard, 13326 Marseilles Cedex III, France.

Mid-September, 1980
American Orthotic and Prosthetic Association Meeting, New Orleans, U.S.A.
Information: M/s. S. I. McCamley, American Orthotic and Prosthetic Association, 1444 N. Street NW, Washington, DC 20005, U.S.A.

27 September–1 October, 1980
33rd Annual Conference on Engineering in Medicine and Biology, Washington DC, U.S.A.
Information: M/s. P. I. Horner, Administrative Director, Alliance for Engineering in Medicine and Biology, 4405 East-West Highway, Suite 404, Bethesda, Maryland 20014, U.S.A.

28 September–4 October, 1980
ISPO 3rd World Congress, Bologna, Italy.
Information: Studio B.C., via Ugo Bassi 10,40123 Bologna, Italy.

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"Prosthetic principles in bilateral shoulder disarticulation or bilateral amelia". G. Neff. Prosthetics and Orthotics International Vol. 2, No. 3.

We have been asked by the author to point out that the work reported in the above paper was carried out in the Department for Dysmelia and Technical Orthopaedics, Heidelberg, under the direction of Professor Ernst Marquardt. The illustrations accompanying the paper were also supplied by Professor Marquardt and showed his patients; the prostheses and special parts were produced at the Department for Dysmelia and Technical Orthopaedics, Heidelberg.

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Ten reprints will be supplied free of charge to the first named author. Additional reprints will be available at cost if th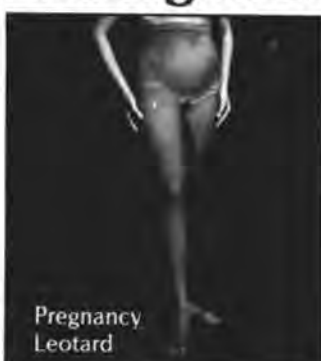ey are ordered when the proofs are returned.